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# "Building Technologies Research for a Sustainable Future"

Chairman Bowman, Ranking Member Weber, and distinguished members of the Subcommittee: Thank you for the opportunity to appear before you today. My name is Joe Hagerman. I lead the Building Technologies Research Section at the U.S. Department of Energy's Oak Ridge National Laboratory in Oak Ridge, Tennessee. I am a building technologies researcher by education and training, with a focus on smart energy-efficient buildings, transactive controls, and building-to-grid research. It is an honor to present this testimony on what DOE's national laboratories are doing to develop, demonstrate, and equitably deploy scientific and technological solutions for clean, resilient, energy-efficient buildings.

## INTRODUCTION

America's homes and businesses consume about 40% of the nation's primary energy[1] each year. In 2020, residential and commercial customers consumed 74% of all the electricity in the nation at a cost of some $332 billion.[2] Most of these buildings were constructed without the benefit of today's efficient technologies and building codes. The potential savings to be gained in terms of lower energy usage and costs and the mitigation of carbon emissions by installing new technologies in this sector are significant. When our nation's buildings are cleaner and more efficient the effect can be profound, improving comfort, safety, and productivity.

At the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL), we leverage our interdisciplinary expertise to drive scientific and technological breakthroughs for building efficiency and sustainability, with a focus on grid-interactive controls, whole-building integrated energy systems, advanced materials for building envelopes, sustainable, energy-efficient equipment, and energy storage/energy conversion technologies.

ORNL is accelerating clean energy innovation throughout the buildings ecosystem. For example, the nation's fastest supercomputer at ORNL speeds our modeling and simulations work to

[1] Energy accounted for before conversion to a secondary form of energy, such as natural gas > electricity.
[2] "Electric Power Monthly," U.S. Energy Information Administration, https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_es1b

analyze the potential for building retrofits down to the neighborhood level. Our nanomaterials science leads to new building materials with extraordinary insulation properties. Our computational science and sensor expertise is driving a new paradigm in energy controls that can significantly lower homeowners' energy bills while helping utilities balance their loads and maintain a secure, resilient power grid. Our engineering expertise is driving breakthroughs for new energy-efficient equipment like cold climate heat pumps and heating, ventilating, and air conditioning (HVAC) systems, climate-friendly refrigerants, and appliances. And our scientists are solving materials and process challenges for efficient, advanced batteries and other unique solutions for grid-level energy storage.

A cornerstone asset for our research is the **Building Technologies Research and Integration Center** (BTRIC) at ORNL, DOE's only designated user facility dedicated to research and development for clean, energy-efficient buildings. BTRIC comprises a 50,000 sq. ft. research campus that includes the flagship MAXLAB, or Maximum Building Energy Efficiency Research Laboratory, focused on developing and analyzing large-scale wall assemblies, equipment, and appliances.

BTRIC capabilities include envelope and equipment laboratories with a range of test chambers to develop components that are more resistant to heat flow, airtight, and moisture- durable. Our flexible research platforms place technologies in realistic, highly instrumented buildings for evaluation. We offer systems from benchtop wind tunnels to computational fluid dynamics modeling to large-scale environmental chambers to advanced building technologies. *(See Appendix for an expanded list of ORNL capabilities.)*

At ORNL, we partner with industry—manufacturers of building products, equipment makers, developers, and other companies in the supply chain of the domestic building sector. By doing so we ensure that our work is targeted to real-world challenges, validated in real-world settings, and is applicable and actionable to the U.S. trades and construction industry. The lab's history of successful technology transfer has meant companies large and small have access to the best that our scientific capabilities and expertise have to offer. Our world-renowned experts have a great deal to offer the country through our collaborative research and partnerships.

During the last fiscal year, BTRIC worked with **157 industry collaborators** and **27 universities**, and is currently conducting research under **25 active Cooperative Research and Development Agreements (CRADAs), 4 active user agreements,** and **13 strategic partnerships.** We also work with **4 other national laboratories** on technology solutions with real-world building applications. We have hosted more than **3,500 visitors** at BTRIC since 2012.

Our bottom line is clear: Positive, demonstrable impact.

BTRIC last year launched a new **technical collaboration program** designed to accelerate our impact through partnerships with industry in conjunction with the DOE Building Technologies Office. The program targets short-term, 3- to 12-month collaborations focused on specific industry challenges in interest areas ranging from HVAC to water heating, materials

development, advancing innovative lighting applications, innovative sensors and controls, and grid-interactive buildings.

The results speak to ORNL's influence. In just the last five years, **more than 15 startups** have been formed based on ORNL-developed technologies, and we have entered **more than 140 new technology licenses** across the lab.

One recent example is the licensing of insulating material to a division of Texas-based **Quanex Building Products. Quanex IG Systems** licensed a method developed by ORNL to produce a low-cost insulating additive material that can increase thermal insulation performance and building energy efficiency. The method synthesizes highly insulating material with minimal chemical solvents allowing manufacturers to reduce their industrial waste and energy usage. This technology will increase energy efficiency in buildings, decrease waste in manufacturing, and supports a domestic manufacturer.

Another example is ORNL's collaboration with Illinois-based **Molex** to develop, demonstrate, license, and deploy low-cost, wireless, peel-and-stick sensors to monitor and manage building energy profiles. These sensor technologies support our pioneering energy controls research, which is reshaping how we manage energy in our homes and businesses and even across geographic regions. Fundamentally, our work with Molex is based on our world-class materials research. We developed new materials and methods that allowed Molex to print sensors, thereby reducing the sensors cost, increasing their durability and utility.

ORNL's extraordinary capabilities are a nexus for our **staff of more than 5,500**, including scientists and engineers in **more than 100 disciplines**. We are home to **9 scientific user facilities** sponsored by the Department of Energy and accessible to guest scientists through user agreements. In a typical year, ORNL welcomes **more than 3,200 guest researchers** onto our campus**.** The sheer volume of connections, interactions, and collaboration are what makes ORNL a special place to work. ORNL fosters great science because we invest in diverse people, expertise, skills, and extraordinary capabilities such as those in neutron science, high-performance computing, as well as applied energy research.

Our goal is clear. ORNL staff are working to accelerate the transition to clean energy, to develop the transformational science behind grid-connected buildings and networked smart communities, and to decarbonize the building sector.

## RECOGNIZED LEADER IN ENERGY EFFICIENCY

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 buildings sector and deploy clean energy technologies:

**Improving energy efficiency with ultrasonic drying technology.** As the United States transitions to a global clean energy economy, advanced building equipment that uses less energy without sacrificing efficiency will play a pivotal role. ORNL researchers collaborate with industry to develop and demonstrate energy efficient building equipment technologies, including the ultrasonic dryer that operates mechanically with piezoelectric transducers instead of heat to shake and vibrate fabric at a high frequency, removing moisture. This technology, which was licensed to Ultrasonic Technology Solutions, demonstrated a faster drying time and used five times less energy than conventional dryers. Another of the technology's licensees is working to scale up the process for use in industrial drying applications, including in the pulp and paper industry.

**Accelerating use of underground geothermal energy storage.** ORNL scientists developed and demonstrated a lower cost, novel geothermal energy storage system that reduces peak electricity demand as much as 37% in homes while helping to balance grid operations. Installed underground, the system stores excess electricity from renewable sources like solar power as thermal energy through a heat pump. The system comprises underground tanks containing water and phase change materials that absorb and release energy when transitioning between liquid and solid states. ORNL's design relies on inexpensive materials and is installed at shallow depths to minimize drilling costs. The stored energy can provide hours of heating in the winter or cooling in the summer, shaving peak demand and helping homeowners avoid buying electricity at peak rates.

**Developing self-healing, highly adhesive materials for building envelopes.** ORNL researchers developed self-healing elastomers that demonstrated unprecedented adhesion strength and the ability to adhere to many surfaces, which could broaden their potential use in industrial applications. Elastomers, commonly used in the construction industry as sealants, are known for their durability. However, they can develop cracks when exposed to certain environmental conditions, leading to air and water leaks. Researchers used a blend of a self-healing polymer with curable elastomers to produce a series of self-healable and highly adhesive material and proved they can self-repair in ambient temperatures and conditions, as well as underwater, with their adhesive force only minimally impacted by surface dust. The materials can be made simply and efficiently through a scalable process enabling a wide range of uses for the building industry.

**Informing the Montreal Protocol on heat-trapping refrigerants.** The international Montreal Protocol, aimed at protecting the ozone layer by phasing down the use of potent greenhouse gas refrigerants and replacing them with climate-friendly alternatives, was informed by multiple ORNL studies. It was thought that soaring temperatures of 100-130 degrees Fahrenheit can degrade air-conditioner performance when using some alternative refrigerants. ORNL demonstrated that similar or better energy efficiency and cooling capacity could be achieved by new refrigerants with less global warming potential compared to baseline hydrofluorocarbon (HFC) refrigerants. A series of DOE-funded reports co-authored by ORNL investigated the performance of HFC alternatives such as hydrofluoroolefin mixtures and hydrocarbons. The

research study evaluated the energy efficiency and cooling capacity of nine low-global-warming-potential options in rooftop and small residential air conditioners in simulated temperature and climate conditions similar to the Middle East and parts of Asia and North Africa. The research enabled industry to accelerate their innovations in order to meet the protocol's goals.

**Advancing materials to support transition to alternative refrigerants.** ORNL researchers demonstrated that metal foam enhances the evaporation process in thermal conversion systems and enables the development of compact heating, ventilation and refrigeration, or HVAC&R, units. Compact and efficient HVAC&R equipment is needed to support the global industry transition to using alternative, environmentally friendly refrigerants. The small-scale evaporator proved metal foam is well-suited for compact systems. The discovery also showed that the presence of a porous open cell or sponge-like metal foam layer in an evaporator's tubes increases the liquid refrigerant's boiling rate, creating an enhanced pool-boiling process that can accommodate much higher heat fluxes compared to conventional technology.

**Modeling existing buildings for energy efficiency.** ORNL researchers developed a modeling tool that identifies cost-effective energy efficiency opportunities in existing buildings across the United States. Using supercomputing, the energy modeling method assesses building types, systems, use patterns and prevailing weather conditions. The modeling approach, which can be performed in minutes from a desktop computer, applies automation to extract a building's floor area and orientation parameters from publicly available data sources such as satellite images. Researchers tested the tool on more than 175,000 buildings in Chattanooga, Tennessee, demonstrating energy-saving opportunities. This research was supported by the supercomputing resources at the Oak Ridge Leadership Computing Facility at ORNL, a DOE user facility offering leadership-class computing resources to researchers from government, academia, and industry who are pursuing some of the largest computing challenges in science. With the Summit supercomputer—the nation's fastest—at ORNL, researchers can model energy efficient retrofits for every building in America.

**Advanced manufacturing for construction molds.** In interdisciplinary work involving our building envelope scientists and additive manufacturing researchers, ORNL developed 3D-printed molds for the manufacturing of precast concrete exterior building 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: they can be built faster with less material waste and have a longer life— accommodating nearly 200 concrete pours vs. the 15 to 20-pour life of traditional molds. These deployed molds likewise demonstrated the use of advanced manufacturing to support a revitalized domestic molds and dies industry. The molds were developed at the Manufacturing Demonstration Facility at ORNL, DOE's only user facility focused on improving the energy and material efficiency, productivity, and competitiveness of American manufacturers.

**Low-cost, energy-dense batteries for grid storage and clean vehicles**. ORNL has a unique partnership with battery startup SPARKZ to collaborate on resolving technical barriers for advanced batteries for grid-level energy storage and electric vehicles. 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. This energy storage research is being performed at the Battery Manufacturing Facility (BMF) at ORNL, DOE's unique advanced battery user facility that provides scientists the ability to analyze every aspect of battery production from new materials to electrode dispersion preparation to finished product and performance testing. The BMF sits within the Grid Research Integration and Deployment Center (GRID-C) at ORNL, which combines multiple electrification research across the buildings, electric utility, and vehicle space.

## CONNECTED SMART COMMUNITIES FOR GRID RESILIENCE

The computational power embedded in the smart appliances and distributed energy generation technologies of today, sometimes referred to as edge intelligence, presents a unique opportunity to better manage the energy systems of our nation's homes and businesses while providing essential stability to the power grid. ORNL is a pioneer in this area, which combines our multidisciplinary expertise in computational science and artificial intelligence with our foundational building equipment and sensors capabilities to create a new paradigm of buildings-to-grid interactive controls.

ORNL achieved an early breakthrough in this research by demonstrating how novel algorithms could be deployed to harness the power of solar installations and rooftop HVAC units to balance energy supply and demand on the laboratory's campus. The project demonstrated the efficacy of software controls to **shape load profiles, stabilize the grid, and smooth the integration of intermittent, renewable energy resources**. These controls were further refined in ORNL's **Yarnell Station research home**, situated in a suburban neighborhood near the lab that allows for additional real-world testing.

ORNL accomplished two community-wide deployments through a partnership with **Southern Company** to install and analyze controls technology in two Smart Neighborhood™ communities in Alabama and Georgia.

The **Reynolds Landing development near Birmingham, Alabama,** is comprised of 62 single-family homes with smart appliances, including water heating and HVAC systems, as well as an adjacent microgrid containing solar, energy storage, and a backup natural gas generator. The **Altus development in Atlanta, Georgia**, is comprised of 40 single-family townhomes, with

testing of controls for HVAC, water heaters, rooftop solar, energy storage batteries, and electric vehicle chargers.

ORNL's controls deployed in these communities managed appliances and HVAC for homeowner comfort, while optimizing microgrid assets using price signals from the utility, weather forecasts, and predicted behavior.

**Key results** of the projects: a **30% to 44% decrease in overall energy consumption** and **34% lower consumption during peak winter demand**; successful **"islanding" of microgrid assets** that continued serving the communities when they were disconnected from the utility grid; and data collection on the **impact of electric vehicles**, with the finding that EVs made up some 15% to 20% of total energy usage in the homes.

These successful deployments likewise support the **expansion of controls technologies across regions**. With widespread implementation of these controls, the thermal capacity of a large number of buildings could serve as energy storage, for instance. Networked microgrids could likewise balance supply and demand on the grid system and support the integration of additional intermittent, clean energy resources like solar and wind. ORNL's expertise in cybersecurity is likewise deployed to ensure the security and resilience of the building-grid interface.

By harnessing the energy of clusters of buildings, grid-interactive controls underpin future smart energy networks, providing demand side management and load control to increase the resilience of the nation's critical energy systems while lowering costs for homeowners.

ORNL is taking on this next-level challenge of demonstrating the impact grid-interactive controls can have at the regional scale in our **Resilient Distribution Systems** project. In partnership with the **Electric Power Research Institute (EPRI)** and the **Tennessee Valley Authority**, ORNL scientists are evaluating the impact that these load-control methods can have on power grid resilience during severe weather and other events. The goal is continuous control of building systems such as cooling, heating, and lighting that maintains occupant comfort while balancing supply and demand at the lowest customer cost and results in the most efficient use of energy resources.

## TAKING THE LEAD ON DECARBONIZATION

ORNL has a rich history in decarbonization breakthroughs, including the invention of a new method and materials for the conversion of $CO_2$ to ethanol, a practical, energy-efficient method of capturing CO2 directly from air, as well as the invention of a new low-cost, 3D-printed device that improves smokestack carbon capture.

The energy-intensive buildings sector presents a big opportunity for decarbonization. The residential and commercial sector accounted for 12% of total U.S. greenhouse gas emissions in

2018, and the industrial sector accounted for 22% of the total.[3] Our vision for decarbonization tracks the DOE Building Technologies Office goal of an overall 50% reduction in energy consumption by the building sector over the next 10 years. The energy efficient technologies developed at ORNL and ready to be deployed in retrofits and new builds represent a key approach for limiting the carbon emissions profile of buildings. ORNL is developing strategies to accelerate decarbonization solutions for homes, businesses, and energy-intensive industrial processes through a variety of innovations, such as:

- **Direct-air carbon capture and advanced equipment technologies**: Developing and demonstrating methods to utilize building air systems for direct-air carbon capture; efficient, low- and high-temperature heat pumps, climate-friendly refrigerants, and other equipment innovations.
- **Modernizing and democratizing weatherization technologies**: Increasing development and demonstration of the newest technologies for building retrofits to achieve decarbonization, with a focus on equitable distribution and relieving high energy stress in frontline communities. Piloting advanced tools for decision-making and retrofitting best practices.
- **New materials and techniques for advanced building construction**: Developing and demonstrating new materials, processes, and assembly techniques for advanced, ultra-efficient building construction.
- **Beneficial electrification:** Developing and accelerating the deployment of more renewable and low-emission electricity sources.
- **Grid-interactive controls:** Expanding home and neighborhood energy controls to the grid scale using distributed artificial intelligence and hardware for automated load sensing and dispatch, promoting a more efficient, resilient, clean energy-sourced power grid.
- **Thermal storage innovation**: Controlling and utilizing the thermal energy storage capacity of homes and businesses to reduce energy consumption and provide grid stability, including the development and deployment of associated advanced materials.

## PARTNERSHIPS TO ACCELERATE THE CLEAN ENERGY TRANSITION

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, academia, and the public sector to ensure our research is targeted and accelerates nascent technologies into the marketplace.

[3] "Sources of Greenhouse Gas Emissions," U.S. Environmental Protection Agency, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

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. We can ensure our research is deployed equitably across all communities by engaging with a variety of place-based partners such as universities who bring their knowledge of regional challenges to the table to ensure our innovations reach into neighborhoods where they are most needed. Building technology research at ORNL is democratized across the scale of single-family homes to housing complexes, commercial buildings and industrial plants in all regions and climates, with a focus on lowering installation and operating cost and boosting energy savings. With cost-effective building retrofits, for instance, our innovations can reach into low-income communities, multi-family housing, and public housing vulnerable to the stress of high energy costs.

ORNL is pursuing collaborations with public housing authority experts, affordable housing manufacturers and utility partners to accelerate our efforts to ensure clean building technologies are equitably deployed in low-income and frontline communities.

ORNL is also 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 startup companies over three years. The program focuses on industries of the future—such as clean energy, smart cities, grid-scale energy storage, battery technologies, artificial intelligence, quantum technologies, advanced communications, and cybersecurity—aligned with the world-leading technical capabilities available at Oak Ridge to more quickly move breakthroughs to deployment.

Our **Innovation Crossroads** technology accelerator program at ORNL, supported by DOE 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

Green jobs in the buildings sector—clean, efficient energy retrofits and new builds focused on deploying sustainable technologies—are growing. The energy efficiency sector employed 2.38 million in 2019, up 3.4% from the year prior, according to a report by the National Association

of State Energy Officials and Energy Futures Initiative.[4] Yet, 91% of construction employers in energy efficiency reported difficulty in hiring experienced, trained workers.

At ORNL, we have several programs designed to prepare the well-trained, clean energy-focused 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 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. 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 Idaho National Laboratory, Sandia National Laboratories, and other industrial and academic partners to develop innovations to secure energy efficient manufacturing, including control systems and intellectual property, as well as 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 17 DOE labs constitute the most comprehensive research and development network of its kind. We 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. buildings sector at the forefront of innovation, lower costs for end-users, mitigate carbon emissions, keep our power grid network operating reliably, and spur the creation of new jobs.

[4] "2020 U.S. Energy & Employment Report," A Joint Project of NASEO and EFI, https://static1.squarespace.com/static/5a98cf80ec4eb7c5cd928c61/t/5ee783fe8807d732d560fcdd/1592230915051/2020+USEER+EXEC+0615.pdf

At ORNL and across the DOE laboratory system, we are open for business. We look forward to continuing our scientific and engineering pursuits in collaboration with industry and other public and private sector partners in support of clean, efficient, and environmentally sustainable buildings for the nation's economic vitality and the health, safety, and prosperity of its people.

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 **Building Technologies Research and Integration Center** (BTRIC), DOE's only designated user facility dedicated to building technologies. The facility focuses on building envelopes, equipment, building systems integration, energy storage and building-to-grid interactions, sensors, transactive controls, and data modeling and simulation.
- 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.
- 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 **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 **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.

## New Capabilities to Support Buildings Research

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 the efficiency and resilience of residential and commercial buildings.

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 buildings 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 building efficiency and **interactive controls for the building-grid interface**. With an exascale system, we can, for example, perform **modeling and simulation of energy efficiency retrofits** for every building in America.

- 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 materials and components** for clean buildings in real time at a faster pace without damaging materials. The research is also supported by the new multi-institutional DOE **Quantum Science Center** led by ORNL.