Testimony of

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Introduction
Madam Chairwoman Stevens, Ranking Member Baird, and members of the Subcommittee, thank you for the opportunity to testify today before the Subcommittee on Research and Technology on the programs, priorities and goals of the National Institute of Standards and Technology (NIST) for the nation. NIST's core mission is to promote U.S. innovation and industrial competitiveness. We constantly target our research programs towards the emerging technologies that will have the greatest impact in advancing the competitive position of the United States.

Preparing for the Future
To continue to be a bedrock of innovation, NIST must continue to reinforce its core competencies and grow new capabilities over the next decade. In planning for the capabilities that NIST will need to best support the nation over the next 10-15 years, we have examined a number of societal trends and potential emerging technological disruptions that could impact the competitiveness of the U.S. What systems will emerge that will require expanded cybersecurity and privacy capabilities? What technologies are likely to change the way cryptography works? What novel products will U.S. manufacturers make, and what new technologies must they use to be competitive? What technological advances will NIST be able to capitalize on to transform and enhance its mission delivery? These questions have shaped NIST's planning and programmatic investments for the future.

NIST worked with stakeholders across government, industry, and academia to find opportunities for greatest impact. The Industries of the Future (specifically Quantum Information Science, Artificial Intelligence, 5G, Advanced Manufacturing, and Biotechnology) were all identified as technological domains that have the potential to transform U.S. manufacturing, communications, health care, transportation, and beyond. These areas will also present NIST new challenges and opportunities to develop new measurement capabilities and other methods to secure and protect the Nation's economic and national security.

NIST and The Industries of the Future
Today, I look forward to highlighting NIST's plans and accomplishments in each of the critical technology domains:

Quantum Information Science
Advances in quantum technologies, including quantum information science, have the potential to transform and revolutionize computing, medicine, manufacturing, artificial intelligence, communications, national defense, and more. Capturing these economic and national security opportunities will require continued sustained investment and improved technology transfer efficiency to ensure U.S. leadership, especially given that other nations have stepped up their quantum-focused programs and investments as well. NIST plays a central role in this critical race for quantum leadership.

NIST is a recognized world leader in the field of quantum science and technology, including four Nobel Prizes awarded to NIST scientists for their discoveries in this field. NIST has been a strong contributor in the National Quantum Initiative. Our expertise in quantum draws directly from our mission to make the most precise and accurate physical measurements possible. Over the last quarter century, NIST has shaped an entire generation of quantum science. A significant

portion of today's quantum scientists have trained in NIST laboratories. NIST's research to develop a measurement infrastructure has enabled quantum information science to advance to where we are today. Consider just a few recent NIST achievements:

- development of a quantum logic clock;
- demonstration of near quantum-limited amplification of weak signals;
- creation of new measurement and error protocols for characterizing quantum many-body systems; and
- pioneering work in quantum simulation.

This past summer—for the first time in history—NIST scientists teleported a computer circuit instruction between two separated ions. This foundational work opens the door to quantum computer programs that can carry out tasks in future large-scale quantum networks.

The expertise of NIST scientists and the unique capabilities of our facilities are leveraged closely with partners in academia through NIST's network of joint institutes -- with JILA, our joint institute at the University of Colorado Boulder, as well as the Joint Quantum Institute (JQI) and the Joint Center for Quantum Information and Computer Science (QuICS) with the University of Maryland. These institutes have driven numerous breakthroughs in fundamental quantum research and have helped trained the next generation of researchers in this emerging field. Together these capabilities make NIST a true hub of quantum-based innovation.

As the U.S. research enterprise works to realize the potential breakthroughs of quantum information science, opportunities for new quantum technologies are emerging that take advantage of the unusual rules that govern the behavior of the fundamental components of matter. NIST is developing robust quantum engineering capabilities for researchers to rapidly create, test, and validate the performance of quantum technology platforms. Building on our expertise in quantum science, nanoscale fabrication, and semiconductor characterization, NIST is focused on creating these measurement capabilities to serve as the building blocks and the basis of standards for future quantum technologies that the U.S. requires to achieve and to lead the world in "quantum supremacy."

Building out this quantum engineering infrastructure will require close partnership and collaboration with industry. To further these efforts, last year NIST established the Quantum Economic Development Consortium (QEDC) in partnership with SRI International, headquartered in Menlo Park, CA. The QEDC brings together players from across industry with the goal to expand U.S. leadership in global quantum R&D and the emerging quantum industry in computing, communications, and sensing.

With funding from both the government and private-sector member organizations, the QEDC will:

- determine workforce needs essential to the development of quantum technologies;
- provide efficient public-private sector coordination;
- identify technology solutions for filling gaps in research or infrastructure;
- highlight use cases and grand challenges to accelerate development efforts; and

- foster access to intellectual property, efficient supply chains, technology forecasting, quantum literacy and workforce development.

Looking forward, over the coming years NIST will focus a portion of its quantum research portfolio on the grand challenge of quantum networking. Serving as the basis for secure and highly efficient quantum information transmission that links together multiple quantum devices and sensors, quantum networks will be a key element in the long-term evolution of quantum technologies.

Artificial Intelligence

Artificial Intelligence (AI) has long been a strategic priority for NIST, also representing a toolkit to remarkably enhance productivity across all areas of our research and development, as well as toward advanced manufacturing applications. An important goal for NIST is to develop the foundation for confidence and trust in AI that results in new research outcomes and an expanded commercial marketplace. International investment in AI is also exploding, and companies, governments and policy makers around the globe are seeking answers that can provide greater confidence in AI technologies. NIST's study and deployment of AI methods, tools, and standards can provide the basis for confidence and trust that is essential for adoption of these technologies.

NIST has made significant contributions to the fields of machine learning (ML) and AI over the years. For example, the MNIST database, a dataset of handwritten digits, is among the most widely used standardized datasets in the U.S. and around the world for training and testing AI systems. NIST scientists worked with the Defense Advanced Research Projects Agency to develop and deploy smartphone-based systems that enabled U.S. marines to seamlessly converse with native Pashto speaking Afghans. These technology developments have also facilitated rapid commercialization of phone-based voice translation systems such as Microsoft Bing and Google Translate.

Today, NIST's efforts in AI are focused along three primary areas of effort:

First, NIST is addressing fundamental questions about the use of AI. NIST has launched an effort to convene the community around key concepts of trustworthy AI, seeking to develop ways to measure, define, and characterize concepts around the accuracy, reliability, privacy, robustness, and explainability of AI systems. Some examples of NIST work in this space include:

- In November, the NIST National Cybersecurity Center of Excellence (NCCoE) issued a draft NIST Internal Report, "A Taxonomy and Terminology of Adversarial Machine Learning."
- In December, NIST issued a report on the performance of face recognition software tools in identifying people of varied sex, age and racial backgrounds: "Face Recognition Vendor Test (FRVT) Part 3: Demographic Effects" (NISTIR 8280). Such data is intended to provide valuable insights to policymakers, developers and end users about the limitations and appropriate uses of currently available AI tools.
- NIST and its NCCoE are planning to launch a testbed to evaluate AI vulnerabilities.

- NIST intends to release a set of draft "Principles of Explainable AI" for public comment.
- NIST is organizing a workshop to convene stakeholders to explore issues of bias in machine-learning based face and speech recognition algorithms.

Secondly, NIST is heavily engaged in using AI across its research portfolio in a host of areas including biometrics, advanced materials discovery, smart manufacturing systems, and the design and characterization of engineered biological systems as just a few examples. Additionally, the outputs of NIST research in general, especially in the terms of well-characterized data sets, as well as our work in advanced microelectronic systems, will help advance the field of AI. These tools will enable researchers to better train and understand AI systems, including the design and manufacture of next-generation hardware required to reliably and safely run AI systems. Some recent examples of NIST effort in this space include:

- NIST researchers are working on ways to utilize AI to automate vulnerability assessments for digital infrastructure and to produce vulnerability ratings using the industry-standard Common Vulnerability Scoring System.
- In advanced materials discovery, NIST has created a high-fidelity database, Joint Automated Repository for Various Integrated Simulations, density functional theory (JARVIS-DFT), with more than 30,000 materials and 500,000 properties to be used as training data that will help accelerate the development of new materials.
- In wireless spectrum analysis, NIST is creating a curated radio frequency (RF) signal database to aid in the development of machine learning models for signal detection and classification. These datasets, which include radar signals similar to those planned for the 3.5 GHz band and include noise and interference, can be used to train and evaluate AI detectors to enable federal-commercial spectrum sharing.
- In manufacturing, NIST is applying AI in its study of agility performance of robotic systems in manufacturing environments so that robots can "learn" behaviors to operate effectively in today's factories. Recently, NIST launched our fourth annual Agile Robotics for Industrial Automation Competition, offering cash prizes to the teams whose robots perform the best in a simulated environment.

Finally, standards engagement is a key element of NIST's mission, and we are deeply involved in multiple standards development bodies around the world. We are working with industry, government, and academia to establish governing principles and develop standards and identify best practices for the design, construction, and use of AI systems. It is vitally important for the U.S. to have a strong, persuasive, and consistent voice with the relevant standards organizations around the world.

- In August 2019, NIST released the report "U.S. Leadership in AI: A Plan for Federal Engagement in Developing Technical Standards and Related Tools" in response to the Executive Order (EO) 13859 directing NIST to issue a plan for federal engagement in the development of technical standards and related tools in support of reliable, robust, and trustworthy systems that use AI technologies. The plan identifies nine areas of focus for AI standards and urges that the federal government commit to deeper, consistent, long-term engagement in AI standards development.

- Twelve NIST experts are currently involved in the joint International Standards Organization (ISO) / International Electrotechnical Committee (IEC) Joint Technical Committee JTC 1, Subcommittee (SC) 42 on Artificial Intelligence, and NIST is the convener for the Big Data work effort in SC 42. NIST works with many companies (including Google, Intel, Microsoft, and Oracle), other federal agencies, and academia to develop U.S. consensus positions on the U.S. Technical Advisory Group for SC 42, supported by the International Committee for Information Technology Standards.
- NIST staff are participating in over a dozen other AI standards activities in various standards development organizations, including the American Society for Mechanical Engineers (ASME), the Institute of Electrical and Electronics Engineers (IEEE), and ISO/IEC. These activities cover topics such as computational modeling for advanced manufacturing, ontologies for robotics and automation, personal data privacy, and algorithmic bias.

NIST's capabilities, ranging from fundamental research to the delivery of the technical foundations of emerging technologies, make it a valuable asset in establishing and maintaining U.S. leadership in AI technologies.

5G and Advanced Communication

Advanced communications are enabling dramatic changes in how consumers, manufacturers, governments and others provide and consume information, transact business, provide and use essential services, and shop, among other tasks. Gartner, a leading research an analytics company forecasted that there will be over 20 billion connected devices by 2020, and other forecasts have projected continued growth with numbers ranging from 60 to75 billion connected devices by 2025. This insatiable societal demand for connectivity will require significant advancements in communication technologies.

The Administration's multifaceted 5G efforts are being led by Director Larry Kudlow of the National Economic Council, and within that framework, NIST is playing a vital role. NIST's programs in advanced communications support secure, reliable, high-speed wireless, and wireline communications critical to U.S. economic competitiveness, safety, and security. NIST measurement science research and support for the development of standards accelerates the deployment of next-generation communication technologies that promise to be faster and more reliable, including fifth-generation wireless networks. These technologies will support self-driving cars, internet of things (IoT) applications, drones, and future AI systems. NIST is committed to solving the measurement and deployment challenges of this fast-moving field to help the U.S. achieve and maintain global leadership in these areas, and also to help U.S. industry establish manufacturing capabilities needed for domestic market supply. The NIST portfolio of activities focused on advanced communications includes:

- the National Advanced Spectrum and Communications Test Network (NASCTN), which is a national network of federal, academic and commercial test facilities that provides the testing, modeling and analyses needed to develop and deploy spectrum-sharing facilities;
- the Public Safety Communications Research (PSCR) program, which is leading the development of standards and performing the associated research, development and

testing to provide the public safety community access to a dedicated, nationwide LTE broadband network (FirstNet);
- developing and improving the measurement tools and technologies to improve spectrum utilization, and novel spectrum sharing techniques to address the current spectrum crunch; and
- providing the measurements and data needed for the development of the next generation of wireless communications systems and improved optical communications technologies.

Some examples of how NIST is driving strengthened national capabilities in the areas of 5G and other advanced communications technologies include:

- Industry consortia, like the 5G Millimeter-Wave Channel Model Alliance. This is a NIST-sponsored international research consortium working to advance breakthrough measurement, calibration and channel modeling approaches for millimeter and submillimeter wave frequencies. Effective use of this wavelength spectrum represents a key enabler for applications related to IoT, virtual reality, autonomous vehicles, and ubiquitous small cell connectivity, a key element of 5G deployment. Launched in 2015 the Alliance has since grown to include nearly 80 organizations.
- NIST experts are participating in 5G standards development activities in multiple fora including IEEE and the Third Generation Partnership Project (3GPP) where they are working on issues of security and radio access.
- Unique NIST facilities like the Large Antenna Positioning System. This facility provides measurement capabilities to pioneer new antenna measurement methods for future 5G wireless communications systems. These systems will operate at higher frequencies and offer more than 100 times the data-carrying capacity of today's cellphones, while connecting billions of mobile broadband users in complex, crowded signal environments. However, their higher frequency signals are more easily distorted and more likely to be affected by physical barriers such as walls or buildings. The unique measurement capabilities developed by NIST will be important in helping industry develop technical solutions such as steerable beam antenna arrays and performance optimizations through artificial intelligence.
- NIST continues to make a significant impact in driving forward innovation in public safety communications technologies. Through PSCR, NIST has engaged numerous groups from both the private and public sectors to address technology challenges faced by the public safety community. These efforts have helped drive advances in everything from the development of security standards for 5G devices and reliable mission critical voice technologies to enabling first responders to take advantage of new performance and safety enhancing technologies like haptics. A key example of the output of this work was on display at the 2019 Boston Marathon. The SiFi router developed by Spectronn, as a result of funding and participation in the NIST Public Safety Innovation Accelerator Program, provided public safety with critical communication and computing capabilities without access to the internet, enabling first responders to always have a backup line of communication and computing if their local network failed either partially or completely.

Advanced Manufacturing

A strong U.S. manufacturing sector is essential to our economic security and national security. As the Trump Administration's National Security Strategy[1] states, "Support for a vibrant domestic manufacturing sector, a solid defense industrial base, and resilient supply chains is a national priority." American manufacturers contributed $2.18 trillion to the U.S. economy in 2016. Manufacturing plays an outsized role in our economy because of its high economic multiplier effect: U.S. manufacturing supports trillions of dollars of production in other parts of the economy by purchasing from and selling to over 80 other industries.

A partner to the U.S. manufacturing sector for more than a century, NIST has a proven track record in delivering useful tools and technical assistance that both existing manufacturers and aspiring start-ups value. NIST's measurement research in manufacturing processes and advanced materials provides a foundation that helps the nation's manufacturers to invent, innovate and create new products and services more rapidly and more efficiently than their competitors around the world. Through targeted research across a broad portfolio of technologies impacting manufacturing from advanced materials to smart manufacturing systems, NIST helps ensure that the U.S. remains a competitive force in advanced manufacturing to ensure our economic and national security. Our partnerships with large and small manufacturers, federal agencies, and academic institutions help us anticipate and meet the needs of rapidly evolving manufacturing industries.

The NIST laboratory programs in support of advanced manufacturing, ranging from work on materials design and discovery to the use of collaborative robots in factories, to biomanufacturing and standards for data exchange and processing information. Examples of some of NIST's work include:

- NIST develops standards and test methods to help industry take advantage of the latest manufacturing robotics technologies. This work includes technical standards for exoskeletons that can dramatically improve the performance of workers on manufacturing floors, warfighters, and the mobility-impaired.
- NIST partners with the pharmaceutical industry to develop widely available reference materials and measurement methods. For example, NIST's monoclonal antibody reference material provides a benchmark for companies to ensure quality measurements of their biological drugs and to spur biopharmaceutical innovations.
- NIST supports large-scale manufacturing needs by developing laser-based measurement techniques to ensure large objects such as aircraft wings are the right size for proper assembly and function.
- NIST is developing approaches to overcoming technical barriers to the adoption of additive manufacturing (also known as 3D printing), such as surface quality, part accuracy, material properties, real-time monitoring, and process modeling.

In addition to the output of NIST's research programs, NIST's extramural programs, which include Manufacturing USA help U.S. industry develop and implement new technology, develop robust supply chains, and refine their systems for efficiency and effectiveness, all while making them more competitive in the global economy.

[1] National Security Strategy published December 2017 https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.

- Manufacturing USA is a network of 14 manufacturing innovation institutes located across the country where companies, universities, community colleges, and entrepreneurs develop new manufacturing technologies with broad applications. The primary goal of the network, which is planned to expand to 17 institutes over the next year, is to ensure that American innovations and inventions currently going offshore for production in competitor nations are scaled up from lab experiments to products and processes that can be used by U.S. manufacturers. Manufacturing USA institutes collectively represent two-thirds of Fortune 50 U.S. manufacturers, over 500 small manufacturers, and eight of the 10 top-ranked research and engineering universities. Nonfederal funding matches federal funding at a 2 to 1 ratio, exceeding the original 1 to 1 goal and demonstrating the value of the network to industry, academia, and the states. Manufacturing USA education and workforce training programs have reached nearly 200,000 individuals and include programs focused on training veterans in advanced manufacturing skills.

As a whole, this suite of programs and investments across our laboratory research and extramural programs is an essential set of resources for the Nation's advanced manufacturing enterprise.

Biotechnology
In August 2019, the President named the bioeconomy as one of the three R&D priorities for FY2021 under the main priority of American Heath & Bioeconomic Innovation.

A key factor in unleashing the full potential of the bioeconomy will be the ability to harness the power of complex biological systems (primarily cells) in a predictable and safe way for the manufacture of advanced therapeutics, sustainable fuels, chemical feedstocks, and advanced materials. Remarkable progress has been made in this field throughout the last decade, particularly with respect to genome read, write, and edit technologies, but there is still a widely recognized need for measurements and standards to enable better predictive engineering, and to support reliable and safe translation of engineered biological systems into products and other use cases**.**

To support the U.S. bioeconomy, NIST is building next-generation measurement science (biometrology) capabilities and engineering biology laboratories for accelerating responsible biotechnology innovations. Along with supporting basic technology research and development, NIST helps facilitate the translation of technologies to scale through global standardization efforts and partnerships with industry. As metrology is central and essential to all engineering biology research, NIST also plays a significant role in convening stakeholders to discuss challenges and solutions as the field moves forward. NIST plays a key role in developing techniques, standards and reference materials used as benchmarks for manufacturing process control and product quality assurance, in order to facilitate commerce for the bioeconomy. The National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL), the Manufacturing USA institute sponsored by NIST with the University of Delaware, and its participants benefit directly from this work. Recent highlights of NIST work in this field include:

- The launch of the NIST Living Measurement Systems Foundry to advance U.S. synthetic and engineering biology efforts. The foundry enables the engineering of cells for reliable and safe use in dynamic and unpredictable environments for applications such as living

therapeutics, environmental sensing, and structured materials fabrication. An automated facility for high throughput testing and measuring of engineering microbes, the foundry provides a mechanism for partnership with other organizations developing measurement approaches.

- The production of world-leading measurements, standards, technologies, and data needed to drive advances in biosciences and biotechnology.
    - The NIST Genome in a Bottle Consortium brings together over 100 industry and academic partners to develop reference standards, methods, and data to enable the translation of whole human genome sequencing to clinical practice. NIST human genome reference standards have helped the Food and Drug Administration approval of diagnostics, provided confidence to enable rapid response of global health issues, accelerated the development of next-gen measurement capabilities, and provided high confidence data underpinning global biological research related to sequencing.
    - The NIST Gene Editing Consortium brings together 32 leading industry, academic, and government partners to identify pre-competitive standards and measurements to meet the needs of the gene-editing field. NIST leads the Measurement Working Group of this consortium and our researchers are actively developing new capabilities for assessing genome editing outcomes based on the inputs of this group. Working with its partners, NIST recently released a list of lexicons as a unified standard set of terms and definitions serving the needs of the genome editing community. This will provide critical support to various scientific and policy discussions.
    - NIST is assisting the growing regenerative medicine industry to meet their measurement assurance and other challenges. NIST has been working with companies and other federal agencies to develop measurement assurance strategies for quantitative measurement of living systems needed for translation and commercialization of advanced therapies, including cell therapy, gene therapy, and tissue engineered products.
    - NIST is developing key microbiome measurements needed to accelerate the availability of microbiome diagnostics and to enable manufacturing of microbiome therapeutics. Researchers are also developing measurements and standards for pathogen detection in biodefense and infectious disease diagnostics.

With continued support NIST can continue to provide the necessary measurement and standards capabilities and infrastructure that will be required to unlock the full potential of the U.S. bioeconomy.

Summary

With NIST's dedicated technical staff, one-of-a-kind facilities, and non-regulatory role, we are well positioned to have an outsized impact in each of these critical areas that promise significant benefit to the U.S. economy, our quality of life, and national security. With the continued support of this Committee, NIST will continue to thrive in its important mission to promote U.S. innovation and industrial competitiveness. Thank you and I would be happy to answer any questions the Committee Members may have.

Walter G. Copan

Under Secretary of Commerce for Standards and Technology and NIST Director

EDUCATION

B.S./B.A. degrees in chemistry and music from Case Western Reserve University, 1975
Ph.D. in physical chemistry from Case Western Reserve University, 1982

Dr. Walter G. Copan was confirmed by Congress as Under Secretary of Commerce for Standards and Technology and NIST Director on October 5, 2017.

As NIST Director, Dr. Copan provides high-level oversight and direction for NIST.

He has had a distinguished and diverse career as a science and technology executive in large and small corporations, U.S. government, nonprofit and other public-sector settings.

Dr. Copan formerly served as president and CEO of the IP Engineering Group Corporation, providing services in intellectual property strategy, technology commercialization and innovation. Until June 2017, he was founding CEO and chairman of Impact Engineered Wood Corporation, an advanced materials technology company. He also is a founding board member of Rocky Mountain Innovation Partners, where he led technology transfer programs and innovation services on behalf of the U.S. Air Force Academy, U.S. federal labs and academic institutions and helped foster entrepreneurial businesses in the Rocky Mountain West. He also served with the National Advisory Council to the Federal Laboratory Consortium for more than 5 years, providing industry inputs to advance the U.S. economic impacts of the federal laboratory system.

From 2010–2013, Dr. Copan served as managing director of Technology Commercialization and Partnerships at DOE's Brookhaven National Laboratory (BNL). Among his accomplishments were leading the creation and implementation of the new DOE technology transfer mechanism, “Agreement for Commercializing Technology” (ACT), to facilitate collaborations between the federal labs and U.S. corporations. He led the “Startup America” initiative on behalf of DOE for entrepreneurial business creation, and he initiated the DOE’s new Small Business Innovation Research – Technology Transfer (SBIR-TT) program, which built upon the experiences of NIST. He served as founding partner and board member of the “Accelerate Long Island” alliance for innovation, economic development and early stage investment.

From 2005–2010, Dr. Copan was executive vice president and chief technology officer at Clean Diesel Technologies, Inc., an international technology development and licensing firm. He spearheaded the company’s transformation, growth and listing on NASDAQ (CDTI), as well as the company’s subsequent merger. Prior to joining CDTI, Dr. Copan served at the DOE’s National Renewable Energy Laboratory (NREL) as Principal Licensing Executive, Technology Transfer. There, he led organizational changes that strengthened relationships with industry and

the investment community and led to the more productive commercialization of energy-related technologies.

After earning dual B.S./B.A. degrees in chemistry and music from Case Western Reserve University in 1975, Dr. Copan began his career in chemicals and materials research at the Lubrizol Corporation (now part of the Berkshire Hathaway Group). He earned a Ph.D. in physical chemistry from Case Western in 1982, and subsequently held leadership positions at Lubrizol in research and development, strategy, business unit management, venture capital, and mergers, acquisitions and strategic alliances in the U.S. and abroad. As managing director, Technology Transfer and Licensing, from 1999–2003, he was responsible for Lubrizol's corporate venturing and open innovation, technology strategy, business development, intellectual assets and the technology licensing business.