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"Domestic Manufacturing for a Clean Energy Future"

Chairwoman Kaptur, Ranking Member Simpson, and distinguished members of the Subcommittee: Thank you for the opportunity to appear before you today. My name is Tom Kurfess. I am chief manufacturing officer and interim director of the Manufacturing Science Division at the U.S. Department of Energy's Oak Ridge National Laboratory in Oak Ridge, Tennessee. I am a mechanical engineer and computational scientist by education and training, focused on the design and development of advanced manufacturing systems by rapidly developing, scaling, and integrating new technologies into production operations. I have spent more than 40 years in manufacturing, working with a variety of companies including small start-ups, medium-sized corporations, large suppliers, and original equipment manufacturers to resolve their greatest manufacturing challenges and enable their success. It is an honor to present this testimony on what DOE's national laboratories are doing to develop, demonstrate, and deploy scientific and technological solutions for domestic manufacturing to support a clean energy future.

INTRODUCTION

A robust domestic manufacturing sector is the backbone of the American economy, ensuring a secure and resilient supply of goods and well-paying jobs. The manufacturing sector is among the top five U.S. employers, providing jobs to more than 12 million workers.[1] In 2018, U.S. manufacturing represented approximately $2.33 trillion dollars of economic activity, approximately 11.6% of Gross Domestic Product. Manufacturing is an economic multiplier: for every $1 spent in manufacturing, another $2.74 is added to the economy.[2] A thriving manufacturing base provides both economic and national security. As recent history has

[1] https://www.census.gov/library/stories/2020/10/manufacturing-still-among-top-five-united-states-employers.html
[2] https://www.nam.org/facts-about-manufacturing/

demonstrated, the ability to manufacture products on our shores is essential in times of global disruption.

At the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL), we leverage our interdisciplinary expertise to drive scientific and technological breakthroughs for the manufacturing sector, with a focus on green manufacturing and advanced batteries because energy efficient processes and clean energy products that enable carbon avoidance are key to U.S. competitiveness and jobs growth.

ORNL is accelerating clean energy innovation throughout the U.S. manufacturing ecosystem. The nation's fastest supercomputer at ORNL speeds simulations to analyze how new materials and manufactured systems will perform in cars and airplanes. Our nanomaterials science leads to strong, lightweight components for clean vehicles and ships. The lab's breakthroughs in advanced manufacturing of tools and dies support the nation's critical supply chain. Our scientists are solving the materials challenges for efficient, safe, advanced and solid-state batteries. ORNL's innovations in design and manufacturing processes are creating better carbon capture devices and wind turbines, and we're developing new, efficient ways to recycle plastics and composites.

We do not perform our work in a vacuum at Oak Ridge. We work side-by-side with manufacturers of every size through a variety of arrangements to give a voice to industry and resolve their real-world challenges. ORNL seeks out partnerships with academia and other public and private partners to ensure our work is targeted, impactful, and deployed.

One way of scaling up our impact throughout the country is our success in deploying the **hub-and-spoke type partnership model** in forming regional alliances for specific manufacturing challenges. By collaborating with academic and other partners based in targeted regions, we benefit from the unique perspective and networks they bring to the table. These partnerships accelerate place-based innovation that can result in real-world impact.

One example is our collaborative research agreement with the **University of Toledo**, targeting advanced design and manufacturing of high-strength, intelligent, lightweight materials for use by the automotive sector. Just last week, ORNL and U-Toledo's College of Engineering co-hosted a **workshop on advanced manufacturing for molds and dies**, with participation from supply chain stakeholders ranging from major automotive OEMs to small- and medium-sized companies. These tools are essential production elements for durable, lightweight components, yet the traditional U.S. molds and dies industry has been in steady decline in recent years despite an increase in demand. Our scientists and engineers outlined the benefits of additive/subtractive manufacturing technologies and associated new materials to complement conventional production of tools and dies, providing a solution to this **critical supply chain challenge** and a business advantage to U.S. industry.

The results of our collaborative research have been remarkable. In just the last five years at ORNL, **more than 15 startups** have been formed based on lab-developed technologies, and we have entered **more than 140 new technology licenses**.

ORNL and **Cincinnati Incorporated** (CI) of Cincinnati, Ohio, together developed the Big-Area Additive Manufacturing (BAAM) technology that is today being sold to industry by CI and used to efficiently produce large, geometrically complex components for direct-use. Using new materials such as carbon fiber-reinforced polymers, the collaboration enabled processing rates 500 times faster and build volumes larger than existing commercial printing systems, leading to less material and energy waste.

Energy startup **SPARKZ** is working closely with ORNL in Tennessee to accelerate safe, efficient batteries with fewer critical materials to support electric vehicles and grid energy storage. SPARKZ has licensed several battery technologies from ORNL and is planning an R&D and prototyping facility to scale the technologies to the marketplace. The ORNL-SPARKZ partnership is ongoing as a DOE Lab Investment Partner Activity focused on maturing lab-scale technologies for commercialization.

ORNL's graphene technology innovation underpins startup **General Graphene** of Knoxville, Tennessee. The company licensed the lab's low-cost roll-to-roll manufacturing process in 2014 and is now employing a 20-person operation that promises to become the country's leading provider of graphene. The material, a one-atom-thick carbon, is 300 times stronger than steel. The research was supported by ORNL's Technology Innovation Program and an ARPA-E grant.

ORNL's extraordinary capabilities are a nexus for our staff of more than 5,500, including scientists and engineers in more than 100 disciplines. In a typical year, we welcome **more than 3,200 guest researchers**. At the DOE Manufacturing Demonstration Facility (MDF) at ORNL, we have partnerships with **205 industry collaborators** and **54 universities,** and we work with **10 other national laboratories** on technology solutions with real-world applications.

ORNL's workforce development initiatives are a point of pride, too. Since its opening in 2012, the MDF alone has **hosted more than 1,000 student interns**, many of whom have gone on to key industry positions in a talent pipeline that supports the next generation of America's manufacturing leaders.

The MDF is DOE's only research facility of its kind, established to provide industry with affordable and convenient access to infrastructure, tools, and expertise to facilitate rapid adoption of advanced manufacturing technologies. MDF capabilities include hybrid additive/subtractive, machining, metrology, carbon fiber/fibers, high volume composites, associated modeling and artificial intelligence. As a user facility supported by DOE's Advanced Manufacturing Office, we work alongside industry and university partners with the goal of democratizing advanced manufacturing technologies, keeping in mind that the overwhelming majority of manufacturing operations in the nation are small to medium businesses. *(see Appendix for an expanded list of ORNL capabilities.)*

The MDF at ORNL houses approximately **100 manufacturing systems**, with some **60%-70% provided by industry partners** under no- or low-cost leases as part of collaboration agreements to improve their technologies. The facility has welcomed **more than 34,000 visitors** since its opening in 2012, including **more than 5,800 companies.** MDF over the course of its operation has worked with partners under **182 Cooperative Research and Development Agreements, licensed 22 technologies** and its research has resulted in **more than 50 patent applications.**

The DOE **Battery Manufacturing Facility** at ORNL is the largest open-access research and development center for batteries, giving scientists and industry partners the ability to analyze every aspect of production from raw materials and electrode dispersion preparation to finished product and performance testing. Its instruments give researchers the tools to study battery materials from the atomic level size up to 7Ah pouch cells.

ACCELERATING THE CLEAN ENERGY TRANSITION

The DOE laboratory complex occupies a distinctive position in the national innovation ecosystem. We bring together experts in multiple disciplines and equip them with state-of-the-art capabilities to solve some of the biggest challenges facing our society today.

Following are recent examples of how ORNL has leveraged its scientific tools and expertise to resolve challenges in the manufacturing sector and deploy clean energy technologies:

Critical supply chains: ORNL COVID-19 manufacturing response. ORNL worked with several companies to accelerate the production of personal protective and other equipment as the COVID-19 pandemic triggered supply chain bottlenecks. The research is part of DOE's National Virtual Biotechnology Laboratory consortium (NVBL) that utilizes the extensive capabilities of the country's 17 national laboratories to work with industry and other institutions to address key challenges in responding to the COVID-19 threat. ORNL used its materials science, fiber production and additive manufacturing expertise and capabilities in several projects, including:

- A collaboration between **Cummins, Inc.**, and ORNL resulted in the ability to produce enough specialty filter media to supply more than **one million face masks and respirators each day** to U.S. healthcare facilities. ORNL, with the help of N95 filter media inventor Dr. Peter Tsai, developed a novel in-line charging device to mass-produce precursor material for carbon fiber production at the CFTF and later worked with Cummins to scale up the technology at its Cookeville, Tennessee facility.
- The same filter media process was utilized in a collaboration with medical device maker **DemeTECH** that resulted in the capability to mass produce N95 respirator masks and **added 1,500 jobs** in Miami, Florida
- ORNL mobilized its expertise in mold development to enable the efficient production of face masks, face shields, and test collection tubes with several partners, including

medical supplies manufacturer **DeRoyal Industries** of Powell, Tennessee, and bottler **Coca-Cola Consolidated** in North Carolina.

- The lab also rapidly developed flow injection molds using 3D printing with partner **Thermo Fisher Scientific**. The company expanded its operations in Kansas to **produce 1 million automated test kits per week** and **added 300 new jobs**. The projects grew partly out of a new collaboration with the U.S. Department of Defense called America's Cutting Edge that targets the development and deployment of machine tooling technology.

Additively manufactured carbon capture technology. ORNL materials scientists, chemists, and manufacturing engineers created a first-of-its-kind aluminum device that significantly enhances the capture of carbon dioxide emitted from fossil fuel plants and other industrial processes. By using additive manufacturing, researchers custom designed a multifunctional device that resolves the challenge of heat produced when solvents are used to absorb carbon in smokestack flue gas treatments. The device integrates a heat exchanger with a mass-exchanging contactor that maximizes the contact surface area between the gas and liquid streams and increases the overall efficiency of the carbon-capture process. The low-cost, 3D-printed device can be easily integrated into existing smokestack carbon capture processes.

Improving wind turbine manufacturing and deployment. As the U.S. transitions to a clean energy economy, advanced materials such as carbon fiber and new manufacturing processes are critical for reducing costs and increasing the competitiveness of alternative energy sources. Working with industry, ORNL scientists demonstrated using the Big Area Additive Manufacturing (BAAM) system developed at ORNL's MDF for the low-cost printing of wind turbine molds. The printed mold, which was made of carbon fiber reinforced with ABS, demonstrated that it was not only possible to bypass numerous steps in the conventional wind mold manufacturing process, but it was possible to directly integrate heating ducts to accelerate material curing time, as well as vacuum and sealing. This simplifies the manufacturing and assembly processes for wind turbine blades, significantly lowering the costs by printing the mold as one part at a rate 10 times faster than conventional manufacturing.

Accelerating use of bioderived materials for large-scale 3D printing applications. ORNL scientists, in collaboration with the University of Maine, used additive manufacturing to print a large-scale boat mold from bioderived materials. The ORNL and UMaine partnership focuses on advancing efforts to produce new biobased materials conducive to 3D printing of large, structurally demanding systems. Using biomass for large-scale printing also furthers the goal of carbon sequestration. Ongoing research focuses on cellulose nanofiber—or CNF—production. By placing CNF from wood into thermoplastics, bioderived recyclable material systems can be developed with properties that may rival traditional materials, possibly even metals. This project accelerates the application and integration of fundamental materials science, plant genomics and manufacturing research to the development of new sustainable bioderived composites, creating economic opportunity for Maine's forest products industry and the nation.

Advanced manufacturing for construction molds. ORNL developed 3D-printed molds for the manufacturing of precast concrete panels. These molds were used in the production of concrete panels that cover a 42-story tower's textured façade in Brooklyn, New York: the Domino Sugar Refinery project. These first of their kind 3D-printed molds offer several advantages over conventional molds. Traditional precast molds made from wood and fiberglass are time intensive. Not only does 3D printing yield highly replicable and long-lasting parts, but it also generates less material waste, and the molds can be used upwards of 200 times vs. traditional molds that typically have a life of 15 to 20 concrete pours. This advantage reduces the marginal cost per piece for large, repetitious projects by distributing the mold's total cost over many more concrete panels. These deployed molds likewise demonstrated the use of additive manufacturing to support a revitalized domestic molds and dies industry.

Carbon fiber composites for strong, lightweight structures. Building on ORNL's rich history in materials science, the DOE Carbon Fiber Technology Facility at ORNL is producing technology solutions for low-cost, domestic carbon fiber production. Our scientists developed a process to replace costly traditional precursors with a textile-grade precursor—typically used to make clothing and carpets—that can produce carbon fiber at roughly half the cost, and we're developing bioderived precursors such as lignin. ORNL has also developed high-volume manufacturing of composites for the transportation industry and less expensive methods to join carbon fiber composites with other materials on vehicles, including the use of lasers to prepare surfaces for bonding, which improves the performance of joints and provides a path toward high-volume automation.

Low-cost, energy-dense batteries for clean vehicles and grid storage. ORNL has a unique partnership with battery startup SPARKZ to collaborate on resolving technical barriers for advanced batteries for electric vehicles and grid-level energy storage. So far, SPARKZ has licensed five ORNL technologies, including: cobalt-free cathodes to address the critical materials supply chain; high-energy density lithium battery design enhancing the storage capacity of batteries; fast-formation cycling for the rapid production of lithium-ion batteries, and new manufacturing processes that support industrial-scale production. The partnership is part of a unique incubator program at DOE, and SPARKZ is exploring sites for a new R&D and prototyping facility in the United States.

GREEN MANUFACTURING AND DECARBONIZATION

ORNL is accelerating the clean energy transition by extending its successful MDF public-private partnership model into the evolving decarbonization manufacturing market to identify and resolve industry's greatest challenges.

Many technology options to decarbonize the U.S. industrial sector are expensive or nonexistent. To address this issue, ORNL will leverage core manufacturing capabilities to develop, demonstrate, and deploy new or existing solutions. The development of **advanced heat**

exchangers for carbon capture utilizing large-scale additive manufacturing is an example of where ORNL additive core capabilities can be exploited.

ORNL research can increase the efficiency of energy-intensive industries such as steel, cement, and bulk chemicals through **electrification of process heating** using advanced transient heating technologies such as microwave, infrared, laser induction and other innovative technologies.

Our **roll-to-roll manufacturing expertise and capabilities** encourage domestic production of clean energy technologies such as solar cells and fuel cell membranes. We can even aid efforts to develop new sources of **clean water** for the nation, such as the advanced membranes to be delivered for purification of wastewater that are a goal of DOE's **National Alliance for Water Innovation** (NAWI), of which ORNL is a founding partner. NAWI is another example of a multi-institutional partnership forged to have widespread impact on the nation. The alliance brings together four national labs, 10 industry partners, and 19 universities from coast-to-coast to examine and resolve critical barriers to lower the cost and energy use of desalination.

The laboratory is also targeting **reduced energy waste through product lifecycles by recycling** printed fiber-reinforced materials and composite parts. ORNL is specifically driving the circular economy of thermal plastics and thermosets in the additive and composites industries as well as replacing petroleum-based resins with bioderived resins and reinforcement nanocrystals and nanocellulose. The **bioderived resins** are being used in large-scale printing of molds for the wind and water industries as well as high-complexity components in an effort to increase the efficiency of and reduce manufacturing costs for a variety of key energy technology products.

ORNL has focused on decreasing energy intensity, or energy use per dollar of GDP, which has been key to significant energy efficiency improvements over the past several decades. One example of our efforts is supporting the **DOE Better Plants initiative** in which scientists and engineers from the national labs work with the nation's manufacturers to improve energy efficiency and competitiveness. These industrial partners typically set a specific goal, usually a 25% reduction in energy intensity over a 10-year period across all their U.S. operations.

PARTNERSHIPS TO ACCELERATE DEPLOYMENT

The user facilities established by DOE are shared resources, representing large-scale capabilities that private industry and universities cannot afford to build and maintain on their own, but that are essential for maintaining U.S. economic competitiveness. The national labs actively seek collaborators from private industry and academia to ensure our research is targeted and moves nascent technologies into the marketplace.

By leveraging the assets of the national lab system through a variety of agreements, private industry can de-risk their investments in innovation and accelerate commercialization. The Cooperative Research and Development Agreements, Strategic Partnership Projects, User Agreements and other vehicles for partnership allow companies to participate in or directly sponsor research across the laboratory system.

ORNL encourages placed-based innovation in its research and partnerships strategy so that technological breakthroughs provide opportunities to communities everywhere in the country. The MDF's hub-and-spoke partnerships, for instance, support the democratization of its technology to companies large and small, and to rural as well as urban centers.

The results have been significant at ORNL. In the last five years:

- More than 15 startups have been formed based on ORNL-developed technologies
- The lab has entered more than 140 new technology licenses.

In its own region, ORNL is partnering with the Tennessee Valley Authority and the University of Tennessee to launch a business accelerator managed by Techstars, a global leader in entrepreneurship development. The Techstars accelerator will provide a 12-week intensive training program and seed investment to 30 elite startup companies over three years. The program focuses on industries of the future—such as clean energy, artificial intelligence, quantum technologies, advanced communications, cybersecurity, battery technologies, grid-scale energy storage, and smart cities— aligned with the world-leading technical capabilities available at Oak Ridge.

Our **Innovation Crossroads** technology accelerator program at ORNL, supported by DOE's Advanced Manufacturing Office and the Tennessee Valley Authority, provides a two-year fellowship to help aspiring energy and advanced manufacturing entrepreneurs develop and de-risk their technology. Throughout the program, these innovators are linked with scientific experts, mentors, and networks to take their world-changing ideas from the R&D stage to the marketplace. Innovation Crossroads has incubated **20 hard-tech startup companies** since its first cohort in 2017.

TRAINING TOMORROW'S WORKFORCE

Manufacturing is a key source of high-paying jobs, with workers earning on average more than $60,000 per year in salary and benefits.[3] Yet, some 89% of manufacturers have unfilled positions because they cannot find qualified applicants, according to a 2018 Deloitte report. The skills gap could leave 2.4 million positions vacant between 2018 and 2028.[4]

At ORNL, we have several programs designed to prepare the well-trained, agile workforce of the future, including:

- **The Oak Ridge Institute** – The Oak Ridge Institute (ORI) is a collaboration of ORNL and the University of Tennessee that is creating a talent pipeline in areas of growing national need and demand, addressing top-tier industry and workforce needs emerging from the introduction of automation and artificial intelligence. The program fosters industry engagement, entrepreneurship and technology implementation to advance

[3] https://www.census.gov/library/visualizations/2020/comm/manufacturing-in-america-2020.html
[4] https://www2.deloitte.com/us/en/insights/industry/manufacturing/manufacturing-skills-gap-study.html?mod=djemRTE_h

economic and community development. ORI has the goal of reaching students from diverse backgrounds and providing development from the technician to the graduate level in emerging fields relevant to the DOE Office of Energy Efficiency and Renewable Energy mission.

- **ORNL Student Programs** – ORNL's science education and research programs include internships across the laboratory. The MDF itself has hosted more than 1,000 interns, providing valuable hands-on experience in advanced manufacturing. ORNL and the Appalachian Regional Commission have also hosted middle and high school students and teachers for 30 years in an immersive, residential STEM experience.
- **CyManII.** ORNL is a partner in the DOE Cybersecurity Manufacturing Innovation Institute (CyManII) addressing the security of the manufacturing sector. Led by the University of Texas at San Antonio, CyManII brings together ORNL with the Idaho National Laboratory, Sandia National Laboratories, and other industrial and academic partners to develop innovations to secure energy efficient manufacturing and supply chains. Integral to the institute's plan is a national education and workforce development program targeting cybersecurity training for 1 million U.S. manufacturing workers.

CLOSING REMARKS

America's national laboratories and their scientific facilities are powerhouses of science, technology, and engineering. The DOE labs offer one-of-a-kind capabilities with unparalleled scientific expertise for real-world results. In collaboration with industry and academic institutions, the labs are developing, demonstrating, and deploying advanced technology that will keep the U.S. manufacturing sector at the forefront of innovation and spur the creation of highly compensated jobs.

At ORNL and across the DOE laboratory system, we are open for business. The national laboratories are eager to collaborate and continue providing research and development for the success of our nation's vital manufacturing sector. We look forward to continuing our scientific and engineering pursuits in support of clean, efficient, and sustainable manufacturing for the nation's prosperity and security.

Together with our university, industry and other strategic partners, the national laboratories will accelerate the technology development cycle and create innovative manufacturing ecosystems that place us ahead of our rivals around the world.

Thank you again for the opportunity to testify today. I welcome your questions on this important topic.

Appendix

ORNL Capabilities

ORNL is DOE's largest science and energy laboratory, with an R&D portfolio that spans the spectrum from fundamental science to demonstration and deployment of breakthrough technologies for clean energy and national security. Our mission includes both scientific discovery and innovation, so we place a high value on translational R&D—the coordination of our basic research and applied technology programs to accelerate the deployment of solutions that will shape our nation's future. Our ability to mobilize multidisciplinary teams and to form partnerships with universities, industry, and other national laboratories is essential to this work.

ORNL has 23 core capabilities (out of 24 total) that are identified by DOE, and these capabilities reflect a combination of exceptional people, equipment, and our facilities. ORNL is home to:

- DOE's largest materials R&D program, which supports three scientific user facilities focused on understanding, developing, and exploiting materials—-the **Spallation Neutron Source** (SNS), the **High Flux Isotope Reactor** (HFIR), and the **Center for Nanophase Materials Sciences** (CNMS).
- The **Oak Ridge Leadership Computing Facility** (OLCF), which hosts the nation's most powerful supercomputer for open science, Summit, as well as growing capabilities in artificial intelligence and machine learning. The OLCF's exascale computing system, Frontier, is scheduled for delivery this year, with the ability to solve calculations more than five times faster than today's top supercomputers, exceeding a quintillion calculations per second.
- The **Manufacturing Demonstration Facility** (MDF), the nation's only designated user facility focused on advanced manufacturing, houses integrated capabilities that drive the development of new materials, software, and systems for the secure production of clean energy products and systems.
- The **Carbon Fiber Technology Facility** (CFTF), DOE's only designated user facility for carbon fiber and fiber innovation to support economic U.S. production of this material of tomorrow for clean energy applications.
- The **National Transportation Research Center** (NTRC), the nation's only transportation-focused user facility, with core capabilities in advanced energy storage and electric drive systems, including fast wireless charging, lightweight materials and multi-material structures for harsh environments, advanced combustion engines and biofuels, data science and analysis, and vehicle cybersecurity, vehicle systems integration, and intelligent mobility systems.
- The **Battery Manufacturing Facility** (BMF), the nation's largest open-access battery manufacturing R&D center for studying materials from the atomic level up to 7 Ah pouch cells. Capabilities span from world-leading high-performance computing to

materials discovery, scaling, prototyping, manufacturing, multiscale evaluation, battery recycling, and integration of energy storage systems.

- The **Grid Research Integration and Deployment Center** (GRID-C), which combines multiple electrification research activities across the utility, buildings, and vehicle space to enable breakthroughs for a resilient and secure power grid.

New Capabilities to Support Manufacturing for Clean Energy

The global race to develop and deploy the most advanced scientific resources is relentless, with the recognition that these facilities give a distinct advantage in the competition to innovate across a broad range of fields from materials science to chemistry to manufacturing systems. These investments are necessary, particularly in the manufacturing sector where it is important to ***innovate faster than competitors can copy***.

A new generation of scientific capabilities is being prepared across the DOE laboratory system, including deployment of the world's first exascale computing systems. These tools have the potential to revolutionize our ability to meet emerging demands in the manufacturing sector. On ORNL's campus, these new capabilities include:

- The **Frontier exascale computing system**, with anticipated delivery in 2021. Frontier's compute power will exceed 1.5 exaflops—solving calculations up to 50 times faster than today's top supercomputers, exceeding a quintillion calculations per second—and enabling ever-more complex simulations.

Exascale computing can significantly enhance our **development of new materials and processes** for better manufacturing and recycling of used materials. With an exascale system, we can, for example, perform fast simulations of how new carbon materials might affect a vehicle or aircraft, reducing the need for experiments and speeding breakthroughs to the marketplace.

- A **Second Target Station** (STS) under development at the **Spallation Neutron Source** will deliver transformative new capabilities for understanding and developing new materials. The STS will deliver cold (long-wavelength) neutrons of unprecedented peak brightness.

The proposed STS will give scientists the ability to simultaneously probe the structure and function of **new, complex materials** across broader time and length scales—all to better investigate atomic structures, vibrations, and magnetic properties.

Studies at the STS will support the development of **quantum materials**, for instance, whose novel and exotic magnetic properties could revolutionize high-density storage devices. The STS will enable researchers to observe the atomic structure and behavior of **complex items such as turbine blades** for clean energy and aircraft in real time at a faster pace without damaging materials. The STS will enable detailed studies of the response of structural materials to manufacturing and extreme conditions. The research is also supported by the new multi-institutional DOE **Quantum Science Center** led by ORNL.