A "HORIZON STRATEGY" FRAMEWORK FOR SCIENCE AND TECHNOLOGY POLICY

for the U.S. Innovation Economy and America's Competitive Success

Christopher Ford, Charles Clancy, and Duane Blackburn, The MITRE Corporation

Executive Summary

President Biden has proposed a new national effort for federal investment in breakthrough technologies to "secure our global leadership in the most critical and competitive new industries and technologies." He has also tasked his incoming Science Advisor to review the nation's science and technology enterprise and to develop recommendations on how to "continue to harness the full power of science and technology on behalf of the American people." This is very timely, for the current U.S. innovation model has in multiple respects fallen short in the face of today's technology competition challenges, including from the state-sponsored technology strategy China is employing in support of its geopolitical objectives.

First, the net American R&D investment portfolio currently struggles to fill the so-called "chasm" in the technology adoption life cycle between basic research and the development of specific, marketable commercial applications. This slows the pace and effectiveness of how new insights are carried forward into full deployment across a range of novel and evolved use cases. Second, the current U.S. innovation model sometimes struggles with complex challenges that cross technological "stovepipes." It presently works well in areas such as software and services, but it seems to be falling short in connection with more capital-intensive and/or interdisciplinary work that is critical to meeting present-day challenges in key areas. Third, private sector actors often have neither the ability nor the incentive to address a range of broader, "ecosystem"-type challenges – or perhaps one should say "technosystem" challenges, as they relate, inter alia, to technology governance questions and the interaction of new technologies with broader societal, legal-regulatory, and policy dynamics – that are nonetheless essential to ensuring that technology is successfully incorporated into the innovation economy.

A new federal agenda for promoting S&T innovation must address itself to these market failures. To do this effectively, what is needed is a national-level effort: a synergy between government, industry, and academic activities to holistically address our nation's most critical S&T priorities – while safeguarding the intellectual property, privacy rights, and autonomy of all participants and stakeholders. This new partnership will need to prioritize and steer federal R&D funding to overcome weaknesses in the current innovation model and to bring the requisite integrative, "system-of-systems thinking" to bear on relevant "technosystem" challenges in prioritized areas.

Its focus should be upon interdisciplinary and cross-sector problems that, despite their national-level significance, are: (a) too "applied" for basic research but too "upstream" for marketization; (b) too intricate and capital-intensive for a start-up; (c) have time horizons too long, risk profiles too steep, and immediately monetizable payoffs too indirect or speculative to justify significant individual investment from most private firms; and/or (d) involve a range of cross-sector coordination, public policy, legal/regulatory, and other governance questions that no single private sector player could address on its own. It should also emphasize S&T governance initiatives to improve incentives facing private actors, to guide and adopt effective technology standards and ensure safety, confidence, and privacy protections across diverse and evolving future technology, to ensure security for various key aspects of the technology supply chain, and to ensure the availability (and nationwide connectivity) of a workforce well equipped for nationwide, decentralized next-generation design and manufacturing innovations.

This report offers an intellectual framework to help shape such an approach suggests organizational forms from which to learn in establishing effective public-private cooperation to enable the U.S. innovation community (across its many governmental, private sector, academic, and FFRDC components) to find a collaborative, voluntary way forward together in implementing a national "horizon strategy" to remedy market failures in today's innovation economy and take advantage of technological opportunities in tomorrow's. It also explains why certain key technology areas – Advanced Manufacturing (AM), Artificial Intelligence (AI), biotechnology, climate and energy, cybersecurity, health informatics, microelectronics, Quantum Information Science, and telecommunications – would likely particularly reward federal attention as part of the Biden Administration's new agenda, and offers suggestions as to several additional points for prioritization in technology governance.

Table of Contents

A "Horizon Strategy" Framework for Science and Technology Policy for the U.S. Innovation Economy and America's Competitive Success

On the campaign trail in 2020, Vice President Joe Biden proposed a new economic program that would, among other things, "make smart investments in manufacturing and technology, give our workers and companies the tools they need to compete, … and spark American innovation to stand up to the Chinese government's abuses."[1] Today, President Biden has the opportunity to make good on his promise of a bold new federal approach to supporting innovation and U.S. competitive success in Science and Technology (S&T). And indeed, the new president has elevated the director of the Office of Science and Technology Policy (OSTP) to cabinet-level status. Moreover, he has directed OSTP's new head to undertake a full-scope review of federal S&T policy that has been likened to the groundbreaking proposals made by White House Science Advisor Vannevar Bush to President Franklin Delano Roosevelt in 1945[2] – a federal technology strategy that helped inaugurate a period from the early 1950s until the late 1960s that has been termed "the 'golden age of American science,'"[3] and under which we still operate.

The challenge for America now, of course, is what the specific contours of such an ambitious new push should actually be. Despite "attempts to fill this void" that began during the previous administration, federal S&T policy still lacks "a long-term strategic framework" – a compelling vision and "overall approach to tie [its various aspects] together."[4]

To help inform the Biden Administration's consideration of these crucial questions, this paper leverages the insights and experiences of the MITRE Corporation – through its operation of six federally-funded research and development centers (FFRDCs) and of a dozen Innovation Centers under the auspices of MITRE Laboratories, a well as its involvement in multiple public-private collaborative activities in the national interest – to suggest an intellectual framework for these initiatives that is tailored to the specific innovation economy and international competitive challenges facing the United States today. In this paper – supplemented by Appendices that explore organizational models for public-private partnership and discuss how these issues fit into broader debates over industrial policy – we offer an account of the "market failures" that currently limit the full potential of the U.S. innovation model in the face of formidable competitive challenges, offer suggestions about organizational forms for effective public-private collaboration, and describe key technology areas that would reward federal attention as part of the Biden Administration's new agenda.

The Current Challenge

The U.S. S&T accomplishments of the aforementioned "golden age" were built, in effect, upon a foundational concept in which the federal government provided large sums for research and development (R&D) in basic science, often carried out through the expanding U.S. research universities, as federal agencies and major corporations both developed the specific technologies needed for their individual missions.[5] (This was especially pronounced in the national security sector, progress in which acquired special urgency after the "Sputnik Shock" of 1957 and the pressures of global competition with the Soviet Union in the Cold War.) During this seminal period, new institutions were established at the federal level to help manage different facets of this broad national effort.[6] Federal research dollars for the university sector also rose from what had been an estimated $20 million (in 1982 dollars) in 1935-36 to fully $8.5 billion in 1985, even as the share of U.S. Gross National Product (GNP) provided by university research nearly doubled.[7] In 1960, the United States accounted for nearly 70 percent of R&D funding in the entire world.[8]

Today, however, some aspects of how the United States has traditionally kept a vibrant innovation base have ceased to work as well as we need them to work. In fact, each key plank of the "golden age" formula – of how government, industry, and academia partnered to this end – has in recent years come under stress.

The U.S. Government has long been willing to invest in basic research not merely so that federal agencies could procure technologies key to their missions, but also on the theory that although private firms have difficulty appropriating the broader societal value from basic research, those returns nonetheless do exceed its cost. Consequently, only the government itself arguably has an incentive to invest heavily in such basic research.[9] And, indeed, federal R&D investments have long been "a critical component of the nation's innovation ecosystem."[10]

Another critical piece of the traditional innovation was provided by private industry, and – for a time, at least – particularly by corporate laboratories. As outlined in a recent paper by Ashish Arora and several coauthors, corporate laboratories contributed to the innovation ecosystem as a result of their affiliation with corporate incumbents that had "strong incentives to focus upon systemic or architectural innovations"[11] in how technology can be integrated and translated into applications, and that had the resources to back expensive and interdisciplinary lines of inquiry:

> *"Research conducted in corporate labs is directed toward solving specific practical problems. … [In some sense,] corporate labs may integrate the best of both worlds. On the one hand, their research is connected to real problems, so that their results are likely to have important industrial applications. On the other hand, this connection is not so strong that the results lie towards the most applied end of the spectrum and have only limited scientific value."*[12]

Much of America's technical innovation in the 20th century, in fact, came from large corporate laboratories whose research and development drove numerous innovations – from the radio to the major advances in the modern electrical grid, transportation systems, commercial flight, and energy. Already large and important before the Second World War and having "replaced individual entrepreneurs as the primary course of American innovation by the 1920s,"[13] corporate laboratories grew considerably in the United States in the postwar period and provided enormous net benefits.

America's research universities also played vital roles in the postwar U.S. innovation boom and received considerable federal R&D funding. The flow of federal funds into basic research in the postwar period helped fuel a dramatic expansion of the academic research sector, which has continued to the present day. Arora and his coauthors recount, for instance, that by the 1980s – accelerated by legislative changes that allowed the fruits of federal-funded university research to be owned and licensed by the universities themselves – American universities had progressed from being "merely the producers of human capital to becoming the dominant producers of scientific knowledge." By 2015, academic institutions were spending $61 billion on both basic and applied research, and their share of total research had risen above one-third.[14]

But the relationship between these three primary sectoral participants – universities, the government, and the private sector – has evolved in important ways since the Cold War "golden age" of American science. Specifically, university research has boomed, but corporate research – or at least, with limited exceptions, the kind of larger-scale institutional laboratory work that had been so important earlier – has flagged. With the expansion of university research, firms were increasingly able to source inventions from the outside and felt such sizeable capital investments in in-house research to be less necessary.[15] At the same time, expanded nontraditional "innovation investor" opportunities such as venture capital (VC) firms emerged, increasingly bankrolling startup companies that sought to become competitors to established operations by building on basic research conducted in universities that they themselves did not have to pay for.[16] This combined to give major companies ever-stronger incentives to focus only upon short-term profits and the exigencies of simply producing and delivering goods and services to the marketplace, and to eschew the cost and uncertainties of longer-term, in-house research.[17]

As a result, a "drastic transformation of the American innovation ecosystem ensued," producing "a new division of innovative labor" in which "many leading Western corporations began to withdraw from scientific research."[18] According to the President's Council of Advisors on Science and Technology (PCAST), in the recent "global reorganization of research," private firms have become, on the whole, less interested longer-term efforts to drive innovation than in investments that give short-term competitive advantage. Increasingly, they prefer to fund "low-risk endeavors – those closer to the development and implementation end of the spectrum … [as a consequence of which] support by U.S. industry for basic and early applied research has stagnated relative to investments in short-term development."[19] Even while the average size of leading U.S. corporations has grown, the market and private value of in-house research investments declined, the absolute amount of research spending in private industry stagnated,[20] and the American corporate sector embarked upon a "long process of withdrawal from research."[21]

Unfortunately, as Kaushik Viswanath has noted, this new division of labor in the American innovation system "has some gaps."[22] Hopes that these processes would continue to keep the American innovation system as vital and dynamic as we need it to be in the face of foreign competition "have not been fully realized."[23]

To begin with, the competitive challenges facing the U.S. innovation base from abroad seem to have been accelerating. In relative terms, federal R&D spending has fallen precipitously as a percentage of Gross Domestic Product (GDP) in comparison to the spending rates of the "golden age," with significant potential implications for the future.

> *"While the United States accounted for the bulk of global R&D funding in the decades after World War II, today the rest of the world is responsible for three-quarters of R&D funding and over 80% of scientific publications. China's R&D funding alone now matches that of the United States. International research collaboration, measured by international coauthorship of papers, has steadily increased to almost 40% of all research in the United States and other leading countries."* [24]

This is not to say that overall U.S. R&D spending has collapsed, for it remains high in comparison to most countries as a percentage of Gross Domestic Product (GDP) and very large in aggregate – even if proportionally behind countries such as Austria, Denmark, Germany, Finland, Japan, South Korea, and Switzerland.[25] In fact, *private* sector investment in U.S. R&D has actually expanded steadily for the last decade or so, though America is today only ninth in the world in terms of R&D expenditure by the business sector as a proportion of GDP.[26]

That said, U.S. *federal* spending on R&D has declined as a percentage of U.S. GDP from approximately 1.2 percent in 1976 to only around 0.7 percent in 2018.[27] The share of U.S. R&D performance funded by the federal government fell from 31 percent in 2010 to 22 percent in 2017, and though the federal government remains the largest source of support for basic research in the United States, that share has fallen below 50 percent since 2012.[28] Federal support for R&D, and indeed the government's *role* in R&D – *e.g.*, in directing resources to priority areas to help meet national-level challenges or to remedy market failures in ways not addressed or addressable by private sector funding – has clearly not been prioritized in the ways that it used to be.

And America's relative position in the global innovation economy has been slipping, as the global concentration of R&D performance has shifted steadily from the United States and Europe to Asia. In particular, China – which recently announced that it will increase its R&D spending by at least seven percent in each of the next five years[29] – is closing the gap in R&D performance, with an average annual growth rate that is nearly three times higher than our own. Today, the United States and China each accounts for about a quarter of total global R&D. As the National Science Board describes it, "this remaking of the global geography of R&D is unlikely to slow soon."[30]

This might yet have been acceptable if indeed the American innovation ecosystem had nonetheless been fully able still to meet our competitive needs. Unfortunately, this does not seem to be the case, and the current model has in certain specific respects fallen short in the face of today's challenges. First, the net American R&D investment portfolio currently struggles to fill the so-called "chasm" that exists in the technology adoption lifecycle between basic research and the development of specific, marketable applications – that is, the (relative) empty space between more well-funded basic research and more well-funded "downstream" commercialization prior to actual market uptake.

Today, some contemporary government R&D efforts, such as the National Quantum Initiative, are often too heavily focused on basic research, to the detriment of applied engineering, commercialization, and workforce strategies. The National Science and Technology Council (NSTC) provides value in helping establish national goals for federal S&T investments, but it still concentrates heavily upon basic research – for which federal sources provided 42 percent of all funding in 2017.[31] (The U.S. private sector has been moving more into basic research funding in recent years, with the share of basic research funded by business increasing from 19 to 29 percent between 2000 and 2017.[32] This is helpful, and it usefully belies the stereotype that *only* universities and non-business laboratories can do such work, but it still does not address deficiencies in the innovation cycle "downstream" from basic research.) Across the board, as David Bailey has noted, there is often

> *"a tendency for policy to be too concentrated on the generation of innovation… and not enough on diffusing what already exists in a way that recognises the structural specificity and specific needs of a local economy. Getting this right requires extensive knowledge exchange and boundary spanning skills."* [33]

As it turns out, "the translation of scientific knowledge generated in universities to productivity enhancing technical progress" has been "more difficult to accomplish in practice than expected" and has failed fully to fill "the gap left by the decline of the corporate lab."[34] The resulting so-called "chasm" that has developed in the innovation cycle slows the pace and effectiveness of how new technological insights are carried forward into full deployment across a range of novel and evolved use cases, and represents a sort of market failure. We are not, therefore, adequately benefiting even from those investments that are being made in R&D.

Second, the current U.S. innovation model sometimes struggles with complex challenges that cross technological "stovepipes." This kind of interdisciplinary work used to be an American strength, exemplified in the past by the work of large-scale corporate laboratories such as those at General Electric, IBM, Bell Laboratories, and DuPont. It is, however, a type of work that in the modern era has tended to be deprioritized, even though universities and start-ups are less well equipped to fill this gap.

All in all, too few of the participants in the current U.S. innovation ecosystem have felt themselves to have an economic incentive to pursue the "more complex innovations."[35] Today, in other words, neither universities nor start-ups generally seem to have compelling incentives to "tackle multidisciplinary problems by integrating multiple knowledge streams and capabilities" and to accomplish the higher-risk, higher-capital cost tasks of trying "to 'translate' research findings into executable solutions."[36] These two aspects of the problem add up to a significant "hole" in the collective U.S. innovation toolkit at a time when the United States' principal geopolitical, economic, and technological competitor is pouring money into emerging technologies in support of its strategic ambitions.

A third problem is that private sector actors often have neither the ability nor the incentive to address a range of broader challenges in the technological ecosystem – the "technosystem," as it were – that must nonetheless be worked through to ensure that a new technology is successfully and appropriately incorporated into actual uses in the future innovation economy. These challenges are basically ones of national technology policy, and they involve such things as setting technology standards and devising appropriate answers to questions about security, safety, confidence, and privacy issues. The federal government's role here, in other words, is inescapable.

Such technological "technosystem" thinking, moreover, is likely to be especially important if we are to reap the full benefits of fields such as Artificial Intelligence and Quantum Information Science – which are likely to have dramatic effects in catalyzing the emergence of potentially transformational use cases throughout the economy while also introducing new concerns – and if we are able to mobilize innovation across the technology sector to meet national-level challenges in healthcare, climate and energy, national security, and elsewhere. Nevertheless, the U.S. Government does not yet address "technosystem" questions in a systematic manner, especially across technological and sectoral boundaries.

On the whole, the current U.S. innovation model still seems to work well in areas such as software and services. It seems to be falling short, however, in connection with certain more capital-intensive and/or interdisciplinary work critical to meeting present-day challenges in arenas that underpin our information economy, such as Quantum computing, Artificial Intelligence, and semiconductors. It also seems to fall short in many areas vital to our safety and economy, such as energy, biotechnology, Advanced Manufacturing, healthcare, and the environment.

Today, while the United States remains a world leader in many areas, it has been losing ground, and – as President Biden's new initiative signals – there is widespread understanding that a new approach is needed. New thinking about the federal government's approach to S&T policy is required in order to target resources and innovative solutions to where they will be most effective in laying the groundwork for a potential *second* "golden age of American science."

Catalyzing a Stronger U.S. Competitive Posture

Understanding these gaps provides a key to understanding the role that President Biden's proposed additions to federal R&D funding – and some targeted reforms in American S&T governance policy – can play in helping the U.S. innovation ecosystem provide better value in the years ahead. The government has traditionally played a major role in fostering innovation through ensuring a well-functioning market though such things as protecting intellectual property (IP) and establishing effective technology standards, tax incentive initiatives and "challenge" prizes, and supporting the technology pipeline that fuels innovation. And indeed, there is a long record of success in seeing government-funded and -managed R&D programs ricochet into private-sector innovation:

- DRAM caching (developed by the Defense Projects Research Agency);
- Lithium-ion batteries (the Department of Energy and the Central Intelligence Agency);
- the Global Positioning System (the U.S. Navy);
- Signal compression (the Army Research Office);
- Liquid-crystal displays (the National Institutes of Health, National Science Foundation, and Department of Defense);
- Micro hard drives (Energy and DARPA);
- Microprocessors (DARPA);
- Cellular technology (Defense);
- Siri (DARPA);
- Multi-touch screens (Energy, NSF, Defense, and the CIA); and – most famously –
- the Internet (DARPA).[37]

The challenge today, of course, is to try to ensure that such synergistic successes can continue with the ongoing development of new technology – and of new technology *use cases* – in the future.

A. National-level Effort and Vision

To that end, what is needed is a new federal effort to build innovation-fostering partnerships: a voluntary coordination of government, industry, and academic activities to holistically address our nation's most-critical S&T priorities. It must integrate such diverse players into a collaborative network to share information about opportunities and solutions, and to coordinate shared, complementary efforts across sectors, institutions, and disciplines in order to help catalyze solutions to the biggest technology-related challenges our society faces. It must do this, furthermore, while safeguarding the intellectual property, privacy rights, and autonomy of all participants and stakeholders. This new partnership will need to prioritize and steer federal R&D funding to overcome weaknesses in the current innovation model and to bring the requisite integrative, "system-of-systems thinking" to bear on relevant "technosystem" challenges that will need to be overcome in prioritized areas such as those outlined in Appendix I.

One of the key elements for success in this regard will be the new U.S. Administration's ability to offer a clear *vision* for a new approach to public-private collaboration to catalyze greater dynamism in America's innovation economy. What is needed, one might say, is a vision of a national "horizon strategy" capable of remedying market failures in today's innovation economy while building the collaborative partnerships that will permit us to take advantage of technological opportunities in tomorrow's.

Such a vision will be especially important in meeting the competitive challenges described in this paper, which call for multi-pronged efforts across an array of technology areas that must be approached on an interdisciplinary and cross-sectoral basis, and across the breadth of "technosystem" issues. This national vision of a "horizon strategy" should provide a compelling rallying point for collaborative and voluntary endeavors, both on a *tour d'horizon basis* – involving government, industry, academic, and FFRDC stakeholders, across a wide spectrum of issue arenas, and in ways that encompass opportunities ranging from more immediate day-to-day challenges of technology governance to the *conceptual* horizon of future technological development, uptake, and application.

These contemporary challenges may resist being crisply summarized in a mobilizing mantra such as the idea of a "space race" to "put a man on the Moon" that energized the technological feats of the Apollo Program of the 1960s. The challenges we face today are nonetheless vitally important. Accordingly, the Biden Administration will need to offer a powerful vision of the technological future that will enjoy sustained institutional support at high levels both in the Executive Branch and in Congress, as well as from motivated private-sector partners.

B. Address the Key Market Failures

To begin with, a new federal agenda for promoting S&T innovation must address itself to the *de facto* market failures described in Part I.[38] With respect to the "chasm" in the innovation pipeline that exists "downstream" of basic innovation yet "upstream" of marketization, for instance, the Administration's revived and refocused federal R&D effort should focus upon that neglected middle-ground domain of cross-domain technology integration and diffusion.

It should also emphasize information-sharing, mutual situational awareness, and coordination across technology areas and industrial sectors – something that is unlikely to occur without a new effort to build such voluntary collaborative opportunities. It should also include a strong emphasis upon S&T governance initiatives across the evolving "technosystem" of relevant technology areas, to improve incentives facing private actors to fill gaps better themselves, to set effective technology standards and ensure safety, confidence, and privacy protections across diverse and evolving future technology, to ensure security for various key aspects of the technology supply chain, and to ensure the availability (and nationwide connectivity) of a workforce well equipped for nationwide, decentralized next-generation design and manufacturing innovations.

Bringing these elements together, therefore, the focus of the new approach should be upon identifying and solving interdisciplinary and cross-sectoral problems that, despite their national-level significance, are:

a. too "applied" for basic research but too "upstream" for immediate commercial marketization;
b. too intricate and capital-intensive for a start-up;
c. have time-horizons too long, risk profiles too steep, and immediately monetizable payoffs too indirect or speculative to justify significant individual investment from most private firms; and/or
d. involve a range of cross-sectoral coordination, public policy, legal/regulatory, and other governance questions that no single private sector player could address on its own.

C. A New Partnership Platform

What qualities will be needed in a new organization, or consortium of organizations? The following pages will offer some suggestions.

To begin with, it is important to recognize the degree to which an effective answer to these challenges represents what is in effect a national-level systems engineering or systems integration challenge. America needs an organizational model for this innovation effort that will supply what David Bailey calls "extensive knowledge exchange and boundary spanning skills"[39] in integrating diverse public, private sector, and academic players into a collaborative network to share information about opportunities and solutions. Such skills are essential if such a network is to coordinate shared, complementary efforts across sectors, institutions, and disciplines in order to help catalyze solutions to the biggest technology-related challenges. Such a new innovation "platform," one might say, will need to play a role at the national, cross-sectoral level not unlike what Henry Chesbrough describes as that of an "innovation architect" which "provide[s] a valuable service in complicated technology worlds" by "developing architectures that partition this complexity, enabling numerous other companies to provide pieces of the system, all while ensuring that those parts fit together in a coherent way."[40]

Such an "innovation architect" must not be prescriptive in ways that stifle innovation or competition, of course, nor should it presume that it – or anyone – can know in advance precisely what is needed or what will emerge as a result of the interplay of innovation and market dynamics in the U.S. technology arena. But such a new platform can play a very important role in helping catalyze innovation by supporting basic research, identifying and helping direct assistance to fill gaps left by existing mechanisms, and by helping coordinate broad partnerships of relevant players in support of U.S. competitive success.

Another key role for this new institution or mechanism would be to provide a locus for improved prioritization. It could help direct attention and participating institutions' collaborative energies toward the key industrial innovations essential to our nation's economy and safety, not only within the next five years, but in decades to come – thus providing crucial cross-cutting thinking on multiple time-horizons. Precisely because additional effort is needed to help address existing market failures, it will be important to provide ways to "shift[] … resources across national goals and across scientific and engineering disciplines"[41] to areas that the current innovation model is failing fully to address not just at present, but in the future. It is for this reason that Bailey and others have called for "a new model of industrial prowess … centered on the nexus of science and technologies embedded in a matrix of industry, government[,] and higher education," and which can "facilitate new network connections… while also validating and demonstrating new technologies to raise confidence and enhance adoption," to address "risky and long-term societal missions."[42] We need a "platform" that can repeatably and systematically catalyze innovation.

The focus of such prioritization would not be upon "picking winners" in some future techno-industrial sweepstakes, but rather upon helping create an environment "out of which 'winners' may arise."[43] But given that the U.S. Government already plays a large role in supporting innovation – and with President Biden planning to expand federal support still further – some prioritization will be unavoidable. Even augmented resources will not be infinite, and our leaders owe it to the taxpayer to have an intelligible method for directing attention to the most pressing needs that are most likely to benefit from additional support. Such a national-level "innovation architect" partnership mechanism can assist with this collaborative prioritization.

As can be seen from Appendix I, there are various organizational models upon which one could draw in building such a partnership between government, industry, and academia. There is little precedent for doing this beyond the "research" aspect of technology development, however – that is, on the sort of "technosystem" basis we advocate here – and almost none for doing so across technology areas. A threshold question, therefore, is whether (or to what degree) to try to bring the entirety of this proposed federal S&T effort within a single framework or instead build a separate "platform" for each distinct technology area.

In order to help ensure situational awareness, coordination where needed, and a coherent overall approach to prioritizing federal R&D spending – especially if additional funds are made available – our recommendation is that some overall, very high-level coordination be provided by a national-level interagency body. This could involve adapting the NSTC to oversee such an undertaking, adding such functions to the National Science Foundation (NSF), or creating a new organization. Such an interagency body would need to coordinate closely with federal, industry, FFRDC, and academic partners to develop and promulgate the kind of compelling vision that needed to build and sustain stakeholder and legislative support over time.

Because of the breadth of issues and diversity of stakeholders involved across the government, private industry and academia, however, the vast majority of the work and coordination would occur on a voluntary basis and collaboratively through more specific public-private sub-partnerships on an issue-by-issue or technology-by-technology basis. These sub-partnerships would be coordinated by an FFRDC, or a consortium of FFRDCs, taking advantage of its (or their) status as a commercially disinterested but technically astute "honest broker" obliged by charter to operate in the public interest. Funding would come from federally provided "seed money" and private sector "matching" funds.

As noted earlier, this "horizon strategy" would have a *tour d'horizon* perspective – in that it would involve a great number of government, industry, academic, and FFRDC stakeholders across a wide spectrum of issue arenas – even as it seeks to identify and draw attention to opportunities all the way out to the conceptual horizon of future technological evolution. Only with such a broad-based, flexible, and voluntary organizational form is our system likely to meet the competitive challenges of this era in ways that play to America's strengths as a free-market, entrepreneurial culture.

Technology Areas for Emphasis

But what can be said at this point about the specific technology areas to prioritize through such new efforts? To provide food for thought in thinking through where it might be most beneficial to address additional federal S&T funding, the following pages outline several key technology areas that have particularly strong claim to receive special attention in the new federal innovation agenda. This is not meant to be either an exhaustive or an exclusive list, but instead merely to suggest some of the ways in which a bold new U.S. approach to innovation-focused R&D and cross-sectorally coordinated technology development could catalyze a range of new opportunities for competitiveness and job creation throughout the American economy.

A. Advanced Manufacturing

The improvement and widespread uptake of Advanced Manufacturing (AM) capabilities – *e.g.*, so-called "3D printing" and associated technologies, which permit unprecedentedly rapid computer-based design, rapid prototyping, and nearly infinitely customizable production of an increasingly wide range of items without the capital-intensive, scale- and standardization-focused rigidities of traditional mass production – have the potential to provide enormous new opportunities for reviving the productivity and competitiveness of the U.S. manufacturing sector. Already, AM is making huge strides in rapidly and cheaply producing custom-made parts for "legacy" equipment and applications that were previously manufactured by conventional means. As this field matures, however, it will also offer growing opportunities for customized design as well as bespoke production, enabling items to be designed from the outset to take advantage of AM's remarkable ability to produce many things much more cheaply than traditional methods, to fill niche markets not conducive to mass production techniques, and indeed to produce novel physical forms that prior methods would find impossible to manufacture at all.

The AM revolution that is today beginning to get underway, moreover, has the potential to unlock such potentialities on a large scale across the economy, yet without nearly the capital-intensity and location-specificity associated with traditional manufacturing centers (*e.g.*, large factory towns or industrial centers). Especially if combined with new workforce programs to encourage STEM-focused training and reskilling – coupled with federally supported efforts to expand access to the digital economy through the provision of broadband Internet access to portions of the country that today still lack it – the maturation of AM technology could make possible the emergence of a new 21st-century manufacturing base.

Significantly, this new manufacturing base could exist on a disaggregated basis, based on a model notably different from traditional factory-based mass production. This new manufacturing economy would be both much more agile, cost-effective, and responsive to market needs than the traditional models, and it would be able to bloom in "micro-industrial" enclaves wherever broadband connectivity, machine tool skills, computer-assisted design capacity, and new AM technology can be brought together.

This chance to catalyze the emergence of archipelagos of computer-based design and AM production capacity across the American heartland thus holds the potential to revive the productivity of the U.S. manufacturing sector, to the great benefit of the overall economy. It may also hold the key to providing next-generation skilled manufacturing opportunities for everyday working Americans in areas of the country that were unable to take advantage of past waves of industrial development, or that have been left behind as the factory-based mass-production manufacturing jobs of previous generations disappeared or moved overseas.

Such a democratization of high-technology manufacturing will not happen overnight. It will likely also require a federal hand in helping ensure the architectures necessary to make it possible. As noted, this would include expanding digital connectivity to all Americans, as well as making AM-related technical upskilling available to a nationally decentralized workforce.

It may also, however, need to include steps to ensure the development and implementation of new data architectures to ensure confidence in such a decentralized marketplace of industrial suppliers and the products that emerge therefrom – *e.g.*, means by which to ensure the cybersecurity of AM designs exchanged between multiple buyers and vendors, methods for the certification of new designs in a customized-production market for which traditional approaches will likely be too cumbersome, and ways to demonstrate the reliable correspondence between items produced and the digital history of their design specifications. These are holistic, "systems" challenges not solely related to AM technology "itself," but involving the integrity and governance of the future AM "technosystem" as a whole. If they can be overcome, however, the AM revolution holds the potential to unlock new levels of 21st-century productivity, and to bring opportunities to portions of the American workforce that have not had good news for many years.

B. Artificial Intelligence

Private sector entities are currently investing large sums of money in Artificial Intelligence (AI) research and applications, but these investment programs leave some significant gaps, and will not provide all of what will be needed if we are fully to realize AI's transformative potential and avoid its pitfalls. Private firms' investment in AI generally focuses upon its commercial application in rapidly evolving areas in which speed-to-market, ease of customer use, and rapidity of market uptake are cardinal objectives. Built-in measures to protect the privacy, integrity, and use-transparency of AI algorithms and data sets, however, are approached with only the attention and robustness that generally lower-risk commercial applications require. The most successful applications of AI and autonomy to date have been in fairly narrow, low-risk contexts such as Internet search engine filters.

Yet if AI is to reach its full potential – especially in higher-risk arenas such as healthcare and telemedicine, autonomous transportation, and various U.S. Government applications (*e.g.*, law enforcement, national security, or tax enforcement) – significantly stronger privacy, integrity, and transparency assurances will be needed in order to provide justified confidence and safety. (AI systems demand huge sets of training data, and they are potentially subject to an emerging set of "counter-AI" attacks designed to provide them with inputs that distort or undermine the integrity of decision-making algorithms that evolve by learning from such data. What's more, in contrast to the formal, "debuggable" code of traditional computer programming, the internal operation and decisional pathways of AI systems are likely to be quite opaque.) As the world is unfortunately discovering with the Internet in the current environment of worsening cybersecurity dangers, an architecture built for speed and ease of use can provide enormous economic and innovation-fostering benefits, but it can be very challenging to retrofit security and privacy into such a system as risks and vulnerabilities accumulate.

We must not make the same mistake with AI by trying to engineer such factors into existing systems only after it becomes clear that their proliferation without such protections has created unacceptable risks. It would be far better to design appropriate integrity measures into AI from the outset, and in ways adequate to permit effective AI implementation in higher-risk applications. (This is not to say that all applications must necessarily be engineered to the same risk standards, of course. The key is to ensure protections commensurate to the risk envelopes involved in each case, as well as more transparency about the datasets and algorithms that underlie particular AI applications, so that informed risk-judgments can be made.) If we cannot do this better, we will face unnecessary dangers, and will likely slow or prevent effective development and acceptance of AI use cases, thus precluding our country from taking advantage of the full benefits that AI-based decision analytics and other applications could bring – even while others are sure to forge ahead regardless.

AI-related research also needs to do more to address the question of how to preserve appropriate levels of privacy for the data that populates the large-scale data sets that feed into AI applications. This, too, is not an area that has been given enough attention by existing commercial R&D investments, in part because the business model of so many of the companies involved revolves around marketing the data they acquire from platform users. For large-scale data analytics in other arenas such as healthcare, however, we will need better ways to do data analytics at scale while preserving appropriate privacy protections if AI is to reach its potential.

Better-engineered privacy protections that facilitate rather than impede "Big Data" analytics could also be a partial answer to what some observers fear may become a Western commercial disadvantage vis-à-vis China in the AI realm. The People's Republic of China (PRC), of course, cares infamously little for privacy protections, and feels free to take maximum advantage – in its own AI work – of the massive datasets available from its domestic technology-facilitated surveillance state and from the overseas operations of its government-overseen technology companies. Western concerns for privacy protection and individual rights preclude emulating China's degree of heedless promiscuity in massive, cross-sectoral data aggregation in support of AI development, but AI research may yet be able to provide ways of closing the competitive gap without sacrificing our values.

This is, therefore, another promising arena for federal R&D attention, and in particular there is a need for innovative forms of partnership between U.S. stakeholders in industry, government, academia, and the FFRDC community. Artificial Intelligence is likely to be a source of power and prosperity only for countries that are able to marshal the R&D resources needed for success across this emerging technology space, and who can mobilize public-private collaborations to help ensure the fairness, interoperability, privacy, and security needed in order to harness this critical technology. Effective federal efforts here could facilitate across-the-board progress in AI applications that will likely have enormous societal benefit, catalyzing technology solutions to broad AI "technosystem" challenges where the private sector is unlikely to do so on its own.

C. Biotechnology

Synthetic biology is a promising new arena in which biotechnology can be harnessed for new uses in helping solve a range of problems and meet needs in the broader economy of materials and things, such as through engineering (or reengineering) bacteria to produce novel materials – at the very least to meet requirements in niche supply chains, or perhaps eventually even on a large scale – or by using cells in information-processing systems, or as sensors. It has been described as "a disruptive technology at the heart of the so-called Bioeconomy, capable of delivering new solutions to global healthcare, agriculture, manufacturing, and environmental challenges."[44]

What this sector still lacks, however, is an open, scalable architectural model suitable for adoption and utilization by an emergent ecosystem of synthetic biology beneficiaries, as use cases for such technologies accumulate. To be sure, there is increasing private sector investment in the development of "bio-foundries," but these efforts generally involve highly proprietary approaches and are capital intensive enough to restrict their availability primarily to large players. Federal support, however, could help ensure the development of open-source design specifications for the integrated bio-design environment and computational infrastructure for a "model" bio-foundry – also supported by R&D funding devoted to such things as the development of better computational tools for the design of biological systems and improved, high-throughput and non-destructive measurement technologies for bioproducts.

Making such an effort part of a broader federal R&D push could provide the key to unlocking involvement in the emerging bioeconomy for a much broader range of participants, bringing smaller businesses and institutions into a sector that might otherwise tend to favor larger-scale operations by well-heeled players. By helping lower entry barriers and facilitate the emergence of numerous, bespoke foundries – each dedicated to user-defined applications that satisfy niche customer needs – this effort could bring about a sort of nationwide "democratization" and geographic decentralization of next-generation bio-manufacturing.

D. Climate and Energy

The Biden Administration has made science-based climate policy perhaps the single highest-profile, "signature" piece of its policy agenda, and the central plank of this effort is climate change mitigation: the effort to reduce greenhouse gas emissions. It is likely to take some time to bring these emissions down to targeted levels, however – and even those levels themselves will not soon reverse the significant climate effects that have occurred to date, nor necessarily prevent dangerous change-accelerating feedback loops spurred by what is already underway.[45] Accordingly, U.S. climate policy should also focus upon the challenges of adapting to existing changes in the global climate, and what to further change proves unavoidable.

As the cascading problems recently created by abnormally cold weather in Texas and wildfires in California already illustrate, more work is needed to understand and improve resilience in the face of climate-related events. Because these challenges clearly create systemic vulnerabilities within the interconnected networks of the U.S. economy and critical infrastructure components, it will not be enough for the government to approach this on an agency-by-agency basis, nor in a "stovepiped" fashion in any given sector of the broader economy.

Current U.S. efforts to approach these problems usually emphasize "macro" level policies such as Paris Agreement emissions targets and "micro" policies related to how climate change affects specific federal agency missions. They still tend to devote too little attention, however, to "meso"-level questions, where uncertainties and risks exacerbated by climate effects cross organizational, jurisdictional, and "mission" boundaries, and threaten to create particularly unpredictable and hard-to-remediate "cascade" effects. Yet this "meso" environment is often where the most challenging tradeoffs must be made in risk-mitigation and resilience decision-making, and where prioritization decisions are likely to be most difficult. Unfortunately, analysis and effective policy development in this zone is generally neglected, being too broad and cross-cutting to occupy any particular agency's expertise and attention (or that of any given private sector actor), but too complex and data-intensive to be addressed by existing government- or system-wide approaches.

To help fill this gap, more effective federal support is needed to develop improved approaches to understanding "meso"-level systems effects in support of adaptation and resilience strategies. This could include, for instance, broad efforts to collect, to facilitate access to and analytical exploitation of – and to develop sophisticated decision-support tools on the basis of –the myriad cross-cutting datasets that will needed in handling such systems-level challenges. (This might, for instance, involve building an environmental resilience framework to help with climate-related threat modeling, vulnerability analysis, and risk assessments, thereby facilitating effective prioritization and optimization of investments, as well as collaborative information-sharing between all who are involved in devising and implementing resilience and mitigation strategies.[46]) The kind of national-level "platform" approach advocated in this paper could play an important role in helping make this happen.

E. Cybersecurity Technology

The arena of cyber technology – and, more specifically, cyber security – cuts across and affects many of these critical technology areas (*e.g.*, AM, post-Quantum computing, AI, and microelectronics), and is also central to other critical issues identified in this paper (*e.g.*, supply chain security). The sheer scale of cyber-facilitated intellectual property theft has ensured that cybersecurity is already an important priority in private sector R&D investment, but there are still roles for the federal government to play in helping meet needs that are unlikely otherwise to be addressed.

To begin with, for instance, there is as yet still very little understanding of how effectively and systematically to undertake national-level investment prioritization in cyber-related R&D, nor much understanding of what the return on investment (ROI) is for such spending. Indeed, it is still remarkably hard to have confidence in the overall rate and value of intellectual property (IP) theft that occurs, and hence also to provide useful baselines for developing performance metrics with which to assess our collective success (or otherwise) in slowing this bleeding. More work is needed on this, especially on a cross-sectoral basis at the national level, and this kind of high-level focus is something that only a government-driven R&D effort can provide.

Areas that could use additional federal support, moreover, also include the certification of cybersecurity tools. The U.S. National Security Agency already provides a valuable service in helping to assess the efficacy of cybersecurity tools once they are already on the commercial market. There is as yet, however, no mechanism for helping build in such quality assurance integrally, during the pre-market stages of tool design and development. More could perhaps be done in this respect.

Additionally, more is needed to help ensure the scalability of cybersecurity answers both "up," as it were, and "down." It is not enough to develop extremely sophisticated answers to high-end cyber threats if these tools and methods will only be affordable for the largest private sector players.

(IP theft, after all, occurs at all levels, and by no means restricts itself to institutions lucky enough to maintain a well-resourced, high-end cybersecurity staff.) It is also an inadequate answer if even the most cost-effective tools are likely to be easily and quickly undermined by failures in basic cyber hygiene protocols – which is all too common, in everyday practice, across the universe of network users.

More attention should thus be paid to the development of solutions that can cost-effectively be employed even by smaller market participants, as well as to means by which ordinary "default" levels of cyber hygiene compliance can be improved. This will require not just software design but broader, higher-level "systems" thinking informed by behavioral science. The federal government should encourage more such work.

Cyber-related solutions may also be an important part of meeting urgent challenges in arenas such as supply chain security, particularly in market contexts in which globalized relationships and a highly decentralized and diverse universe of providers make it difficult to preclude the involvement of an untrusted vendor or malicious intrusions. In the often opaquely multi-player and combinatorial software supply chain, for instance, the recent "Solar Winds" hack suggests the importance of developing and implementing a standard scalable, interoperable "software bill of materials" (SBOM)-based supply chain metadata approach, in order to track the composition and provenance of every component in a software product, provide metadata integrity for each component, and use that metadata to systematically characterize and manage risk. It may be that there is no way to develop such architectural assurances across the entire software ecosystem without federal direction.

F. Health Informatics

As the SARS-Cov-2 catastrophe of 2020-21 demonstrates, the effective and large-scale use of health informatics can be critical to helping manage high-consequence events such as a pandemic. Yet there remains important work to be done on ensuring the interoperability of health data sets for effective data-sharing across the health sector lest we miss important opportunities to leverage advancements in informatics, genomic sequencing, and clinical care in driving discoveries and innovations in "personalized" medicine for all.

Work is being done on this in the private sector, and the federal government has invested in regulations related to health system interoperability, but we can yet do more to build upon existing foundational work on advanced health surveillance, as well as to support the development of robust networks and coalitions of health systems that can deliver rapid insights into clinical and genomic outcomes.

We are still far from ensuring privacy-compatible interoperability and effective data-sharing across the health sector as a whole. The U.S. healthcare landscape remains rife with incompatible technology standards, software, and systems, and this can lead to missed opportunities by undermining clinical quality measures, clinical decision support, health risk assessment, transfer of patient health records across organizations, and patient- and population-level analytics. Improvements in this area would permit more effective responses in a range of health-related questions, not merely in epidemiology but also more generally in understanding (and modeling) the community-level health effects of policy and program changes and in evaluating and communicating risks and strategies for prevention and treatment, as well as in developing tools and metrics to study and monitor risks, exposures, disease progression, and population health outcomes. More effective ways to draw upon and understand patterns in real-world health data and records – and to employ such analytics in support of efforts to assess the efficacy of new medicines or other treatments – would also be of enormous benefit in facilitating timely responses to whatever is around the corner in the "next" pandemic.

G. Microelectronics

At present, the United States is the world leader in microelectronics chip design, and much work is underway in the private sector on the technologies that will contribute to the "next-generation" state of the art. We also still lead the world in a range of microelectronics technologies not used specifically for computation, including optical materials, advanced materials for radiofrequency sensing and communications, and other such things. The United States remains in an excellent position in some aspects of the global competition in microelectronics, and is by far the world leader in semiconductor R&D.

Nevertheless, the U.S. industry also has significant weaknesses in other aspects. For one thing, it suffers from workforce challenges of the sort discussed, more broadly, elsewhere in this paper. A survey conducted in 2017, for instance, found that 82 percent of semiconductor industry executives reported a shortage of qualified job candidates, driven by an insufficient number of U.S. students completing advanced degrees in relevant fields and possessing relevant skills, as well as difficulty recruiting foreign students trained at U.S. universities.[47]

Supply chain security is another pressing challenge, particularly given that each segment of the global supply chain for semiconductors reportedly directly involves an average of 25 enterprises from 23 countries, making it potentially subject to disruption from unforeseen events, or as the result of deliberate compromise or denial.[48] Furthermore, microchip foundries are gradually being consolidated into fewer and fewer locations – now principally outside the United States – and we have become enormously dependent upon foreign providers, principally in China, for the packaging of chips into the form factors that are assembled into larger systems, and for the manufacture of many constituent parts, as well as for overall device assembly.

The U.S. semiconductor industry, moreover, has only limited flexibility to adjust production capacity across vendor product lines in the event of supply chain problems. It also has no manufacturing capacity at all for some types of cutting-edge lithography tools, and minimal capacity in outsourced assembly, packaging, and testing, with the result that even if the United States were to onshore foundries to increase domestic manufacturing capacity, it would still have critical downstream supply chain dependencies on China – as well as Taiwan, which is increasingly threatened by Chinese belligerence.[49] At the same time, previous U.S. Government efforts to support onshore "trusted" fabrication for particularly high-consequence components are falling steadily behind the commercial state of the art even while becoming prohibitively expensive, while federally supported "zero trust" supply chain concepts and "secure by construction" design and fabrication techniques remain still in their infancy and commercial incentives in a highly competitive private sector do not yet fully align with the trust architectures that will likely be required in the future.

Given this potential fragility, it will be essential to ensure systematic identification, prioritization, and mitigation of associated risks and the implementation of state-of-the-art supply chain risk management. We need to establish an effective supply chain monitoring and resilience capability in order to provide persistent situational awareness around each element of the semiconductor supply chain – from the sourcing of materials all the way through later phases such as design, production, and transportation.

Finally, the semiconductor industry – despite its world-leading R&D – suffers from some of the problems discussed earlier in this paper with regard to the "chasm" between basic research and later stages in the commercialization of new technology. Specifically, there remains a substantial gap in the industry's ability to rapidly and effectively to translate fundamental research into prototyped, developed capabilities deployable at commercial scale. To date, there is no existing entity with the mandate, resourcing, and cross-sector reach necessary to develop promising research projects to the point of maturity where they can be adopted by industry, and to engage with major semiconductor customers from substantial end-markets (*e.g.*, large technology companies and consumer electronics firms) to inform investment priorities.

U.S. industry and our country's future competitiveness thus face profound "technosystem" problems in microelectronics, in response to which we must think through a national investment strategy to meet challenges. We are likely in need of federal catalysts, for instance, for new "secure-by-construction" tools and processes in order to address sidechannel security concerns and ensure a fully trusted supply chain. Because the answers to the security and strategic manipulation threats presented by untrusted supply chains originating in or passing through China are unlikely to be purely "American" answers, moreover, the U.S. Government has a critical role to play in building international partnerships with like-minded countries so that these challenges can be met on a collaborative collective basis.

H. Quantum Information Science

Quantum computing is today receiving considerable funding from private sector entities each eager to be the first to produce workable postclassical computational designs; foreign governments such as that of China are also pouring colossal sums into such work. These funding sources dwarf what the U.S. Government has hitherto supplied.

Even in the current federal R&D environment, however, more funding is being provided on basic research in the Quantum field than on questions related to the myriad "technosystem" issues of applied engineering, commercialization, and workforce strategy that will be needed in order to make Quantum computing a reality and catalyze new use cases for it across the global economy. (It is also possible that Quantum funding suffers from a "Holy Grail" effect, with more researchers directly chasing the arguably still distant goal of a general purpose Quantum computer than doing more incremental and elementary work on how to control and operate Quantum systems in general – *e.g.*, learned through work on things such as Quantum sensors – of the sort that will give us the skills and understandings needed to devise and implement Quantum applications as the field matures.) Here again, therefore, as in so many other areas we have addressed in this paper, thinking about "technosystem" questions and the challenges of "translating" basic science insights into transformative use cases lags behind, and "systems thinking" will need to be applied across broad sectors with genuinely national-level focus. Only a collaborative, federally overseen effort is likely to be able to ensure this.

Among such "technosystem" issues will be the formidable challenge of what happens to "legacy" datasets and communications when workable Quantum decryption becomes available – and with its extraordinary processing power makes mincemeat of most existing cryptography and data-security architectures. Preparing for life in a Quantum world, therefore, will entail a prioritized build-out of "post-Quantum cryptography" (PQC) in a way that up-guns existing cryptographic algorithms to levels, and forms, that are likely to be resistant to Quantum computer attack in ways and to degrees that few, if any, current approaches are. (By definition, moreover, this work will need to be done *before* Quantum computing becomes available to any untrusted actor – which is to say, soon.) The federal government has an important role to play here, beginning with the establishment of validated PQC standards toward which public and private sector actors alike would thereafter be expected to build; such work is underway today, but it must be brought to fruition.

I. Telecommunications

Finally, the competitive challenges facing the Western telecommunications sector from state-subsidized Chinese firms such as Huawei – which, with assistance from such subsidies and also the benefit of IP theft, has been underselling suppliers elsewhere in the world[50] – have thankfully been becoming increasingly well understood. It is already, and should continue to be, a priority for U.S. leaders and officials in likeminded democracies to ensure that cost-effective future telecommunications networks remain available from trusted suppliers who can be relied upon not to use control of such networks for industrial or other espionage, and not to cut off or manipulate access to those networks as a tool of strategic and political influence.

Beyond the (admittedly enormous) importance of preventing *de facto* instrumentalities of the Chinese Communist Party from taking over fifth-generation (5G) networks around the world, however, it should also be a focus of federal R&D and technology governance policy in the United States to ensure the creation and maintenance of a U.S. technology "technosystem" that is as conducive as possible to the build-out of 5G-and-beyond telecommunications networks and applications in the years ahead, and to ensure that the standards and architectures for such technologies support safe, secure, and reliable functionality in ways consistent with Western values (rather than those of the authoritarian PRC surveillance state).

In economic and societal terms, the greatest benefits of 5G technology will likely derive not from the existence of such high-data-throughput networks per se, but rather from what such connectivity permits in terms of the improvement of existing wireless applications and the development of new use cases across an array of emerging areas in tomorrow's 5G economy.[51] Just as the development of 4G networks led to the rise of a new array of unforeseen new markets, products, services, and growth opportunities, so will 5G empower new and critical services that one can probably not predict today – but that will probably be responsible for most of the aggregate societal impact and value of 5G connectivity.[52] In yet another example of how "technosystem" thinking is essential for America's success in the mid-21st-century technology economy, ensuring the development of an innovation-conducive marketplace for these follow-on applications must therefore be part of the United States' telecommunications strategy. Our collective efforts, in other words, must go beyond simply facilitating the provision of cost-effective build-out of 5G networks in themselves.

As for the technologies involved in creating that connectivity, it may also be possible for federal R&D support and incentives to encourage evolution of 5G networks away from the traditional "telco" model – in which large providers operate networks in portions of the electromagnetic spectrum purchased from the government – into forms more conducive to innovation over the long term. It is also likely that such shifts would benefit the long-term competitive position of U.S. industry.

Such a future architecture would likely be a much more "cloud-native" approach, based upon the seamlessly integrated use of multiple entry points to cloud-based functions that are themselves connected by a core network, but in which the bulk of the actual computing that occurs would be pushed much closer to the "edge" of the system than is the case today. "Virtualizing" as much of the radio access network (RAN) as possible would allow transition to the much more widespread use of general-purpose servers and switches instead of purpose-built hardware, permitting the network to be far more dynamic and adaptable, facilitating faster innovation, avoiding vendor lock-ins, ensuring supply security, and perhaps even lowering cost.[53]

Such evolution would also play to U.S. competitive strengths in cloud-based services, software development, and higher-end commodity servers, thus having the benefit not merely of speeding the development of transformative 5G applications but also of blunting the state-sponsored advance of China's state-sponsored technology giants. At the same time, such an evolution of 5G networks could help lay the foundations for a further evolution into 6G technologies and beyond – which, by allowing further massive increases in data volume and effective utilization of "edge"-based computing, have the potential to revolutionize human-machine interactions and lead to the development of new use cases across the technology economy just as 4G did for person-to-person communications and 5G is beginning to do for machine-to-machine connectivity.

Governance Issues in the U.S. Innovation "Technosystem"

Beyond the development of a new platform for coordinating support for S&T innovation, the U.S. innovation system would also benefit from other reforms or adjustments. The following pages outline six measures that should probably be part of a new national S&T agenda.

A. Technology Standards

The federal government has long played a critical role in the establishment of standards to help guide, channel, and facilitate the widespread adoption of technological innovation. This is important both at home, through institutions such as the National Institute of Standards and Technology (NIST), and abroad in various multinational fora.

Domestically, federal engagement with industry and academic partners in setting such standards can be a powerful catalyst, preventing market fragmentation into interoperable technological "silos" based upon incompatible standards that can retard the development of innovative applications and the discovery of novel use cases. Effective standards can also help unlock powerful new potentialities by promoting public confidence in emerging technology applications, and in setting baselines that permit better and safer collaboration across the innovation ecosystem.

Recent examinations of the innovation economy, for example, have stressed the importance of setting wireless telecommunications standards,[54] of ensuring the safety and security of autonomous systems, and of ensuring accuracy, integrity, and appropriate privacy protections in the employment of the large, cross-cutting data sets that will be vital to next-generation data analytics and decision-support tools, safe and unbiased AI systems, and to any number of evolving "Big Data" use cases in the future.[55] Setting appropriate standards may also be important in protecting intellectual property in more decentralized, "open" models of technological innovation that allow the safe capture of value from research and development work undertaken abroad, especially in connection with promoting the development of more robust, resilient, and "trust"-worthy technology supply chains (see below).[56]

Abroad, effective standards-setting is today doubly important because of the emphasis placed by America's technological competitors – and, in particular, China – upon acquiring influence within international standards-setting bodies and using that influence to set rules designed to tilt the international playing field in favor of their own firms and against Western ones. As Rasser and Lamberth note, China is pursuing "a comprehensive strategy to have Chinese-origin technologies be the foundation for global technology platforms and reduce its dependence on foreign intellectual property (IP) and standards," and more forward-leaning and leadership is needed from the United States and other technologically advanced partners in response.[57]

American leadership in these regards has, in the past, helped preserve U.S. technological competitiveness, and has been a crucial ingredient for widespread innovation and the safe and effective adoption of new technologies in many areas.[58] Today, in light of the Chinese challenge, more is likely needed in this vein, in order to ensure appropriate "norms for the responsible use of technologies consistent with liberal democratic values," including "foundational and emerging technologies and their broad application such as for AI, surveillance technology, and cyberspace."[59]

B. Incentives

The issue of tax incentives for innovation-fostering R&D is beyond the scope of this paper, but it is worth noting that historically, in addition to what it spends on such work directly, the federal government *indirectly* finances billions of dollars in R&D spending through tax preferences for R&D in the private sector, tax deductions for charitable contributions to institutions of higher education and nonprofit organizations, reimbursements on government procurement contracts, and grants-in-aid to graduate students and postdoctoral fellows.[60] In light of this history, various commentators have urged the U.S. Government to improve present-day tax incentives for R&D, such as by increasing the R&D tax credit – which in the United States is now said to be "smaller than that of most member countries of the Organization for Economic Co-operation and Development."[61]

C. Supply Chain

As too many sectors of the U.S. economy have discovered – and as discussed more specifically above with regard to microelectronics – it has also become clear that many U.S. supply chains are "dangerously brittle and present vulnerabilities that must be addressed."[62] The globalized extension of supply chains in the technology economy over the last generation has produced important benefits from specialization and economies of scale, but it is now apparent that it is possible to have *too* much cost-optimization if it comes at the expense of systemic fragility. Today, it is increasingly obvious that at least some critical sectors face dangerous vulnerability to disruptions that may be either inadvertent (*e.g.*, natural disasters, pandemics, or other such calamities) or deliberate (*e.g.*, embargos or other restrictions employed as tools of influence), as well as from corruptions or manipulations either by criminals or by state-level actors as a tool of strategic policy (*e.g.*, the insertion of corrupt hardware or software).

Such supply chain concerns have been particularly prominent in the telecommunications sector,[63] and they have become almost shockingly acute in the software supply chain in the wake of the infamous "SolarWinds" hack involving insertion by the Russian foreign intelligence service of malware into the networks of thousands of U.S. companies and government agencies through an audacious compromise of the cybersecurity software supply chain.[64] Nevertheless, they apply across a number of technology fields. Finding answers that add security while not choking off the benefits of widespread cost-optimal sourcing, and without requiring that supply chains always be laboriously and uneconomically re-created "onshore," will be challenging, but this is essential. For both economic and national security reasons, such supply chain concerns deserve heightened and enduring U.S. federal attention.

Such work, both at home and abroad, may be especially important in the years ahead to the degree that the private sector continues recent trends toward "open" networks for knowledge acquisition. As some writers have suggested, now that some "three-quarters of new knowledge [is being] generated outside the United States,"[65] much of the American private sector has been "transitioning from closed to open innovation" and needs to learn how to "embrace external ideas and knowledge in conjunction with internal R&D."[66] (Such trends may already be even more established overseas – with Japanese industry having for years employed intercorporate alliances and cross-licensing to help firms acquire elements of the technology matrix needed by individual firms.[67])

This increased reliance upon non-local sources of knowledge has clearly had enormous benefits, but it can also create vulnerabilities. The challenge for public policymakers is to help participants in such "open" knowledge architectures devise and implement ways to operate them safely. Remembering Adam Smith's dictum about the importance of defense relative to opulence,[68] it is certainly possible that there might exist truly essential elements that, in effect, *must* be retained (or reclaimed) "onshore" if a country is not to court disaster.

But the remedies need not always be so drastic. In some cases – especially if sufficient attention is given to "technology diplomacy" in constructing collaborative partnerships with government and industry in likeminded states – it may be possible to cut untrusted suppliers out of the supply chain by replacing them with trusted partners. In other cases, it may even be possible to implement architectures that provide appropriate transparency and trust in products themselves, even if one might have "zero trust" in their providers. (In this respect, *trust in supply* is a better mantra than just *trust in supplier.*) Such technological responses will also likely need to include the development of a new, end-to-end framework for ensuring the integrity of software supply chains – one that manages risk through standardized Software Bill of Materials (SBOM)-based supply chain metadata, improves code and component signing infrastructure, and hardens the software build and distribution infrastructure.[69] The answers will surely vary from one area to the next, but in an "open knowledge" era, supply chain integrity and resilience will clearly need to be a high priority.

D. Technology Controls

Because of the importance that both licit and unlawful technology transfers continue to play in China's technology and national security strategy – with cyber-facilitated intellectual property theft already constituting what former U.S. National

Security Agency Director Keith Alexander has called "the greatest wealth transfer in human history" – the federal government also has a vital role in ensuring appropriate regulation of technology transfers. Circumspection is needed here, of course, because the free flow of ideas is one of the engines of innovation and technological progress, to the collective benefit of all. But it is nonetheless important, for both national security reasons and those of overall competitiveness, to deny opportunities for technology theft – and to punish such theft where it is discovered, thus lowering the incentive to engage in such activity in the future – as well as to prevent transfers of *especially* sensitive items or know-how to one's competitors, particularly where such information is likely to be used to the would-be recipient's military and geopolitical advantage.

This challenge can and should be approached in a number of ways, including through improving the sophistication, scalability, and accessibility of robust cyber defenses and crafting better IP theft-related technology standards. It must include, however, close attention to thwarting key aspects of our competitors' technology-acquisition strategies through effective export controls – not only on high-technology items and materials, but also upon intangible "deemed exports" – undertaken both on a national basis and in close coordination with an ever wider group of likeminded technology possessor countries in Europe, East Asia, and elsewhere.[72]

E. Oversight and Auditing

Any expansion of federal R&D funding across a broad swath of technology areas should be accompanied by efforts to ensure that federal R&D spending is appropriately accounted for. This certainly does not mean the creation of unwieldy and constraining bureaucratic mechanisms. If the government is to play an effective role in prioritizing federal support and ensuring that programming fills real gaps in the existing U.S. innovation model, however – rather than simply duplicating what can be done as well or better elsewhere – it will be important to ensure visibility into the various ways in which taxpayer money is being spent across the federal system. Appropriate oversight and accountability across the range of federal efforts, therefore, should be built into the new federal S&T agenda from the outset.

F. Supporting Workforce Quality

It is also critical to remember that the role of America's universities in the innovation ecosystem is hardly limited to actually conducting research: they also train our future innovators. Yet at present, the United States does not produce as many high-skilled members of the Science, Technology, Engineering, and Mathematics (STEM) workforce as it needs.[73] (This challenge has already been mentioned, for instance, with regard to microelectronics, but it is unfortunately a much more general problem in the S&T arena.)

For this reason, writers who have explored America's current innovation needs and competitiveness challenges touch almost invariably on workforce management issues and questions of human capital strategy for training and job skills across the entire value chain – not merely in terms of training more Americans (and training them more appropriately for enduring survival and success in a rapidly changing technology environment) but also in attracting and retaining the best talent available *overseas* as well (with due concern for technology transfer threats in areas of special sensitivity).[74] This may be particularly important given the nature of what Rasser and Lamberth have described as "meeting the China challenge," which they pointedly analogize to the "Sputnik" moment of 1957, which led to the passage of the National Defense Education Act (NDEA) of 1958 to expand such things as federal funding in education, and student loans for STEM training.[75]

It would be a mistake, moreover, to think of these issues solely through the prism of STEM training in higher education, for formidable future-workforce challenges also exist with regard to creating and sustaining the human capital needed to take advantage of innovation opportunities in areas such as networked, bespoke, next-generation manufacturing, and in other aspects of America's future innovation economy. Particularly in a context in which time-to-market figures for the transition of new technologies from initial innovation to large-scale commercial uptake have been collapsing since the early 1900s, ensuring that our S&T workforce – broadly construed – has the agility to succeed on such timescales will also be vital.

This also suggests an important federal role in ensuring the large-scale build-out of the digital connectivity that will be needed for Americans – far beyond merely those located in a handful of high-technology "corridors" or "hub" areas – to take advantage of such opportunities and thus help decentralize innovation and its translation into economic productivity, growth, and job creation. Thus are issues of access and equity in the digital economy linked to the creation of a more productive innovation ecosystem.

Such a push for innovation-facilitating workforce programs can be distinguished in significant ways from past exhortations to develop a full-blown U.S. industrial policy. (See Appendix II.) Whereas, historically, many industrial policy agendas seem to have been driven by a desire to protect faltering industrial sectors or to lessen the socio-economic impact of market-driven disruption on particular communities,[76] a 21st-century workforce innovation initiative would have as its conceptual driver not specifically the need to ameliorate the impact of disruption but instead the ambition to foster innovation and overall economic competitiveness. If successful, of course, such a federal policy – analogized to the NDEA of 1958, perhaps – would likely indeed have considerable ameliorative impact, inasmuch as it would help a wider swath of Americans participate in the innovation economy. The lodestar of such an effort, however, would be the need to accelerate disruption, at least for others, in the sense that such initiatives would help the American economy thrive and would increase U.S. competitiveness vis-à-vis foreign challengers at a difficult time of rapid technological innovation and geopolitical competition.

"Horizon Strategy" Less as "Apollo Program" Than "Athena Agenda"

The Biden Administration's proposed overhaul and expansion of federal R&D funding – as part of a bold new vision for U.S. science and technology policy re-thought from the ground up in the Vannevar Bush mold – comes at a critical oint for the future of the U.S. innovation ecosystem and our country's competitiveness. Such a new initiative is needed indeed.

As Appendix I shows, we have no shortage of organizational models upon which to draw as the United States builds a new national "horizon strategy" to boost its innovation economy and meet the technology challenges presented by China's belligerently self-aggrandizing rise. Whatever the details of its execution, however, it is clear that the backbone of this new U.S. effort must be some form of public-private partnership (PPP).

What's more, such a PPP approach – or, more likely, network of PPPs, for this agenda is likely to call for different partnerships between governmental, private sector, academic, and FFRDC stakeholders depending upon the area of technology in question – will need to be of unprecedented complexity. As outlined in Appendix I, there are many historical examples of PPPs being formed to address specific technology challenges, from high-mileage cars to semiconductor fabrication, and from nanotechnology to next-generation telecommunications. What we so far lack, however, is precedent for a PPP architecture – presumably under some loose federal aegis at the level of the NSCT, OSTP, or NSF, in order to ensure some broad overall coordination and situational awareness – that stretches across the great swathes of variegated technological endeavor that we have discussed in this paper.

Building such a new system will require both haste and very careful circumspection. But doing so is essential, for without such a structure, federal policy interventions and PPP efforts to support the innovation economy will likely address national needs only haphazardly, perhaps leading us actually to miss our collective mark as we try to take advantage of emerging-technology possibilities and remedy the market failures outlined herein. The new federal effort, therefore, must begin with a *conversation* – or more specifically, a series of discussions, presumably convened by top-level federal S&T policy officials, but involving as principal participants a wide range of stakeholders across the public, private-sector, academic, and FFRDC innovation space – in order to begin working through how we can collectively organize ourselves to these ends.

This process of discussion and collaborative PPP self-organization among American stakeholders will be critical, and it is in important ways both conceptually and procedurally *antecedent* to the process of actually trying to identify and allocate funding and attention to the most promising technology opportunities. This voluntary process, moreover, may not be easy or swift, making it all the more essential that we begin promptly.

Yet despite the difficulty and complexity of such self-organization, the voluntary character of the process is vital. We may be organizing ourselves in response to the challenges presented by Beijing's aggressive, state-sponsored model of technology development, but we neither can nor should model our own answer upon China's authoritarianism.

In responding to the challenge of Beijing's strategy – one, as we have seen, of anointing "national champions" and showering them with market-distorting state largesse in order to crush foreign competition, and of coercing private-sector entities to support the "fusion" of the country's civilian technology sector with its defense industrial base in order to make both into *de facto* instruments of Chinese Communist Party power – we must develop a distinctly *American* answer. We need an organizational approach, therefore, that remains true to our own values by eschewing such coercion, instead hewing to a more collaborative and voluntary model of collective endeavor. To accomplish this, the conversations required to bring these myriad U.S. partners on board must begin immediately.

All of this, we are convinced, can indeed be done if the new U.S. administration promptly takes the lead in beginning such a collaborative dialogue. This technology agenda may lack the single, iconic focal point of "putting a man on the Moon" that captivated America's attention and called forth the best of our creativity and industriousness during the Apollo Program, but it is in its own way a "moonshot" nonetheless. In an age of emerging technologies likely to be as disruptive as they are transformative, we face the limitations of our current domestic innovation economy even while encountering competitive pressure from a geopolitical rival determined to subsidize and deploy such technologies for its own self-aggrandizement – and to the profound disadvantage of the United States and its allies, and indeed democratic societies everywhere. This perhaps not quite another "Sputnik moment," but it is a formidable challenge all the same.

For we do stand at a transformational moment across the entirety of the innovation economy. This is the case not merely in terms of what these new technologies permit humanity to do in the world, but also in terms of how emerging tools – in such fields as computing capacity, data analytics and decision-support, telecommunications connectivity, and AI – may help us better *understand* that world and its complexities, employing "system of systems of systems" approaches to meet extraordinarily complex challenges in critical arenas such as climate, energy, national security, and healthcare.

Perhaps we should thus turn from the flashy imagery of the Greek sun god to a deity more suited to the task ahead of us. Today's technology agenda calls less for the drama of Apollo and more for the broad-mindedness and creativity of an Athena – the goddess of wisdom, justice, and strategy who was, moreover, patroness of the world's first (more or less) democratic polity, the great eponymous city of Athens. President Biden has the opportunity to launch an "Athena Agenda" to revitalize the U.S. innovation base and enhance America's competitive posture. We hope this paper will help inform and contribute to such an effort.

Appendix I

Organizational Models for National Innovation Partnership

Various models exist upon which one might draw today in building such an innovation platform. There is much to learn from, therefore, though we must also be careful to adapt the platforms organizational form to today's needs and not simply reflexively copy what appears to have worked in the past, in different circumstances and with different participants.

1. U.S. Federal Precedents

Traditionally, innovation initiatives in the U.S. federal system during the "golden age" of post-Sputnik science were often managed through the creation of new federal institutions. Some of these operated on an epic scale. Perhaps most famously, of course, NASA ran the "Moon shot" of the Apollo Program, with spending levels that – at its peak – amounted to nearly 4.5 percent of the entire federal budget.[77] Similarly, by 2008, the National Institutes of Health (NIH) alone was responsible for funding nearly 30 percent of all medical research in the United States.[78]

Yet such federal efforts have most often been task-specific, and tied to a particular sponsor or discrete mission, such as the Defense Advanced Research Projects Agency (DARPA) for the Department of Defense, the Advanced Research Projects Agency-Energy (ARPA-E) for the Energy Department, the Intelligence Advanced Research Projects Agency (IARPA) for the U.S. Intelligence Community, the national laboratories (among them Los Alamos, Livermore, Sandia, Oak Ridge, Idaho, Brookhaven, Pacific Northwest, and Argonne) that report to the National Nuclear Security Administration (NNSA) or other portions of the Department of Energy, and various FFRDCs that do work for specific federal sponsors. Institutions with genuinely national-level, cross-sectoral focus are comparatively rare.

Federal instrumentalities are often good at integrating different disciplines and private sector and academic partners in order to answer agency-specific needs, especially where basic technology already exists, even if it is relatively unexplored and requires much improvement.[79] ARPA-type models are felt to be at their best "when pursuing defined technical goals in areas with either clear customer demand or existing expertise."[80] They sometimes struggle, however, to move beyond incremental advances into "transformational change,[81] and when they are "asked to translate research projects into programs of record or sustained development projects." "A national research and development agency," David McCormick and his co-authors note, "would need to overcome both these obstacles."[82]

Among federal organizations, however, a conspicuous exception to this mission-specificity can be found in the very broadly focused National Science Foundation (NSF), which by 2003 was providing about 20 percent of federal support for basic research conducted in academic institutions around the country.[83] This has led some to suggest the possibility of expanding NSF's mission and funding, or at least to use its organizational model to anchor or inspire a new institution – *e.g.*, an independent agency operating at a high level across the landscape of federal departments and agencies, a new FFRDC, or a consortium of such organizations.

2. Foreign Approaches

It is also worth being aware of – and able to learn from – approaches to innovation challenges that have been taken in other countries. One should avoid slavish emulation, of course, as this historically tends to fare poorly: each country must devise an approach that plays to and leverages its strengths, and innovation models are not always transferrable from one context to another. In the history of industrial policy debate, there is often a temptation simply to try to copy the methods adopted by one's economic and technological competitor, but merely copying the competition is rarely a recipe for long-term success, let alone dominance.

It is also critical to bear in mind that in the mid-21st-century context, the main competition comes from the People's Republic of China – a country whose competitive strategy we surely do not wish to emulate, inasmuch as it is built upon a foundation of authoritarian oppression, which is leveraged to coerce compliance with the government's "whole of system" strategies. To be sure, such a model has some strengths in terms of permitting consistent focus over time and in largely precluding deviations from plan. These are not things, however, that are necessarily conducive to success in dynamic innovation over the long term, and adopting methods of Beijing-style socio-economic coercion is not an available option for a developed democracy in any event. Instead, we need a competitive strategy of our *own,* tailored so as to play to our particular strengths and to remedy our particular weaknesses, and that is consistent with our values.[84]

Nonetheless, there may still be things we can learn from foreign efforts to support competitive technology innovation, particularly from how these challenges have been approached in other developed democracies. German federal programs, for instance, have traditionally involved direct research support for various industries, such as aerospace, energy, and electronics. Most of this support, however, tends to be "channeled through intermediary institutions, research institutes, or the trade associations," and has often been "balanced with programs to encourage small firms to incorporate generic technologies – including microelectronics, sensors, and some micro machine technologies" in ways "open to any firm that fulfills formal eligibility criteria" and that are intended to "avoid overturning market signals."[85] (The German approach is also said to have focused heavily upon achieving quantitative success metrics, such as increasing the gross value-added share of manufacturing across key industrial areas to meet specific percentage targets.[86])

This seems to have had some success in encouraging technology *uptake*, and in keeping German industry in a good competitive position in things like high-technology manufacturing, and may indeed offer lessons for the United States with regard to vocational upskilling or re-skilling to take advantage, on a geographically disaggregated basis, of next-generation manufacturing technologies. It is less obvious, however, that the German model is well suited to driving broad change across an entire interdisciplinary and cross-sectoral landscape.

For its part, France has long sought technological autarky in its national policies, particularly with respect to military technology. These efforts, however, have not had too much success in the civilian arena – at least not outside "capabilities that can be built through highly centralized and coordinated technology programs such as nuclear power, ocean exploration, telecommunications, and aerospace"[87] – and are probably inadequate as an inspiration for the kind of cross-sectoral, interdisciplinary effort the United States now needs.

In Japan, firms have traditionally been effective in creating intercorporate alliances through which companies can acquire "elements of the technology matrix" they need but cannot provide through internal R&D,[88] but these skills did not prevent the broader Japanese economy from a "lost decade" of stagnation in the 1990s. Japan's malaise of that period had many causes, of course, but among them – and reportedly dimming the prospects for long-term recovery and productivity growth – is said to have been "the corporate sector's seemingly innate conservative approach [to] physical and human capital."[89]

More recently, in response to present-day innovation challenges – including competitive pressures from China – the European Union has promoted what are called "Research and Innovation Strategies for Smart Specialisation," which are today "the main component of the EU's 2014–2020 'Innovation Union', being described as the world's biggest and boldest industrial policy experiment ever undertaken." As David Bailey and his coauthors explain, this approach

> *"revolves around public-private partnerships in which state funds are prioritised and allocated to specific 'activities' in particular technological fields in uncharted technologies, and fields or domains which have the potential for 'entrepreneurial discovery', knowledge spill-overs, innovation, scale, agglomeration and commercial exploitation."* [90]

This EU effort is thus said to be "a return to a more vertical and selective mode of policy intervention" than Europe is traditionally known for, with an emphasis upon "entrepreneurial discovery" on the theory that "private actors are best placed in the market to identify new opportunities for commercial exploitation." In this view,

> *"opportunities may arise at the interstices of sectors, for example in material science where a range of materials (such as ceramics, metals and polymers) are now being used as part of a range of applications resulting in new products and industrial efficiency. Hence the focus is upon 'activities' and experimentation rather than supporting specific sectors per se."*[91]

In the United Kingdom – now, of course, no longer part of the European Union – "the government has identified four 'Grand Challenges' that they believe will transform their society from 2030 through 2040": AI and data; the impact of an ageing society; the imperative of "clean growth"; and the "future of mobility."[92] The EU emphasis upon "entrepreneurial discovery" in areas of disciplinary and sectoral overlap, as well as the British focus on "grand challenges" deserving of special attention, can perhaps both teach us something in the United States.

3. Partnership Models

One promising approach to these challenges may lie in the area of establishing a new Public-Private Partnership (PPP) initiative "spanning government, industry, academia, national laboratories, and international allies" – that is, an effort not entirely unlike what has recently been suggested to support U.S. competitiveness in the telecommunications sector, but with a wider, cross-sectoral focus. In exploring this approach, Thomas Woodson's 2016 study of PPPs in the health sector[93] provides a good frame of reference.

According to Woodson, PPPs can play an important role as "knowledge brokers" and "'system integrators' that leverage the resources and capabilities of a network of public, philanthropic and private sector partners'" to "drive innovation, stimulate R&D and negotiate among other organizations in the … innovation system." The need to partner due to increased complexity, he writes, makes PPP approaches particularly valuable in helping "overcome market deficiencies," such as by spreading risk and aggregating resources and creativity when "some innovations have high technical risk that prevent them from being economically attractive, while other innovations have low monetary return."[94] PPPs may allow the pursuit of "technologies that traditional [firms in any given industry] would not consider."[95] Such partnerships are not a panacea,[96] but this approach indeed claims to be able to provide many of the "innovation platform" benefits that we presently need in a broader national context.

There are many examples of PPPs from which present-day national leaders can perhaps learn in crafting approaches to meet America's contemporary innovation challenges. As Rassler and Lamberth recount, for instance, when the U.S. semiconductor industry struggled to compete against foreign competition from Japan in the mid-1980s, the U.S. Government established a PPP for "Semiconductor Manufacturing Technology" (Sematech). Involving a consortium of 14 American semiconductor firms, Sematech received about $870 million from DARPA, and a comparable amount in matching funds contributed by the U.S. firms.[97]

Sematech is credited with playing an important role in helping the United States meet the challenge, not only by catalyzing specific technological innovations but also by helping change the organizational culture of the U.S. semiconductor industry to make its technologists more focused upon the need to "identify important goals, such as reducing circuit line widths to reduce chip size, or manufacturing challenges, such as reducing chip defects, and research the best way to solve them." It also facilitated adaptation to changes in the semiconductor market, helping participants be "willing to make repeated shifts in strategy as market needs changed."[98]

And indeed Sematech appears to have been broadly successful. According to Robert Hof,

> *"before Sematech, it used to take 30 percent more research and development dollars to bring about each new generation of chip miniaturization …. That increase dropped to 12.5 percent shortly after the advent of Sematech and has since fallen to the low single digits. Perhaps just as important, Sematech set a goal in the early 1990s of compressing miniaturization cycles from three years to two. The industry has done just that since the mid-1990s, speeding innovation throughout the electronics industry and, consequently, the entire economy."*[99]

As a result, "Sematech has become a model for how industry and government can work together to restore manufacturing industries – or help jump-start new ones."[100]

To be sure, Sematech has been criticized by some on account of the Defense Department's role in supporting commercial R&D beyond simply that which supports military applications, and for creating a self-perpetuating organization.[101] Nevertheless, Sematech is today regarded as a model for other efforts, such as the National Alliance for Advanced Transportation Battery Cell Manufacture[102] and the Energy Department's SunShot Initiative[103] for reducing solar energy costs.

Other examples of such PPP efforts that have been pursued over the years include the Partnership for a New Generation of Vehicles (PNGV) established in 1993 by the U.S. Government in cooperation with the then-leading U.S. automakers – General Motors, Ford, and Chrysler – in order to spur the development of more energy-efficient vehicles. Eventually involving eight federal agencies, the U.S. Council for Automotive Research, several universities, and the U.S. national laboratories, PNGV has also "come to be seen as a model," even if not necessarily in exactly the ways anticipated. As recounted in 2001 around the time of its termination at the request of the U.S. automakers themselves, PNGV was said to be

> *"proceeding according to schedule; it increased the profile of advanced technology opportunities; and it led to better working relationships between the federal government and automakers. It also indirectly led to technology advancement – by inspiring more aggressive investments by European and Japanese automakers that, in turn, through a boomerang effect, inspired US automakers to do likewise."*[104]

This was not, perhaps, a stunning success, and PNGV's abovementioned achievement – its "boomerang effect" in spurring foreign competitors to work harder, thereby in turn panicking U.S. industry to do better itself – was surely not precisely what had been planned. Nevertheless, PNGV has been said to offer lessons in the importance of design elements, among them: (a) including small, innovative companies, universities, and independent research centers as project principals; (b) including energy suppliers who influence the design and choice of advanced technologies; (c) facilitating broad participation in partnership policy and technical committees; and (d) awarding public R&D funds on a competitive basis, outside the partnership, as seed grants to small and innovative technology suppliers and research institutions.[105] A RAND Corporation study in 1998 has also praised aspects of the PNGV model, such as the clarity of its focus upon a "clear, easily understood primary goal" (a car capable of traveling 80 miles on a gallon of gasoline), strong high-level administration support, motivated industry partners and strong public support, and "[t]he ability to draw on the substantial technical resources within the federal laboratories.[106]

A more recent example of a competition-focused industry consortium can be found in the announcement in 2020 of a "Next_G Alliance" intended to "advance North American mobile technology leadership" in the telecommunications sector "in 6G and beyond over the next decade" and to "encompass the full lifecycle of research and development, manufacturing, standardization and market readiness." (The MITRE Corporation was a founding member.) Its initial focus, it declared, would be upon developing "a 6G national roadmap that addresses the changing competitive landscape and positions North America as the global leader in R&D, standardization, manufacturing and adoption of Next G technologies." The Alliance aimed to align North American industry on a core set of priorities to support these goals, and to define strategies to facilitate "rapid commercialization of Next G technologies across new markets and business sectors and promote widescale adoption, both domestically and globally."[107]

A further recent example of a broad cross-sectoral collaboration can be seen in the "COVID-19 Healthcare Coalition" (a.k.a. "C-19") that was established in March 2020 to help U.S. healthcare system leaders and public health officials respond to the SARS-Cov-2 virus. This effort brought together a voluntary coalition of more than 900 members, including healthcare organizations, technology firms, non-profit organizations, academic institutions, and startups. (It was co-chaired by the MITRE Corporation, which capitalized upon its FFRDC status in playing a commercially disinterested role as "honest broker" between private sector entities that, prior to the pandemic, had been in some cases cutthroat competitors.) Over the course of 2020, C-19 helped the U.S. health sector respond to pandemic-related challenges such as providing personal protective equipment (PPE) for healthcare workers, and it worked to deploy the critical infrastructure needed to enable collaboration and shared analytics in support of pandemic-released research and response.[108]

That said, neither of these recent examples probably provides much of a model for our current challenge. The COVID-19 Healthcare Coalition was not a carefully planned national effort to respond to broad innovation-economy challenges and foreign competitive pressures, but instead an ad hoc emergency response to the exigencies of the onrushing global pandemic. Although the coalition coordinated closely with government, moreover, it was in itself a purely private-sector collaboration. As for the Next_G Alliance, it was also a private sector undertaking, and it is too early to assess its impact upon North America's telecommunications competitiveness. For these reasons, we should probably look elsewhere for models adequate to our current competitiveness needs in "meeting the China challenge."

A different PPP in the technology sector that is frequently described as a good model to emulate, however, is the National Nanotechnology Initiative (NNI), established by the U.S. Government in the year 2000 in order to use federal funding to accelerate technology development in the nanotech arena, with an initial federal investment of $475 million.[109] NNI's objective was to "fill major gaps in fundamental knowledge of matter and to pursue the novel and economic applications anticipated for nanotechnology." With eight federal agencies participating, it coordinated the nanotechnology-related activities of 25 federal departments and independent agencies under the broad aegis of the NSTC and its Nanoscale Science and Engineering (NSET) Subcommittee.[110]

Perhaps much as Daniel Sperling recounted PNGV as having catalyzed responsive competitive technology initiatives from automakers in Europe and Japan,[111] the NNI prompted nanotech efforts in other countries as well, with the result that by 2004 about 62 countries had established some sort of nano-initiative of their own.[112] Yet the American effort was enormous, with per capita federal R&D spending on nanotechnology growing nearly sixfold between 2000 and 2010, so that by 2008, nanotech's share of all federal R&D money had grown from 0.39 percent to 1.5 percent. Cumulatively over the first decade of its existence, with overall spending amounting to more than $12 billion, NNI arguably ranks as "second only to the space program in the U.S. civilian science and technology investments."[113]

NNI has been credited with success in fostering the U.S. nanotechnology industry and innovation space – spawning, as Mihail Roco recounts, a

> *"thriving interdisciplinary nanotechnology community of about 150,000 contributors has emerged in the U.S., along with a flexible R&D infrastructure consisting of about 100 large nanotechnology-oriented R&D centers, networks, and user facilities, and an expanding industrial base of about 3,000 companies producing nanotechnology-enabled products."*[114]

It also helped catalyze qualitative changes in the emerging U.S. nanotechnology sector. NNI is said to have given rise to a vibrant multidisciplinary, cross-sector, international community across the various dimensions of the nanotechnology enterprise, which spurred changes in the scientific research culture through energizing interdisciplinary academic research collaborations, and encouraging

> *"increasingly unified concepts for engineering complex nanostructures 'from the bottom*

> *up' for new materials, biology and healthcare technologies, digital information technologies, assistive cognition technologies, and multicomponent systems."* [115]

NNI, therefore, can likely offer some important lessons to leaders today seeking effective ways to direct federal R&D spending and partnership collaborations toward tomorrow's breakthrough arenas. One point of particular emphasis in this regard is one that we have already seen: the degree to which such "deep tech" challenges increasingly resemble massive, complex "systems integration" problems that require much more holistic solutions than just a mad dash after just "the new technology itself."

One of the lessons of NNI appears to be that in any realm that has the potential to "fundamentally transform science, industry, and commerce, and … [give rise to other] broad societal implications," approaches to technology governance must be "focused on many facets, not only on risk governance":

> *"Properly taking into account the roles and views of the various stakeholders in the society – including their perceptions of science and technology, human behavior factors, and the varying social impacts of the technology – is an increasingly important factor in the development of any emerging, breakthrough technology."* [116]

Doing this well requires a very broad perspective and deftness in integrating efforts across many disciplines – including not just in science and engineering, but also in such diverse areas as sociology and behavioral science, operations research and systems engineering, legal and regulatory affairs, and even politics. In genuinely transformational technology arenas, such partnership efforts involve much more than "just" technology, so an effective program may also require doing this sort of integration at scale. It may require, in other words, work on a sort of "system of systems of systems" basis, as participants work through the implications of their innovations and try to facilitate effective technology governance policy solutions that will not just speed uptake but also ensure broad trust and confidence in how such potentially disruptive changes are being addressed.

A second lesson of NNI relates to the importance of being able to kick off such efforts with a broad and compelling vision of what is needed. Mihail Roco credits NNI's success in part to the overall guidance provided by the NSTC after an elaborate, months-long process overseen by the White House Economic Council and by OSTP, and also involving the Office of Management and the Budget (OMB) and PCAST – not to mention supported by hearings and legislative involvement in both chambers of the U.S. Congress.[117] The Biden Administration's technology innovation push should thus bear this lesson in mind as well: articulating a persuasive guiding vision is essential to shaping the effort, enlisting and maintaining support not only from would-be participants but from the legislature and the public at large, and promoting consistency of focus and attention over time.

4. International Partners and Partnerships

A final lesson to bear in mind when considering organizational forms for the Biden Administration's new technology push relates to the *international* aspects of our response. Given the nature of the challenge we face, it would be a mistake to regard the answer as being a purely American one, and this makes the development and maintenance of international partnerships essential to success.

As Rasser and Lamberth point out, the United States has "an unmatched strategic advantage over China in this technology competition: a global network of allies and partners," and "[h]arnessing this network for multilateral collaboration is critical to the success of a national technology strategy." Accordingly, they urge the establishment of "a network of like-minded countries to collaborate on technology policy": a broad "multilateral technology alliance with a core group of like-minded countries to collaborate on technology policy" and "focus their efforts on collaborative research on next-generation technologies, securing and diversifying supply chains, protecting critical technologies, and cooperating on international standard-setting and norms creation."[118]

This dovetails closely with recommendations made by McCormick and his coauthors, who similarly advocate the establishment of "partnerships dedicated to the principled, multinational development and fielding of core technologies" that take advantage, in particular, of "America's longstanding military and intelligence partnerships, including its robust intelligence-sharing relationship with the 'Five Eyes' partners." Such a coalition of friendly democracies – perhaps including India – could

> *"set standards for the adoption and use of emerging technologies, and they would not only optimize each country's resources and capabilities but also increase the interoperability of their respective technologies – a boon for military alliances and economic partners alike. Similarly, encouraging academic and talent exchange programs among this group of close partners would help develop knowledge and innovative capacity both at home and abroad."*[119]

To these authors, this is eminently good advice, and should be an important part of U.S. efforts going forward.

Appendix II

Industrial Strategy in Response to Competitive Challenges

Questions about the U.S. Government's role in supporting the nation's R&D ecosystem have long engendered a degree of controversy over whether it is proper for the government to be engaged in "industrial policy."[120] Nevertheless, the federal government has played a large role in supporting American S&T innovation for generations, especially in response to the challenges presented by technology competition from authoritarian geopolitical competitors.

Debates over the U.S. Government's role ebb and flow over time, having gone through at least two full cycles since the beginning of the 1980s alone. In 1982, for instance – in the wake of the political traumas, geopolitical challenges, and economic malaise of the 1970s – Robert Reich argued in the *Harvard Business Review* that the government "must promote the adjustment of labor to structural changes in the world economy in advance of industry decline." In his view, a U.S. industrial policy was needed in order to help the country respond effectively to the competitive strategies then being employed by countries such as Japan and some European states, since "[i]n many industries, international competition has become a race in which the first manufacturer to achieve high volume and gain experience can underprice all potential rivals." Government, he believed, "can provide a head start in this race by subsidizing the growth of such industries and the technologies on which they rest." This would allow it to

> *"reduce the cost of adaptation in two ways: (1) by smoothing the movement of capital and*

> *labor out of declining industries[;] and (2) by ensuring the availability of both capital and labor to promising sectors of the economy …."*[121]

Such ideas of broad governmental intervention, however, "cut against the grain of strong political trends in the 1980s," which turned out (in contrast to the 1970s) to be a period in which U.S. competitiveness did not look so bad after all. By the early 1990s, however, the tables had turned once more, again producing calls for an explicit U.S. industrial policy. Kevin Phillips argued at the time, for instance – once more in the *Harvard Business Review* – that "a new political compromise is in the making," since "[b]oth major political parties are [now] placing less reliance on free-market assurances; hardly anyone dissents from the general wisdom of greater strategic thinking."[122]

Yet that effort, too, ran aground, not least because of "strong opposition to technology policy in the Congress" after 1994.[123] And indeed many arguments were made against a U.S. industrial policy at the time. Not least, it was argued that involving the government in "picking winners and losers" – that is, identifying which industrial sectors needed and deserved support and which did not – would itself be a losing proposition because "[t]he knowledge necessary to determine in advance what will be successful simply does not exist." Even if such knowledge did exist, it was further claimed, decisions would likely end up being made by lobbying and political influence rather than on the economic and technological merits.[124]

To this day, opposition to "industrial policy" still centers on concerns that "government failure" – in the form, for instance, of the imposition of market-distorting regulations and subsidies, or misguided choice-making in industrial policy itself – is as likely to be an impediment to progress as any purported lack of an industrial policy, that the requisite knowledge to intervene effectively isn't available in the first place, and that "government interventions designed to foster, upgrade, reorient, or protect particular industries" are likely only to worsen one's competitiveness problems. Skeptics of industrial policy have also pointed out the degree to which Japan's much-vaunted industrial policies of the 1980s helped lead to a generation of economic stagnation beginning in the 1990s, as well as the fact that industrial policy interventions in the developing world have heretofore often been disappointing.[127]

Nevertheless, though full-blown Reichian industrial policy remains controversial and much debated, the general idea of "public investment in science and technology is generally politically considered palatable."[128] The fact that the U.S. Government has provided a great deal of federal R&D funding for many years underlines this point.

Furthermore, even free-market critics of industrial policy tend to admit that there are at least *some* circumstances in which government intervention will be appropriate. In fact, the pioneering 18th-century sage of free-market commerce, Adam Smith, himself conceded in his 1776 masterpiece *The Wealth of Nations* that it would "generally be advantageous to lay some burden upon foreign [industry], for the encouragement of domestic industry … when some particular sort of industry is necessary for the defence of the country." "The first duty of the sovereign," Smith wrote, is "that of protecting the society from the violence and invasion of other independent societies," with national defense being, he memorably put it, "of much more importance than opulence." Accordingly, Smith felt that it was indeed appropriate to restrict commerce in uneconomic ways if that is what it took to preserve such defense.[129] On the basis of such reasoning – and sometimes in fact explicitly invoking Adam Smith – even critics of industrial policy have thus tended to accept, in principle at least, that national security is an appropriate reason to engage in governmental interventions that might otherwise be unacceptable infringements upon market dynamics.[130]

This "Smithian exception" is particularly significant today. In the contemporary context, the most important international economic competition facing the United States in the science and technology arena is not from democratically governed U.S. military allies such as Japan or West Germany – which had been the concern of industrial policy advocates going back to Robert Reich's 1982 article – but rather the increasingly assertive, authoritarian, oppressive technology-empowered surveillance state of the People's Republic of China (PRC). Today's S&T challenge, in other words, is somewhat more reminiscent of the geopolitical "Sputnik Shock" of the 1950s than it is the scenarios of "mere" economic competition that have fueled U.S. industrial policy debates in more recent decades.

For indeed the PRC *has* been working to weaponize its technological sector for strategic advantage. The challenge is not merely that China is promoting state-subsidized "national champion" firms and trying to use its political influence in international bodies to tilt the market playing field of international markets against us, though it is.[131] Beijing is also investing heavily in technologies it believes likely to prove transformational both for economic competitiveness and in giving it a first-mover advantage in what is anticipated to be a "Revolution in Military Affairs" (RMA) driven by advances in Artificial Intelligence (AI), Quantum computing, "Big Data" analytics, aerospace technology, and other fields.[132] It has also been accelerating efforts to "fuse" its civilian and defense industrial base in order to allow Chinese Communist Party (CCP) leaders to leverage technology seamlessly between these sectors in support of Beijing's overall domestic and geopolitical objectives.[133]

To take just one example, it has been said that the Chinese telecommunications giant Huawei "would not exist today" without massive state subsidies and a range of other "protectionist and mercantilist policies by the Chinese government."[134] Yet the company is now "the largest investor in [telecommunications] R&D in the world," spending "about as much … as Nokia, Ericsson, and Qualcomm combined,"[135] and seemingly being on a trajectory – as one commentator put it in early 2020 – such that if Huawei continued to seize market share, "we could be facing a global 5G-infrastructure market with only one provider."[136] Moreover,

> *"… [r]esearchers have uncovered ties between leadership positions in Huawei and the People's Liberation Army, the Communist Party, and the Ministry of State Security. There is also evidence of cooperation between Huawei and Chinese state-backed hackers, such as Boyusec and APT3. Other risks in working with Huawei have been identified, such as existing exploits in handsets and equipment identified by the National Security Agency (NSA); allegations of bribery or corruption; and sanctions violations, including allegations of re-exporting U.S. technology to Iran, Sudan, and Syria."* [137]

Huawei and its fellow PRC technology giants are also developers and providers of

> *"the surveillance and information-facilitated coercive technologies that are making this oppressive police state possible, and jurisdictions such as the oxymoronically named Xinjiang Uighur Autonomous Region are where the pilot programs and proof-of-concept studies for these technologies of repression are being developed and carried out. These technologies are vital to China's repressive campaign against Uighurs, ethnic*

> *Kazakhs, Kyrgyz, and other members of Muslim minority groups, resulting in the detention of at least one million individuals in internment camps since April 2017. These companies have helped the Chinese Party-State develop these tools, they are working with Chinese Communist Party authorities to test these grim methods on China's own population, and through their foreign engagements they are making the export of such techniques into a key component of how Beijing is promoting and expanding its own repressive governance model worldwide. … Significantly, the modern 'China Model' is built upon a foundation of technology-facilitated surveillance and social control. These techniques for ruling China have been – and continue to be – in critical ways developed, built, and maintained on behalf of the Party-State by technology firms such as Huawei, Tencent, ZTE, Alibaba, and Baidu."* [138]

It would certainly be wrong to assume that such PRC-supported technology entities are "ten feet tall."[139] Nonetheless, the PRC's infrastructure and investment programs, such as the Belt and Road Initiative (BRI), and its push to export its internet governance model, "have challenged America's position in the global economy over the past decade."[140]

All of this adds up to a considerable strategic problem with ineradicable entanglements with and implications for S&T policy. As Martin Rasser and Megan Lamberth summarize it in a recent paper,

> *"[t]he United States faces a challenge like no other in its history: a strategic competition with a highly capable and increasingly resourceful opponent whose worldview and economic and political models are at odds with the interests and values of the world's democratic states. A rising China poses a fundamental challenge to the economic vitality and national security of the United States and its allies and the currency of liberal democratic values around the world. Technology – a key enabler for economic, political, and military power – is front and center in this competition. … China represents a dynamic and fast-growing challenge to American global technological leadership. China is no longer a nation of copying but is engaging in true innovation and is a serious technological competitor. In a number of critical technology areas – AI, quantum sciences, biotechnology – China is at a position of rough parity or has surpassed the United States.*[141]

And indeed, the literature on industrial policy *has* begun to reflect a need to "meet the China challenge" – a phrase which even appears in the title of Rasser and Lamberth's recent paper on these issues at the Center for a New American Security – leading to an increasing openness to the concept even from staunch friends of the free market. As Thomas Hemphill has observed, "a major impetus for the development of … emerging national industrial strategies" today is "the 'Made in China 2025 strategy' being pursued for strategic advantage by Beijing under its system of 'state-guided capitalism."[145]

Similarly, while in a recent article, David McCormick and his coauthors note the importance of not taking security-based restriction so far that it "sap[s] America's competitive advantage," they also urge attention to "the power that resides at the intersection of economics and national security." The also observe that "[t]oo often, security concerns related to economic decision-making get short shrift," and suggest that the U.S. Government "[s]upport domestic development in strategic sectors or technologies in which foreign firms are heavily subsidized by competitor states." A keen awareness of the "China Challenge" thus underlies a growing belief that "it will be ever more important to integrate national security and economic decision-making" in the future.

This increasing focus upon the technological prowess of an authoritarian and increasingly self-assertive China has been accompanied by a growing feeling that – as described in the main body of this paper – the existing U.S. innovation model has been, if not precisely failing, then at least functioning less and less well in certain key respects. Recent talk of a sort of quasi-industrial policy thus also represents, it has been said, "a deep-seated dissatisfaction with the prevailing open-market mode,"[146] and a feeling that the "social contract" that underlay federal S&T policy during its "golden age" has been "seriously challenged."[147]

Especially in the face of "a new technological transformation, and the arrival of radical and disruptive technologies associated with the applications of artificial intelligence, automation[,] and machine learning,"[148] such concerns have driven many observers to conclude that something better is indeed needed. As Hemphill has noted – and as past generations of sometimes powerfully economically transformative federal R&D funding help illustrate – the United States has in some sectors at least *implicitly* pursued an industrial strategy all along, even though it has done so "in an inconsistent manner."[149]

In Chris Hill's striking phrasing, whether one likes it or not, "the modern developmental state … is awash in technology policy."[150] It is difficult not to agree with Doug Brake, therefore, that "[w]hether or not one is willing to call it 'industrial policy,' 'competitiveness policy,' or simply a 'strategy,' a nation must have a plan of some kind."[151] To this end, modern treatments have tended to focus less on trying to "pick winners" than upon "addressing systemic and market failures; the task … is to create an environment (or stable/seedbed) out of which 'winners' may arise."[152] This focus tends to describe itself as being upon "national industrial strategy" rather than "industrial policy":

> *"National industrial strategy is an evolution of 20th-century industrial policy. Unlike traditional 20th-century efforts at industrial policy (which focused on public policy efforts to maintain domestic primacy of declining, older industries), national industrial strategy recognizes (and generally accepts) the international global economy as a foundation of competition. Most important, national industrial strategy focuses on technologically emerging industries as well as the national government working collaborative in a partnership with these emerging industries to meet future growth challenges and opportunities. Another aspect of national industrial strategy involves the recognition of themes or challenges that will drive the implementation of the strategy for a period of years into the future."* [153]

Rather than trying to prop up sagging sectors or specific industrial concerns or pick "winners," in other words, the ambition of this sort of "industrial strategy" approach is to use long-term planning and sustained federal investment

> *"to create a strategic national-level framework for technology policy by making the proper investments in R&D, education, and infrastructure, and by setting policies for areas such as taxes, regulations, and immigration that align with free market principles and comport with American values."* [154]

This, then, is the context in which to understand the stakes as the Biden Administration builds its new S&T policy.

References

1. Joe Biden for President Campaign, "The Biden Plan to Ensure the Future Is 'Made in All of America' by all of America's Workers" (undated), *available at* https://joebiden.com/made-in-america/.
2. See, e.g., Carl Zimmer, "Biden to Elevate Science Advisor to His Cabinet," *New York Times* (January 15, 2021), *available at* https://www.nytimes.com/2021/01/15/science/biden-science-cabinet.html.
3. Lewis M. Branscomb, "America's Emerging Technology Policy," Discussion Paper 91-12, B*elfer Center for Science and International Affairs* (December 1991), *available at* https://www.belfercenter.org/publication/americas-emerging-technology-policy.
4. Martin Rasser & Megan Lamberth, "Taking the Helm: A National Technology Strategy to Meet the China Challenge," *Center for a New American Security* (January 13, 2021), at 9 & 11-12, *available at* https://www.cnas.org/publications/reports/taking-the-helm-a-national-technology-strategy-to-meet-the-china-challenge.
5. Branscomb, *supra*.
6. Among these were the Atomic Energy Commission (AEC), the Office of Naval Research (ONR), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA).
7. Ashish Arora, Sharon Belenzon, Andrea Patacconi, & Jungkyu Suh, "The changing structure of American innovation: Some cautionary remarks for economic growth" (June 20, 2019), at 15, available at https://static1.squarespace.com/static/593d9b08be65945a2e878544/t/5d31ac9b33ae9b0001d88216/1563536539717/c14259.pdf.
8. Rasser & Lamberth, *supra*, at 10.
9. Branscomb, *supra*.
10. Duane Blackburn et al., "The Innovation Landscape and Government's Future Role" (MITRE Corporation: June 2016), at iii.
11. Arora et al., *supra*, at 34.
12. *Id.* at 35.
13. *Id.* at 1.
14. *Id.* at 6 & 20.
15. *Id.* at 4-5 & 45-46.
16. Henry W. Chesbrough, "The Era of Open Innovation," *MIT Sloan Management Review* (April 15, 2003), at 35 & 38, *available at* https://sloanreview.mit.edu/article/the-era-of-open-innovation/.
17. Kaushik Viswanath, "Why Corporate America Gave Up on R&D," *Marker* (July 7, 2020), available at https://marker.medium.com/why-corporate-america-gave-up-on-r-d-43238193c29b.
18. Arora et al., *supra*, at 19, 4, & 2.
19. President's Council of Advisors on Science and Technology, *Transformation and Opportunity: The Future of the U.S. Research Enterprise* (2012), *quoted* in Blackburn et al., at 10.
20. Arora et al., *supra*, at 3, 5, & 25-26.
21. Viswanath, *supra*.
22. *Id.*
23. Arora et al., *supra*, at 46.
24. David Cheney, Christopher T. Hill, & Patrick Windham, "America Needs a New International Strategy for Science, Technology, and Innovation," *Issues in Science and Technology* (January 28, 2021), *available at* https://issues.org/international-science-technology-innovation-policy/.
25. *See, e.g.*, UNESCO Institute for Statistics, "How Much Does Your Country Invest in R&D?" (undated), *available at* http://uis.unesco.org/apps/visualisations/research-and-development-spending/.
26. *Compare* National Science Board, "Research and Development: U.S. Trends and International Comparisons," NSB-2020-3 (January 15, 2020) [hereinafter "NSB I"], at 7, *with* UNESCO, *supra*.
27. Rasser & Lamberth, *supra*, at 10.
28. NSB I, *supra*, at 7-8.
29. *See* Dennis Normille, "China announces major boost for R&D, but plan lacks ambitious climate targets," *Science* (March 5, 2021), *available at* https://www.sciencemag.org/news/2021/03/china-announces-major-boost-rd-plan-lacks-ambitious-climate-targets.
30. NSB I, *supra*, at 7-8.
31. National Science Board, "U.S R&D Performance and Funding" (January 2020) [hereinafter "NSB II"], *available at* https://www.ncses.nsf.gov/pubs/nsb20201/u-s-r-d-performance-and-funding.
32. NSB II, *supra*.
33. David Bailey et al., "Industrial policy: new technologies and transformative innovation policies?" *Cambridge Journal of Regions, Economy and Society*, vol.12, no. 2 (May 17, 2019), at 169-77, *available at* https://academic.oup.com/cjres/article/12/2/169/5490915.
34. Arora et al., *supra*, at 4.
35. Viswanath, *supra*.
36. Arora et al., *supra*, at 19-20 & 36. American

universities have been doing some "applied and translational research with the potential to delivery innovations, new industries, and market efficiencies," but those universities themselves today face "critical pressures," including from instability in their revenue streams, demographic shifts in the U.S. population, changes in the organization and scale of research, and shifting relationships with government and industry, not to mention growing competition from *foreign* universities as other countries expand their own R&D funding. Blackburn et al., *supra*, at 10, & 19-20.

37. Blackburn et al., *supra*, at 7; *see also* Nicole Perlroth, *This Is How They Tell Me the World Ends: The Cyber-Weapons Arms Race* (New York: Bloomsbury, 2021), at 98 (mentioning CIA role in developing lithium-ion batteries in order to improve the power and lifespan of surveillance devices).

38. The policy community must also resist the temptation to try to do *more* than simply address itself to those failures. This is neither the time nor the place for yet another attempt to develop a broad-brush industrial policy that aspires simultaneously to right all perceived wrongs across the U.S. economy. Simply addressing even the specific market failures described herein will be work enough.

39. Bailey et al., *supra*.

40. Chesbrough, *supra*, at 39.

41. "National Policies in Support of High-Technology Industry" (Horst Siebert, moderator), *International Friction and Cooperation in High-Technology Development and Trade: Papers and Proceedings* (1997), at 83 (comments by Chris Hill), *available at* https://www.nap.edu/read/5902/chapter/10.

42. Bailey, et al., *supra*.

43. Bailey et al., *supra*.

44. Meriem El Karoui et al., "Future Trends in Synthetic Biology – A Report," *Frontiers in Bioengineering and Biotechnology* (August 7, 2019), *available at* https://www.frontiersin.org/articles/10.3389/fbioe.2019.00175/full.

45. *See, e.g.*, National Security, Military, and Intelligence Panel on Climate Change, "A Security Threat Assessment of Global Climate Change: How Likely Warming Scenarios Indicate a Catastrophic Security Future" (February 2020), at 9, *available at* https://climateandsecurity.org/wp-content/uploads/2020/03/a-security-threat-assessment-of-climate-change.pdf.

46. *See* Cathy Pennington, "Strengthening Our Resilience to Environmental Change Is a National Security Imperative," MITRE Center for Data-Driven Policy (September 2020), at 3, *available at* https://www.mitre.org/sites/default/files/publications/pr-20-2572-strengthening-our-resilience-to-envionmental-change-is-a-national-security-imperative.pdf.

47. Chris Richard, Karthik Ramachandran, & Ivan Pandoy, *SEMI-Deloitte Workforce Study: Looming Talent Gap Challenges Semiconductor Industry* (2018); Semiconductor Industry Association, comments to the National Institute of Standards and Technology on "Current and Future Workforce Needs to Support a Strong Domestic Semiconductor Industry (83 Fed. Reg. 32842)," (August 15, 2018), *available at* https://www.semiconductors.org/wp-content/uploads/2018/11/NIST-workforce-RFI-august-2018.pdf.

48. *See* Stephen Ezell, "An Allied Approach to Semiconductor Leadership," Information Technology and Innovation Foundation, (September 2020), *available at* https://itif.org/sites/default/files/2020-allied-approach-semiconductor-leadership.pdf.

49. *See, e.g.*, Lara Seligman, "U.S. warns of China's growing threat to Taiwan," *Politico* (Marcy 15, 2021), *available at* https://www.politico.com/news/2021/03/15/china-growing-threat-taiwan-476170.

50. *See generally, e.g.*, Doug Brake, "A U.S. National Strategy for 5G and Future Wireless Innovation," *Information Technology & Innovation Foundation* (April 27, 2020), *available at* https://itif.org/publications/2020/04/27/us-national-strategy-5g-and-future-wireless-innovation. Huawei has been indicted by the U.S. Department of Justice for a variety of criminal offenses allegedly committed over the course of "decades-long efforts by Huawei, and several of its subsidiaries, both in the U.S. and in the People's republic of China, to misappropriate intellectual property, including from six U.S. technology companies, in an effort to grow and operate Huawei's business." U.S. Department of Justice, "Chinese Telecommunications Conglomerate Huawei and Subsidiaries Charged in Racketeering Conspiracy and Conspiracy to Steal Trade Secrets" (February 13, 2020), *available at* https://www.justice.gov/opa/pr/chinese-telecommunications-conglomerate-huawei-and-subsidiaries-charged-racketeering.

51. *See generally, e.g.*, Enrique Duarte Melo et al., *Building the US 5G Economy*, Boston Consulting Group (September 2020), at 10, *available at* https://api.ctia.org/wp-content/uploads/2020/09/

Building-the-5G-US-Economy-1.pdf.; *see also* Brake, *supra*.

52. *See generally, e.g.*, U.S. National Telecommunications and Information Administration, *National Strategy to Secure 5G Implementation Plan* (January 6, 2021) [hereinafter "NTIA"], at 6, *available at* *https://www.ntia.gov/files/ntia/publications/2021-1-12_115445_national_strategy_to_secure_5g_implementation_plan_and_annexes_a_f_final.pdf*; Melo, *supra*, at 8.
53. *See generally, e.g.*, Brake, *supra*.
54. Brake, *supra*.
55. Blackburn et al., *supra*, at vii-viii; *see also, e.g.,* McCormick et al., *supra*.
56. Cheney et al., *supra*.
57. Rasser & Lamberth, *supra*, at 7.
58. McCormick et al., *supra*, at 7.
59. Rasser & Lamberth, *supra*, at 7.
60. "National Policies in Support of High-Technology Industry," *supra*, at 80 (presentation by Chris Hill).
61. McCormick et al., *supra*; *see also* Brake, *supra* (urging increase of the Alternative Simplified Credit "from 14 percent to one that is significantly higher – at least 28 percent").
62. Rasser & Lamberth, *supra*, at 6.
63. U.S. National Telecommunications and Information Administration, *National Strategy to Secure 5G Implementation Plan* (January 6, 2021) [hereinafter "NTIA"], at 4-5, *available at* *https://www.ntia.gov/files/ntia/publications/2021-1-12_115445_national_strategy_to_secure_5g_implementation_plan_and_annexes_a_f_final.pdf*.
64. *See, e.g.*, Eric Parizo, "SolarWinds Hack Lessons Learned: Finding the Next Supply Chain Attack," *Dark Reading* (January 11, 2021), *available at* https://www.darkreading.com/omdia/solarwinds-hack-lessons-learned-finding-the-next-supply-chain-attack/a/d-id/1339871; The White House, "Imposing Costs for Harmful Foreign Activities by the Russian Government" (April 15, 2021), *available at* https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/15/fact-sheet-imposing-costs-for-harmful-foreign-activities-by-the-russian-government/.
65. Cheney et al., *supra*.
66. Chesbrough, *supra*, at 37-38 & 41.
67. *See, e.g.*, "National Policies in Support of High-Technology Industry," *supra*, at 76 (presentation by Y. Takeda).
68. *See* Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776) [hereinafter *Wealth of Nations*], at Book IV, Chapter II, *available at* https://www.gutenberg.org/files/3300/3300-h/3300-h.htm.
69. *See* Charles Clancy, Joseph Ferraro, Robert Martin, Adam Pennington, Christopher Sledjeski, and Craig Wiener, "Deliver Uncompromised: Securing Critical Software Supply Chains," *MITRE Corporation* (March 9, 2021), *available at* https://www.mitre.org/sites/default/files/publications/pr-21-0278-deliver-uncompromised-securing-critical-software-supply-chains.pdf.
70. *Quoted by* Josh Rogin, "NSA chief: Cybercrime constitutes the greatest transfer of wealth in history," *Foreign Policy* (July 9, 2012), *available at* https://foreignpolicy.com/2012/07/09/nsa-chief-cybercrime-constitutes-the-greatest-transfer-of-wealth-in-history/.
71. *See generally, e.g.*, Rasser & Lamberth, *supra*, at 6.
72. *See generally, e.g.*, Assistant Secretary of State Christopher Ford, "Export Controls and National Security Strategy in the 21st Century," *Arms Control and International Security Papers*, vol. 1, no. 16 (August 19, 2020) *available at* https://irp-cdn.multiscreensite.com/ce29b4c3/files/uploaded/ACIS%20Paper%2016%20-%20Export%20Control%20strategy.pdf; Assistant Secretary of State Christopher Ford, "Technology Transfer Diplomacy and the Challenge of Our Times," remarks to the Multilateral Action on Sensitive Technology (MAST) plenary (September 15, 2020), *available at* https://www.newparadigmsforum.com/p2770.
73. *See, e.g.*, Blackburn et al., *supra*, at iv & 21-22.
74. *See, e.g.*, Melo et al., *supra*, at 12; Rasser & Lamberth, *supra*, at 5 & 10.
75. *See, e.g.*, Rasser & Lamberth, *supra*, at 16.
76. *See, e.g.*, Robert B. Reich, "Why the U.S. Needs an Industrial Policy," *Harvard Business Review* (January 1982), *available at* https://hbr.org/1982/01/why-the-us-needs-an-industrial-policy.
77. *See* Rasser & Lamberth, *supra*, at 16.
78. *See* Arora et al., *supra*, at 44.
79. Arora et al., *supra*, at 44.
80. David H. McCormick, Charles E. Luftig, & James M. Cunningham, "Economic Might, National Security, and the Future of American Statecraft," *Texas National Security Review*, vol. 3, no. 3 (Summer 2020), *available at* https://tnsr.org/2020/05/economic-might-national-security-future-american-

statecraft/.

81. Arora et al., *supra*, at 44.
82. McCormick et al., *supra*.
83. *See* Chesbrough, *supra*, at 38-39.
84. The element of *values* is also important insofar as our competitive success seems likely to depend upon marshalling support from and coordinating the efforts of a broad array of likeminded international partners. Such partners would likely be alienated were the United States to pursue strong-arm tactics of the sort used to coordinate economic strategy inside the PRC. (China, after all, is a country which has no true friends and allies in a world increasingly alarmed by its aggressive rise – and one that, in its apparent drive for eventual systemic paramountcy rooted in a soaring historical sense of self-regard, does not even seem to *want* such partnerships in the first place.)
85. "National Policies in Support of High-Technology Industry," *supra*, at 73 (presentation by J. Nicholas Ziegler).
86. Thomas A. Hemphill, "From Industrial Policy to National Industrial Strategy: An Emerging Global Phenomenon," *Bulletin of Science, Technology and Society*, vol. 38 (May 21, 2020), at 39, 41.
87. "National Policies in Support of High-Technology Industry," *supra*, at 74-75 (presentation by J. Nicholas Ziegler).
88. *Id.* at 76 (presentation by Y. Takeda).
89. Naoki Abe, "Japan's Shrinking Economy," *Brookings Institution* (February 12, 2010), *available at* https://www.brookings.edu/opinions/japans-shrinking-economy/.
90. Bailey et al., *supra*.
91. *Id*.
92. Hemphill, *supra*, at 41.
93. NTIA, *supra*, at 3. David McCormick and his coauthors warn that "[c]lose public-private partnerships can become politicized, introducing cronyism and preferential investment," but they also note that "risk does come with the territory." McCormick et al., *supra*. And indeed, no approach is without risks. Given the existence of at least a partial failure in the current U.S. innovation model, moreover, there are also major risks from *inaction*.
94. Thomas S. Woodson, "Public Private Partnerships and merging technologies: A look at nanomedicine for diseases of poverty," *Research Policy*, vol. 45, no. 7 (September 2016), at 1410, 1411, *available at* https://www.sciencedirect.com/science/article/pii/S0048733316300518; *see also id.* at 14 & 16.
95. Id. at 1413. At least in the health sector with regard to efforts to combat diseases of poverty, Woodson adds, PPPs also believe themselves to be "the best organizations at picking technology," because "academia and industry have incentives that lock them into certain research trajectories and prevent them from choosing a viable research path." *Id.* at 1414.
96. Woodson notes, for instance, that "[e]ven if PPPs solve the technical challenges associated with developing inclusive emerging technologies, there are still obstacles with funding, regulations, and patents that can derail technology development and diffusion for marginalized groups." *Id.* at 1416. Nevertheless, if the "public" component of the PPP in question is a federal entity of sufficient stature and breadth of vision – such as, for example, OSTP, one imagines that such follow-on challenges might yet be overcome.
97. Rassler & Lamberth, *supra*, at 17-18. Robert Hof recounts the financing somewhat differently, describing a five-year DARPA commitment of $100 million per annum. Robert D. Hof, "Lessons from Sematech," *MIT Technology Review* (July 5, 2011), *available at* https://www.technologyreview.com/2011/07/25/192832/lessons-from-sematech/. Nevertheless, the basic point remains the same: federal money, with private matching funds, was able to bankroll the project.
98. Hof, *supra*.
99. Hof, *supra*.
100. *Id.*
101. *See, e.g.*, Robert M. Byron, "Sematech: A Case Study: Analysis of a Government-Industry Partnership," thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Information Technology Management, U.S. Naval Postgraduate School (September 1993), *available at* https://apps.dtic.mil/dtic/tr/fulltext/u2/a273166.pdf.
102. *See, e.g.*, Rebecca Smith, "U.S. Firms Join Forces to Build Car Batteries," *Wall Street Journal* (December 18, 2008), *available at* https://www.wsj.com/articles/SB122957206516817419.
103. *See, e.g.*, U.S. Department of Energy, "DOE Pursues SunShot Initiative to Achieve Cost Competitive Solar Energy by 2020" (February 4, 2011), *available at* https://www.energy.gov/eere/solar/

articles/doe-pursues-sunshot-initiative-achieve-cost-competitive-solar-energy-2020.

104. Daniel Sperling, "Public-private technology R&D partnerships: lessons from US partnership for a new generation of vehicles," *no. 8* (2001), at 247, 247-48, 250-51, & 255, *available at* https://escholarship.org/uc/item/2q59d0bz.

105. Sperling, *supra*, at 255.

106. Robert M. Chapman, "The Machine that Could: PNGV, a Government-Industry Partnership," *Rand Corporation* (1998), at xiv, *available at* https://www.rand.org/content/dam/rand/pubs/monograph_reports/1998/MR1011.pdf.

107. Alliance for Telecommunications Industry Solutions, "ATIS Launches NextG Alliance to Advance North American Leadership in 6G" (October 13, 2020), *available at* https://www.atis.org/press-releases/atis-launches-next-g-alliance-to-advance-north-american-leadership-in-6g/.

108. *See generally, e.g.*, COVID-19 Healthcare Coalition, "Delivering Impact and Value" (August 2020), *available at* https://c19hcc.org/impact-report/.

109. Woodson, *supra*, at 1412.

110. Mihail C. Roco, "The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years," *Journal of Nanoparticle Research*, no. 13 (2011), at 427, 428 & 434-35, *available at* https://link.springer.com/article/10.1007/s11051-010-0192-z.

111. Sperling, *supra*, at 247.

112. Woodson, *supra*, at 1412; *see also* Roco, *supra*, at 438 (giving list of key countries with their own projects).

113. Roco, *supra*, at 421 & 428.

114. Id. at 436.

115. Id. at 431-32.

116. Id. at 438.

117. Id. at 427-28 & 434.

118. Rasser & Lamberth, *supra*, at 21 & 7.

119. MCormick et al., *supra*.

120. *See generally, e.g.*, Bailey et al., *supra*.

121. Reich, *supra*.

122. Kevin Phillips, "U.S. Industrial Policy: Inevitable and Ineffective," *Harvard Business Review* (July-August 1992), *available at* https://hbr.org/1992/07/us-industrial-policy-inevitable-and-ineffective.

123. "National Policies in Support of High-Technology Industry" (Horst Siebert, moderator), *International Friction and Cooperation in High-Technology Development and Trade: Papers and Proceedings* (1997), at 80 (comments by Chris Hill), *available at* https://www.nap.edu/read/5902/chapter/10.

124. Michelle Clark Neely, "The Pitfalls of Industrial Policy," *Federal Reserve Bank of St. Louis* (April 1, 1993), *available at* https://www.stlouisfed.org/publications/regional-economist/april-1993/the-pitfalls-of-industrial-policy.

125. Samuel L. Gregg, "The Trouble with Industrial Policy," *Public Discourse* (August 3, 2020), *available at* https://www.thepublicdiscourse.com/2020/08/64708/.

126. Gregg, *supra*.

127. Shanta Devarajan, "Three reasons why industrial policy fails," *Brookings Institution* (January 14, 2016), *available at* https://www.brookings.edu/blog/future-development/2016/01/14/three-reasons-why-industrial-policy-fails/.

128. Bailey, *supra*.

129. Through this prism, Smith claimed the Navigation Act to be "perhaps, the wisest of all the commercial regulations of England." Smith, *Wealth of Nations*, *supra*, at Book IV, Chapter II, & Book V, Chapter I, Part I, *available at* https://www.gutenberg.org/files/3300/3300-h/3300-h.htm.

130. *See, e.g.*, Gregg, *supra*; Vincent Smith, "Opulence versus security," *AEI Ideas* (December 6, 2019), *available at* https://www.aei.org/american-boondoggle/opulence-vs-security/.

131. *See, e.g.*, Brake, *supra*.

132. *See, e.g.*, Assistant Secretary of State Christopher Ford, "Why China Technology-Transfer Threats Matter," remarks at the U.S. Naval Academy (October 24, 2018), *available at* https://www.newparadigmsforum.com/p2279.

133. *See, e.g.*, Assistant Secretary of State Christopher Ford, "Preventing U.S. Industry's Exploitation by China's 'Military-Civil Fusion' Strategy," remarks to the U.S. Chamber of Commerce (April 2, 2020), *available at* https://www.newparadigmsforum.com/p2505.

134. Brake, *supra*; *see also, e.g.*, McCormick, et al., *supra*.

135. Brake, *supra*.

136. McCormick, et al., *supra*.

137. Brake, *supra*.

138. Assistant Secretary of State Christopher Ford, "Huawei and its Siblings, the Chinese Tech Giants: National Security and Foreign Policy Implications," remarks at the Multilateral Action on Sensitive Technologies (MAST) plenary meeting at the U.S. State Department (September 11, 2019), *available at* https://www.newparadigmsforum.com/p2431.

139. In one example, Huawei failed rather embarrassingly in its effort – supported by local government officials, who donated radiofrequency spectrum for the purpose – to deploy a telecommunications network across the entire Russian Federation. *See* CTIA, *Building the 5G Economy: The Wireless Industry's Plan to Invest and Innovate in the U.S.* (January 25, 2021), at 35, *available at* https://www.ctia.org/news/report-building-the-5g-economy-wireless-industry-plan-to-invest-and-innovate-in-the-united-states.

140. McCormick et al., *supra*.

141. Rasser & Martin, *supra*, at 4 & 10.

142. *Id,* at 1.

143. Hemphill, *supra*, at 39 & 41.

144. McCormick, et al., *supra*.

145. *Id.*

146. Bailey et al., *supra*.

147. Branscomb, *supra*.

148. Bailey, et al., *supra*.

149. Hemphill, *supra*, at 42.

150. "National Policies in Support of High-Technology Industry," *supra*, at 80.

151. Brake, *supra*.

152. Bailey et al., *supra*.

153. Hemphill, *supra*, at 40.

154. Rasser & Lamberth, *supra*, at 18-19.

ABOUT THE AUTHORS

Dr. Christopher Ford is Senior Advisor for Geopolitical Policy and Strategy at MITRE Laboratories. He previously served as U.S. Assistant Secretary of State for International Security and Nonproliferation, and performed the duties of the Under Secretary for Arms Control and International Security.

Dr. Charles Clancy is Senior Vice President of the MITRE Corporation, General Manager of MITRE Laboratories, and MITRE's Chief Futurist. Before joining MITRE, he served as the Bradley Professor of Cybersecurity at Virginia Tech and as Executive Director of the Hume Center for National Security and Technology.

Mr. Duane Blackburn is Deputy Director of the Center for Data-Driven Policy at the MITRE Corporation – which leverages the experiences, insights, and models generated by MITRE's 8,000+ employees to support more effective, data-informed policymaking – and is a former analyst and Assistant Director at the White House Office of Science and Technology Policy.

MITRE's Mission

MITRE's mission-driven teams are dedicated to solving problems for a safer world. Through our public-private partnerships and federally funded R&D centers, we work across government and in partnership with industry to tackle challenges to the safety, stability, and well-being of our nation.

MITRE | SOLVING PROBLEMS FOR A SAFER WORLD™