Written Testimony of Dr. Kelvin K. Droegemeier
Regents' Professor of Meteorology and Weathernews Chair Emeritus
Roger and Sherry Teigen Presidential Professor
University of Oklahoma
and
Former Director
White House Office of Science and Technology Policy (OSTP)

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I thank Chairman Lucas, Ranking Member Lofgren, and Members of the Committee for the privilege of testifying on the important topic of U.S. competitiveness in science and technology. I also am grateful to Committee staff for the hard work they do behind the scenes each and every day, and in organizing this hearing.

My name is Kelvin K. Droegemeier, and I am Regents' Professor of Meteorology, Weathernews Chair Emeritus, and Roger and Sherry Teigen Presidential Professor at the University of Oklahoma. I also am former Vice President for Research at the University of Oklahoma, former Oklahoma Cabinet Secretary of Science and Technology, and former member of the National Science Board (2004-2016), serving the last four years as Vice Chairman. From 2019 until 2021, I served as Director of The White House Office of Science and Technology Policy (OSTP) and Science Advisor to the President. For two and a half months during my time at OSTP, I also served as Acting Director of the National Science Foundation. I am testifying today solely in my roles as an academic teacher, researcher, administrator, and contributor to national science and technology policy. My views and recommendations do not reflect those of the University of Oklahoma or its Board of Regents.

This Committee has long been a bi-partisan champion of science and technology, and over many years has enacted important legislation to foster national prosperity, economic security, quality education, and international competitiveness through research, especially that which is born out of human curiosity but ultimately finds its way into practical uses which transform society. Nowhere has this been more evident than during the COVID-19 pandemic, where fundamental research in biology, mathematical modeling, human behavior, biochemistry, advanced telecommunication, artificial intelligence, supply chain management, manufacturing and, of course, human health, allowed us to lead the world in understanding and taking measures to address a global crisis.

The pandemic made ever clearer the importance to humanity of science and technology research and development, and thus I deeply appreciate this Committee's work on the CHIPS Act of 2022, which contains numerous provisions that will help ensure U.S. leadership in science and technology. Among the most important is a bottom-up quadrennial assessment of our entire science and technology research and development enterprise, along with the creation of a National Science and Technology Strategy. I worked toward exactly these same goals while at OSTP, so I am especially encouraged to see this Committee hold a hearing on U.S. competitiveness through the lens of these important activities. I also appreciate the opportunity to provide input, and I stand ready to help in whatever ways you believe to be most beneficial.

1. The Big Picture: U.S. Global Leadership in Science and Technology

Countless reports have been written about the evolution of U.S. global leadership in science and technology (S&T) following World War II, underpinned in many respects by Vannevar Bush's 1945 seminal treatise, *Science: The Endless Frontier*.[1] Consequently, I need not recount here the many extraordinary S&T outcomes pioneered by the U.S. and its international collaborators, which have contributed to economic prosperity, national security, improved health and quality of life, and a brighter outlook for future generations. However, I do wish to describe what I consider to be the two most important factors in achieving this success, and which should figure prominently in the National S&T Strategy (hereafter NSTS) required by the CHIPS Act.

The first concerns our values and freedoms – the freedom to discover and create; the freedom to debate, challenge, and speak freely; the freedom to share; a free market system to transition research outcomes into practice for the benefit of humanity; and the freedom to pursue our own pathways and dreams. Importantly, and not surprisingly, these values are congruent with the very values by which research itself is conducted, namely, honesty, integrity, transparency, accountability, impartiality, objectivity, reciprocity, rigorous civil debate, respect, and merit-based competition.

The U.S. has always been a beacon of values and freedom to the world, and that beacon shines brightly from our research enterprise. **In a world where values and freedoms are not universally treasured and reinforced, and where authoritarian regimes seek to undermine longstanding norms and international order, the U.S. must maintain its global leadership position in S&T not only by virtue of its contributions, but also by *leading with its values*. Consequently, the NSTS should be built upon a set of principles and values that reflect the essence of our Nation's foundation and the conduct of research itself.**

The second factor concerns the multi-sector U.S. S&T enterprise, comprising academic institutions, which perform research and educate the next generation workforce; state and Federal government organizations, which both fund as well as perform research; for-profit companies, which innovate research outcomes to create products and services beneficial to society; and non-profit organizations, which fund research, help identify future priorities, organize and support professional communities, and contribute to policymaking. Our well over $600 billion yearly expenditures in S&T research and development (R&D) occur within this powerful ecosystem, which boasts trillion-dollar companies, support structures which have funded numerous Nobel Laureates and countless other scholars, five or more of the world's top 10 research universities (depending upon the source of the rankings), and 17 U.S. Department of Energy (DoE) National Laboratories which are unique in the world. **Therefore, it is vitally important that the NSTS be structured as a *whole-of-Nation plan*, involving all sectors of the U.S. S&T R&D ecosystem in an integrated manner – from planning through execution. As noted below, every sector should "see itself" in the plan and be able to use the plan to help chart its course for the future.**

2. The U.S.-China S&T Relationship: Collaboration, Competition, and Concerns

S&T R&D inherently are both domestic as well as multi-national activities, ranging from individual faculty collaborations on fundamental/curiosity-based research to massive, long-term corporate projects or multi-national facilities such as telescopes and particle accelerators. The benefits of such collaborations, and the contributions made to them by foreign nationals studying or working in the U.S. – including individuals from China – are well established[2 3 4] and have yielded important benefits for society. Examples include the rapid identification of the COVID-19 virus and development of vaccines and other therapies to combat it; the first image of a black hole shadow; and foundational theories of turbulence in fluids, to name but a few. Collaboration quite often yields the best outcomes by bringing to the table a diversity of ideas and perspectives, thereby enriching the research and promoting learning and a broadening of views.

Collaboration between the U.S. and China in S&T can be evaluated in a variety of ways, ranging from funded projects or formal publications involving researchers from both nations to educational exchange programs. As an example of the former, in 2020, 22% of all science and engineering (S&E) articles produced in China had international co-authors[a], while in the U.S., the figure was 40%.[5] Slightly over 26% of U.S. international articles had U.S. and Chinese co-authors, up from 14% in 2010.[5] Indeed, the number of publications having both U.S. and Chinese co-authors grew steadily from approximately 10,000 in 2007 to approximately 62,000 in 2019.[6] About one-third of the papers in 2019 had authors with dual U.S.-China affiliations, though that number fell sharply through 2021.[6]

As in most aspects of society, including sports, private business, and even families, competition is valuable if pursued in an appropriate manner. S&T research is no exception, and **China clearly is seeking to establish global dominance in S&T and thus is an important competitor for the U.S**. Xi Jingping, President of the People's Republic of China (PRC), stated the following during an address on May 28, 2021 to the Chinese Academies of Sciences and Engineering, and the China Association for S&T[7]:

> *"Science and technology self-reliance and self-strengthening should always be considered a strategic support for national development. Scientific and technological development must target the global science and technology frontiers, serve the main economic battlefields, strive to fulfill the significant needs of the country and benefit people's lives and health. Scientists and engineers must closely follow current trends, take the initiative, confront problems head-on, and overcome difficulties."*

China has made significant investments in S&T and has begun to reap significant benefits from them. Its strategic innovation triangle[7] involves a 15-year medium-long term S&T Plan, Education Reform Plan, and Talent Plan. China's internal expenditures on R&D grew in 2020 to

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[a] From the source document, "articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a whole count basis (i.e., each collaborating country or economy is credited with one count). Articles without international co-authorship are counts of articles with one or more institutional addresses all within a single region, country, or economy, which include single-author articles and articles coauthored under the same institutional address. International articles are articles with institutional addresses from more than one country or economy.

over 2.4% of gross domestic product (GDP) and could reach 2.8% if current trends continue.[7] By comparison, the U.S. in 2020 expended 3.45% of GDP.[8] Gross domestic R&D expenditures by China in 2019 were $526 billion compared with $658 billion for the U.S.[9] In terms of purchasing power parity (PPP)[b] dollars, China has been accelerating its investments rapidly since the early 2000s and likely has overtaken the U.S. by now in both real dollars and percentage of global share.[10] China's R&D spending focuses mostly on experimental and applied work conducted at enterprises other than universities.[7] Since approximately 2010, the source of Chinese government funding for R&D has shifted from the central to local governments.[7]

One important measure of originality in innovation, and the translation of research outcomes into practical benefits for society, is the patent. A recent article by the Center for Strategic and International Studies[11] notes that, based upon raw aggregated data, China began to emerge in 2010 as the world's leader in patent applications and grants, exhibiting significant yearly increases thereafter. Conversely, U.S. trends have been much more modest, resulting in China having more than twice the number of patent applications in 2020.[11] Of course, a more important measure is the number of patents granted, and by that measure, China has a roughly 50% lead compared to the U.S.[11] One must be careful in interpreting this figure, however, because it is believed[12] that much, if not most of China's patents do not have value in the marketplace, and that factors other than the desire to protect intellectual property for innovating products and services are at play.

Turning to education, in 2016, China produced more than twice the number of first (baccalaureate) university degrees in S&E compared to the U.S. (which produces the second most).[13] Some 15 years earlier, China was in third place globally. As of 2018, the U.S. awarded slightly more S&E doctoral degrees than China (41,071 compared to 39,768).[14] In 2020, the U.S. awarded 42,622 S&E doctoral degrees,[15] with 13.4% awarded to temporary visa holders from China.[16] Also in 2020, nearly three-quarters of doctoral recipients on temporary visas in the U.S. said they intended to remain here, which is an increase of some four percentage points since 2010.[17]

It has been said that research and innovation anywhere are good for research and innovation everywhere, and that a rising tide lifts all boats. Both are true. However, **the U.S. cannot rely on the global rising tide of S&T research and innovation to lift its boat. It must develop a bold, transformative S&T Strategy that allows it to sail higher, move more quickly, unleash the creative talents of every individual, collaborate intentionally, and lead globally with its values (see below)**. The CHIPS Act provides an opportunity to do just that.

3. Thoughts on Developing the National S&T Strategy and Quadrennial S&T Review

Congress has provided the Nation with an important and unprecedented opportunity to take full stock of its current capabilities in S&T across all relevant sectors, and to develop a forward-

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[b] According to the Organization of Economic Cooperation and Development (OECD; oecd.org/sdd/purchasingpowerparities-frequentlyaskedquestionsfaqs.htm#FAQ1), "PPPs are the rates of currency conversion that equalize the purchasing power of different currencies by eliminating the differences in price levels between countries. In their simplest form, PPPs are simply price relatives that show the ratio of the prices in national currencies of the same good or service in different countries. PPPs are also calculated for product groups and for each of the various levels of aggregation up to and including GDP."

looking strategy congruent with and supportive of other Federal plans and strategies for which S&T are foundational to domestic success and global leadership. I offer in this section views and recommendations regarding the NSTS and Quadrennial S&T Review (hereafter QSTR).

Point #1. Scope and Structure of the NSTS. As noted previously, it is vitally important that the NSTS be structured as a whole-of-Nation plan, involving all sectors of the U.S. S&T R&D ecosystem in an integrated manner – from the very inception of planning through execution. Every sector should "see itself" in the plan, and organizations within each sector should be able to use the plan to help chart their course for the future in a manner that supports national goals but is not dictated by them. **Additionally, and very importantly, participating stakeholders should be drawn from sources in addition to the most prestigious and highly ranked organizations.** In the case of academic institutions, this includes but is not limited to individuals from EPSCoR (see below) jurisdictions, Minority Serving Institutions (MSIs), Historically Black Colleges and Universities (HBCUs), emerging research institutions (ERIs, defined as institutions having less than $50 million per year in Federal research expenditures), rural institutions, and two- and four-year institutions.

Although developing the QSTR and NSTS will be monumental tasks, even more difficult and important will be ensuring their effective use. We are all too aware of massive strategic plans which mostly sit on the shelf and then are set aside after elections. This must not be the case here, which leads to the next point.

Because the NSTS and QSTR are arguably broader than any assessments or plans ever developed, it will be impossible to construct them in a traditional manner, e.g., by mining numerous reports from Federal agencies, private companies, academia, and non-profit organizations, and conducting listening sessions and focus groups. Consequently, **the power of artificial intelligence (AI) should be brought to bear to assemble and synthesize information across all sectors and key organizations, identify gaps and needs, draw comparisons with the plans of other nations, and empower the developers of NSTS and QSTR to propose bold new ideas and pathways.** AI was shown to be profoundly important in the COVID-19 pandemic, especially in synthesizing information from the thousands of publications which were emerging at extraordinary speed (see below). AI can play an even greater role with the NSTS and QSTR.

Point #2. A Plan Like No Other. The NSTS should put forth a strategy that is **highly transformative and disruptively creative**, taking a bottom-to-top approach that enables a seamless ecosystem among all sectors of the U.S. S&T R&D enterprise. It should be like no other plan, domestic or international, and do what research itself does: ***Inspire* us with bold ideas, *unite* us in our work, and *guide* us into the future**.[18]

Although we tend to speak about innovation in the context of S&T, it is important to recognize that **policy and administrative frameworks can be equally innovative**. Our ability to work across sectors is significantly challenged,[19] and researchers are overwhelmed by rules and regulations that tie our hands rather than loosen our creative capabilities. The fact that faculty in our universities spend, on average, between 42% and 44% of their time on administrative activities, unrelated to research,[20] is completely unacceptable – especially given that these percentages have not changed meaningfully in over two decades despite the addition of research administrative and regulatory compliance personnel at many universities. And indeed, those percentages likely will increase with additional administrative tasks related to safeguarding research, as noted below. These and other challenges have been known for many years, yet no significant relief has been forthcoming despite well-intentioned attempts. The NSTS and QSTR have an opportunity to drive the needed change.

Because many of the needed changes are difficult to achieve *en masse*, **the NSTS could propose a set of experiments (e.g., in academic-corporate partnerships; Federal research assistance awards to academic researchers) in which specific stifling regulations are temporarily suspended or streamlined (e.g., via Executive Order) as a proof-of-concept, with the outcomes used to implement broader change**. The COVID-19 pandemic provided an unfortunate experimental framework where, owing to urgency and uncertainty, capabilities were developed which otherwise would not have occurred (e.g., the CORD-19[21] data base of publications and artificial intelligence applications, the nascent National Strategic Computing Reserve,[22] and of course, Operation Warp Speed[23]). Lessons learned from these and other activities should inform bold recommendations within the NSTS.

Point #3. Leave Politics Behind. The NSTS and QSTR should be **entirely apolitical and bi-partisan**, avoiding some of the political overtones in previous plans and assessments. The best way to accomplish this goal is to begin with a set of **guiding principles** to which all S&T sectors and political parties can agree, and use them as a North Star when challenging issues tend to create division on specific topics. I am pleased Congress chose The White House Office of Science and Technology Policy (OSTP), rather than specific departments or agencies, as the focal point for developing the NSTS and QSTR. Its current leadership is exceptionally qualified to lead these initiatives and has demonstrated its ability to view S&T through an objective lens.

Point #4. Broaden the Engagement of Institutions. Considerable focus has been placed recently, including in the CHIPS Act and with good reason, on providing additional funding for research to MSIs, HBCUs, and ERIs. However, often overlooked is the fact that such institutions lack the administrative capabilities to assist their faculty and other researchers in identifying and pursuing funding, managing awards once received (including the significant amount of reporting and compliance involved), commercializing intellectual property, developing multi-sector partnerships, and addressing issues of foreign government interference (see below). Consequently, simply providing more funding for research, without addressing the administrative challenges, can set such institutions up for failure, or at least significant problems.

Steps are being taken to address this capability gap to enable many more academic institutions to participate in the U.S. research enterprise. One unique example is the NSF GRANTED (Growing Research Access for Nationally Transformative Equity and Diversity) program[24], which "focuses on addressing systemic barriers within the nation's research enterprise by improving research support and service capacity at emerging research institutions." **It is important that the NSTS recognize the value of engaging every type of institution in the U.S. academic research enterprise, building upon the GRANTED concept and creating not only research, but also administrative**

partnerships across the spectrum of our Nation's institutions – large and small, public and private, long established and just getting started.

Point #5. Take the Long View. Congress has detailed in the CHIPS Act several key components of the NSTS, including that it spans four years. I support that idea. However, **the NSTS should be constructed within the context of a 25-year "horizon or arc," which does not identify specific technologies or research areas of investment – for doing so is impractical – but rather describes, in broad strokes, a U.S. vision for its future in terms of research, education, technology, domestic and international partnerships, and national and international norms of behavior**. By taking such a long view – which in fact is precisely how China operates – the U.S. could have, perhaps for the first time since World War II, a multi-decadal national context for its S&T future, within which resides a specific plan for the next four years.

This approach has the benefit of preserving the ability of the research and technology communities to take the lead in determining which activities should receive the greatest attention and resources. Although it may be tempting to create prioritized lists of specific S&T topics to be pursued (e.g., quantum computing, biotechnology, artificial intelligence, climate change), I believe we do not have such luxury. Rather, these and numerous other areas represent high priorities for the future in today's exciting but dangerous world. Consequently, the NSTS should identify **foundational elements of these and other societal imperatives** (e.g., data, communication, computation, experimentation) and ensure *they* are addressed – thus allowing numerous activities which build upon them to emerge and thrive.

Point #6. It Boils Down to People. One cannot overstate the importance of human capital to the future of U.S. science and technology research and education. Countless reports have been written about the trajectory of demographics in the U.S., the need for both a skilled STEMM (science, technology, engineering, mathematics, medicine) workforce and a skilled technical workforce, the importance of international students and workers, and the need to engage those who are traditionally underrepresented, underserved, and under-resourced. Hundreds of billions of dollars have been invested in a wide array of initiatives, national strategies have been written, and important progress is being made.

However, the NSTS and QSTR provide the U.S. with an opportunity, as never before, to coordinate workforce development on a national scale with broad national goals that involve all sectors of the S&T enterprise. I personally believe **the U.S. needs a national STEMM workforce/talent initiative, similar in many respects to the GI Bill**, which could both leverage and in some cases supplant current individual workforce initiatives and achieve what they alone have been unable to do. Namely, identify and educate what the National Science Board calls the Mission Millions.[25] **Such an initiative, which should include a participant service component to the Nation as well as a commensurate program to substantially build the teaching workforce,** would in my view be much more efficient, and lead to greater progress much more quickly, than the current array of (in many cases) disconnected programs. It also could address important issues raised in a new report by the National Academies of Science, Engineering and Medicine on diversity, equity and inclusion in STEM organizations.[26]

Additionally, the future of education, industry requirements for workers, and how individuals view themselves is not about degrees and years of service, but rather about skills, competencies, and credentials. **The NSTS is ideally positioned to provide a bold vision for moving toward a skills-based education and workforce environment, where an assemblage of demonstrated skills and capabilities is recognized as the coin of the realm**. The winds of change already are blowing in this direction, and the multi-sector approach for NSTS is ideally suited toward engaging this topic in a coordinated national manner.

Point #7. The Essential Role of Partnerships. As noted previously, the U.S. multi-sector S&T enterprise is extraordinary in its historical evolution, capabilities, and achievements. Yet, partnerships among the sectors, and even across Federal agencies, remain onerous and overly complicated owing to regulations, differing perspectives, and historical inertia. Progress happens, but the cost in terms of time and talent is far greater than it should be. Why are partnerships important and why do we need them? Because partnerships bring together people, ideas, funding, facilities, and other resources to achieve certain important goals which otherwise would be unattainable.

One relatively simple solution – which is applied occasionally – is to **have the heads of Federal R&D agencies develop relationships with heads of private non-profit and for-profit companies to "set the table" for the strategic manner in which they might partner**. All three types of organizations have different philosophies, administrative and governance structures, capabilities, and rules and laws under which they operate. This is in fact an extraordinary strength that can be leveraged in partnerships, for when two or more join together, amazing things can happen. Yet, all too often, we leave it to individual researchers or centers to build S&T relationships with companies or non-profit foundations. In many cases, the researchers are not skilled in building such relationships, especially for institutions which traditionally have not engaged in such activities. Although such interactions need to occur, we need to add strategic, institutional-leader-to-institutional-leader coordination that establishes a framework for partnering, which then can be executed by others within the organizations. This will greatly broaden the number and type of institutions participating in partnerships and lead to collateral benefits such as local and regional economic development, especially in disadvantaged regions.

Indeed, regional innovation is key, and important strides are being made in this regard, e.g., by the NSF Regional Innovation Engines and DoE Innovation Hubs. In fact, a recent report[27] on the future of the NSF EPSCoR (Established Program to Stimulate Competitive Research) program emphasizes jurisdictional (i.e., state-level) transformation via the collective engagement of universities, state government, for-profit companies, business organizations such as Chambers of Commerce and the Business Roundtable, and non-profit organizations.

Point #8. Safeguard Science and Technology. In developing the NSTS, we must recognize, as Congress did in writing the CHIPS Act (and NDAA as well), that **the U.S. faces new and ever-changing threats of foreign interference to its S&T enterprise**. Examples include failure to protect confidential information in grant proposals and subverting the peer review process, failure to disclose required information including conflicts of interest and commitment, misappropriation of research results and credit, and outright theft of intellectual property.[28] [29] [30] [31] [32] [33] [34] [35] [36] In partial response, OSTP established in 2019 the Joint Committee on the Research Environment (JCORE)[37] within the National Science and Technology Council (NSTC). A particularly important JCORE sub-committee addresses issues of research security to ensure an **appropriate balance exists between the openness needed for U.S. research to thrive, including via principled international collaboration, and the protection of research ideas, methodologies, processes, data, and technologies prior to their formal publication or intellectual property protection.**

Numerous activities are underway to address research security challenges, starting with National Security Presidential Memorandum #33 (NSPM-33), issued in January, 2021.[38] An NSTC report was issued that same month on recommended practices in research security for research organizations (universities, private companies, independent research institutes),[39] and in January, 2022, OSTP issued guidance to Federal R&D agencies on implementing NSPM-33.[40] Numerous others activities are underway, as specified in the CHIPS Act and NDAA, including in the former the creation by NSF of a Research Security and Integrity Information Sharing Analysis Organization (RSI-ISAO). Additionally, workshops and studies are underway by government organizations, disciplinary societies, professional associations, and the National Academies of Science, Engineering and Medicine (NASEM).

Universities are responding as well, and the Massachusetts Institute of Technology (MIT) created an especially thoughtful approach to engaging with China[41] that is being considered by other institutions. Yet, the cost of such actions is significant, not only monetarily to taxpayers viz Federal funding agencies and research institutions, but also to researchers themselves in the form of increased administrative overhead at the expense of conducting research.[42] **We must be careful to empower our researchers, not constrain them unnecessarily.**

At the end of the day, research security boils down to behavior – namely, playing by the rules. This means understanding the rules, seeing them modeled, knowing how to comply with them, and being aware of the consequences of non-compliance. **Here again is an opportunity for the U.S. to lead with its values – to welcome foreign collaborators who may be less familiar with ethical conduct in research based upon the environments in which they were educated and trained, and to ensure their behavior, <u>as well as the behavior of everyone in the U.S. research enterprise</u>, reflects the highest professional standards and adherence to laws and policies.**

<u>Point #9</u>. <u>Bring Benefits to the Public</u>. The general public is the most important stakeholder in the U.S. S&T enterprise. This point was underscored by the National Science Board in its Vision 2030 report[25], for which one pillar of its roadmap is Delivering Benefits from Research. **The NSTS likewise should emphasize the delivery of benefits to the public, not only in the form of products and services, but also in U.S. leadership regarding the ethical conduct of research as well as the ethical use of technology**. With regard to the latter, the U.S. has long been an international leader, e.g., in the set of ethical principles for AI, which in May, 2019 was adopted by 42 OECD (Organization for Economic Cooperation and Development) nations[43].

Point #10. Don't Play to Not Lose. For my final point, working at a university in which football is far more than a topic of casual conversation, I know well, as do others, that one does not win games by playing to not lose. Although S&T research and education are not games and are not about winning and losing *per se*, they are in fact influenced by the manner in which the U.S. develops its "game plans" and executes them, especially in the context of funding. **The U.S. is positioned, with development of the NSTS, to have a very strong and powerfully unique S&T game plan for the future, leading with its values, working with the international community, and investing wisely and boldly to ensure it remains the highest ship on the seas.**

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