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Chairman Bowman, Ranking Member Weber, and members of the Subcommittee, thank you for this opportunity to discuss building technologies research, development, demonstration, and deployment (RDD&D) efforts that benefit all Americans.

My name is Roderick Jackson, and I serve as the laboratory program manager for building technologies research at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory, or NREL, in Golden, Colorado. One of 17 national laboratories, NREL is DOE's primary national laboratory for renewable energy and energy efficiency research and development. Building technologies is one of 16 key research programs at NREL. Our building technologies portfolio includes research, development, and market implementation activities, with the goal of improving the energy efficiency of building materials and practices for all.

At NREL, I have been recognized as a Distinguished Member of Research Staff and am also serving a three-year appointment to the American Council for an Energy-Efficient Economy (ACEEE) Research Advisory Board. I am a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and am active in the National GEM Consortium, mentoring underrepresented leaders in engineering and science at the master's and doctoral levels.

Before joining NREL, I was a group manager at Oak Ridge National Laboratory, where I managed the Building Envelope Systems Research Group and led the development of connected communities research, specifically with Alabama Power's Smart Neighborhood, Southern Company, and DOE. It was the first project in the southeastern United States to connect high-performance homes with a community microgrid that co-optimized benefits for individual homeowners, while also providing a community-scale benefit to the grid. I was also the technical lead for the Additive Manufacturing Integrated Energy (AMIE) demonstration project. In nine months, AMIE brought together experts from multiple research teams across the lab, 20 partners from industry, and DOE scientists to design, develop, and demonstrate a 3D-printed house that shares power wirelessly with a 3D-printed electric vehicle.

Commercial and residential buildings represent the largest sector of the U.S. energy economy, comprising roughly 75% of our nation's electricity, 39% of our total energy use, 35% of our carbon emissions, and more than $400 billion in annual utility bill expenditures. As a result, there is no pathway to a sustainable energy future that does not include a transformation in how we consume, store, and generate energy in our nation's buildings. Consequently, to achieve a sustainable future, building technologies RDD&D is central and is more pressing than it has ever been before. Federally funded building technology R&D is leading the way by prioritizing investments in building technologies that make the kind of impactful change required to meet our sustainability goals and ensure a bright future for all.

In my testimony, I will discuss:

- Highlights of current DOE and national laboratory RDD&D that increase energy efficiency and improve low-carbon buildings on the path to a sustainable future
- Successful examples that demonstrate the impact of this research
- How we must look forward through the lens of equity.

Highlights of Current DOE and National Laboratory RDD&D that Increase Energy Efficiency and Improve Low-Carbon Buildings

Grid-Interactive Efficient Buildings

A sustainable energy future will be defined by energy that is clean, reliable, resilient, affordable, and equitable. As the United States transitions to this future, the generation, storage, transmission, and consumption of energy is rapidly changing. Traditionally, we have managed our energy system through large, centralized power plants and utilities that generate sufficient power at the time and scale required to match electricity demand. However, the sustainable energy system of the future will include a greater share of variable renewable energy, growing peak electricity demand as transportation is electrified, and transmission and distribution constraints. This transition is currently happening and is in fact accelerating; however, a more balanced approach is needed to manage the electric grid of the future that leverages demand-side flexibility and energy storage.

Because buildings consume approximately 75% of current electricity demand, a more interactive relationship with the electrical system could provide a more optimal and cost-effective pathway to achieving a sustainable energy future. Leveraging energy efficiency, greater connectivity, advanced data science and analysis, and next-generation materials, sensors, and controls, buildings can be designed to synergistically interact in real time with the electric grid to provide demand flexibility that enables a more optimized, resilient, reliable, and affordable energy system. DOE is leading the charge in this new paradigm with buildings playing a pivotal role in the future energy system and has appropriately titled this initiative Grid-interactive Efficient Buildings (GEB).[1]

GEB's core concepts are focused on how flexible building loads can be integrated and controlled to benefit consumers, the electric grid, and society more broadly. The scope of GEB is intentionally focused on technological capabilities and the potential of residential and commercial buildings to enable and deliver grid services, including greater energy efficiency. With future buildings expected to incorporate far greater numbers of controllable assets and interconnected loads, DOE supports important research into how these diverse resources can be optimized in real time. Widespread controllability could enable buildings to become responsive and flexible resources for more stochastic energy demand and supply on the grid and thereby become bulk grid assets capable of demand response and flexibility services.

DOE has authored multiple reports that detail GEB research and strategic direction for whole-building controls, sensors, modeling, and analytics[2]; windows and opaque envelope[3]; heating, ventilating, and air

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[1] "Grid-Interactive Efficient Buildings." https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings

[2] Roth, Amir. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75478.pdf

[3] Harris, Chioke. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75387.pdf

conditioning (HVAC), water heating, appliance, and refrigeration[4]; and lighting and electronics[5]. However, in this testimony, I will only provide R&D highlights of selected technology areas: sensors and whole-building controls, modeling and simulation, thermal storage, and building equipment.

Sensors and Whole-Building Controls

To realize the potential of GEB, advancements are needed in the integration of sensing with computing and communications to monitor and control the physical environment.[6] State-of-the-art sensor and controls integration in commercial buildings is estimated to generate energy savings as much as 30%. However, a new generation of controls strategies leveraging low-cost sensing is needed to implement flexible demand strategies for GEB, while not compromising occupant comfort or productivity. These strategies leverage advances in computing and data science such as artificial intelligence, model predictive control, and distributed and cloud computing.

Multiple examples can show how innovation in controls is leveraged for whole-building flexibility. NREL-developed **foresee**™ is an R&D 100 award-winning smart-home software for automating home assets such as appliances, batteries, and rooftop solar, and for using predictive algorithms to anticipate utility prices, weather forecasts, and power use in order to schedule operation in a way that maximizes efficiency.[7] Now a commercial product available for licensing, **foresee** is being improved to incorporate recent breakthroughs in grid forecasting.

In support of DOE's Building Technologies Office (BTO), NREL is developing a learning-based building controller that is scalable to buildings of different sizes and types without the need for building-by-building customization. As a result, the controller will avoid the expertise and cost of detailed engineering models. Additionally, the controller will prioritize the needs of the building occupant while optimizing grid services and system resilience.

A final example of leveraging controls innovation to advance the future of GEB is an NREL lab directed research and development (LDRD) project. This LDRD is focused on advancing the fundamental science necessary for controlling, forecasting, and optimizing large-scale integrated energy systems. The integrated controls will provide a platform for optimizing GEB loads with electric vehicle charging to help balance power supply and demand. These controls could respond to real-time pricing and demand to autonomously manage energy exchange between an electric vehicle fleet, commercial building, and residential homes, while also maintaining occupant comfort.

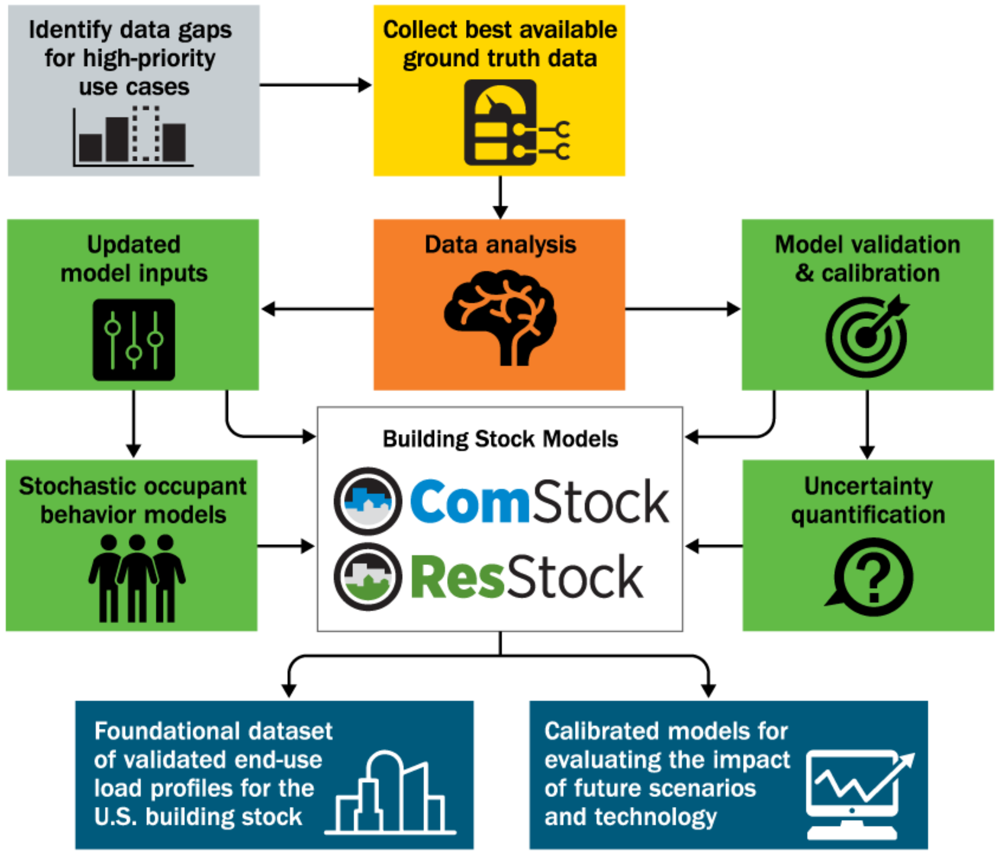
Modeling and Simulation

Modeling and simulation are key to realizing the future of GEB by providing a platform to understand, plan, and optimize the performance of buildings in varying scenarios. The development of modeling and simulation software and advanced analytics tools is an essential resource to predict and analyze building system-level effects and performance. Building energy modeling (BEM) software and associated tools provide the detailed and validated algorithms and capabilities needed by building designers and researchers to accurately model whole-building system energy performance to inform promising early-stage and advanced R&D, standards, policy, and investment decision-making. To achieve a sustainable

[4] Goetzler, Bill, et al. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75473.pdf
[5] Nubbe, Valerie, et al. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75475.pdf
[6] Radhakrishnan et al. 2020. https://www.nxtbook.com/nxtbooks/ieee/bridge_2020_issue3/index.php#/p/18
[7] Jin, Xin, et al. 2017. https://www.sciencedirect.com/science/article/pii/S0306261917311856?via%3Dihub

energy future that ensures reliability, resiliency, and efficiency, BEM resources that provide an understanding of future energy loads under varying scenarios will largely facilitate this desired outcome.

I will now describe examples of integrated BEM software and advanced analytics tools, supporting new research and innovations in building science and energy efficiency.



National-Scale Modeling of U.S. Residential and Commercial Building Stock

NREL researchers have used supercomputing to run tens of millions of simulations using statistical models of commercial (ComStock™) and housing stock (ResStock™) characteristics. With this data, researchers have uncovered tens of billions of dollars in potential annual utility bill savings through cost-effective energy efficiency improvements. Detailed information on the technical and economic potential of residential energy efficiency improvements and packages is available for 48 states.[8] Policymakers, program designers, and manufacturers can use these results to identify improvements with the highest potential for cost-effective savings in a particular state or region, as well as help identify customer segments for targeted marketing and deployment. This is an example of federally supported BEM R&D that is used to fuel private sector innovation toward a clean energy economy. Additionally, these tools are being used to develop foundational datasets of validated end-use load (e.g., HVAC, water heating) profiles for the entire U.S. building stock at an unprecedented granularity. Coupled with calibrated

[8] "ResStock." https://resstock.nrel.gov/

models, the impact of future technology and weather scenarios can be evaluated and understood to minimize negative impacts.[9]

Initially supported by NREL's LDRD funds, ResStock supports 9 BTO projects and 13 private sector use cases and is answering important research questions that ultimately impact energy usage and load flexibility in U.S. housing. A recipient of the 2019 R&D 100 Award, ResStock helps identify impactful energy efficiency opportunities and millions in cost savings.

Community-Scale Modeling

To create sustainable energy communities of the future, we must extend the scale of our ability to model the benefits of advanced building energy efficiency and energy flexibility strategies. An understanding of community- and urban-scale integration with on-site renewable generation, battery storage, and community-scale energy systems is required. To this end, NREL developed URBANopt™ as an open-source software development kit to provide a foundational platform from which a variety of end-user-facing software applications can be built. URBANopt removes the barriers to incorporating continually updated building, distributed energy resource, electrical distribution, and thermal system models into end-user software applications. The platform makes advanced energy science analysis accessible for community-scale modeling of a universe of potential use cases. Industry partners include SOM and Ladybug Tools.

The low-income Oceano neighborhood in California's San Luis Obispo County is an example of how resources such as URBANopt can be leveraged to assess pathways to sustainable energy communities. Modeled insights from URBANopt were used to develop site-specific pathways for achieving a zero net energy community. As a result of the analysis for the Oceano community, energy saving measures available through incentive programs may provide $777,000 savings in distributed energy resource costs necessary to achieve zero net energy. With tools like URBANopt, our neighborhoods can become more sustainable, affordable, and resilient themselves, while providing similar benefits to the broader energy system. Similar to ResStock, URBANopt started as an idea supported by LDRD funding that received subsequent BTO support for further development through the innovation process.

Thermal Storage

In a sustainable energy future powered by renewable energy, energy storage will be needed to balance any temporal mismatch between energy generation and demand. Because thermal end use loads (e.g., space conditioning, water heating, refrigeration) represent roughly half of building energy demand, thermal energy could be stored as a complement and/or alternative to electrochemical energy storage to balance supply and demand. A preliminary order-of-magnitude analysis indicates the energy storage required to support thermal loads in the country from clean energy sources will be on the order of 1,000 GWh or more.[10] When considered in conjunction with the rapidly increasing need for electrochemical battery storage for electric vehicles, the additional storage requirement to meet thermal loads could put increased supply chain pressure on a critical material supply, especially if lithium-ion were to be used to support thermal loads in buildings.[11] Consequently, the need for thermal energy storage solutions developed at an accelerated speed and scale in order to meet sustainable energy targeted timelines represents a grand challenge for building technology R&D.

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[9] "Distributed Reinforcement Learning with ADMM-RL." 2019. https://www.nrel.gov/docs/fy19osti/74798.pdf

[10] Preliminary analysis conducted by NREL and LBNL staff.

[11] Ferrare, M., et al. 2019. "Demonstrating Near-Carbon-Free Electricity Generation from Renewables and Storage." *Joule*.

A challenge of this magnitude benefits significantly from federally funded R&D. However, further benefit could be achieved through a federally coordinated approach with industry, national laboratories, and academia to rapidly move innovative concepts through the stages of technology readiness at a much faster pace than traditionally achieved. This type of coordination will leverage the core R&D expertise at national laboratories like Lawrence Berkeley National Laboratory (LBNL) and NREL with industry so research outcomes will be relevant and immediately scalable. Collaboration between NREL and LBNL has already generated significant advances in the science and development of thermal storage materials and systems, as documented in multiple science and engineering journals.[12,13,14]

While thermal energy storage has a potentially lower levelized cost of storage than lithium-ion battery storage, significant research investment is needed to realize this potential. In a recent NREL publication, an analogous adaptation of the storage energy/power tradeoff curve—foundational in the design of battery systems—was developed for thermal storage.[15] More lessons from the R&D pathway for electrochemical battery storage can be leveraged to accelerate thermal storage as a viable energy storage solution.

Building Equipment
Building equipment provides some of the largest potentials for reducing energy consumption within residential and commercial buildings. They are responsible for more than 50% of energy use in buildings and are major drivers of peak loads on the electrical grid.

To reach the full potential for demand flexibility in buildings, continued R&D is needed to support advancements in the efficiency of building equipment. Advancements include development of low-greenhouse warming potential (GWP) refrigerants and systems, non-vapor compression heat pumps, separate sensible and latent cooling, and fuel-driven heat pump systems.[16] Additionally, to support greater demand flexibility to achieve GEB goals, greater integration is needed for sensors and advanced controls capable of interoperable integration with other whole-building controls and smart technologies. Lastly, as thermal storage solutions are developed, opportunities to integrate into building equipment (e.g., HVAC and water heating) should continue to be explored through R&D. Next-generation space heating, ventilating, air-conditioning, water heating, and refrigeration technologies must be developed to provide increased efficiency and flexibility at acceptable costs to enable a sustainable energy future.

Advanced Building Construction

During the last 80 years, labor productivity in the U.S. construction sector has been largely stagnant,[17] which hinders U.S. competitiveness and limits the transition to a sustainable energy future with affordable building construction and retrofit costs. DOE's Advanced Building Construction (ABC)

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[12] Kishore, Ravi Anant, et al. 2021. https://www.sciencedirect.com/science/article/pii/S0306261920316913
[13] Booten, Chuck, et al. 2021. https://www.sciencedirect.com/science/article/pii/S2542435120306140
[14] Lilley, Drew, et al. 2021. https://www.sciencedirect.com/science/article/pii/S0306261921001707
[15] NREL. 2021. https://www.nrel.gov/news/press/2021/nrel-heats-up-thermal-energy-storage-with-new-solution-meant-to-ease-grid-stress-ultimately-improving-energy-efficiency.html
[16] Bouza, Antonio. 2018. EERE. https://www.energy.gov/sites/default/files/2018/05/f51/Bouza%2C%20Tony_%20HVAC%20WH%20Appliance%20BTO%20Peer%20Review%202018.pdf
[17] McKinsey Global Institute. 2017. https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution

Initiative targets this opportunity with a vision to integrate higher levels of energy efficiency into new construction and retrofits and to unite the industry behind building solutions that are affordable, appealing, high performance, and low carbon. Behind the breakthroughs envisioned for ABC, DOE is sponsoring RD&D that modernizes and simplifies methods to deploy clean energy technologies.

The ABC Initiative looks at a multitude of construction options that improve affordability, speed deployment, and integrate efficiency while establishing superior comfort and resilience for occupants. DOE has brought together extensive collaboration from industry within the ABC Collaborative, which shares resources and supports cooperation among builders, designers, manufacturers, and engineers to promote breakthrough construction concepts. ABC invests in new innovations that could help stimulate quick growth in the building sector, such as modular design, off-site fabrication, 3D printing, and robotics. To maintain industrial competitiveness while reducing dependence on limited natural resources, sustainable building manufacturing and retrofits should embrace a circular economy perspective where materials are sustainably produced and recycled. Through ABC, DOE is helping industry and government recognize and apply these concepts in a way that also fits with DOE's broader mission of ensuring secure and resilient energy for grid-interactive buildings.

One opportunity to further advance equitable building innovation at a national scale is to develop an ABC prototyping facility that would serve as a collaborative hub between national laboratories and industry, where advanced building manufacturing and assembly processes could be developed and proven. Additionally, the facility would create local and national workforce training opportunities to gain hands-on experience with subtractive manufacturing tools, construction robots/co-bots, and drones. Given a facility and technical assistance to test, prove, and refine ABC approaches, the U.S. construction market will be much better prepared to adopt new technologies for energy efficiency integration, low-carbon goals, circular economy, resilience, and long-term affordability.

The ABC Initiative covers multiple technical and non-technical barriers, but in this testimony, I will only highlight research activities related to the opaque building envelope and windows.

Building Envelope

The building's envelope—the barrier that buffers comfortable indoor conditions against outdoor weather—is the largest contributor to primary energy use in buildings. Improvements to envelope efficiency, through new materials, air sealing, spatial design, and insulation, could cost-effectively reduce energy use and simultaneously improve occupant comfort. A key component of DOE's building technologies and research portfolio is to optimize building envelopes for efficiency and resilience, both for new constructions and retrofits. New materials, such as high R-value insulation, tunable thermal conductivity materials, and thermal storage will play an important role in this effort.[18] Envelope improvements could also enable greater load shifting for demand flexibility to offset the need for energy storage in the future energy system, while also providing other grid services.

The largest challenge to advanced building construction is the development of low-cost, minimally disruptive retrofit solutions for the more than 125 million existing buildings in the United States. Current retrofit practices to achieve energy benefits that exceed traditional weatherization strategies are costly, often difficult, and highly disruptive. Without a "step-change" reduction in the costs and

[18] "Funding Opportunity Announcement: Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT)." 2020. EERE. https://eere-exchange.energy.gov/Default.aspx#FoaIdaff0bc6d-95b0-4aa6-901b-2ef0a53e8f7e

improved installation practices, the barrier to achieving building decarbonization and resilience goals necessary to facilitate a clean energy future is difficult to overcome.

Technical innovation and engineering breakthroughs are being investigated as viable pathways to address retrofit challenges. One such example is in the field of robotics. BTO is working with national laboratories and industry to identify robotics solutions that streamline envelope retrofits through the American-Made Challenge. This challenge, named the E-ROBOT Prize, solicits technology submissions from U.S. companies, which are accelerated through a research-support program that incorporates national laboratories and then awarded funds to further develop their solutions.[19] Robotics solutions from this challenge will be used to catalyze the development of minimally invasive, low-cost, and holistic envelope retrofits that are faster, safer, and easier for workers.

Windows

Windows are responsible for about 10% of total energy use in buildings and have a direct impact on end uses that comprise 40% of the total load.[20] However, as we transition to a sustainable and clean energy future, the impact of windows on peak electricity demand will be significant and must be appropriately addressed. Next-generation windows can reduce peak load and enable greater demand flexibility, while also improving occupant thermal comfort and productivity. Since playing an early and major role in the development and market adoption of high-efficiency windows (composed of low-emissivity glass and improved framed performance applications), federal investments have led the frontier of innovation in next-generation materials for windows and window systems.

Current R&D is focused on insulated glass units (IGUs) and frames, improved dynamic light control, and improved durability. An emerging R&D opportunity in windows is building-integrated photovoltaics (BIPV), where photovoltaic (PV) panels are integrated directly into building envelope elements (e.g., roof structures, louvers, rainscreens, windows, and skylights). By using the existing building structure, in some applications this technology can reduce the cost of generating clean distributed energy. Leveraging core expertise in PV development and breakthrough PV materials such as perovskites, NREL has developed new energy-generating window designs that dynamically tint in response to solar heating. The work has been highlighted in *Nature Communications*.[21] BIPV is an exciting new research opportunity for the glazing and facade industry.

Connected Communities that Achieve a Collective Outcome Greater Than the Sum of Its Individual Parts

As controllability for individual buildings and their devices expands, new possibilities emerge to aggregate buildings with other local energy resources into connected communities, in which multi-building management could benefit resilience, demand response, reliability, and greenhouse gas reductions.[22] Through the Connected Communities funding program, DOE promotes multidisciplinary

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[19] "E-ROBOT Prize." https://americanmadechallenges.org/EROBOT/

[20] Harris, Chioke. 2020. https://www.energy.gov/sites/default/files/2020/05/f74/bto-20200504_Draft_Windows_RDO.pdf

[21] Rosales, B.A., et al. 2020. "Reversible multicolor chromism in layered formamidinium metal halide perovskites." *Nature Communications*. https://www.nature.com/articles/s41467-020-19009-z

[22] Olgyay, Victor, et al. 2020. NREL. https://www.nrel.gov/docs/fy20osti/75528.pdf

research to demonstrate how groups of buildings and other resources, such as electric vehicles and solar PV, can reliably and cost-effectively serve as grid assets using demand flexibility.[23]

Located in a suburb of Birmingham, Alabama Power's Smart Neighborhood was launched in 2018 and comprises 62 single-family homes. Equipped with connected appliances, highly efficient design and equipment, electric vehicle chargers, and advanced controls, this Smart Neighborhood is an example of the possible outcomes of GEB when applied at the community scale. The homes are connected as a neighborhood-level, islandable microgrid, which includes community PV, a battery storage system, and a backup natural gas generator. This project, led by Oak Ridge National Laboratory (ORNL) and Southern Company, provides an opportunity to achieve greater outcomes as a collection of GEBs working in concert together to meet individual building occupant needs, while collectively providing aggregate benefit to the grid. At ORNL, I had the opportunity to develop this project in partnership with BTO, the DOE's Office of Electricity, and Southern Company. The challenge of prioritizing homeowner comfort, while optimizing the overall energy system (i.e., electricity grid, community solar, and back-up fossil fuel generator) was significant and required a public/private partnership to not only address research challenges, but to foster an accelerated path to market adoption. The research is ongoing; however, early results have been promising and have prompted BTO to replicate this project in different climate, building types, and distributed energy resources (e.g., on-site PV and battery storage) combinations. Other DOE national laboratories, such as the Pacific Northwest National Laboratory and NREL also have ongoing connected community projects. To fully capture the benefit of connected communities across the United States, continued R&D is needed to properly characterize benefits and impacts, while also minimizing risks.

Advanced Research on Integrated Energy Systems

Innovation at the intersection of distinct technology domains such as building energy use, on-site solar photovoltaics, battery and thermal storage, and electric vehicle charging offer new opportunities for increased system level optimizations. However, there are also increased uncertainties that include system-level performance, technology interoperability, and controls integration. These challenges exist within each individual building, but also extend to large-scale integration. While field tests such as the connected communities provide insight into expected real-world performance, it is often beneficial to complement demonstrations with representative laboratory evaluation within complex and integrated projects. These complementary laboratory studies provide a controlled environment as an intermediate platform to de-risk field tests, while also enhancing final results and findings.

An example of a platform for validation and de-risking integrated technology solutions at a relevant scale is the NREL ARIES platform (Advanced Research of Integrated Energy Systems).[24] ARIES expands the single technology research view to provide a more complete picture that uncovers opportunities and risks at the overlap of technologies. The ARIES platform is a flexible, integrated research space that physically matches real energy systems from the single building scale to the tens of megawatts scale. With ARIES, we can understand the interplay of diverse building designs and technologies with other energy resources in a truly plug-and-play environment. This makes it possible to pivot and stay ahead of the rapidly evolving sector, and to evaluate the latest innovations in a safe environment so they can proceed to have a wide impact on grid efficiency, reliability, and affordability.

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[23] "Funding Opportunity Announcement: Connected Communities." 2021. EERE. https://www.energy.gov/eere/solar/funding-opportunity-announcement-connected-communities

[24] "ARIES: Advanced Research on Integrated Energy Systems." NREL. https://www.nrel.gov/aries/

Integrated Analysis Leads to Impactful Outcomes

Across the national laboratories and through collaboration with industry, DOE has access to state-of-the-art modeling capabilities, which are the engine behind high-detail analyses of U.S. energy systems. The most recent example of groundbreaking integrated analysis that leverages DOE national laboratory expertise and resources is the LA100 study.[25]

Los Angeles 100% Renewable Energy Study (LA100)

To support the ambitious goals to achieve 100% renewable energy power system by 2045, NREL worked with the city of Los Angeles, the Los Angeles Department of Water and Power (LADWP), and other stakeholders to identify viable pathways, while also understanding the implications of different actionable steps.

NREL modeled and analyzed different projections for LADWP's customer electricity demand, local solar adoption, power system generation, and transmission and distribution networks, while working with local institutions to examine changes to air quality and the potential for jobs and economic development. The analysis included millions of simulations—of thousands of buildings—to examine how adoption of building energy efficiency and demand flexibility could impact total cost and infrastructure upgrades required to achieve a 100% outcome. Core to this analysis was demand load projects under different scenarios and strategies provided by building stock models, developed by NREL through initial LDRD funding and subsequent BTO support for development.

> LA100 is the most comprehensive, detailed analysis to date of an entirely renewable-based electric grid as complex and large as the LADWP power system.

As we look to identify actionable plans for other local governments and jurisdictions across the United States, granular building load data as provided by resources, such as URBANopt, ResStock, and ComStock, are foundational to understand and optimize the impact and benefits to individual occupants. Continued research would ensure appropriate occupant-based impacts are fully considered and determined.

Successful Demonstration Models Put Research Into Practice

Validating and demonstrating research in the actual built environment is a critical step in bringing ideas to market and gaining the confidence of builders, developers, architects, and other stakeholders. Across the economy, NREL and DOE work with public and private organizations of all sizes to demonstrate and quantify breakthrough technologies, share expertise and best practices, and give the U.S. building market an edge. A strong coupling with R&D is critical to achieving meaningful R&D outcomes with clear impact at scale. Examples of demonstration projects that leverage building technologies R&D are highlighted below.

Better Buildings Initiative: Partnerships for a Resilient and Innovative Energy Future

DOE's Better Buildings Initiative is designed to improve the lives of the American people by driving leadership in energy innovation. Through Better Buildings, DOE partners with public- and private-sector market leaders to make the nation's residential, commercial, and industrial buildings more energy efficient by accelerating investment and sharing of successful best practices.

[25] "LA100: The Los Angeles 100% Renewable Energy Study." https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html

Better Buildings partners advance new technologies through testing and validation, a Technical Field Validation program, an Integrated Lighting Campaign, and a Buildings-to-Grid Working Group. Through the program, Financial Allies extend billions in financing across a wide range of sectors and communities, making projects possible at a scale that is reshaping the marketplace. Finally, the program supports and strengthens the American workforce, increasing worker skillsets through apprenticeship programs and on-the-job training to fill staffing gaps in the buildings workforce and meet the requirements of technologically evolving equipment.

Building America: Bridging Gaps Between Emerging Technologies and Industry Adoption

Building America accelerates industry adoption of emerging residential building technologies by engaging industry, academia, and national laboratories in applied research, development, and demonstration of high-performance home solutions. Partners address current challenges facing the housing industry, including a growing need for "smart home" technology integration and advanced construction technology to improve construction productivity and housing affordability.

Building America has successfully introduced at least 20 energy-efficient housing innovations to the market to date, including advancements in insulation, air-sealing, HVAC, water heating, and building systems integration. A recent analysis estimates up to $30 in energy savings for every $1 spent by Building America.[26] The program has demonstrated reductions of primary energy use intensity by at least 60% in new single-family homes and at least 40% in existing single-family homes relative to 2010 average baselines across all U.S. climate zones.

Program goals for the coming decade center on dramatically reducing energy use in residential buildings while ensuring overall affordability, health, safety, and resiliency:

- New residential buildings will use 50% less energy and be widely available at 50% lower brick-and-mortar cost compared to baseline homes by 2030. Moreover, these efficiency gains will be achieved while enabling the energy system of the future and providing impressive improvements in health, safety, durability, comfort, and grid-interactive capabilities.
- For existing residential buildings, advanced technologies and processes will lead to retrofit of a minimum of 3% of the existing housing stock annually, resulting in retrofitted buildings that use 75% less energy relative to baseline buildings, without sacrificing comfort, affordability, or performance.

Building America's strategic path to this vision includes critical investments in high-performance, energy-efficient technologies in residential buildings to transform how we build in the United States. NREL works closely with BTO, other national laboratories, and the construction industry to provide an accelerated pipeline of R&D innovation that is scaled in the construction marketplace.

Wells Fargo Innovation Incubator: Building Tech Catalyst to Success

The Wells Fargo Innovation Incubator (IN^2) is a $50-million collaboration between the Wells Fargo Foundation and NREL that provides technical assistance and validation to promising cleantech startups to accelerate innovative and sustainable technologies to market for housing, commercial buildings, and

[26] EERE. 2018. https://www.energy.gov/eere/buildings/downloads/evaluation-building-america-and-selected-building-energy-codes-program

agriculture. Founded in 2014, the Incubator has supported 46 companies that have each received up to $250,000 in non-dilutive funding to engage expertise and facilities at NREL and the Donald Danforth Plant Science Center.[27] Each company is matched with a team of researchers with relevant expertise, labs, and equipment to support a collaborative technical assistance project. Technology challenges and/or innovation opportunities identified through this collaboration that require additional R&D often pursue and are awarded funding through DOE.

> "Because we've worked with NREL, we can say we meet performance criteria. We've got the data, we know the data, and we can provide it to regulatory agencies."
> – Aaron Holm Co-CEO, Blokable

The IN^2 partnership enables national laboratory expertise and facilities developed through federally funded R&D to directly fuel and support private sector innovation. While more than 90% of startup companies fail, more than 55% of companies participating in IN^2 exit the program with commercially ready products and services. IN^2 participants have received a combined $410 million in external funding after joining the program, and the IN^2 portfolio of companies has seen 73% growth in employment overall.

In spring 2021, IN^2 is preparing to launch two new cohorts of companies: one focused on affordable housing technologies and the other on indoor agriculture. NREL looks forward to continuing successful partnerships that leverage federal R&D to enable market innovation and adoption.

Looking Ahead Through the Lens of Equity

Social inequities that permeate society are acutely prevalent in the energy industry, and more specifically, in the buildings sector. For example, as highlighted in the ACEEE assessment of energy burdens across the United States,[28] the median energy burden of Black households is 43% higher than White households. The report authors identify drivers that include housing age, housing type, location, and the condition and efficiency of the building equipment and envelope. With energy efficiency as a foundational pillar of the clean energy transition, coupled with the research activities highlighted in this testimony, there will surely be beneficial outcomes, such as reduced energy burdens, for all Americans. However, too often the benefits and burden of energy innovation and the energy transition are not proportionally distributed. For example, Black-majority census tracts installed 69% less rooftop PV than no-majority tracts of the same household income,[29] and less than half of U.S. community solar projects include low-income households.[30] A departure from this trend exists through President Biden's Justice40 initiative. We should now ensure the benefits, as well as costs, of the energy transition are not only more equitably distributed, but we must also make sure those who have historically suffered the most are the first to benefit.

As articulated in this testimony, buildings are central to the transition to a clean energy economy; therefore, buildings must be central in the approach to achieve energy equity and justice. Examples of

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[27] IN^2. 2020. https://in2ecosystem.com/wp-content/uploads/2021/02/IN2_2020_Annual_Report.pdf

[28] Drehobl, A., et al. 2020. *How High are Household Energy Burdens?* ACEEE. https://www.aceee.org/sites/default/files/pdfs/u2006.pdf

[29] Sunter, Deborah, et al. 2019. "Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity." *Nature Sustainability* 2: 71-76. https://doi.org/10.1038/s41893-018-0204-z

[30] Gallucci, Maria. 2019. "Energy Equity: Bringing Solar Power to Low-Income Communities." *Yale Environment 360.* https://e360.yale.edu/features/energy-equity-bringing-solar-power-to-low-income-communities

centering equity in energy technology innovation and the energy transition are most often focused on the deployment phase of the "research, development, demonstration, and deployment" spectrum. While important and essential, deployment represents one of the final stages of technology innovation and adoption. As a result, in many cases it will be more difficult to equitably deploy technology that was developed without regard to equity. In other words, this approach could be akin to attempting to force a square peg into a round hole. As an alternate approach, the R&D community should take the additional step of centering equity into the early stages of the technology readiness level (TRL).

Permeating equity throughout the RDD&D spectrum will not only increase the impact and effectiveness of attempts to equitably distribute the benefits of the clean energy transition, but it is essential to achieve our overall clean energy goals. Due to historical underinvestment, the challenges faced by low-income communities and communities of color to transition to a low-carbon, safe, reliable, and resilient clean energy system are different and, in most cases, distinctly more difficult to overcome. As a result, the need for science, engineering, and innovation are more pressing. For example, a recent New York Times study outlined how communities of color can be 5 to 20 degrees hotter in the summer than more affluent communities in the same city.[31] Many times the number of residents of these communities live in housing with poor efficiency space conditioning and poor building envelope efficiency. While weatherization measures are helpful, deep energy retrofit innovations that are possible through BTO initiatives like Advanced Building Construction are needed to truly address the significant challenges these communities have.

Scientific breakthroughs will continue without a doubt, especially with continued federal support, but we have the ability, wisdom, and foresight to ensure those milestones provide equity in energy to all Americans. I hope you will join us in championing equity-centered technology research, development, and demonstration.

In summary, to meet our nation's decarbonization goals set by the Biden Administration, while also continuing American leadership in energy innovation, we should continue to prioritize RDD&D investments in building technologies. Significant science and technical hurdles persist, such that continued federally funded building technologies RDD&D remains critical. However, this investment can ensure we are able to meet our sustainability goals and ensure a brighter, more equitable, future.

I am appreciative of this opportunity to appear before the Subcommittee on a topic of vital national importance, and I look forward to answering any questions you may have.

[31] New York Times. 2020. https://www.nytimes.com/interactive/2020/08/24/climate/racism-redlining-cities-global-warming.html

Dr. Roderick Jackson is the laboratory program manager for buildings research at NREL. He sets the strategic agenda for NREL's buildings portfolio, while working closely with senior laboratory management. The portfolio includes all research, development, and market implementation activities, which aim to improve the energy efficiency of building materials and practices. He also guides discussions with the U.S. Department of Energy (DOE) Building Technologies Office to expand research ranging from grid-interactive efficient buildings to mechanical and thermal properties of building materials. He helps identify industry partnership opportunities to advance building envelope and equipment technologies.

At NREL, Dr. Jackson was recognized as a Distinguished Member of Research Staff. He is serving a three-year appointment to the American Council for an Energy-Efficient Economy (ACEEE) Research Advisory Board, which began in 2021. He has been a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers and has received several awards in his career, including the National GEM Consortium Alumni of the Year and Greater Knoxville Business Journal's 40 under 40.

Dr. Jackson came to NREL from Oak Ridge National Laboratory, where he was the group manager for Building Envelope Systems Research. He was on the forefront of connected communities research, leading an effort that established Alabama Power’s Smart Neighborhood. Working with Southern Company and DOE, it was the first project in the southeastern United States to connect high-performance homes with a community microgrid, deploying a transactive microgrid approach.

Another of Dr. Jackson's notable industry accomplishments is a result of his role as the technical lead for the Additive Manufacturing Integrated Energy (AMIE) demonstration project at Oak Ridge National Laboratory. With his leadership, AMIE brought together experts from multiple research teams across the lab, 20 partners from industry, and DOE scientists to design, develop, and demonstrate a 3D-printed house that shares power wirelessly with a 3D-printed electric vehicle. The first-of-its-kind research was completed in just nine months.