Testimony of William B. Bonvillian, Senior Director, Special Projects, MIT Office of Open Learning and MIT Lecturer, to the Senate Committee on Commerce, Science and Transportation at the Hearing on April 14, 2021 on the "Endless Frontier Act".

Senators Cantwell, Wicker and Members of the Committee,

Thank you for the opportunity to meet with you today.

I want to emphasize at the outset that this is important legislation that needs to pass. We are facing a challenge to technology leadership that we have not faced before. Our growing trade imbalance in high-tech industries,[1] the fall in our real manufacturing value added output,[2] our declining position in international innovation ranking systems,[3] and the weaknesses in our defense industrial base[4] make it clear that American technological leadership in both innovation and production has eroded.

As this Committee understands, strong competitors are making economic and technology advancements that threaten to displace U.S. leadership.[5] Our current systems are simply not competing well. This requires us to adopt a new advanced technology strategy. Without it the United States will in all likelihood continue to lose market share in a host of advanced industries, including aerospace, life sciences, semiconductors, advanced communications and protocols, and Internet applications, with negative implications for innovation, national security, and, importantly, living standards.

My testimony covers three topics: 1) organizing to meet the tech development challenge, 2) regional innovation, and 3) workforce education. Under each topic, I will make general points about these areas as well as some suggestions for how the legislation can help deal with these three critical areas.

I. Organizing to meet the Tech Development Challenge:

The U.S., starting in the post-World War II period, organized its research and development (R&D) around mission agencies, so that the research would serve the mission. The National Institutes of Health became part of Health and Human Services, DARPA and the other defense research organizations became part of the Department of Defense, and the Office of Science served the Department Energy. Overall, this decentralized science approach has worked well, and helped us bring science into specific missions. It was a basic research model because the U.S. had been weaker in science at the outset of the war while it completely dominated world manufacturing by the end of the war. So the U.S. didn't have to consider the implementation stages, it needed to strengthen and retain the science base it built during the way.[6] But now we have a series cross-cutting technologies that will serve many missions – AI, quantum, new high performance computing, robotics, biotechnology, cybersecurity, advanced materials, etc. Where do we put a new innovation focus for this range of new technologies?

NSF is our one major, broadly-focused R&D agency not tied to a specific, and narrower, mission. It does basic science research in a range of fields and it is famous for it. But our current problem is technology, not simply basic science - we need a new technology development thrust, and this has not been NSF's job. So, the approach of this legislation is to form a technology-

focused sub-unit within the agency – the proposed new Technology Development Directorate at NSF. Some argue this will create a culture clash within NSF. Yet we have a long history of basic and more use-inspired, applied working in tandem and the cultures can be complementary – DARPA works alongside the Office of Naval Research, and ARPA-E alongside the DOE's Labs and Office of Science,.

Creating this tech directorate challenges us to think hard about the follow-on stages to research. To get to new technology as opposed to new science, we need to get through a series of stages, post-research. New technologies must move through: research, development, prototype, testing, demonstration, scale-up/piloting, initial market, full production. The proposed legislation recognizes this. It has inserted institutional elements to match the process:

- R&D in critical technology areas – with earlier stage research elements at existing NSF directorates, and later stage research as well as development to be performed at the new Technology Directorate.
- Development and prototyping – at University Technology Centers, and importantly, these can be consortia, including industry participants.
- Testing and demonstration – new test beds to prove and demonstrate the new technology so they can get into the risk range that industry and other kinds of capital can work with.
- Scale-up – could be supported at Commerce Department-designated Regional Innovation Hubs – for scaling-up toward production– preparing the regional tech infrastructure for introduction

U.S. technology history is littered with technologies innovated *here* in the U.S., that did not scale-up here, and were produced *there*.[7] Flat panel displays, solar panels, lithium ion batteries, drones, the list goes on and on. A core goal of this bill is to get the new critical technologies into range of industry acceptance – *here*. The new technologies require de-risking to get into the scope of risk and corresponding costs industry can absorb in implementing them.

Enhancement - Connecting the New Pieces: This bill puts key new pieces on the table, but all these pieces, as the sponsors and the Committee understand, need to be connected. They won't work if they are separate stovepipes. There need to be ties between NSF basic research and the NSF technology directorate. There need to be direct ties from there to the University Technology Centers then to Testbeds for testing and demonstration, then these need to tied to the Regional Hubs to be established through the Commerce Department for scale-up and pilot production.

We need to build a new house of innovation, and we can't do that if the foundation is in one place, the walls in another place, and the roof in a third. So the bill, for example, requires the Tech Directorate to work with (and transfer funding to) existing directorates, and by making clear that the University Technology Centers can be part of the regional hubs.

Innovation economists and technology policy experts have long indicated that innovation must be connected. They tell is that technology-based innovation is the dominant driver of economic growth. They tell us that to innovate, you must have strong R&D, and you must have a strong talent base staffing that R&D system. They also tell us that "innovation organization" is a critical third innovation factor. Innovation needs a series of strong actors, from university

research, to gov't research support and labs, to strong companies and supplier systems. You need strong actors and the actors have to connect with each other, so the handoffs are easy and smooth. The new pieces this bill creates will need organizational linkages to each other.

And there is another reason for these close connections: there needs to be two-way street – exchanges so that the tech development influences the R&D not just the R&D influencing the tech development. A linear model doesn't work well – a two-way street is critical so the actors can assist and teach each other. This is another reason why linkages are key between the new pieces. Shared, cross-cutting technology strategies that work linking each of the new institutional elements called for in the bill, shared advisory boards, and federal agency oversight that emphasizes connections are all part of the solution. There are connections in the bill, but these could be expanded.

Enhancement – Connecting the Other R&D Agencies: NSF is not going to be the only agency doing work on the 11 "key technology focus areas" - we have other mission R&D agencies that are doing important work as well. DOD must continue working on AI and Quantum, for example. We need to find ways to get them contributing together with this new NSF thrust. Agency collaboration is hard in our decentralized science system. And Congress is part of the problem because the appropriations process doesn't cross agencies. We need a mechanism for agency cooperation and sharing. The Office of Science and Technology Policy (OSTP) has its National Science and Technology Coordination (NSTC) mechanism. Better is the mechanism developed for the National Nanotechnology Initiative (NNI).[8] It has a coordination office and, while participating agencies don't share funding with each other, they work on common strategies and attack common R&D problems, cross-fertilizing ideas. We will need such a mechanism here. In addition, we have already created 16 Advanced Manufacturing Institutes, which provide another critical ingredient, and, as discussed below, they need to be further tied in, including into the Regional Innovation Hubs.

Enhancement – Assuring Adequate Resources for R&D at the Technology Directorate: The legislation makes generous percentage allocations to the various program it authorizes – to the University Research Centers, to existing NSF directorates, testbeds, etc. But only a limited amount appears to remain after all those allocations for all the remaining purposes. I believe the new Directorate needs more flexibility than that; a significant percentage should be set to support research awards from Directorate itself. Much of the initial work resulting from the legislation will need to happen through the new Directorate's substantial competitive research portfolio in later stage R&D -- these advances will feed all the other follow-on elements in the new system. We will need more breakthroughs to build on, so adequate support here will be a keystone for the system. In addition, I believe the Directorate should use a strong program-manager model aimed at the major technology challenges in the new technology areas, setting milestones for its research portfolios. It has been granted DARPA-like authorities and that is fully appropriate.[9]

II. Regional Innovation

Innovation is like real estate: location matters. Some regions move ahead, some are left behind – why? How can we bring more growth to more areas? The Regional Innovation Hubs in the bill, to be set up through the Commerce Department's EDA and NIST programs, could be a way to encourage regional innovation. How do we make regional innovation work?

We have been studying this for years - Michael Porter's work on innovation clusters dates back over two decades.[10] There has been much regional experimentation - we have many kitchens trying many ingredients and there is no exact recipe. Different regions can make different recipes work. Throwing innovation tasks at struggling regions, however, often does not work. Yet there are examples now of places that have become hubs of activity. Let me try to summarize a large literature in a few words.

Most believe we need regional ecosystems for innovation to thrive.[11] Typically, such an ecosystem includes an area education and research institution as an anchor for tech research and talent. Ecosystems also seem to need an organized public sector[12] engaged with the private sector – including companies and area business groups – pursuing a joint strategy. Solid larger firms linked to solid supply chains of smaller firms are another ingredient. Regions need to build on their existing regional strengths – not every area is going to be a biotech hub. Workforce education has become an increasingly significant component of a solid regional ecosystem – a number of regions are now encouraging companies and startups to come to or stay in their location because they can offer a trained and skilled workforce tied to employer needs. This mean strong workforce programs for new skills at area community or technical colleges are also a component. Another feature of the legislation is grants to communities to help them build strategies for their regional assets. To summarize a few key points, there needs to a broad engagement in innovation – a big tent – not a narrow single-innovation focus; strong locally-based firms need to be engaged as "anchor tenants;" a connection is needed to the talent pipeline – state university and skills education programs, for example - which will be key to companies; and state and local governments need to be strongly supporting the effort.[13]

Pittsburgh, is an example of a regional success story.[14] It was famously dependent on one industry, and when that steel sector declined, much of the city's well-being was affected. Starting in the 1980s, it was able to leverage existing assets – including strong area universities and state governments that developed on a bipartisan basis a long-term, continuing economic strategy. This combined state and local government, education institutions and heavily-involved business interests, that together advanced high-growth industries and higher-wage jobs. And it included grass-roots citizen involvement. A series of advanced technology centers were formed with area universities, which were at the core of the strategy. So, an advanced technology strategy, building on existing assets, can work for regional innovation. And significant technology advances in areas like computing, robotics and health care followed.

If the Regional Innovation Hubs anticipated in the legislation take on the innovation scale-up role they will need to be located in regional ecosystems that can pull together existing assets like those listed above. To effectively compete for these, they will need to have firms interested in implementing one or a mix of the new technologies and be able to muster their regional actors to show how they can help implement them.

The Regional Hubs (funded through the Commerce Department in the bill) are not the same as the NSF University Tech Centers the bill will create – and that is as it should be. The University Centers will primarily be for R&D through prototyping. More is needed beyond that for successful innovation, and those further steps are outside the NSF role. Additional actors are then

needed to move from those research-to-prototyping stages for work on the scale-up of new technologies. Not only universities are needed but regional industry associations, with both small and larger firms and their supply chains, community and technical colleges, and support from area government and economic development organizations. The Hubs are mechanisms to bring this additional combination of actors together. To apply an analogy to the role of the Regional Hubs, once you have the prototype for a new airplane wing, someone has to make sure there's an airplane to put it on and an airline to use it. University Tech Centers can be tied to follw-on Hubs. Are there enough of these Hubs to reach enough areas? While these regional efforts won't work unless adequately funded, the Committee might consider a larger number of Hubs with somewhat less funding for each to stretch regional innovation opportunities further. Not every area will be in a position to compete for these now, so importantly the bill also includes support for regions to develop their own innovation strategies. I saw a similar effort by the Commerce Department to support state manufacturing strategies, as the initial advanced manufacturing institute ideas were being considered, and it provided states with a major boost in developing state manufacturing strategies.

Enhancement - The link to manufacturing: The Hubs also have a different role from the Advanced Manufacturing Institutes, which are focused on particular production technologies, while the Hubs will pursue broader technology advances. In particular, the Hubs will need to help bring the new technologies into area companies for actual production. But a key asset they should take advantage of is the 16 existing advanced manufacturing institutes. These Institutes are each focused on one advanced manufacturing area, but regional companies and regional economies will have to adopt a series – they will have to adopt a combination of, for example, 3D printing, digital production, AI, robotics, etc., to optimize production for the new technologies. Many other nations will be after the same advanced technologies listed in this bill – unless we have the most efficient production systems, they won't be made here. The bill calls for coordination between the Regional Hubs and the Institutes, but the Hubs should be required to link to a mix of manufacturing institutes to that can bring their expertise to bear on the groups of advanced production technologies that will be needed for the new tech development areas. The Hubs can be enablers in a broader technology context for the advances the Institutes are nurturing in manufacturing.

The legislation also provides for a significant expansion of the Advanced Manufacturing Institutes, which should be viewed as complementary to the Hubs. These Institutes are both national and regional, the Hubs more regional. The Institutes must develop new production technologies available nationally, and implemented regionally, and the Hubs can help with that regional introduction. The Manufacturing Institutes are organized around particular technology topic areas, and while the bill calls for many more Institutes, there are really not that many different new manufacturing technology topic areas. Yes, we need some more institutes around additional technology topics, but we also need to deepen the efforts around existing manufacturing technologies, to give existing Institutes better ability to better reach not just industry leaders but bring their technologies to small and mid-sized manufacturers and enable new manufacturing skills. The legislation should call not simply for new Institutes, but funding should be broadened for manufacturing technology demonstration and training centers, strengthened small company and workforce programs, and satellite centers for existing institutes in additional locations. The legislation also expands the Manufacturing Extension Partnership

program, another important and complementary program, to play a role in the introduction of the new technologies and to work with the Manufacturing Institutes and the new HUBs.

III. Workforce Education

We know that R&D advances require a robust talent development system – so the bill has funding for STEM talent to be educated in the new technology areas. We need this. But one area that needs more emphasis is not only science and engineering researchers but the technical workforce. Technologies will never go into production unless there is a strong technical talent base to implement and produce them.

The U.S. doesn't really have a workforce education *system* – it is missing.[15] Ask an American what high school or college look like and they know, but ask what our workforce education system is and you get a blank stare. Ask many Europeans, and they know – they benefit from systems that closely link work and learning. Our workforce needs to upskill – new IT technologies have entered many sectors, for example –and we don't have an adequate system to train our workers for it. Jobs that require these higher skills are now going begging.

As noted above, some regions are starting to use workforce education as a core economic development strategy. For example, South Carolina is using its state-wide apprenticeship program built around its system of technical colleges to appeal to new and keep existing employers. And now it is developing a new youth apprenticeship program that starts in the junior year of high school – led by the Charleston area.[16] These and efforts in other states reflect a new reality – we have a demographic shift, an aging workforce with a smaller number of new entrant workers. And we have a growing skills gap in the new skills employers increasingly need. When we start to add the new technology this bill envisions, this problem will get worse.

Workforce education is an area where both the NSF and Commerce programs have a role, building on their existing work. In all these programs, the agencies need to work with both business and labor to ensure success.

Enhancement - The Regional Technology Hubs can help take on the workforce task: Talent, including technical talent, will be a key element for successful regional innovation. While the bill allows Hubs to have workforce programs, this should be a major Hubs effort, working with area community and technical colleges, with state colleges and secondary schools, to train for the new skills required.

Enhancement - The Apprenticeship Program: The draft of the bill I was provided calls for an apprenticeship program in the new skill areas sponsored by the Commerce Department. One approach would be for these apprenticeships to be tied to the Regional Hubs to help in their skill building in the new technologies.

Enhancement - Can NSF's ATE program help with technician talent in the new technologies? NSF already has a strong Advanced Technical Education (ATE) program; it plays a critical role in updating community college curricula and programs in advanced skills. As noted, the Technology Directorate's education program needs a technical workforce education component in addition to its STEM element – let's take advantage of ATE and include a stronger

workforce education element for the technicians and technologists we will need in these new and emerging fields. The bill has a set-aside for community colleges and calls out the ATE program, but the bill could give more guidance on how ATE can contribute, in support of both the new Directorate and the Hub programs.

Summary:

Overall, as I said in my opening comment, this is important legislation that will play a key role in renewing our innovation leadership. It speaks directly to our national and economic security in ways no other recent legislation has. The U.S. innovation system is at a crossroads, and this bill presents an opportunity to take a strong new path.

Concerning the organizational elements in the bill, the pieces are there that can take us through the stages of innovation –

- R&D in critical technology areas at existing NSF directorates and the new Technology Directorate.
- Development and prototyping – at University Technology Centers, which can be consortia, including industry participants, and in the tech transfer program.
- Testing and demonstration – with new test beds.
- Scale-up – assisted by the Regional Innovation. Hubs

We also need to make sure the new pieces form a system, that there are links to other R&D agencies working in these areas, and ensure the right resources and organization for the new Technology Directorate.

Concerning regional innovation, since innovation has to be implemented and scaled-up in regions, the Regional Hubs can play this role. They, in turn, can link to the Advanced Manufacturing Institutes which can assist them with the new production systems and processes to turn critical technologies into products.

Concerning the workforce, the technical workforce along with the STEM workforce will play a key role in the emergence of the critical technologies. That technical workforce can be supported through the Technology Directorate, working with NSF's existing ATE program. The Regional Hubs can also play a key role in regions on workforce readiness for the critical technologies – the workforce will be vital to scale-up. And the apprenticeships can be linked to the Hubs as well.

The Endless Frontier Act offers a very important, indeed historic, opportunity for the U.S. to build up its innovation system based on the critical technologies we must have for our national and economic security.

[1] The U.S. ran a trade deficit in advanced technology products of $133 billion in 2019 compared to a trade surplus in these goods of $4.5 billion in 2001. Trade in Goods with Advanced Technology Products, U.S. Census, https://www.census. gov/foreign-trade/balance/c0007.html.
[2] U.S. Share of Global Manufacturing Value Added (controlled for the value of the U.S. dollar) declined from 25% in 2005 to 18.4% in 2014. Adams Nager, Trade vs. Productivity, What Caused Manufacturing's Decline, ITIF Feb. 2017, ITIF, citing United Nations Statistics, National Accounts Main Aggregates Database (GDP and its breakdown at current prices in US dollars, all countries for all years). U.S. Manufacturing value added as a percentage of GDP declined from nearly 20% to 11.2% between 1990 and 2021, Statista (based on UN and World Bank data), https://www.statista.com/chart/20148/manufacturing-value-added-as-percent-of-gdp-in-major-economies/
[3] See, for example, South Korea Leads World in Innovation as US Exits Top Ten, Bloomberg innovation Index, Bloomberg, 2/2/21, https://www.bloomberg.com/news/articles/2021-02-03/south-korea-leads-world-in-innovation-u-s-drops-out-of-top-10;
[4] Office of the Secretary of Defense, Military and Security Developments Involving the People's Republic of China, 2020, Annual Report to Congress, Department of Defense, August 2020, 73, 85, 88, 105, 113, 123, https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF.
[5] Robert D. Atkinson, Time for a New National Innovation System for Security and Prosperity, *Prism* (National Defense University journal), v.9, n.2, March 2021, 60-61, http://www2.itif.org/2021-PRISM-9-2-new-national-innovation-system.pdf?_ga=2.76279189.1863482471.1617915091-1416244290.1617639922
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[7] Bonvillian and Singer, *Advanced Manufacturing*, 57-58.
[8] National Nanotechnology Initiative, https://www.nano.gov/about-nni
[9] The DARPA model is relevant to the proposed Directorate. See, Bonvillian, Windham and VanAtta (eds.), *The DARPA Model for Transformative Technologies* (Cambridge, UK: Open Book Publishing 2020), https://www.openbookpublishers.com/product/1079.
[10] See, for example, Michael Porter, Clusters and the New Economics of Competition, *Harvard Business Review*, Nov.-Dec. 1998, https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition. For a summary of limitations in the theory, see, for example, Yasuyui Motoyama, What was New About Cluster Theory? *Economic Development Quarterly*, V. 22, n. 4, Nov. 2008, 355-363, https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.910.884&rep=rep1&type=pdf.
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[13] Ben Armstrong Industrial Policy and Local Economic Transformation, *Economic Development Quarterly* (Aug. 2021) (forthcoming).
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[15] William B. Bonvillian and Sanjay E. Sarma, *Workforce Education, A New Roadmap* (Cambridge, MA: MIT Press 2021).
[16] Bonvillian and Sarma, *Workforce Education*, 199-206.