BUILDING TECHNOLOGIES RESEARCH FOR A SUSTAINABLE FUTURE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTEENTH CONGRESS

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C O N T E N T S

March 25, 2021

BUILDING TECHNOLOGIES RESEARCH FOR A SUSTAINABLE FUTURE

THURSDAY, MARCH 25, 2021

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 1:04 p.m., via Webex, Hon. Jamaal Bowman [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Building Technologies Research for a Sustainable Future

Thursday, March 25, 2021
1:00PM ET

Cisco WebEx

Purpose

The purpose of this hearing is to examine building technology research and development needs to reduce building energy usage and emissions. Witnesses and Members will discuss building technology research, development, and demonstration activities at the Department of Energy (DOE) including grid interactive buildings, advanced building design, construction, and technologies such as improved building envelopes, windows, and lighting with a focus on the equitable distribution of the results of buildings research. New structures as well as retrofitting existing buildings will be discussed. The hearing will also examine ways that Congress and the Administration should consider directing the activities of the DOE Building Technologies Office (BTO). Legislative language to authorize and support such activities passed the House of Representatives in the 116th Congress as part of H.R. 4447, the Clean Economy Jobs and Innovation Act, but this language was not enacted.

Witnesses

- **Dr. Nora Esram**, Senior Director for Research at American Council for an Energy-Efficient Economy
- **Dr. Roderick Jackson**, Laboratory Program Manager for Buildings Research at National Renewable Energy Laboratory
- **Dr. James Tour,** T.T. and W. F. Chao Professor of Chemistry at Rice University
- **Ms. Jacqueline Patterson**, Director of the NAACP Environmental and Climate Justice Program
- **Mr. Joseph Hagerman**, Group Leader for Building Integration and Controls at Oak Ridge National Laboratory

Background

Buildings contribute about 40% of the total CO_2 emissions of the United States,[1] and make up 39% percent of U.S.'s total energy consumption.[2] The building sector includes but is not limited to residential homes, commercial buildings, schools, and factories. The sector will only continue to grow; it is projected that 2.48 trillion square feet of buildings will be constructed by 2060.[3]

Building technologies can increase energy efficiency, comfort of occupants, and resilience, as well as reduce emissions. Advanced building technologies can also improve grid security and reduce costs associated with electricity generation. More than $400 billion is spent per year to power buildings in the U.S. and increasing efficiency can reduce that cost.[4] Reducing energy costs can be especially important for families struggling with electricity bills, which was almost one third of households according to a 2018 U.S. Energy Information Administration report.[5] A Rand Corporation report calls for increased research into improving the efficiency of affordable housing, as these buildings are generally older and less energy efficient than U.S. real-estate assets at large. Although the report notes that the rate of investment in improving multifamily energy efficiency has increased, it finds that more can be done to continue to improve the cost savings to renters.[6]

DOE has set goals to reduce the energy use of buildings by 30% by 2030, with a longer-term goal of 50% or more.[7] Technologies to retrofit existing buildings are important to meeting these goals as it is predicted that nearly 85% of current buildings will still be operating in 2050.[8] There are many improvements that need to be made as retrofits can be cost prohibitive. Although technologies such as next generation windows and building envelopes are being researched at DOE, building renovations currently affect only 0.5-1% of the building stock annually.[9] According to research carried out by the National Renewable Energy Laboratory (NREL), even buildings that are a decade old can greatly benefit from retrofitting due to HVAC systems and complex controls that lose efficiency over time. NREL notes that air flow devices and building controls are constantly improving, and performance can improve significantly when these are upgraded.[10]

Extreme weather events such as Winter Storm Uri, that led to the Texas blackouts, as well as wildfires, hurricanes, and floods pose significant and growing threats to buildings. Buildings can be constructed or retrofitted to increase resilience against these physical threats. They can also be designed to address current and projected risks over their lifetime, including considerations of

[1] https://www.eesi.org/topics/built-infrastructure/description
[2] https://www.eia.gov/tools/faqs/faq.php?id=86&t=1
[3] https://architecture2030.org/buildings_problem_why/
[4] https://www.energy.gov/eere/buildings/about-building-technologies-office
[5] https://www.eia.gov/todayinenergy/detail.php?id=37072
[6] https://www.rand.org/content/dam/rand/pubs/research_reports/RR2200/RR2293/RAND_RR2293.pdf
[7] https://www.energy.gov/sites/prod/files/2020/02/f72/doe-fy2021-budget-volume-3-part-1.pdf part 1 pg 185
[8] https://www.urbangreencouncil.org/content/initiatives/bring-retrofit-market-scale
[9] https://architecture2030.org/existing-buildings-operation/
[10] https://www.nrel.gov/climate-neutral/whole-building-retrofits.html

regional differences such as natural hazard exposure, resource availability, and fuel mix and energy production.

Research supported by BTO is targeting improvements in building energy efficiency through the Grid-interactive Efficient Buildings (GEB) Initiative.[11] In addition to overall efficiency, this research focuses on making equipment more intelligent through next-generation sensors, controls, and communication. These capabilities aim to give building occupants more control in managing building comfort while saving money on energy bills. Such technologies would also enhance electric grid reliability and resilience.

Building Technologies Office

Within DOE's Office of Energy Efficiency and Renewable Energy, BTO works to develop cost effective energy savings solutions to address the problem of building emissions and increase energy efficiency. This includes technologies to build new buildings and residential homes as well as retrofit existing structures. Their research spans a variety of technologies related to energy efficient grid interactive buildings, windows and building envelopes, wireless sensor platforms, building construction techniques, modeling, lighting systems, heating, ventilation, air-conditioning, and refrigeration systems and other appliances.[12] BTO received $290 million to carry out these activities in Fiscal Year 2021.[13]

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[11] https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings
[12] https://www.energy.gov/eere/buildings/building-technologies-office
[13] https://docs.house.gov/billsthisweek/20201221/BILLS-116RCP68-JES-DIVISION-D.pdf

Chairman BOWMAN. Good afternoon, everyone. Welcome to our hearing entitled "Building Technologies Research for a Sustainable Future." This hearing will come to order. Without objection, the Chairman is authorized to declare recess at any time.

Before I deliver my opening remarks, I wanted to note that, today, the Committee is meeting today virtually. I want to announce a couple of reminders to the Members about the conduct of this hearing. First, Members should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones. Please also keep your microphones muted unless you are speaking. Finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the hearing.

I now recognize myself for an opening statement.

Good afternoon, and thank you to all of our witnesses who are joining us virtually today to discuss the importance of sustainable buildings research. This is a critical component of fighting the climate crisis.

In my State of New York, we have some of the most densely populated cities in the country. We also have some of the most aggressive climate goals in the world. Thanks to a broad coalition of social movements, New York State passed the *Climate Leadership and Community Protection Act* in 2019. Part of this law was the inspiration for President Biden's Justice40 Initiative, which will channel 40 percent of the Federal Government's climate investments into marginalized communities. Also in 2019, New York City passed a first-of-its-kind law to cut greenhouse gas emissions from buildings. Now, we need to come together as a nation and build on these victories at the Federal level.

When we think of reducing emissions, we often think of renewable power or electrifying our transportation sector. But another large source of emissions, especially in New York, is buildings. Currently, about 40 percent of our country's carbon dioxide emissions comes from the structures that we live, work, and sleep in, and that we depend on for life-sustaining care. This goes to the heart of why we need to address climate change, inequality, and racism together.

As we have been discussing on this Committee, when climate disasters strike, redlined communities of color and low-income people are hit hardest. They're the first to lose power when the electricity grid is strained, as we saw in Texas. And these are the same communities that struggle with housing and utility costs. They face health risks from toxic materials in buildings, including in public housing that we have allowed to fall into a state of disrepair. In my district and around the country, the people who live in these buildings have been dying at higher rates from COVID, partly because of co-morbidities caused by the fossil fuel economy. We need sustainable buildings now, and we need to rebuild our communities from the ground up.

The Department of Energy (DOE) invests millions of dollars every year in improving building technologies in a variety of ways. DOE, along with other Federal science agencies, plays a role in making buildings more resilient to extreme weather. DOE also researches energy efficiency and increased electrification in buildings, with an emphasis on ensuring the equitable distribution of the effects of this clean energy research.

Let's also think about how Federal research can become more interdisciplinary. Social scientists, for example, have started exploring how green investments in neighborhoods can lead to gentrification. This process is not only unjust but can undermine climate goals. Instead of cutting emissions for everyone, this can create a low-carbon economy for people with privilege, while displacing communities of color and other low-income people out of dense, walkable neighborhoods. We need a combination of natural science, engineering, and social science to guide equitable and effective green investments for everyone.

And research alone won't be enough. The other work that DOE must continue to focus on is how to get the results of this research into the hands of the communities that need it most. A week ago, I released a proposal to heal our K–12 school system from the impacts of climate change and the pandemic, and from decades of disinvestment. A huge part of this plan is focused on retrofitting public school buildings and removing toxic materials, beginning in the highest-need districts. Schools can become living laboratories for the energy transition, putting students and young people at the center of the Green New Deal, and launching STEM (science, technology, engineering, and mathematics) careers across the country.

Big problems require big solutions, and that is exactly what we will be pursuing together on this Committee. I am excited to chair the Energy Subcommittee this Congress and to hold this first Subcommittee hearing on such an important topic. Investing in building technologies means investing in a safe, healthy future for our country and for the entire world. I want to thank our excellent panel of witnesses assembled today, and I look forward to hearing your testimony. With that, I yield back.

[The prepared statement of Chairman Bowman follows:]

Good afternoon, and thank you to all of our witnesses who are joining us virtually today to discuss the importance of sustainable buildings research. This is a critical component of fighting the climate crisis.

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This goes to the heart of why we need to address climate change, inequality, and racism together. As we have been discussing on this Committee, when climate disasters strike, redlined communities of color and low-income people are hit hardest. They're the first to lose power when the electricity grid is strained, as we saw in Texas. And these are the same communities that struggle with housing and utility costs. They face health risks from toxic materials in buildings, including in the public housing that we have allowed to fall into a state of disrepair. In my district and around the country, the people who live in these buildings have been dying at higher rates from COVID—partly because of co-morbidities caused by the fossil fuel economy. We need sustainable buildings now, and we need to rebuild our communities from the ground up.

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I want to again thank our excellent panel of witnesses assembled today, and I look forward to hearing your testimony. With that, I yield back.

Chairman BOWMAN. The Chair now recognizes Mr. Weber for an opening statement.

Mr. WEBER. Well, thank you, Mr. Chairman, and welcome to the Committee. We're going to have a little fun. We're going to be a lighthearted Committee, and we're going to be very serious about our work, serious about what we do with energy and for our country, so I appreciate you being here Chairman Bowman. All of my thanks I want to add to all the witnesses for being with us here virtually this afternoon.

I will tell you that, today, we're going to discuss building technology research and development (R&D) needs. And while I'm excited to hear about the critical work being performed by the Department of Energy's Building Technologies Office and, quite frankly, all across DOE, I want us all to be mindful of the role that industry can and should play in this area, especially where there is a clear incentive and an ability to take up mature technologies.

I say this as someone who knows the building industry firsthand. In the 1970's, I couldn't even spell air conditioning or what we call AC in Texas, but by the mid-'90's I was actually running my own AC company. And I can tell you this: Whether it's through regulation, taxation, mandates, businesses suffer when the government gets heavy handed and intervenes, so we have to take a very careful approach.

Today, we must also remember that we have limited Federal research and development dollars. The Department of Energy mainly supports building technology research and development through their Office of Energy Efficiency and Renewable Energy, which I am inclined to mention is the highest funded applied energy office at the Department with a budget this past year alone of $2.8 billion with a B. That's why I have long prioritized investment in basic and early stage research that will drive innovation into the next century and not just for building technologies but across our entire energy and efficiency portfolio.

DOE's world-leading national laboratories support that type of cutting-edge research that we're talking about here today. National labs around the country, from Oak Ridge and NREL (National Renewable Energy Laboratory) to Argonne and Lawrence Berkeley National Lab, are leveraging DOE's unique capabilities and user facilities to support critical discoveries in innovative material science, data analytics, and advanced sensors and controls. And private-public partnerships with these labs are exactly how we get the most bang for our taxpayers' buck when investing taxpayers' dollars in this research. DOE partnerships with industry and academia enable the development of new technologies that can increase the energy efficiency of building envelopes, improve construction practices, and meet the demand for greater energy generation capacity.

Today, we will hear from Dr. Jim Tour of Rice University in my home State of Texas, who will give us his perspective as one of those partners. As a professor of chemistry along with materials science and nanoengineering, Dr. Tour's research focuses on advanced building materials like, for example, lighter, stronger concrete that is a result of turning waste into a manufacturing additive called graphene. I look forward to hearing his testimony on how fundamental materials research can transform building technologies and at the same time how successful public-private partnerships have supported these innovations.

And just like Dr. Tour's example of turning trash into treasure, we can support a future that protects our environment for the next generation and is affordable for all Americans. But we won't necessarily accomplish this by doing what we call in Texas, just throwing in the kitchen sink and billions of dollars at a broad, unspecified portfolio. Instead, we should make our clean technology affordable through significant investment in fundamental research paired with targeted and responsible investments in applied energy R&D.

That is why, this week, I was proud to sign on as one of the original cosponsors of Ranking Member Lucas' *Securing American Leadership in Science and Technology Act*. This legislation supports a diverse, all-of-the-above clean energy strategy and prioritizes critical research to establish U.S. leadership in industries of the future, like advanced materials and manufacturing. This long-term strategy for investment in basic research and infrastructure is how we in Congress should support innovative building technologies. It creates a pipeline from lab to market and is the most direct and efficient path to a more sustainable future for both new and current buildings.

Thanks to the witnesses. Thank you, Mr. Chairman. I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you, Chairman Bowman, for hosting this hearing, and thank you to all our witnesses for being with us virtually this afternoon. Today is the first Energy Subcommittee hearing of the 117th Congress and I'm looking forward to continuing the bipartisan successes that have marked my time here.

Today, we will discuss building technology research and development needs. And while I am excited to hear about the critical work being performed by the Department of Energy's Building Technologies Office and across all of DOE, I want us all to be mindful of the role industry can and should play in this area, especially where there is a clear incentive and ability to take up mature technologies.

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Today, we must also remember that we have limited federal R&D dollars. The Department of Energy mainly supports building technology research and development through their Office of Energy Efficiency and Renewable Energy (EERE), which I am inclined to mention is the highest funded applied energy office at the Department with a budget of $2.8 billion this past year alone. That's why I have long prioritized investment in basic and early stage research that will drive innovation into the next century. Not just for buildings technologies—but across our entire energy and efficiency portfolio.

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I want to thank all of our witnesses for being here and I look forward to a productive discussion, Mr. Chair. Thank you and I yield back the balance of my time.

Chairman BOWMAN. Thank you, Mr. Weber.

The Chair now recognizes the Chairwoman of the Full Committee, Ms. Johnson, for an opening statement.

If Ms. Johnson is not present at this time, the Chair is going to move forward.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Good Afternoon and thank you Chairman Bowman for holding this hearing today, as well as to all of our witnesses for being here.

The sustainability of our buildings is a topic that touches on every American across the country.

Buildings make up almost 40% percent of the total energy consumption in the United States, and reducing that consumption can not only decrease our electric bills, but also significantly reduce our greenhouse gas emissions.

My own city of Dallas, Texas is the fastest growing metropolitan area in the U.S. Our growing population supports a growing economy, but we must ensure that new infrastructure to meet these needs is built with the most up-to-date technologies to provide efficiency, comfort, and resilience.

Existing buildings are another key component of federal research, development, and demonstration activities. Many of the advancements that have been made on improving heating, cooling, windows, and lighting can be more easily applied to new construction projects, but our existing buildings are not going away any time soon. Retrofit technologies can help to equitably distribute local and federal resources, as some of the communities that could most use healthier, cleaner, and more resilient buildings have aging infrastructure.

As we have seen with recent, devasting events in my home state of Texas, ensuring the resilience of our grid is paramount. When constructing new buildings, grid connectivity could be a key element in alleviating energy demand and improving reliability through next-generation sensors, controls, and communication technologies. I look forward to hearing how our national labs and the Building Technologies Office within the Department of Energy can help us achieve these goals.

Buildings affect all aspects of our daily lives, and we should be doing everything we can to ensure that we are laying a foundation for these technologies to improve our infrastructure for decades to come.

Thank you again to our witnesses for being here, and with that I yield back the balance of my time.

Chairman BOWMAN. At this time I would like to introduce our witnesses. Dr. Nora Esram is the Senior Director for Research of the American Council for an Energy-Efficient Economy (ACEEE). Dr. Esram overseas ACEEE's research programs on buildings, transportation, industry, and behavior. Dr. Esram holds a Ph.D. in architecture from the University of Illinois Urbana-Champaign and is a licensed architect.

Dr. Roderick Jackson is a Laboratory Program Manager for Buildings Research at the National Renewable Energy Laboratory. His portfolio includes a broad range of research, development, and market implementation activities that aim to improve the energy efficiency of buildings materials and practices. He holds a bachelor's, master's, and Ph.D. in mechanical engineering from the Georgia Institute of Technology.

Dr. James Tour is a T.T. and W.F. Chao professor of chemistry, professor of computer science, and professor of materials science in nanoengineering at Rice University. He received his bachelor's degree from Syracuse University and his Ph.D. in chemistry from Purdue University.

Ms. Jacqueline Patterson is the Director of the NAACP Environmental and Climate Justice Program. She has worked as a researcher, program manager, coordinator, advocate, and activist working on women's rights, violence against women, HIV and AIDS, racial justice, economic justice, and environmental and climate justice. She received her master's degree in social work from the University of Maryland and a master's degree in public health from Johns Hopkins University.

Last but certainly not least, Mr. Joseph Hagerman is a Section Head for buildings technology research at Oak Ridge National Laboratory. He leads the lab's research in building envelope materials and equipment, as well as in integrated building performance and multifunctional equipment integration. He holds a master's in civil engineering from the Fu Foundation School of Engineering and Applied Science at Columbia University and earned his bachelor's in architecture from Mississippi State University.

Thank you all for joining us today. As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you all have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel.

We will start with Dr. Esram. Dr. Esram, please begin.

TESTIMONY OF DR. NORA ESRAM, SENIOR DIRECTOR FOR RESEARCH AT AMERICAN COUNCIL FOR AN ENERGY-EFFICIENT ECONOMY

Dr. ESRAM. Thank you. Chairman Bowman, Ranking Member Weber, and Members of the Committee, thank you for inviting me to testify on the topic of building technologies research and development. I bring with me today my 20 years of knowledge and experience as an architect, an educator, a lab scientist, and now as a Research Director at American Council for an Energy-Efficient Economy.

Building efficient technologies are known to lower energy costs and create local jobs, but the biggest opportunities are still ahead. Improving efficiency of buildings has the potential to reduce U.S. greenhouse gas emissions by 20 percent. The industry needs help from the Federal Government and science community to develop integrated solutions and productive processes to upgrade existing buildings faster.

Building retrofits also improve occupants' health, comfort, productivity, and community resilience. Today, many of our buildings don't serve us well. For instance, when COVID–19 hit, public health experts suggested increasing indoor ventilation and filtration to lower this ease of transmission risk, but many legacy building systems can't handle that. When offices were sitting empty during the lockdown, they still consumed 40 to 100 percent of their usual energy. That's a huge waste. When the power went out across much of Texas, many poorly insulated homes quickly dropped to near freezing temperature. Imagine if these houses could have been kept warm with a heating device as small as a hairdryer. That's not a dream. That's efficiency building technologies.

Thanks to decades of Federal investment in research, we have many technologies to make buildings efficient, healthier, and resilient for everyone. But we don't know yet how to expeditiously deliver these technologies to existing buildings. Improving construction productivity offers a path. If construction labor productivity were to catch up with the progress made by other sectors, we will gain $1.6 trillion economic growth globally. A third of that is in the United States.

Many countries are moving onsite construction toward a manufacturing inspired mass production platform. We'll lose our competitive edge if we don't take bold actions. Transforming the building industry would also provide an opportune time to reduce embodied carbon in building materials and products.

I also believe a strong and a creative workforce is key to success. We need to equip the building contractors and specialized trades with knowledge and skills to adapt to new technologies. We need to educate and attract a new generation of innovators and entrepreneurs. Buildings of the future are machines that interact with the grid and transportation systems. Workforce development is a creative and interactive process. Therefore, we need Federal R&D support to grow tomorrow's building leaders outside the classroom.

I urge Congress and DOE to take bold actions to lay a solid foundation for a successful transmission of the building sector. First, spur modernized approaches to accelerate deep energy retrofits and create local jobs. Second, train and diversify our workforce and inspire a new generation of leaders. Third, drive enduring market transformation through integration of efficiency with health, resilience, and other societal goals. Last but not least, collaborate with local and State governments and community-based organizations to create proactive, replicable solutions for all.

I truly believe that we are facing a paradigm shift. Together, we can both create and witness history. Thank you again for the opportunity to testify, and I look forward to your questions.

[The prepared statement of Dr. Esram follows:]

ACEEE Testimony
American Council for an Energy-Efficient Economy

Testimony for Building Technologies Research for a Sustainable Future

To the Subcommittee on Energy of the U.S. House Committee on Science, Space, and Technology

BY NORA WANG ESRAM, PH.D.
SENIOR DIRECTOR FOR RESEARCH, AMERICAN COUNCIL FOR AN ENERGY-EFFICIENT ECONOMY
MARCH 25, 2021

Introduction

Thank you for the opportunity to testify on the topic of building technologies R&D. The American Council for an Energy-Efficient Economy (ACEEE), a nonprofit 501(c)(3) organization founded in 1980 by researchers at universities and national laboratories, acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors. We produce more than 30 reports and other resources each year on technologies, programs, and policies to reduce energy consumption, mitigate climate change, and advance an equitable and just clean energy system. We have a long history of providing testimony to Congress, as well as state and local policymakers, based on our research findings.

Summary

Both the public and private sectors have historically viewed investments in building energy efficiency technologies as win-win strategies to reduce energy costs and create local jobs. As we shift more attention to combatting climate change and promoting clean energy, energy efficiency technologies are sometimes perceived as less-transformative or less-aggressive approaches to meeting ambitious climate goals. This perception fails to recognize the interconnectivity of building systems with other fundamental aspects of society. Buildings interact with the energy network and are critical to meeting other needs, such as health and resilience. For example, a house with lower internal thermal loads (thanks to efficient lights and appliances) and lower external thermal loads (thanks to improved envelope insulation) needs a much smaller heating and cooling system to keep occupants comfortable. Such a house would need a smaller onsite photovoltaic or battery system to become zero-energy. In addition, an efficient house is healthier, more comfortable, and can better shelter its occupants in place during extreme weather conditions.

Our research finds that building energy efficiency has the potential to reduce U.S. greenhouse gas emissions by nearly 20% by 2050[1]. However, slow uptake of building retrofits and insufficient private investment in building efficiency improvements demonstrate that existing barriers—such as the lack of consumer demand and value proposition for efficiency-oriented

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[1] Nadel, S., Ungar, L., (2019). Halfway there: Energy efficiency can cut energy use and greenhouse gas emissions in half by 2050. American Council for an Energy-Efficient Economy. Available at www.aceee.org/research-report/u1907

businesses—need to be addressed in a more accelerated and innovative fashion. Energy efficiency is shifting from product efficiency to process and system efficiency. More research and innovation must focus on the processes through which building technologies are deployed and the context in which they are applied.

We strongly support a broad range of building technologies programs to achieve urgent carbon reduction while also equitably benefitting communities. This testimony focuses on specific recommendations to enhance the impact of the Department of Energy's (DOE) Building Technologies Office (BTO). BTO's programs are highly capable and well positioned to play a pivotal role in advancing low-carbon building technologies, expediting energy efficiency retrofits, and driving enduring transformation of the building industry, all while achieving equitable outcomes. BTO should expand its research, development, and demonstration (RD&D) efforts as follows: **(1) Accelerate deep energy retrofits through innovative processes, such as manufacturing-inspired mass production; (2) Retool the workforce and inspire a new generation of leaders in the building sector; (3) Drive enduring market transformation through integration with health, resilience, and other societal goals. In pursuing these three goals, BTO should collaborate with state and local governments and community-based organizations to create proactive, replicable, equitable solutions.**

Congress should clarify that BTO has the authority to expand its scope to include construction, health, resilience, and financing. Congress should also direct BTO to work collaboratively with other DOE offices and federal agencies to create foundational programs and establish self-sustaining mechanisms for lasting impacts.

Increase productivity in building construction industry to promote deep retrofits and job growth

Improving productivity in the building construction industry can simultaneously expand the reach of deep energy retrofits and create jobs. Since 1945, productivity[2] in U.S. manufacturing, retail, and agriculture has grown by as much as 1,500%, while productivity in construction has barely increased at all.[3] Compared to large-scale players in heavy construction and large-scale housing development, many of the fragmented specialized trades—which mostly work on small real estate and retrofit projects—have even lower productivity.[4] Low productivity translates to higher costs for owners, lower profitability for contractors, and lower wages for workers. This situation contributes to slow uptake of retrofits and stagnation in energy efficiency improvements to existing buildings. Almost 80% of the nation's 124 million homes (as of 2019) are at least 20 years old, and more than 50% are at least 40 years old.[5] Less than 0.02

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[2] Labor productivity is defined as value added by construction workers per hour of work and its growth over time, adjusted for inflation.

[3] Sveikauskas, L., Rowe. S., Mildenberger, J., Price, J. & Young, A. (2016). Productivity growth in construction. *Journal of Construction Engineering and Management*, 142 (10). DOI: 10.1061/(ASCE)CO.1943-7862.0001138.

[4] Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M., & Brown, S. (2017). Reinventing construction: A route to higher productivity. McKinsey Global Institute. Available at www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution

[5] U.S. Census Bureau. (2019). American Housing Survey. Available at www.census.gov/programs-surveys/ahs.html

percent of homeowners reported home remodeling in 2017; less than half of these remodeling projects included residing, reroofing, insulation, or HVAC replacement[6]. The vast majority of commercial buildings are small—about half of buildings are 5,000 square feet or smaller, and nearly three-fourths are 10,000 square feet or smaller[7]—and are an underserved market sector. Unfortunately, most individual players in the building construction industry lack incentives, information, and tools to combat these challenges in the construction industry.

To meet the Biden administration's goal of upgrading 4 million buildings and weatherizing 2 million homes[8] over four years, the construction industry needs to be reinvented. McKinsey & Company has already identified seven ways[9] to improve construction productivity by 50%–60%.[10] Many of these identified areas will benefit greatly from federally funded R&D. **We suggest that BTO focus on two areas: (1) creating innovative solutions using a manufacturing-inspired mass production platform and processes and (2) retooling the workforce and inspiring a new generation of leaders in the building sector.**

Accelerate deep energy retrofits through innovative processes

Some on-site construction can be moved to a manufacturing-inspired mass production platform and process. This includes off-site manufacturing of building components for both new and existing buildings and using lean manufacturing principles to cluster and streamline retrofits to reduce variable costs. BTO's Advanced Building Construction (ABC) Initiative has taken the first step to create highly productive construction practices that integrate energy-efficient solutions. We applaud BTO's endeavor and urge Congress to support BTO in expanding and scaling up its efforts.

To ensure that the ABC Initiative can successfully industrialize and modernize U.S. construction and renovation, BTO needs to work with a variety of partners on supply- and demand-side interventions, such as establishing manufacturing capacity, creating financing mechanisms, and

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[6] Joint Center for Housing Studies of Harvard University. (2019). Improving America's Housing. Available at www.jchs.harvard.edu/sites/default/files/reports/files/Harvard_JCHS_Improving_Americas_Housing_2019.pdf

[7] U.S. Energy Information Administration. 2012. Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/reports/2012/buildstock/.

[8] According to Ariel Drehobl's Testimony before the Subcommittee on Energy of the U.S. House Committee on Energy and Commerce (October 01, 2020), the Weatherization Assistance Program (WAP) currently serves about 100,000 homes per year through DOE funding and leveraged funds from the Low-Income Home Energy Assistance Program (LIHEAP) and other sources. This number is far below the 15.7 million severely energy burdened households in the United States. At the current rate, it would take 360 years to weatherize all eligible households through WAP.

[9] They are (1) reshape regulation and increase transparency, (2) rewire the contractual framework, (3) rethink design and engineering processes, (4) improve procurement and supply-chain management, (5) improve on-site execution, (6) infuse the construction industry with digital technology, new materials, and advanced automation, and (7) reskill the workforce.

[10] Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M.… & Brown, S. (2017). Reinventing construction: A route to higher productivity. McKinsey Global Institute. Available at www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution

increasing procurement of ABC technologies in various market segments. The partners include, among others, other DOE offices (e.g., Advanced Manufacturing Office, Office of Weatherization and Intergovernmental Programs, Office of Economic Impact and Diversity, Loan Office); other federal agencies (e.g., Department of Housing and Urban Development, Department of Agriculture, Federal Emergency Management Agency, Economic Development Administration, NIST/Manufacturing Extension Partnership); government-sponsored enterprises (e.g., Fannie Mae, Freddie Mac); state and local governments; trade associations; and stakeholders focused on equity and justice concerns.

Many of these interventions need building R&D support. For example, **BTO should develop consistent data collection and performance evaluation methods, build knowledge infrastructure for cost comparison and carbon emission calculations, and quantify and verify energy equity and justice-related benefits provided by the ABC approaches. BTO, working with other relevant federal agencies, should assess the impact of integrating ABC technologies with local economic development plans and carbon reduction goals on local economies, communities, and workforces. BTO should explore how ABC can improve quality of life for marginalized communities[11] across the United States, such as through lower energy bills, improved home health and comfort, and the creation of local workforce opportunities.**

Retool the workforce and inspire a new generation of building leaders

Workforce development is inseparable from increased productivity and innovation. Federal R&D support is needed to create a skilled, diverse workforce—and a pipeline of young workers—who can speed up retrofits and maintain and operate the buildings of the future.

First, innovative construction processes, as discussed above, require training a workforce to use the latest equipment and digital tools to assemble pre-framed building components onsite and to streamline retrofits. Specialty trades and contractors are the first line of support for building owners. They play a significant role in implementing energy efficiency solutions. Helping them gain a competitive edge will, in return, accelerate uptake of retrofit solutions by leveraging existing markets for building renovations.

Second, advanced building technologies and systems (e.g., building submetering, building energy management systems (BEMS), automated fault detection and diagnostics (AFDD)) require building managers to gain new skills, such as data management. This creates a challenging learning curve for building managers, which has hindered the adoption of sensor and control innovations. The market penetration of BEMS and AFDD each was only about 4% in 2018.[12] As BTO is advancing grid-interactive buildings, there is a critical need for building

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[11] Marginalized communities are those most affected by community decision making and whose life outcomes are disproportionately affected by societal structures. These groups can include people of color, low-income residents, youth, the elderly, recently arrived immigrants, people with limited English proficiency, people with disabilities, and people experiencing homelessness. In some contexts, marginalized communities may be referred to as disadvantaged or underserved communities.

[12] U.S. Energy Information Administration. (2020). Trends in commercial whole-building sensors and controls. Available at www.eia.gov/analysis/studies/buildings/commercial/sensors/pdf/sensors_controls.pdf

managers to gain new knowledge and skillsets to operate complex building systems that can provide grid services without compromising occupants' needs. As more building managers become familiar with these new technologies, wider adoption could have benefits beyond building operators. For example, AFDD could help ensure the proper performance of building systems in public housing, where operation and maintenance resources are sparse.

Third, the sustainable buildings of the future will rely on a new generation of innovators and entrepreneurs. The jobs that attract millennials tend to be occupations dealing with software, data, or management.[13] Transformation of the building and construction industry requires rethinking the building profession (which is typically narrowly defined as architects, builders, or contractors, but can be expanded to include data scientists, software engineers, etc.) to attract the younger generation and cultivate our future building workforce starting as early as in K-12 schools. For example, BTO's Solar Decathlon has created an environment that inspires and trains tomorrow's buildings leaders outside of the classroom. As a Solar Decathlon alumna, I have personally benefited from my Solar Decathlon experience and have witnessed the energy of thousands of young Solar Decathlon graduates who want to work in the clean energy sector. Many of us have chosen to devote our careers to energy efficiency and renewable energy, thanks to Solar Decathlon.

Last but not least, a vibrant workforce needs diversity. The building industry has historically been too homogeneous, made up of only 11% women and 11.4% non-white individuals.[14] The pressing labor shortage in energy efficiency and building construction creates an ideal opportunity for workforce development programs to reach out to groups of people who may have been ignored in the past. Diversifying the construction workforce not only fills the talent gap that continues to grow as baby boomers retire, but also boosts creativity and invites those with new perspectives to develop energy efficiency solutions that will be more applicable to and more successful in diverse communities.

Congress should direct BTO to lead and support workforce development in the above four areas. BTO should develop new initiatives beyond training curriculums and certificates. Successful workforce development requires consistent commitment and creativity. BTO should leverage its R&D capabilities to reinvent traditional training and education in the buildings professions, ultimately creating more interactive processes, deepening civic engagement, and incubating leadership.

Drive enduring market transformation through integration with health, resilience and other societal trends and goals

The direct economic benefits of reduced energy consumption have traditionally been the primary criteria used to evaluate energy efficiency technologies and solutions. However, it is crucial to recognize that many energy efficiency projects have significant non-energy benefits,

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[13] Renzulli, K.A. (2019). The job millennials want most pays $98,500. CBNC. Available at www.cnbc.com/2019/02/21/the-10-jobs-millennials-most-want.html

[14] U.S. Bureau of Labor Statistics. (2020). Labor Force Statistics from the Current Population Survey. Available at www.bls.gov/cps/cpsaat18.htm

such as improved occupant productivity, decreased illness from indoor air quality problems, and reduced environmental pollution. These non-energy benefits can have large indirect economic benefits, which energy efficiency project valuation methodologies often ignore. For example, a recent report by Stok found that owner-occupants and tenants could gain $115 per square foot 10-year net present value from personnel savings and $14 per square foot from utility and maintenance savings through office retrofits that enhance indoor environments.[15] The societal impacts of low-quality, inefficient buildings are not captured in the cost-benefit analysis typically performed for building upgrades. Rather, these costs of inefficient buildings are borne elsewhere, such as through catastrophic property damage during extreme weather events or by populations with illnesses exacerbated by sub-optimal housing. Energy efficiency can support community resilience by strengthening local energy systems and delivering more-reliable, more-affordable energy for local governments, households, and businesses.[16]

Currently, even with significant public financial assistance and utility incentives, progress in energy retrofits is extremely slow, and many energy efficiency projects are limited in scope and impact. Some one-off demonstrations or pilots are incapable of scaling up after financial assistance is depleted or their lower-hanging fruits are picked. Utility energy efficiency programs have achieved large savings from efficient lighting, such as light-emitting diodes (LED); now, they need other technology opportunities because LED technology has achieved substantial market penetration.[17] Many known barriers to market transformation, such as lack of capital, uncertainty in predicted savings, and split incentives between owners and tenants, boil down to the fact that, in many cases, energy efficiency has not yet been fully integrated into the products and processes that consumers want and businesses value. Decades of scientific research have proven the impact of the built environment (e.g., lighting, comfort, and air quality) on human circadian rhythm, the immune system, cognitive function, and task performance. A review of 63 high-quality studies shows a 5.7% average improvement in productivity and a 37% reduction in absenteeism when indoor air quality and thermal comfort are improved.[18] Unfortunately, this knowledge has yet to be fully utilized to guide technology and strategy development in the building energy sector to promote positive human outcomes—the most valuable, desirable outcomes for business owners and individuals. **To drive market transformation and produce lasting impact, BTO should consider broader, public-good impacts of integrated energy and building services and invest more in cross-sector R&D to align energy and carbon reduction goals with other societal goals, such as health and social equity. Three recommendations are discussed below.**

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[15] Attema, J. E., Fowell, S. J., Macko, M. J., & Neilson., W. C. (2018). The financial case for high performance buildings.

San Francisco: stok, LLC. Available at stok.com/research/financial-case-for-high-performance-buildings

[16] Ribeiro, D., Mackres, E., Baatz, B., Cluett, R., Jarrett, R., Kelly, M., & Vaidyanathan, S. (2015). Enhancing community resilience through energy efficiency. American Council for an Energy-Efficient Economy. Available at www.aceee.org/research-report/u1508

[17] U.S. Energy Information Agency. (2020). Utility energy efficiency spending and savings declined in 2018. Available at www.eia.gov/todayinenergy/detail.php?id=42975#

[18] Wang. N., Rotondo, J. A. (2020). Energy and health nexus: Making the case for building energy efficiency considerations of occupant health and productivity. Pacific Northwest National Laboratory. Available at www.pnnl.gov/sites/default/files/media/file/EED_0831_BROCH_HealthyBuildings_v4.pdf

First, Congress should direct and support BTO in conducting more research on the non-energy benefits of efficiency technologies to building occupants and the broader economy. The complexity of human health and behaviors increases the uncertainty of measuring and verifying non-energy outcomes. BTO is in a unique position to lead development of consistent methods to quantify the non-energy benefits of building systems and services. Some states (e.g., MA, CA) have started studies to identify and investigate these non-energy benefits. A consistent approach supported by an interoperable platform across vendors and service providers is vital to establish credibility and accumulate knowledge and evidence at a faster pace. BTO should support public- and private-sector building owners to build business cases to advance human-centered building systems and develop crosscutting strategies to fully leverage resources beyond the energy sector. A 2020 ACEEE study identified at least six sources of health-related federal funding that could be used to support residential energy efficiency programs (via the departments of Health and Human Services, Housing and Urban Development, and Treasury), representing $2 billion that could be used to provide weatherization and/or complementary services to households in need.[19] For example, Johns Manville and its installation contractors have been working in conjunction with the South Coast Air Quality Management District (AQMD) to implement a residential energy efficiency retrofit program for groups of homes in disadvantaged communities located in Coachella Valley in California, leveraging environmental mitigation funds established by Assembly Bill No. 1318[20] and utility incentives. With an average cost of approximately $4,000 per home, the program reduces household energy use by 18% while improving home comfort and helping the AQMD achieve its air quality goals.[21] Johns Manville also uses lean manufacturing principles to minimize the project's overhead cost and significantly increase the productivity of its contractors. BTO could help develop replicable models to help scale up similar solutions nationwide. It is important for BTO to partner with community-based organizations and environmental justice organizations to identify non-energy benefits, ensure that those benefits reach marginalized communities, and involve community organizations in accelerating building retrofits while also creating jobs.

Second, BTO should anticipate changes in the building sector and incorporate energy efficiency into what businesses and consumers will need in the near future. In the commercial sector, the amount of space devoted to scientific laboratories in the United States has increased 70% in the past 10 years.[22] The race to develop coronavirus therapies and vaccines has further ramped up investment in lab space. In many areas, building owners have been converting offices to life science facilities[23] and apartments[24], or turning empty stores into e-

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[19] Hayes, S., Gerbode, C. (2020). Braiding energy and health funding for in-home programs: federal funding opportunities. Available at: www.aceee.org/research-report/h2002.

[20] AB-1318 South Coast Air Quality Management District: emission reduction credits: California Environmental Quality Act. Available at leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=200920100AB1318

[21] Rowan, D. (2020). South coast air quality management district residential energy efficiency retrofit project (Coachella Valley). ROWAN Engineering, Inc.

[22] Session, P. (2020). Here comes the life sciences land rush. Available at www.bloomberg.com/news/articles/2020-09-15/life-sciences-labs-are-hot-covid-era-real-estate?srnd=citylab

[23] Ibid.

commerce fulfillment centers[25]. The upcoming wave of adaptive reuse presents huge building retrofit opportunities beyond normal tenant buildouts; there are many emerging opportunities to develop more affordable housing at a faster pace[26]. BTO should embrace these solutions that not only reduce building energy use but also help building owners become flexible enough that they can better adapt to unforeseen future changes. For example, the pandemic has accelerated the demand for more flexibility in office space. In the short term, some offices have been redesigned for the new reality of social distancing. In the long term, more agile office spaces are needed to support the transformation of the office from a place where individuals spend an entire day working to a place where staff visit occasionally to collaborate, meet with clients, or retreat.[27] Uncertainties about and fluctuations in occupant density make building operation challenging if a building is not equipped with energy management technologies and strategies. A few studies, such as those by the University of California at Davis,[28] Carbon Lighthouse,[29] and Hatch Data,[30] show that empty office buildings have been consuming a significant amount of energy during the COVID lockdown (up to 100% of usual). In a more-competitive real estate market where fewer tenants are willing to pay a hefty utility bill for a half-empty office, there will likely be more appetite for modular and more-efficient HVAC equipment, miscellaneous load-management technologies, and building automation.

Third, lifecycle carbon in buildings constitutes another R&D gap. The increasing societal interest in and policy support for "Buy Clean" policies provides a unique opportunity to reduce lifecycle carbon in buildings. The building construction industry accounts for 5% of global energy use and 10% of global greenhouse gas emissions.[31] A primary source of these emissions is the manufacture of building construction materials such as steel, cement, and glass. These Buy Clean proposals have focused on the materials approach (e.g., specifying materials with low embodied carbon). Perspectives on whole-building performance (e.g., selecting alternative

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24 Orton, K. (2019). A man worked at the IRS for 10 years, then he came back to live where his cubicle was. Available at www.washingtonpost.com/realestate/what-once-was-your-cubicle-can-now-be-your-home/2019/10/16/6f12cafe-f01a-11e9-8693-f487e46784aa_story.html

25 Reonomy. (2020). Repurposing retail in the wake of COVID-19. Available at www.reonomy.com/blog/post/recycling-empty-retail-spaces

26 HUD User. Adaptive reuse in suburban housing markets. Available at www.huduser.gov/portal/pdredge/pdr-edge-featd-article-030518.html

27 Rubin, C. (2020) The office is dead. Available at marker.medium.com/the-office-is-dead-16be89f25d01

28 Meier, A. (2020). Saving energy in buildings when nobody is in them. Available at www.ase.org/blog/saving-energy-buildings-when-nobody-them

29 Carbon Lighthouse. (2020). COVID shows that even empty buildings must use energy. Available at www.carbonlighthouse.com/covid-building-occupancy-energy-use/

30 Hatchdata. (2020). How is U.S. office building energy use being affected by the coronavirus crisis? Available at hatchdata.com/assets/Hatch-Data-Research-Report-2020-04-06.pdf

31 United Nations Environment Program (2020). 2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector. Available at https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf.

materials, reducing waste, considering the trade-off between embodied carbon and operational carbon emissions) haven't yet been integrated. Furthermore, the building sector has not yet made significant efforts to consider lifecycle carbon in building standards. **Congress should direct and support BTO in creating initiatives to drive low lifecycle carbon in building materials, equipment, and construction processes.** This focus will create market pull for low-carbon products that are better for occupant and enviornmental health, thereby improving the business case for the manufacturing industry. Such a focus will also drive innovations in building design, construction, and manufacturing processes. In collaboration with DOE's Advanced Manufacturing Office, BTO should engage industry leaders and innovators to develop business cases for transformative technologies that enable new buildings to meet low-carbon standards with little cost burden or even with added value. BTO should lead or support the development of lifecycle carbon calculations in buildings. Finally, BTO should develop strategies for expanding and accelerating the market demand for and availability of low-carbon alternatives through near- and medium-term voluntary market strategies. These can include labeling and certification programs, technical assistance, incentives, purchasing and procurement guidelines, voluntary codes, and education/awareness activities.

Conclusion

Federal R&D focusing on buildings can accelerate the deployment of advanced energy efficiency and clean-energy technologies in the existing buildings stock, which would normally take a century to undergo a complete turnover. Expeditious building retrofits are critical to decarbonizing the U.S. building sector. A highly efficient retrofit model comprises high productivity in building construction, a skillful and inclusive workforce, expanded value propositions beyond energy cost savings to attract wider public interest and private-sector investment, and multiple sources of public-sector funding. **Congress should direct and support BTO to use its RD&D capabilities to do the following:**

- **Spur modernized strategies that increase construction productivity, accelerate deep retrofits, and create local jobs.**
- **Grow and diversify the building-sector workforce. This workforce includes specialty trades and contractors, building and facility managers, and a new generation of innovators and entrepreneurs.**
- **Create the knowledge infrastructure needed to quantify the non-energy benefits of building efficiency technologies and integrate these benefits with local economic development plans and carbon reduction goals.**
- **Integrate energy efficiency into the products that consumers and businesses value, and develop innovative solutions that help building owners achieve greater flexibility and resilience.**
- **Reduce lifecycle carbon in buildings through standardization and a whole-building approach that drives innovation.**

The advancement of building technologies is not only about materials, equipment, and products; it also includes processes, systems, and workforce development efforts. Ambitious carbon reduction goals require that BTO apply bold ideas and innovative approaches to revolutionize the fragmented and misaligned building construction industry. Efficiency is a means to achieve other societal goals, such as improved health, social equity, and economy prosperity. Market transformation for sustainable buildings requires a holistic view that integrates all these goals. BTO should expand its R&D efforts to develop integrated approaches that can yield environmental, economic, and health benefits, particularly for marginalized communities. Such approaches can also help building efficiency programs increase funding opportunities (e.g., by weaving together resources from health and resilience programs), expand services, and reach more households. To achieve broader success, BTO should collaborate with other DOE offices, other federal agencies, state and local governments, trade associations, and stakeholders focused on equity and justice concerns. The building sector is facing a paradigm shift. As the global building and construction industry seeks to increase productivity and decrease lifecycle carbon, our U.S. construction industry could be left behind. We must be proactive by taking bold action. Congress should support BTO in building a solid foundation that sustains a successful transformation of the building industry

Dr. Nora Wang Esram is the Senior Director for Research of the American Council for an Energy-Efficient Economy (ACEEE). Dr. Esram oversees ACEEE's research programs on buildings, transportation, industry, and behavior. Prior to joining ACEEE, Dr. Esram worked at the Pacific Northwest National Laboratory as a chief engineer and a team lead in the Electricity Infrastructure and Buildings Division for ten years, where she received Director's Award for Exceptional Engineering Achievement. Dr. Esram holds a Ph.D. in architecture from the University of Illinois, Urbana-Champaign. She is a licensed architect in Washington.

Chairman BOWMAN. Thank you, Dr. Esram. Dr. Jackson, you are now recognized.

TESTIMONY OF DR. RODERICK JACKSON, LABORATORY PROGRAM MANAGER FOR BUILDINGS RESEARCH AT NATIONAL RENEWABLE ENERGY LABORATORY

Dr. JACKSON. Thank you to the Subcommittee for giving me this opportunity today to provide a testimony on a topic of critical national importance and deep personal passion. So my bio is included in the written testimony for reference, so I won't get into those details, but I wanted to provide a personal perspective of who I am and my passion.

So my father, Louis C. Jackson, was one of 16 children, and out of 16—and out of 11 boys, they all built houses. So construction was a deep passion for my dad, so much so that he first introduced it to me when I was only 3 years old. I think my first job was to go out on the jobsite and pick up all the straight nails.

A little after finishing my undergraduate degree, he and I formed L&R Jackson Construction back in my hometown of Canton, Mississippi. However, my personal passion for science and engineering drew me back to Georgia Tech to complete my Ph.D., but the legacy my dad and my brothers, [inaudible] was never far from my heart.

I have since been able to marry my love for science with family legacy, and that brings me here today. Unfortunately, my dad passed away on January 19th, 2021, but the opportunity to provide testimony on the future of the industry he so—he loved so dearly is immensely fulfilling.

So let's talk science. Because buildings consume about 3/4 of our current electricity demand, they can be a large part of the sustainable energy solution. By leveraging energy efficiency, greater connectivity, advanced data science and analytics, along with next-generation materials, sensors, and controls, buildings can be designed to synergistically interact in real-time with the electric grid to provide demand flexibility, all while not compromising comfort, health, or productivity.

DOE is leading the charge in this new vision for the pivotal role that buildings can play and has appropriately titled this initiative Grid-Interactive Efficient Buildings. In my written testimony I highlighted how modeling, sensors, and controls enable this future of Grid-Interactive Efficient Buildings by providing a platform to understand, plan, and optimize the performance of buildings in varying scenarios. I provided ResStock as an example of an idea first cultivated by laboratory directed R&D funds and developed by DOE funding and support. It is now currently being used by multiple research activities, as well as private-sector use cases.

In my written testimony I also highlighted the need for thermal energy storage because thermal end uses like space conditioning, water heating, and refrigeration represent roughly half of our building energy demand. Thermal energy could be stored as a complement as well as an alternative to battery energy storage to balance supply and demand.

Now, I'm particularly excited about a publication—NREL publication in this month's *Nature Energy* journal. It presented an analogous adaptation of the energy/power tradeoff curve that has been foundational in the design and advancement of battery systems. This and others are really just some of the examples of opportunities that we can use to further accelerate the deployment of thermal storage as a viable energy storage solution.

So as we continue to advance the science of—science and engineering of individual Grid-Interactive Efficient Buildings, there are actually new possibilities that emerge to aggregate a collection of buildings with other local distributed resources into connected communities. So not only can we then see optimized solutions where the total is indeed greater than the sum of the individual parts, we can also enable innovation at the intersection of these diverse and distinct technology domains.

However, unfortunately, according to a recent McKinsey study, labor productivity in the United States has remained stagnant over the last 80 years, approximately marking the time when the first Jacksons began to master the carpentry trade. So this reality not only hinders U.S. competitiveness, it limits the transition to a sustainable energy future with affordable building construction and retrofit costs. The DOE's Advanced Building Construction (ABC) Initiative targets this opportunity with a vision to integrate higher levels of energy efficiency into new construction and retrofits.

But—so as we transition to a sustainable energy future, we have to ensure the benefits as well as the costs are more equitably distributed. Our examples of centering equity in energy technology innovation and energy transition are most often focused on the deployment phase of the research, development, demonstration, and deployment spectrum. However, while this is important and essential, deployment is the final stage of that technology spectrum I just described. And so as a result, in many cases, it actually may 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. So, as an alternative, the R&D community, the community to which I belong, should take the additional step of centering equity into the early stages of the technology development pipeline.

And then also due to historical under-investments, the solutions faced by low-income communities are actually different and actually distinctly more difficult to overcome in many cases, hence the need for science, engineering, and innovation are even more pressing.

So in summary, thank you for this opportunity. And to meet our Nation's goal and continue our American leadership in energy innovation, we should continue to prioritize the R&D investments in building technologies. I look forward to any other questions you may have. Thank you.

[The prepared statement of Dr. Jackson follows:]

Prepared Statement of Dr. Roderick Jackson
Distinguished Member of Research Staff
Laboratory Program Manager for Building Technologies
National Renewable Energy Laboratory

U.S. House of Representatives Committee on Science, Space, & Technology
Subcommittee on Energy
Hearing on "Building Technologies Research for a Sustainable Future"

March 25, 2021

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

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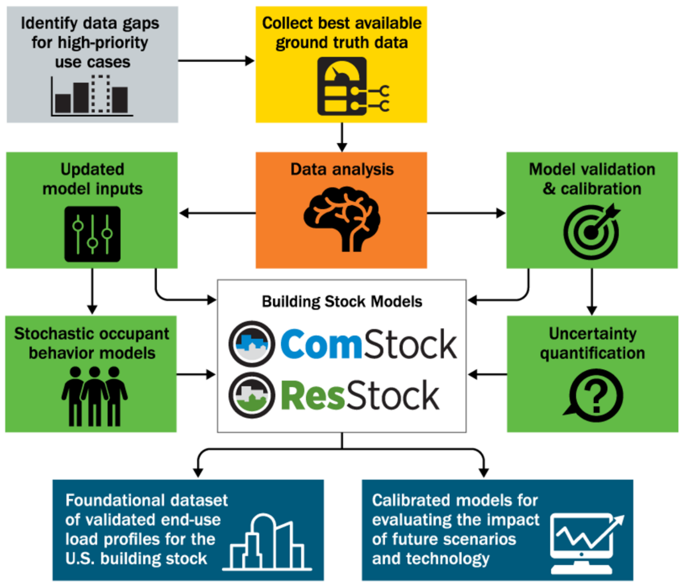
[4] Goetzler, Bill, et al. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75473.pdf
[5] Nubbe, Valerie, et al. 2019. DOE. https://www1.eere.energy.gov/buildings/pdfs/75475.pdf
[6] Radhakrishnan et al. 2020. https://www.nxtbook.com/nxtbooks/ieee/bridge_2020_issue3/index.php#/p/18
[7] Jin, Xin, 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.

[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

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[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

[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

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[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.

Chairman BOWMAN. Thank you so much, Dr. Jackson. Dr. Tour, you are now recognized.

TESTIMONY OF DR. JAMES TOUR, T.T. AND W. F. CHAO PROFESSOR OF CHEMISTRY AT RICE UNIVERSITY

Dr. TOUR. Thank you, Mr. Chairman. I'm a professor of chemistry, material science, and nanoengineering at Rice University and part of the Welch Institute for Advanced Materials. I have 730 research publications, 234 of those on the topic of graphene. I have over 50 U.S. patents plus 90 international patents on graphene. In the past 6 years alone, my academic research has led to the formation of 14 companies, eight of those in nanomaterials, and two of them now public companies.

On March 15, 2017, I gave testimony before the Energy and Commerce's Subcommittee on Digital Commerce and Consumer Protection on the topic of graphene and attaining U.S. preeminence. Four years later, I'm here to report that the future has arrived.

What is graphene? Think of it as carbon chicken wire. That's what it looks like, chicken wire in its atomic arrangement but on the one-atom-thick scale. Graphene is a non-toxic, naturally occurring carbon material, and it's a glomerate to the natural mineral graphite. It is very slow to enter the carbon dioxide cycle, and hence it can be considered a terminal carbon sink with near zero contribution to greenhouse gas emissions.

Graphene is a revolutionary material for building construction, but until recently, affordability and access to sufficient quantities made it only a dream for those applications. In 2018, a graduate student in my laboratory Duy Luong, working under funding from the Air Force Office of Scientific Research, discovered a process that we call flash graphene. We immediately filed patents to protect the technology, and companies were formed 1 year later, Universal Matter Inc. and Universal Matter Limited.

The process can take any carbon material, any carbon material and convert it into graphene in less than 1 second using only electricity, no water, no solvents, no additives other than carbon itself. This new graphene manufacturing process will lower the cost by a factor of 10, therefore making it economically viable for use in building materials.

The majority of waste products generated by human beings are carbon-based. If it's not rocks or water, it's probably carbon. We can take coal, petroleum coke, unsorted plastic waste, discarded food, mixed household waste, any other carbon source and convert it into graphene. Our production rate is doubling every 9 weeks, thereby projecting to hundreds-of-tons-per-day scale within 3 years. With grants from the Department of Energy and Department of Defense in collaborations with the Army Corps of Engineers, ERDC (Engineer Research and Development Center), Argonne National Laboratory, and several large automotive, concrete, asphalt, and wood manufacturers, we're developing graphene for concrete, asphalt, aluminum, plastics, polymer foams, lubricants, rubber, wood, fabric, and paint composites. By adding just .1 weight percent, that's 0.1 weight percent to cement, we get a 35 percent enhancement in compressive strength. It means we could use 1/3 less cement for construction. And since cement and concrete constitute 8 percent of all worldwide carbon dioxide emissions, that could translate into a remarkable diminution of emissions.

Concrete alone is a $30 billion new market opportunity for graphene. Zero-point-five weight percent addition of graphene to asphalt will triple the life of the road. Zero-point-zero-five weight percent of graphene to carbon fiber composites will lower the weight of an aircraft by 20 percent, translating into enormous fuel and carbon dioxide reductions, all made possible by this U.S. invention.

Through Rice University's carbon hub, we're developing methods to convert natural gas into hydrogen and graphene with near zero carbon dioxide emissions. That's clean hydrogen fuel from natural gas. The next step is developed—is to develop entirely new classes of graphene composites that can substitute for the energy-intensive 2,500-year-old materials that we use today like concrete and steel while providing a non-toxic carbon sink for most human waste products.

The takeaway from my testimony is this: First, continue to foster basic support of basic and applied research directed toward advancement and deployment of new materials. A few years ago, graphene was only viewed as appropriate for ultrahigh-end aerospace and device applications but not anymore. The bipartisan *Endless Frontier Act* could embody an interesting approach to achieve the requisite research and translational goals.

Second, it remains challenging to go from the lab bench to the build site with market profitability. Congress has immense power and influence over tax policy and administrative and regulatory burdens that can make or break our startup companies.

Third and finally, streamlining the green card process for scientists and engineers that have received their Ph.D.'s in the United States so that people like Duy Luong, the Vietnamese graduate student that discovered the flash graphene process in my laboratory, can stay to develop their discoveries in our Nation's companies. We just need to do it right, safeguarding U.S. intellectual property through background checks and security oversight. Thank you.

[The prepared statement of Dr. Tour follows:]

REVOLUTIONARY BUILDING MATERIALS

ORAL TESTIMONY

Testimony before the House Committee on Science, Space and Technology, Subcommittee on Energy, hearing on "Building Technologies Research for a Sustainable Future"

Thursday, March 25, 2021, 1:00 p.m. EDT

PLACE: Online via videoconferencing, United States House of Representatives

James M. Tour, Ph.D., Professor

Department of Chemistry, Department of Materials Science and Nanoengineering, Department of Computer Science, The NanoCarbon Center and The Welch Institute for Advanced Materials

Rice University, Houston Texas

I am a professor of Chemistry, Materials Science and NanoEngineering at Rice University, and part of the Welch Institute for Advanced Materials.

- I have 730 research publications; 234 of those being on the topic of graphene.
- I have over 50 U.S. plus 90 international patents on graphene.
- In the past 6 years alone, my academic research has led to the formation of 14 companies, 8 of those in nanomaterials, and two of them now public companies.

On March 15, 2017, I gave testimony before the Energy and Commerce's Subcommittee on Digital Commerce and Consumer Protection on the topic of graphene and attaining US preeminence. Four years later, I'm here to report that the future has arrived.

What is graphene? Think of it as carbon chicken-wire! That's what it looks like, chicken-wire, in its atomic arrangement, but on the one-atom-thick scale. Graphene is a nontoxic naturally occurring carbon material and its agglomerates are the natural mineral graphite. It is very slow to enter the carbon dioxide cycle and hence it can be considered a terminal carbon sink with near-zero contribution to greenhouse gas emissions.

Graphene is a revolutionary material for building construction, but until recently, affordability and access to sufficient quantities made it only a dream for those applications. In 2018, a graduate student in my laboratory, Duy Luong, working under funding from the Air Force Office of Scientific Research, discovered a process that we call "flash graphene". We immediately filed patents to protect the technology and companies were formed one year later: Universal Matter Inc. and Universal Matter Ltd. The process can take any carbon material—any carbon material—and converted it into graphene in less than one second using only electricity; no water, no solvents, and no additives other than carbon itself. This new graphene manufacturing process will lower the cost by a factor of 10 thereby making it economically viable for use in building materials.

The majority of waste products generated by human beings are carbon-based. If it's not rocks or water, it's probably carbon. We can take coal, petroleum coke, unsorted plastic waste, discarded food, mixed household waste, or any other carbon source and convert it into graphene. Our production rate is doubling every nine weeks, thereby projecting to the hundreds of tons per day scale within three years. With grants from the Department of Energy and the Department of Defense, and in collaborations with the Army Corps of Engineers (ERDC), Argonne National Laboratory, Pacific Northwest National Laboratory, and several large automotive, concrete, asphalt and wood manufacturers, we are developing graphene for concrete, asphalt, steel, aluminum, plastics, polymer-foams, lubricants, rubber, wood, fabric and paint composites.

By adding just 0.1 wt% to cement, we get a 35% enhancement in the compressive strength. It means we could use one third less cement for construction. And since cement and concrete constitute 8% of all worldwide carbon dioxide emissions, that could translate into a remarkable diminution of emissions. Concrete alone is a $30 billion new market opportunity for graphene. 0.5 wt% addition of graphene to asphalt will triple the life of the road. 0.05 wt% of graphene to carbon fiber composites will lower the weight of an aircraft by 20% translating into enormous fuel and carbon dioxide reductions. All made possible by this US invention.

Through Rice University's Carbon Hub, we are developing methods to convert natural gas into hydrogen and graphene with near-zero carbon dioxide emissions. That's clean hydrogen fuel from natural gas.

The next step is to develop entirely new classes of graphene composites that can substitute for the energy intensive 2500-year-old materials that we use today, like concrete and steel, while providing a non-toxic carbon sink for most human waste products.

The take-away from this testimony:

First: Continue to foster support of basic and applied research directed toward the advancement and deployment of new materials. A few years ago, graphene was only viewed as appropriate for ultra-high-end aerospace and device applications, but not anymore. The bipartisan Endless Frontier Act could embody an interesting approach to achieve the requisite research and translational goals.

Second: It remains challenging to go from the lab-bench to the build-site with market profitably. Congress has immense power and influence over tax policy and administrative and regulatory burdens that can make or break our start-up companies.

Third: Streamline the Green-Card process for scientists and engineers that have received their PhDs in the US, so that people like Duy Luong, the Vietnamese graduate student that discovered the flash graphene process in my laboratory, can stay to develop their discoveries in our nation's companies.

Thank you.

James M. Tour, a synthetic organic chemist, received his Bachelor of Science degree in chemistry from Syracuse University, his Ph.D. in synthetic organic and organometallic chemistry from Purdue University, and postdoctoral training in synthetic organic chemistry at the University of Wisconsin and Stanford University.

After spending 11 years on the faculty of the Department of Chemistry and Biochemistry at the University of South Carolina, he joined the Center for Nanoscale Science and Technology at Rice University in 1999 where he is presently the T. T. and W. F. Chao Professor of Chemistry, Professor of Computer Science, and Professor of Materials Science and NanoEngineering.

Tour has about 730 research publications and over 200 patents, with an H-index = 153 and i10 index = 683 with total citations over 110,000.

In 2020, he became a Fellow of the Royal Society of Chemistry and in the same year was awarded the Royal Society of Chemistry's Centenary Prize for innovations in materials chemistry with applications in medicine and nanotechnology. He was inducted into the National Academy of Inventors in 2015. Tour was named among "The 50 Most Influential Scientists in the World Today" by TheBestSchools.org in 2014; listed in "The World's Most Influential Scientific Minds" by Thomson Reuters ScienceWatch.com in 2014; recipient of the Trotter Prize in "Information, Complexity and Inference" in 2014; and was the Lady Davis Visiting Professor, Hebrew University, June, 2014. Tour was named "Scientist of the Year" by R&D Magazine, 2013. He was awarded the George R. Brown Award for Superior Teaching, 2012, Rice University; won the ACS Nano Lectureship Award from the American Chemical Society, 2012; was the Lady Davis Visiting Professor, Hebrew University, June, 2011; and was elected Fellow of the American Association for the Advancement of Science (AAAS), 2009.

Tour was ranked one of the Top 10 chemists in the world over the past decade, by a Thomson Reuters citations per publication index survey, 2009; won the Distinguished Alumni Award, Purdue University, 2009; and the Houston Technology Center's Nanotechnology Award in 2009. He won the Feynman Prize in Experimental Nanotechnology in 2008, the NASA Space Act Award in 2008 for his development of carbon nanotube reinforced elastomers, and the Arthur C. Cope Scholar Award from the American Chemical Society for his achievements in organic chemistry in 2007. Tour was the recipient of the George R. Brown Award for Superior Teaching in 2007.

He also won the Small Times magazine's Innovator of the Year Award in 2006, the Nanotech Briefs Nano 50 Innovator Award in 2006, the Alan Berman Research Publication Award, Department of the Navy in 2006, the Southern Chemist of the Year Award from the American Chemical Society in 2005, and The Honda Innovation Award for Nanocars in 2005. Tour's paper on Nanocars was the most highly accessed journal article of all American Chemical Society articles in 2005, and it was listed by LiveScience as the second most influential paper in all of science in 2005. Tour has won several other national awards including the National Science Foundation Presidential Young Investigator Award in Polymer Chemistry and the Office of Naval Research Young Investigator Award in Polymer Chemistry.

Chairman BOWMAN. Thank you, Dr. Tour. Ms. Patterson, you are now recognized.

TESTIMONY OF MS. JACQUELINE PATTERSON, DIRECTOR OF ENVIRONMENTAL AND CLIMATE JUSTICE PROGRAM, NAACP

Ms. PATTERSON. Thank you so much. It's an honor to be here with you all. And I appreciate being—having the opportunity to share these brief remarks.

So the NAACP, when we first started doing this work, people were surprised that we were working on energy, much less the sustainable building sector. However, as one considers the extreme disparities in equality, safety, and health of the places where African American communities especially live, learn, and work, play, and worship, for us the historic social, political, and economic disenfranchisement has been detrimental to generational well-being.

In 1861 and 1862 the United States Government passed the *Morrill* and *Homestead Acts*, which were intended to give land grants to White Americans for colleges and those seeking land to farm. These acts were also accompanied by offers of subsidies to facilitate the acquisition and use of the land. As slavery was not abolished in the United States until 1865, many enslaved and freed African Americans were unable to benefit from these acts, and a lack of legal services meant that African Americans who managed to acquire land couldn't even write legally binding wills that would facilitate legalized inheritance of property.

This is all tied to the fact that overall economic insecurity has resulted in extreme income and wealth differentials that persist over centuries. Even now at $171,000 in net worth of a typical White American family is nearly 10 times greater than that of a Black American family at $17,150. And for Black American single women-headed households, the average family net worth is only $5. At 44 percent, African Americans are least likely to be homeowners, whereas it's 75 percent of White Americans and overall 65 percent for the Nation.

Historic and modern-day redlining practices impact everything from whether we own homes, where we own homes, and the quality of the homes and other resources to which we have access. Also impacting is the quality of the infrastructure in our communities such as levees that protect our homes, and property values that finance our schools are also—also affects the quality of the buildings in which our schools are housed.

Subpar quality of the buildings and structures in our communities means that we are inundated by energy burden, which challenges our finances, indoor air pollution which sickens our family, and poor housing stock, which renders us vulnerable when disaster impacts.

African Americans have the highest energy burden, which means that the amount of income that goes toward energy in the buildings we occupy is the highest of any other racial and ethnic group. African Americans are also more likely to have our energy shut off for nonpayment, too often with fatal impacts as we pay the price of poverty and racism with our very lives when a candle or a space heater or carbon monoxide has taken the lives of too many seeking to heat or light our homes when our finances can't meet the demands of our bills.

Yet we're more likely to suffer from the pollution being emitted from energy production as we are more likely to live near coal-fired power plants, oil and gas refineries, waste-to-energy incinerators, et cetera, and we pay the price with our health. We are more likely to bear the impacts of climate change that results from emissions from buildings.

We also know that energy improvements, whether it's weatherization, retrofits, and clean energy like solar are tied to homeownership and credit ratings, which are compromised by the historic and current factors I've already described.

COVID–19 means that we are in buildings more due to remote working and due to the need for isolation, which means we are using more energy and also are more exposed to indoor air pollution.

With 2020 being the hottest year on record as part of the progression of increasingly hotter years, as well as greater weather extremes, our ability to cool and heat our homes reliably and affordably becomes increasingly more critical. Yet communities and populations most impacted by these disparities are underrepresented in the building sector and professions, including those working on building standards in terms of organizations, architects, and beyond. For example, just .03 percent of certified architects are Black women, while, again, $5 is the average wealth of a single Black woman-led household, thereby arguably rendering us as Black women as the No. 1 critical stakeholder in the future of buildings.

Key steps to right the wrong—right the historic and present-day wrongs include campaign-finance reform so that money interests don't have their thumb on the scale of the change we need to have in advancing energy justice for all. Dismantling the weapons of mass distraction, including the formulas that tie property values with quality of infrastructure and services at the local level, increasing investments in BIPOC, Black, indigenous, and people of color in education and leadership in STEM, increasing resources for job and business opportunities for BIPOC communities, and shifting wealth to community-led endeavors to develop sustainable, affordable, safe, and healthy infrastructure, including buildings.

In 2018 the NAACP launched——

Chairman BOWMAN. Ms. Patterson, your time is expired.

Ms. PATTERSON. Oh, thank you. Sorry.

[The prepared statement of Ms. Patterson follows:]

Subcommittee on Energy of the House Committee on Science, Space, and Technology Hearing

"Building Technologies Research for a Sustainable Future."

TESTIMONY—Jacqueline Patterson, NAACP

People have been surprised to hear why the NAACP, as a Civil Rights organization, has a program that focuses on the energy sector, much less the sustainable buildings sector.

However, as one considers the extreme disparities in quality, safety, and health of the places where African American communities especially live, learn work, play, and worship, one must examine the differentials through the lens of a complex set of intersection individual, familial, community, and societal factors and systems intersectional with social, economic, political constructs. And all of these factors are tied to our civil and human rights.

In our nation, that means who you are and where you live matter to one's relationship with each and every one of these systems and factors:

For African Americans, historic social, political, and economic disenfranchisement has been detrimental to generational wellbeing while culture, brilliance, and sheer survivalist grit have been protective factors.

This all intersects with the building sector in myriad ways.... It has been 400 years since the start of since the first enslaved Africans arrived after making the TransAtlantic journey as commoditized cargo in the hulls of ships. Though emancipation came in 1863, enslavement takes many forms. And in many, institutionalized ways, structural racism continues to exploit and oppress every second of every minute, of every hour of every day and that extends to the places we call home, work, school, faith houses, critical service hubs, and recreational centers....

In 1861 and 1862 the United States government passed the Morill and Homestead Acts, which were intended to give land grants to white Americans for colleges and those seeking land to farm. These acts were also accompanied by offers of subsidies to facilitate the acquisition and use of the land. As slavery was not abolished in the United States until 1865, many enslaved and free blacks were unable to benefit from these acts.[1] Lack of legal services meant that African Americans who managed to acquire land couldn't even write legally binding wills that would facilitate legalize inheritance of property

Overall economic insecurity has resulted in extreme income and wealth differentials that persists over centuries. Even now, at $171,000, the net worth of a typical white family is nearly ten times greater than that of a Black family ($17,150) And for black single women headed households, the average family net worth is $5

At 44% African Americans are least likely to be homeowners versus 75% for white Americans and 65% overall for the nation.

Historic and modern-day redlining practices impact everything from whether we own homes, where we own homes, and the quality of the homes and other resources to which we have access. Also impacted is the quality of the infrastructure in our communities such as levees that protect our homes and property values that finance our schools, which also affects the quality of the buildings in which our schools our housed.

Siting of our communities in flood plains, urban heat Islands, near toxic facilities, and supported only by crumbling Infrastructure ......all of this put our communities at compounded risk.

Quality buildings/structures in our communities mean that our communities are inundated by energy burden which challenges our finances, indoor air pollution which sickens our families, and poor housing stock which renders us vulnerable to disaster impacts.

African Americans have the highest energy burden which means that the amount of income that goes towards energy in the buildings we occupy is the highest of any other racial and ethnic group. African Americans are also more likely to have our energy shut off for non-payment, too often with fatal impacts as we pay the price of poverty and racism with our very lives when a candle or a space heater, or carbon monoxide has taken the lives of too many seeking to heat or light our homes when our finances can't meet the demands of our bills.

Yet, we're more likely to suffer from the pollution being emitted from energy production as we are more likely to live near coal fired power plants, oil and gas refineries, waste to energy incinerators, etc. and we pay the price with our health. We are also more likely to bear the impacts of climate change that results from emissions from buildings.

We also know that energy improvements (weatherization, retrofits, solar, etc.) are tied to homeownership and credit ratings which are compromised by the historic and current factors I've already described.

COVID 19 means we are in buildings more due to remote working, and due to the need for isolation which means we are using more energy and are also more exposed to indoor air pollution

With 2020 being the hottest year on record and it's part of a progression of increasingly hotter years, as well as greater weather extremes, our ability to cool our homes and heat our homes reliably and affordably becomes increasingly more critical.

YET communities and populations most impacted by these disparities are under-represented in the building sectors and professions including those working on Building Standards Orgs, Architects, and beyond. For example, .03% certified architects are black women

Key steps to right the historic and present-day wrongs include: 1) campaign finance reform so that monied interests don't have their thumb on the scales of the change we need to have energy justice for all; 2) dismantling the "Weapons of Math Destruction" including the formulas that tie property values with quality of infrastructure and services at the local level; 3) increasing investments in BIPOC education and leadership in STEM; 4) resources for job and business opportunities for BIPOC communities; and more.

In 2018, the NAACP launched the Centering Equity in the Sustainable Buildings Sector Initiative with the following goals: Diversifying leadership and decision making in the buildings sector; Equity based principles and standards; and Shift investments to infrastructure and buildings in low income/low wealth communities and BIPOC communities. To achieve its aims, the Centering Equity in the Sustainable Building Sector Initiative consists of sustainable Building organizations, architects/landscape architects, affordable housing professionals, public health workers, educators, energy advocates and others,

Practices and measures of the CESBS include training and education, design charrettes, model projects in communities, equity-based community participatory research, score card projects for evaluation of progress towards equity, and policy change, including equity-based building codes.

When it comes to centering equity in the building sector, we must get out of a scarcity mentality. It is possible to design our buildings to be regenerative and to be based on biomimicry so that we are living in harmony with nature. It is possible for us to reduce the amount of energy that we are using and stop wasting 45% of the energy we generate. It is possible for us to generate the energy we need from natural sources such as wind and solar. It is possible for us ALL to have buildings where we live, learn, work, play, and pray that are energy efficient, safe, and healthy.

What we need is the radical imagination, innovation, investment, and the bold action to make these possibilities reality at scale.

Jacqueline Patterson is the Director of the **NAACP Environmental and Climate Justice Program**. Since 2007 Patterson has served as coordinator & co-founder of Women of Color United. Jacqui Patterson has worked as a researcher, program manager, coordinator, advocate and activist working on women's rights, violence against women, HIV&AIDS, racial justice, economic justice, and environmental and climate justice. Patterson served as a Senior Women's Rights Policy Analyst for ActionAid where she integrated a women's rights lens for the issues of food rights, macroeconomics, and climate change as well as the intersection of violence against women and HIV&AIDS. Previously, she served as Assistant Vice-President of HIV/AIDS Programs for IMA World Health providing management and technical assistance to medical facilities and programs in 23 countries in Africa and the Caribbean. Patterson served as the Outreach Project Associate for the Center on Budget and Policy Priorities, and Research Coordinator for Johns Hopkins University. She also served as a U.S. Peace Corps Volunteer in Jamaica, West Indies.

Patterson's publications/articles include: "Jobs vs Health: An Unnecessary Dilemma", "Climate Change is a Civil Rights Issue", "Gulf Oil Drilling Disaster: Gendered Layers of Impact", "Disasters, Climate Change Uproot Women of Color"; "Coal Blooded; Putting Profits Before People"; "Just Energy Policies: Reducing Pollution, Creating Jobs": "And the People Shall Lead: Centralizing Frontline Community Leadership in the Movement Towards a Sustainable Planet"; and book chapter, "Equity in Disasters: Civil and Human Rights Challenges in the Context of Emergency Events" in the book Building Community Resilience Post-Disaster.

Patterson holds a master's degree in social work from the University of Maryland and a master's degree in public health from Johns Hopkins University. She currently serves on the International Committee of the US Social Forum, the Steering Committee for Interfaith Moral Action on Climate, Advisory Board for Center for Earth Ethics as well as on the Boards of Directors for the Institute of the Black World, Center for Story Based Strategy and the US Climate Action Network.

Chairman BOWMAN. Don't worry. We'll come back to you when we get to questions. Thank you so much.

Mr. Hagerman, you are now recognized.

TESTIMONY OF MR. JOSEPH HAGERMAN, GROUP LEADER FOR BUILDING INTEGRATION AND CONTROLS AT OAK RIDGE NATIONAL LABORATORY

Mr. HAGERMAN. Thank you. Chairman Bowman, Ranking Member Weber, and distinguished Members of the Subcommittee, thank you for the opportunity to virtually 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 Lab in Oak Ridge, Tennessee. I'm a building technologies researcher by education and training.

I'm not going to take our time today to discuss how much energy is consumed in buildings. We all pay energy bills at the end of the month. In fact, last year, buildings used 74 percent of all the electricity in the Nation at a cost of over $332 billion. I think we can all agree that's a big bill.

I want to focus today on the impact that Oak Ridge has made with the support of DOE Building Technologies Office. It is our thesis that when our Nation's buildings are cleaner and more efficient and—the effect can be profound, improving comfort, safety, productivity, and it will take American labor and American jobs to realize these benefits.

So what's Oak Ridge doing? Staff at the lab are accelerating clean energy innovation throughout the buildings' ecosystem. Our Nation's fastest supercomputer at Oak Ridge's speeds modeling and simulations to analyze the potential for retrofits down to the neighborhood level for every building in America. Our nanomaterials science leads to new building materials with extraordinary insulation and self-healing properties. And our engineering expertise continues to drive breakthroughs for new energy-efficient equipment like cold climate heat pumps, climate-friendly refrigerants, and advanced next-generation appliances. A lot of this sounds like science fiction, but it's not. It's science fact, and that's the current seat of the lab, transformational science.

The cornerstone for our research is of course our facilities, particularly the Building Technologies Research and Integration Center or BTRIC. BTRIC is DOE's only user facility dedicated to accelerating breakthroughs for clean energy-efficient buildings. But the largest contributor to our work is our partnerships. We partner with industries, universities, and communities, and we make good partners because success to my staff is clear: make positive, practical impact.

Let me share with you about working with the lab. The sheer volumes of connections, interactions, and collaborations are what make Oak Ridge a special place to work. We foster great science because we invest in great diverse people, expertise, and skills. And equally important we have clear goals. Our first goal is that Oak Ridge will continue to lead the building energy efficiency research for the Nation. One example is how Viral Patel and his team at Oak Ridge developed piezoelectric drying science that mechanically shakes and vibrates fabric at a high frequency to remove moisture. They demonstrated a faster drying time with five times less energy that will one day reshape conventional residential dryers. To me that's transformative.

But let's transform it again here today by recognizing that these innovations can also provide a solution to the hard-to-decarbonize industrial sector. This is another important thesis to the lab's research and science. Our advancements can apply to other processes, and it's my hope that American companies engage with us to decarbonize all sectors.

Our second goal, Oak Ridge will continue to pioneer connected smart communities for grid resilience, benefiting consumers and the grid equally. Group leader Heather Buckberry worked with Southern Company, Alabama Power, and Georgia Power to provide and prove that homes and businesses can provide a central stability to the grid. Heather and her team demonstrated that more than 30 percent decreased overall energy consumption and an approximately 35 percent lower demand during peak winter, all with no impacts to comfort. More importantly, residents engage with their buildings and controls in no different way than normal, and that's Heather's thesis: Control science can be done behind the scenes, and with Oak Ridge's deep bench in cybersecurity, we can guard the associated data and control actions.

Goal No. 3, Oak Ridge will help lead the Nation in meeting our decarbonization goals. Another group leader Kashif Nawaz is developing direct air carbon capture solutions with building equipment technologies. Looking forward, Kashif hopes to develop concepts and methods for net negative carbon buildings where equipment can efficiently heat, cool, dehumidify the air while capturing CO_2, all possible by relying on transformative science, not science fiction.

In closing, Oak Ridge is a foundational partner that can accelerate the clean energy transition across the Nation to all communities, and the challenges ahead to the Nation are great. I believe they are bigger than one person, one team, or one lab alone. It's going to take all of us, not some of us, to achieve our goals, but from great challenges, great opportunities emerge, opportunities for equities, collaboration, and allies across the sciences, and opportunities to create good-paying American jobs while we're at it.

I'm proud to work for my staff every day and honored to work at Oak Ridge National Laboratory. Thank you.

[The prepared statement of Mr. Hagerman follows:]

Written Testimony of Joseph W. Hagerman
Section Head for Building Technologies Research
Oak Ridge National Laboratory

Before the
Committee on Science, Space, and Technology
Subcommittee on Energy
U.S. House of Representatives
March 25, 2021

"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

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[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.

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[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.

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At the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL), Joe Hagerman serves as the Section Head for Building Technologies Research, where he leads building envelope materials and equipment research as well as integrated building performance and multifunctional equipment integration.

Hagerman is an expert in transactive energy and controls, building-to-grid research and smart buildings. In his career he has guided the negotiation of several federal regulatory initiatives on emerging topics such as connected equipment, building cybersecurity, interoperability, and equipment characterization.

Prior to joining ORNL in 2019, Hagerman was the Senior Technical Advisor to the Department of Energy's (DOE) Energy Efficiency and Renewable Energy's Assistant Secretary. In this role, Hagerman steered transactive controls and building-to-grid integration research, and coordinated the development of VOLTRONN, a cybersecure, distributed building control system that interacts with a home's HVAC (heating, ventilation, and air-conditioning) and water heater developed jointly by ORNL and Pacific Northwest National Laboratory. After his time at DOE, Hagerman served as the National Rural Electric Cooperative Association's Deputy Chief Scientist, where he managed a federal research program dedicated to cybersecurity, distributed controls, and application energy concepts. He previously served as project manager for the Building Technologies Group at the Federation of American Scientists, with a focus on addressing environmental and energy injustices with energy-efficient, affordable construction. He's also held consulting positions with Steven Winter Associates and Booz Allen Hamilton.

Hagerman is the recipient of the 2016 DOE Secretary Honor Award for his work on appliance standards to meet the Climate Action Plan, and also received the DOE Distinguished Service Award in 2010 and 2014. In 2005, he received the Metropolis Next Generation Award and the 2005-2006 Rafael Viñoly Fellow from Rafael Viñoly Architects, New York City.

He holds a master's in civil engineering from the Fu Foundation School of Engineering and Applied Science at Columbia University and earned his bachelor's in architecture from Mississippi State University.

Chairman BOWMAN. Thank you, Mr. Hagerman.

At this point we will begin our first round of questions. The Chairman recognizes himself for 5 minutes.

Dr. Esram, thank you for your testimony. I appreciated your emphasis on the need to align carbon reduction with other social goals such as health and equity. I want to zero in on the health piece. We know that redline communities and poor people in this country face multiple health threats from buildings. Our public school and public housing infrastructure, for example, has major issues with mold, asbestos, and other toxins.

What do we know about the health benefits of deep energy retrofits at this point, and what do we still have to learn? Can you paint a picture for us for how life could be better in a highly efficient, zero-carbon home or workplace?

Dr. ESRAM. Well, thank you for the question, Chairman Bowman. What we know, decades of scientific research have proven the impact of a built environment on the human circadian rhythm, immune system, cognitive function, and task performance. There are plenty of literature. But what we don't know is how to fully integrate these nonenergy benefits with technology and strategy development that speaks to the consumers and the investors. And there are no standard methods to quantify and monetize these benefits in a trustworthy way for consumers.

A quick example is when we buy organic food, we trust USDA (United States Department of Agriculture) organic stamps. There's a standard way to measure these nonenergy benefits for organic food and procedure, but we don't have those for buildings, for healthy buildings.

Just to—yes, that's my answer in a simple way. Thank you.

Chairman BOWMAN. Thank you. Thank you very much.

Ms. Patterson, thank you for being with us today. Can you speak more to the challenges involved in bringing sustainable building technologies to redlined and low-income communities? I'm wondering what the CESBS (Centering Equity in the Sustainable Building Sector) program has learned about what the main barriers are and what we need to do to surmount those barriers. How can we scale up weatherization, energy efficiency, and electrification efforts in low-income and affordable housing, for example? What do you see as some of the research and policy needs here?

Ms. PATTERSON. Thank you so much. So—yes, so there are a lot of questions in that one question. But—so first definitely some of the barriers are really just lack of investment in these communities both in—not only in terms of homes but also in terms of various structures and communities. And so whether we have—the challenge I spoke of before with housing in terms of the historic challenges that resulted in people in the disproportionate homeownership and so much in terms of these kind of weatherization, retrofitting, clean energy. All of that is tied to homeownerships and being able to be—get financing mechanisms to—equity in one's home. And so that's definitely a barrier.

In terms of ways that we can shift this is everything from making sure that there are economic opportunities to bring up the economic well-being of people so that they can make those investments and the homeowners themselves but then also shifting—and so that's from an individual standpoint, but also shifting as well to communities that have been under-invested in historically over time, shifting away from this notion that all of the—what's available in terms of public financing through property values, which we know just kind of continues to have the same communities not having the types of resources that are needed and really thinking about new and innovative economic ways of lifting all boats because we know that there's been attempts through—whether it's the opportunity zones or other types of mechanisms but that have not necessarily been successful in actually lifting the well-being and the economic status and what's available in terms of finance for those communities. So we're actually advancing this transformational climate finance initiative to significantly invest in these communities and making sure that, whether it's social impact investing or municipal bonds or other finance mechanisms, that they're being brought into communities in ways that aren't extractive or that actually put communities in the driver's seat so that these actually work for them. And the Centering Equity in the Sustainable Building Sector Initiative is a multi-sector initiative that pushes policies, and that's everything from renewable portfolio standards to making sure that building codes are also tied to the economic engine to be able to ensure that people can be up to the standards we're putting forward in building codes. So I don't know how much longer I have to respond, but I'll pause there [inaudible]. Thank you.

Chairman BOWMAN. That was perfect. Thank you so much. I now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you, Mr. Chairman. I want to go to you, Dr. Tour. I want to make sure that what I think I heard, I heard. Are you with us, Dr. Tour?

Dr. TOUR. I am.

Mr. WEBER. OK, good. You've got 730 publications, 230 of those are on graphene, and there was how many patents and how many companies formed as a result?

Dr. TOUR. I have over 150 patent families, but 50 U.S. on graphene and 90 international on graphene, started 14 companies, eight of those in nanomaterials.

Mr. WEBER. Thank you for that. You said a decade ago your program was supported 90 percent by Federal funds and then 10 percent by industry and that that was normal for many research groups. Then, due to a number of factors, you started appealing to industry and showing them how your fundamental research in nanoscience could address some of their technical needs. And boy, the numbers you just reiterated for us, if they don't prove you were successful, I don't know what does.

Dr. TOUR. Yes.

Mr. WEBER. This might surprise some people who think industry only wants applied research. So, Dr. Tour, can you talk more about basic research, how it can deliver applications for industry, and specifically in the building technology sector, please?

Dr. TOUR. Right. So thank you for that, Representative Weber. I—so what happens is I do basic research. I'm a scientist primarily. And—but the transition is something that we need to look for. How do I transition this into something that can be applied and utilized? And when we make discoveries, right away, we need to be thinking how can I apply this? And if we just publish a paper and just think somebody else will apply it, it just doesn't work. We need to carry that banner several more steps forward to show them how it might work. I don't have to bring it all the way to the building, but I have to bring it to a point where some company is really interested.

So for many years we would license our technology to big companies, and for one reason or another it would stall in those big companies. So about 6 years ago I made a categoric decision we are going to start our own companies, and we're going to start our own companies and build upon those because then we can control the technology and push it forward.

And success breeds success. After we were successful with one or two, then investors started coming and wanting to fund more and more. And part of that, as I say, you've got to continue to fund some of the basic work in my laboratory that will broaden the applications of these, and that then spawns new companies. So that's basically how we've done it.

Mr. WEBER. Well, and that's a great segue because when you talk about broadening and spawning new companies—as you know, as a Texan, Houston is an active hub for the oil and gas industry and also the aerospace industry, and so these large industries have become interested in your work. And can you explain that why many of the, quote, building technologies, end quote, research projects have applicability actually to more than just the skyscraper construction business? What other applicabilities does it have?

Dr. TOUR. Well, it has to do with roads, as well as concrete for building, with paints, for wood composites. Everything is about light-weighting and using——

Mr. WEBER. Right.

Dr. TOUR [continuing]. Less materials. And when we use less materials, there's less carbon dioxide emissions, less energy put into them, and the processes that we've come up with—so, for example, just plastics, high density polyethylene is $2,000 a ton. We put in $30 a ton to convert waste plastic into graphene that can strengthen a huge amount of plastic with that. So these innovations have great implications for the energy industry and for lowering carbon emissions.

Mr. WEBER. Sure. Well, I'm just about out of time, so I will go ahead and yield back, Mr. Chairman, and thank you for your indulgence.

STAFF. Mr. Casten is next.

Mr. CASTEN. Thank you so much. Always a pleasure in this panel, Mr. Chairman and to our witnesses. This is a hugely timely hearing not least because as we sail into thinking about infrastructure bills, we have some real opportunities I think to modernize our Federal building stock, public housing, Federal buildings, the whole scope of that. It's going to be real important to understand as we are prudent stewards of taxpayer capital where the biggest bang for the buck is.

So I want to start, Dr. Esram, I wonder in the work you've done or your colleagues have done at ACEEE, as you're looking at building efficiency technologies, not the ones of the future but the ones we can deploy today, what kind of simple payback can owners realize on these technologies? And if you had to pick sort of your top three absolute no-brainers that every building owner should do, what would they be?

Dr. ESRAM. That's not a very easy to answer question. I would pick lighting and water heater and probably, you know, some HVAC (heating, ventilation, and air conditioning) systems depending on the home location, the building types. Yes, that is usually—we have done a lot of research. For most of the new technologies, they pay for themselves. However, they may not pay fast enough to speak to the consumer's needs. There are additional benefits as we discussed in the health, resilience, and productivity. They haven't been really translated in a way that the consumer will value more with energy efficiency. If there were a way to quantify, monetize those, I think we can do retrofitting much faster than we're doing now.

Mr. CASTEN. OK. Well, would that be a good area for further research then to try to figure out how to monetize and understand those benefits?

Dr. ESRAM. Yes, definitely.

Mr. CASTEN. OK.

Dr. ESRAM. We have a lot of pieces of technologies. We don't know how to build efficient, affordable, healthy resilient building at the same time. We—they haven't been put together yet.

Mr. CASTEN. OK. Well, part of the reason that I started by asking about proven technologies is that a number of years ago I had the pleasure of touring the Bullitt Center in Seattle, Washington, that my friend Denis Hayes has been responsible for. Many folks on this Committee know Denis is one of the co-founders of Earth Day. That building uses about 10,000 BTUs per square foot in a city that averages 90,000, so almost 1/10 of the energy use with no compromise on the—it's a beautiful building. It's a wonderfully comfortable place to work, and they've done it with some low-tech stuff like natural lighting, with some high-tech stuff like continuous commissioning, and then really interestingly with the regulatory reforms that they actually had to work to get the local utility to pay them for the benefit they provided the utility for reducing peak energy demand in the city of Seattle. And that building was commissioned in 2013. There's no reason that technology couldn't be widely deployed other than perhaps people having access to capital and what those returns are. Can you tell us a little bit about the split incentive problem in buildings? Are you familiar with that term?

Dr. ESRAM. Yeah, of course. The split incentive meaning if the landlord is paying for the retrofits and the saving will be from the tenants because, you know, they are getting the saving on their utility bills.

Mr. CASTEN. So when you say that the analysis of some of the benefits is—some of the—and I'm going to misquote you here, but some of them have a good payback, some of them don't. How much would that move if we solve the split incentive? So if we took a holistic approach, how many of these problems you—or the challenges you described would go away if we said what is the total societal savings that would come from these investments? If we frame it that way, what are—do you have—does it change your answer at all?

Dr. ESRAM. Yeah, absolutely. You know, in the commercial real estate there's like a 3, 30, 300 rules that on average you pay $3 dollars per square foot for utilities, $30 for rent, and $300 for your personnel, your salaries. So if we're able to quantify all the non-energy benefits and pick a package and the investors, the building owners, the business owners, the tenants all have more incentives to work together to upgrade the buildings.

Mr. CASTEN. Well, thank you. And I see I'm about out of time, but perhaps we can follow up afterwards because I think, again, as we think about making significant investments in our Federal building stock, we've got a real incentive to save a lot of money for future generations. But as we think about how much money we're willing to spend and how to finance that, it's going to be important that we quantify those things as much as we can and would welcome the opportunity to work with you and your colleagues to quantify that as we move forward. Thank you, and I yield back.

STAFF. Ranking Member Lucas is next.

Mr. LUCAS. Thank you, Mr. Chairman. I want to thank you and the Ranking Member. This is a fascinating hearing, and some really impressive witnesses today.

With that, Dr. Tour, I'd like to turn to you and note that the *Securing American Leadership in Science and Technology Act*, SALSTA as a lot of us like to refer to it, creates a long-term strategy for investment in basic research and infrastructure to ensure American competitiveness in industries of the future.

So with that, I turn to you. In your testimony you noted that you or your companies have received grants from both the Department of Energy and the Department of Defense and you've also collaborated with the Army Corps of Engineers. Having worked with different agencies, do you think a more coherent, governmentwide strategy on Federal science and research efforts could assist Federal agencies and the national laboratories in being a more effective partner to researchers?

Dr. TOUR. Yes, absolutely. Anything that can be done to assist these interactions were we can work across because the national labs have tremendous facilities, facilities that we at universities would love to be able to access. And working with the national labs has been terrific. I mean, we have representatives here today from Oak Ridge. We've published papers just recently with Oak Ridge, and we're doing more. And so to facilitate this and then it's not just—then it goes from me to then the companies. The companies are able to work, and so we have both me at Rice University and the companies working with the Army Corps of Engineers, the companies doing much bigger projects. We're doing the nano-sized projects, they're doing the macroscopic projects, but all working toward the same direction. So whatever Congress could do to streamline that would be terrific.

Mr. LUCAS. And how do you think such a strategy would impact international competitiveness in next-generation technologies like building efficiency?

Dr. TOUR. Yes, so one of the things that we have done in the past because we didn't have access in the university to certain equipment is we've established collaborations with overseas universities, and that's a shame. I mean, if we could keep it all here in the United States, that would be much better. And this has to do with the nanomaterials that are going to go into making building materials with a lot less footprint of energy. Like I said, concrete and cement, 8 percent of all CO_2 emissions. If we could lower that, it is tremendous. And then the jobs then it all effects right here. So it would be very good if we could streamline that and have to be less dependent on the excellent access to equipment, particularly in Asia.

Mr. LUCAS. Dr. Tour, our legislation I mentioned, *SALSTA*, also aims to expand our American STEM workforce pipeline and its investment in infrastructure needed to maintain domestic research facilities. So I'd ask you the following. What role does infrastructure—and by that I mean world-class laboratories, top-notch instruments, collaboration, collaborative user facilities—have in attracting and keeping researchers here in the United States?

Dr. TOUR. This is a very big deal. We have a brain drain going on right now because students are going back to their home countries rather than becoming professors in the United States, which they have traditionally done, because of the lack of equipment and the lack of deep support from government agencies toward academic research. And they are going home because the packages they can get are much better. I've testified to Congress before on this same issue, that the brain drain that is currently happening in the United States is frightening. Many of these people would have stayed in the United States had the packages been here, had the equipment been here. So if we want to keep the first-class people here, we've got to have the infrastructure to maintain this.

Mr. LUCAS. Let me conclude by saying, Ms. Patterson, I very much appreciate your comments about the *Morrill Act of 1862*. Hopefully, with time and generational societal change we are overcoming those deficiencies.

I'm very proud of the efforts made by Congress in 1890 to create the 1890 land-grant universities and the 1994s. At some point this is not the right venue we should discuss how we address the proper funding of the 1890's. I have one of those in my district, Langston University, an outstanding facility, but making sure the necessary resources are there so that they can be fully utilized by people.

With that, I yield back the balance of my time, Mr. Chair.

STAFF. Ms. Stevens is next.

Ms. STEVENS. OK, great. Well, thank you all so much, and thanks to our Chairman. And congratulations to him on his first hearing on a critical topic with some great witnesses.

So our energy efficiency sector employees, you know, just shy of 2.5 million people according to the latest data that we have from 2019, and it's projected to grow at about, you know, 3.4 percent year-over-year, and that's according to the National Association of State Energy Officials and Energy—our Energy Futures Initiative, yet 91 percent of construction employers in energy efficiency reported difficulty in hiring experienced, trained workers. And we certainly hear from our construction and building trade stakeholders here in Michigan about our critical workforce shortage, which has been obviously exacerbated by COVID–19.

And energy efficiency in buildings, as we've been talking about, has an enormous potential to be a job creator, and we want to have equity, we want to have inclusion, we want to target the needs, as our Chairman was discussing.

So, Mr. Hagerman, you discussed the need for workforce development and training in the energy efficiency sector. You touched on that. Can we shed some light on the role that the Federal Government can maintain to help fill this gap, and could you also comment on programs at Oak Ridge National Lab that are working to address this need?

Mr. HAGERMAN. Absolutely. So, first, thank you for that wonderful question. And as I said in my—with my written and my oral testimony, jobs are—American jobs are so critical as we start to decarbonize all the sectors and we actually achieve energy efficiency savings for the Nation particularly because these are jobs that are—should be un-outsourceable, right? We need real people to go in buildings and make them more efficient.

So let me first to speak to what Oak Ridge is doing. And of course I think we need to do more. We always need to do more to train the available workforce that are actually going to make good on the retrofits and all the other activities that American companies want to pursue. But we do three main things. One, we have the Oak Ridge Institute, which is a collaboration with University of Tennessee, where we're trying to grow the talent population and pool, pipeline to actually train and educate the workforce of the future. In one example, a colleague of mine works in the power electronic space. That's a space where I think that we need to spend a little bit more time and focus on actually making sure that Americans lead the intellectual pursuits in power electronics and advanced power electronics. It was a little concerning in the renewable space we saw Huawei as the No. 1 seller of solar——

Ms. STEVENS. Right.

Mr. HAGERMAN [continuing]. At one point in time, right? So we need to——

Ms. STEVENS. Yes, we need this to be American jobs. No, and, Ms. Patterson, thank you so much for your testimony. I wanted to give you back some of your time because I know 5 minutes goes quick. But you say the lack of representation in certain energy efficiency fields specifically that only .3 percent of architects are Black women. So let's talk about this a little bit more. What are some ways—and, you know, I've been working on this in my career before I got to Congress, very focused on this now, but what are ways in which we can target and train workers particularly in communities of color in an appropriate and significant way?

Ms. PATTERSON. Thank you so much for that question. Yes, so we have been working with Department of Energy specifically and through the Solar in Your Community Initiative and also through their Solar Energy Technology Office around how do we start to deploy both kind of the skills and resources to support kind of skills building, as well as providing resources for entrepreneurs and vendors so they can be competitive in this market.

So one of the—so everything from policymaking like local-hire provisions and disadvantaged business enterprise provisions that are tied directly to these contracts I think is critical so that [inaudible]—and then also ways that we can look at the investments in—I think, as we talked before, in terms of the HBCUs (Historically Black Colleges and Universities) and other educational institutions to ensure that we have a pipeline, the good kind of pipeline in terms of pathways for folks to enter into these professions are critical as well and really working closely with those institutions to help to build. And then also the skills training in terms of vocational training but it's not necessarily through the university, but those—making pathways like we—we're working—we're starting a Solar Vets Initiative to help to train—that's just—that's tied to the solar that's resources that are available that we'd love to see—I think they've cut back on their funding. We'd love to see that reignited and fully funded in terms of the Solar Vets Initiative, as well as really some funding that would target women. We did a project that was doing——

Chairman BOWMAN. Ms. Patterson, just finish up your last thoughts. Sorry about that.

Ms. PATTERSON. Yes, it's no problem. So working with things like grid alternatives [inaudible] and others that were specifically trying to train women and making sure that we have funding [inaudible]—thank you.

Ms. STEVENS. Thanks. I yield back, Mr. Chair. Thank you.

STAFF. Mr. Baird is next if he's available.

Mr. BAIRD. I am.

STAFF. OK. You may proceed.

Mr. BAIRD. Thank you, sir. You know, I really appreciate your having this hearing, Mr. Chairman and Ranking Member Weber. Now, I see our Ranking Member Lucas is on here, too, and he's always got an interesting perspective.

But the thing that I was very interested in, Dr. Tour, I'm going to start with you because I found this carbon sink and the materials you mentioned kind of fascinating. And you know we have a tremendous capability at DOE with the computer capacity that we have to be able to advance this kind of technology. So I hope we can see a strong future partnership between the industry and our national labs and all this kind of research. But I would just like for you to elaborate on using the material to make cement, airplanes, building materials, and how we get that to our rural communities and some of our more remote situations. So that's the question.

Dr. TOUR. Yes, so thank you, Representative Baird. This is a real material that is transforming right now. So, like I said, our production rate is doubling every 9 weeks, so a single factory within 3 years will be able to produce hundreds of tons of this per day in about 3 years, and that's the projection rate. This—the collaborations right now are happening with companies that are testing these in concrete and asphalt, and one of those entities is the Army Corps of Engineers, ERDC, in Mississippi because they have the capability to do this, and then there's agreements with companies. We are working with big auto manufacturers taking their waste plastic because they're responsible now at least overseas—they're responsible—the American companies that sell overseas are responsible for their plastic in the E.U. now from every vehicle, and it's almost 200 kilograms of plastic in a car. We've converted that into graphene, we've given it back to them to put it into new plastic that goes into cars, so it's really a wonderful cycle here.

And the energy savings are real material. This is real material going into then construction, concrete, wood composites with wood manufacturers, so this is really beginning to transform this. And this is one of the things that's been permitted by keeping this in a small company where I can help to control this and say, no, we got to get this into these products, as well as small companies contacting me that want to deploy this. I say, OK, we're not in the big scale deploying right now, but that's going to come within a few years and we marked down their names and we want to see this deployed.

Mr. BAIRD. Fantastic. I find that extremely interesting. And with the ag background, some of the materials that you could have access to, including forest products that can be converted into this kind of material is of great interest to me, so I'm glad to see the research that we do, the research that you've done making that kind of progress.

If any of the other witnesses would like to or care to make a comment, feel free to do so at this time. I got about a minute and 25 seconds left.

Mr. HAGERMAN. I—so this is Joe Hagerman with Oak Ridge National Lab and, you know, partnerships are a key to our science, right? They are one of the fuels for our science. In our BTRIC user facility we have 19 active CRADAs (cooperative research and development agreements) where we're actively working with companies, and companies seek us out. And DOE has just announced or has announced a technical collaboration program that companies can use and leverage Oak Ridge to solve their problems, and I think that's a wonderful way that we can augment U.S. companies and make them get to the results that we know they can have.

Mr. BAIRD. Yes, I think it's important, too, that our national labs—I'm very pleased that they're able to do some of the basic research sometimes that the industry cannot really justify, that that then leads into the kinds of things we're talking about here, so thank you very much. And I yield back.

Dr. JACKSON. Can I add as well?

Mr. BAIRD. Sure.

Dr. JACKSON. Yes, so I'd like to add as well, coming from a background of being a general contractor before going into the national lab, really understanding that most general contractors are small and don't have the research budgets, and so the role of DOE and a national lab being able to provide research and through programs such as Building America where Building America is actually taking technologies that are developed in the lab and working with builders boots on the ground to actually deploy this, as well as retrofit contractors, and so that's just one example. Better Building is another. And then the ABC, Advanced Building Construction, is yet another initiative that is intending to do that, to be that venue, and now we can develop science, take science, develop it into products and bridge that gap, so those contractors like myself back in the day could help get technologies developed and deployed.

Mr. BAIRD. Excellent point, excellent point. I yield back. Thank you.

STAFF. Ms. Bonamici is next.

Ms. BONAMICI. Thank you, Chair Bowman and Ranking Member Weber. Thank you to all of our witnesses for joining us today and for your expertise.

I know that residential and commercial buildings—we know this—are notoriously challenging to decarbonize. But to address the climate crisis, we need to meaningfully repair and rebuild our Nation's infrastructure in a resilient and sustainable manner. So last year I joined my colleagues on the Select Committee on the Climate Crisis. We released a bold, comprehensive, science-based climate action plan to reach net zero emissions no later than midcentury and net negative thereafter. Our plan includes many policies to eliminate emissions from new buildings by 2030, increased homeowner incentives for energy-efficient affordable housing. And I look forward to working with my colleagues on this Subcommittee and the Full Committee to advance these policies.

Dr. Esram, I represent a district in northwest Oregon. I know you're in the Pacific Northwest as well. In the district I represent, the Orchards, which is—was completed in June of 2015, at the time was the largest certified multifamily Passive House building in North America. They anticipated in its 57 units to have a 90 percent energy reduction for heating and 60 to 70 percent overall savings in energy use compared to a typical building of its size. Not far from the Orchards is the headquarters of the First Tech Federal Credit Union, which is a five-story 156,000 square-foot building built of cross-laminated timber (CLT).

So in northwest Oregon the industrial sector is turning to mass timber as an alternative to steel and concrete, and cross-laminated timber, when harvested using sustainable forest management practices, can sequester and store massive amounts of carbon dioxide. There are still questions about the lifecycle assessments of CLT, but the material raises the possibility of storing massive amounts of carbon in buildings for decades or perhaps in perpetuity.

So, Dr. Esram, in your testimony you noted that the R&D gap in our understanding of lifecycle carbon—that there is an R&D gap. So what initiatives could the Department of Energy's Building Technologies Office advance to better address embodied carbon and operational carbon emissions in building materials, equipment, and construction processes?

Dr. ESRAM. Well, thanks for the question, Congresswoman. The most-needed R&D gap is a standardized way to calculate the lifecycle impact of all these materials and also from a holistic perspective to consider building as an integrated entity, not just pieces, you know, the concrete [inaudible]. I think we need to think about what is a target, how to standardize it, and also give innovation or freedom to the architect, to the builders to create low-embodied carbon buildings and not just really at a surface level and go one step deeper, standardization, and the most holistic view of looking at embodied carbon buildings.

Ms. BONAMICI. And what difference would it make if we had those standards?

Dr. ESRAM. I think that will make the industry being more innovative to actively think about how can they create building products that—increase—include multiple benefits for the society and for the building owners and for the building occupants because currently our so-called lifecycle analysis is too narrowly defined on the economic payback of certain technologies or constructions. It's just——

Ms. BONAMICI. That's helpful. And I don't want to cut you off, but I really want to get a question in to Ms. Patterson. And, Ms. Patterson, Portland State University recently released a study demonstrating how historically racist redlining housing policies in northeast Portland have exacerbated the effects of warming temperatures and poor air quality and we—for Black people and people of color. Extreme heat events are expected to increase in frequency and intensity because of the climate crisis and, as a result, these same historically underserved neighborhoods will face health risks of increasing temperatures, higher energy bills, and inequitable access to green spaces.

And we know that many Federal programs like the DOE's Weatherization Assistance Program can't meet current demands. So what does this mean for our BIPOC communities and how can Congress better support innovative residential weatherization and energy practices, particularly for frontline households?

Ms. PATTERSON. Thank you so much. Yes. So I think one key strategy is to really think about spending priorities across the board and think about models that are multi-solving so that we don't just think about energy retrofits that are just focused on energy reference retrofits through the Department of Energy but we think about how we do energy retrofits that are tied to other—you know, that are financed through health funding because we know that having better indoor air quality and better temperature moderation and so forth are better for multiple reasons and also tied to resources from Department of Labor. So we've put together kind of cross-sector packages in order to be able to truly fund these and recognize that it's not just about providing one single thing, but it's about lifting the quality of housing and the quality of health and well-being and think about how each of these sectors contribute to that goal. So I think really multi-solving is the key—key term here and therefore multisector or multi-funding approaches.

Ms. BONAMICI. Great, thank you. And I see my time is expired. I yield back. Thank you, Mr. Chairman.

STAFF. Mr. Garcia is next.

Mr. GARCIA. Thank you, Mr. Chairman. Chair Bowman and Ranking Member Weber, thanks for pulling this together. This is actually very interesting discussions here. I want to thank all of our guests and actually congratulate you all for your achievements and your successes in being leaders in your respective fields.

I've got two questions. The first is for Dr. Tour and the second is for Dr. Jackson. Dr. Tour, this graphene discussion is very interesting. When I saw the writeups for this, I was doing some homework yesterday in preparation for today, and what I was looking at initially was whether or not the use of graphene would become a potential environmental risk like what we've seen with PFAS creeping into our water tables. I'm sure you're familiar with what PFAS is, the polyfluoroalkyl substances. We have a contamination problem in California with PFAS getting into our waters. And while I was doing that research, I was reading that graphene is actually as it is effectively an allotrope of carbon, right? It's a derivative of sort of an activated carbon. And I was reading articles where graphene may actually be used to remove PFAS as a potential filtrate opportunity. Have you seen any research or done any research to where the use of graphene within water filtration systems can help mitigate our PFAS problems that we're seeing in some of our local communities?

Dr. TOUR. Yes, I don't know particularly with PFAS, but I know that graphene, these carbon materials are indeed being used for water filtration. In fact, I have a company that's actually doing that, using graphene in water filtration systems. And so—and the thing about graphene is it's already naturally occurring. If you have graphite in a riverbed, it's shearing off slices of graphene. It's already naturally occurring, and that's what makes it all the more attractive in that it's a naturally occurring material, hard to access, but for water filtration, the PFAS problem, there are other ways that we're addressing that. And actually my group is addressing particularly that problem, so I know something about that. And we've just recently gotten some grant money to do that through the Department of Defense to try to address specifically that PFAS problem.

Mr. GARCIA. If it's OK, maybe you and I can take it offline, but I'd love to connect you with our local water districts here in my district in southern California. They're struggling with this right now, as many are, but they're on the precipice of making very significant investments, and I just want to ensure they're looking at all options before we go too far downrange. A lot of Federal assistance going into those types of programs as well, as you know, so I would love to be able to connect you offline if we can with some of our folks on our end.

Dr. TOUR. I would be glad to.

Mr. GARCIA. Thank you, sir. Dr. Jackson, it's hard to believe that solar power for residential applications has been around for, what, 30 years now, maybe even a little bit longer. Can you talk to us a little bit about the generational shifts in solar power? I know the cost curve is coming down. You know, it's Moore's law really, right? It's double-capacity, half-price every, what, 5 or 6 years. We're seeing that real-time. Is it just an improvement in efficiencies and costs, or are there other sort of revolutionary increments in terms of the technology? I know the integration of solar into roof tiles now is a new thing, but can you talk to us about how the solar industry is actually—what is the state-of-the-art and why is that so important right now?

Dr. JACKSON. So I think that's a great question. I think we've seen some of the trends because of multiple things. I think it's a multifold, one being the materials. We have been able to go from some of the traditional semiconductor-type materials that we used 30, 40 years ago, and now we're actually using even some of organics so even one of the things that's been—really NREL has been leading on is perovskites (PV) is one where you can basically paint it on. There's YouTube videos of painting on of PV device.

And so one of the things—then the next step is what we do as we continue to advance the curve is the soft costs, the cost of integration, because if you make a supercheap material but it takes a lot integrate it, then the overall effective cost is still high. So that's been coming down as well.

Then finally where I see this going is now what we're seeing—actually, it was a *Nature Communications* paper last year where we took those advances in perovskites and other types of materials and said what if you actually integrated those into your window—into your building façade? So now you can see that window that actually is glazing. You can see out of it, but by innovating some technology that we have, you can make it where it switches, where it's a clear window when it's kind of the light it isn't as clear, but then when the sun is readily available, it can actually serve as a glaze to help with glare while also collecting solar. So you have a—so it's taking that perovskites, those types of innovations and incorporating into traditional façade and windows to be able to take solar innovation to the building envelope to the next level.

Mr. GARCIA. That's fantastic. I can go on for hours on this stuff. Thanks, guys, for sharing, very interesting technologies. And I yield back. I'm out of time. Thanks, guys.

STAFF. Ms. Ross is next.

Ms. ROSS. Thank you, Mr. Chairman, and thank you for having this be our first hearing. It's really fascinating.

I want to talk a little bit about your initial theme for the hearing, and so—which is how do we get some of these technologies that are good for our environment and good for people's health in affordable housing. And right now in my district I have a—I'm from the Research Triangle area. It's a growing area. And we are coming up against a real battle to get more affordable housing. At the same time, old—what used to be called housing projects are being torn down because they are—they're past their useful lives and the living conditions are not as good, and we're replacing them.

And so I'd love to know from any of the panelists where there are good examples of sustainable, healthy, affordable housing projects in this country or in other countries so that when we build again, we build in a way that all residents get the health benefits, get the energy-efficiency benefits, and we get the environmental benefits. So to anybody, it looks like we have a few people who want to jump in. Yes.

Mr. HAGERMAN. So this is Joe Hagerman with Oak Ridge. I can talk a little bit about our work with Clayton Homes, so Clayton Homes is the largest affordable housing manufacturer I think in the Nation. We're working with them to apply some of the connected-community principles into their manufactured housing and make those homes safer, more efficient, and healthier in terms of indoor air quality. And this is really about adding controls into their normal product and making those things world-class and really taking the lessons learned from our previous projects in Alabama, Georgia, and with EPRI, the Electric Power Research Institute.

Ms. ROSS. And as a follow-up, how can we in Congress create incentives to do that? So, you know, some people who are in the affordable housing business are in it as a business. Other people are in it because they really care about the residents. Are there any triggers or incentives that we in Congress could provide to have that—these practices—best practices be more widespread?

Mr. HAGERMAN. Oh, absolutely. So another project we have with the Knoxville Community Development Corporation, they're actually actively decarbonizing their buildings, and they—those are actually their words, right? And so I think we as a lab have really learned a lot from that in terms of seeing retrofits, and as you talk about best practices for retrofits, they need to pivot to see those as decarbonization events because it would make the house healthier for the homeowner and they'd pay one less bill at the end of the day as well. So I think those incentives to really kind rethink retrofits is a whole—and incentives to help decarbonize or make the justification to decarbonize would help.

Ms. ROSS. Thank you. Does anybody else know of examples around the country or around the world, any of the other panelists?

Dr. JACKSON. I'll give some—I'll give an example [inaudible] because I think one of the things we have to be [inaudible] to ensure that we approach the affordable housing challenge particularly with retrofits. Those are distinctly harder. As the Chairman mentioned, in—because—in New York we've seen—the *New York Times*, we've talked about like some of the urban heat island effects, and so a lot of times in projects you see the actual temperature change—the temperature dynamics in those environments are different, so we have to think through them differently to make sure that we have the right solution for the right application.

And so a—we've seen in Europe—some of the things they've done in Europe is they use modular construction and actually replace the whole building façade. Now, those are some of the things that the Advanced Building Construction Initiative through the DOE's funding were actually trying to say how can we take the best from those things like we—in Energiesprong that's done in Europe and say what does that look like or what is a modular-type approach that can be used here or a panelized approach and say for these types of affordable construction, how do we do the best thing for that? Because just because it worked in a market rate or advance market community doesn't mean it's going to work in an affordable community. And I think that's the—that's the challenge that we face is if we do that, we have—we end up with a less optimal or a less correct solution for those communities that actually need more investment.

So to your question of what we can do, I think we need to have a very focused effort on the affordable community so that we can make sure we're developing the right solutions for those challenges.

Ms. ROSS. Thank you, Mr. Chairman, and I yield back.

STAFF. Mr. Feenstra is next.

Mr. FEENSTRA. Thank you, Mr. Chair and Ranking Member Lucas.

Before I start, I just want to thank each of the witnesses for their testimony and sharing their extensive research and opinions with us. Iowa's 4th District, where I'm from, is no stranger to leading an energy and environmental design. With over 65 LEED (Leadership in Energy and Environmental Design)-certified buildings in my district, northwest Iowa takes its sustainable buildings very seriously.

Additionally, I'm an original cosponsor on Ranking Member Lucas's *SALSTA's Act* that includes an increase in the investment in the DOE's Office of Science. Their research can help support the next generation of clean energy and efficiency and technology.

Dr. Jackson and Dr. Hagerman, I got a question. Retrofitting existing buildings, which we have a lot of here in the 4th District, is one way to avoid the embodied carbon and cost produced from the building and construction process. What are some of the most cost-effective and carbon-reducing retrofitting techniques that can be utilized today?

Dr. JACKSON. So I'll start. I think the most cost—one of the things is it's kind of—you know, as an engineer, it depends. It depends on the application in many instances. So for the climate, one of the things that you would do is the building façade to ensure that you get the biggest bang for your buck because that helps you with resilience, particularly as we look forward with climate change and making sure that the building works today but it also works 50 years from now. So the best you can do is a building façade.

And so now going back to the question Dr. Esram mentioned before, we need to ensure that we understand the embodied impact of the materials that go into that façade, and so that's why we need to continue to advance the research in what—in embodied energy so that as we do those façade retrofits that can be done today, they can use the least-embodied energy approach. So those are—that's one of the most readily available.

Mr. HAGERMAN. So this is Joe Hagerman from Oak Ridge, and I would answer controls and retuning, so controls, if you can get your controls right, tune up the equipment, you can save a lot of money, and then once we have controls available, we can make the schedules fit people's active lives. And then we can also expose those controls to the utilities so we can start using and leveraging those buildings as a resource of the grid to make the grid more resilient, just as we're making your house more resilient.

Mr. FEENSTRA. That's very good. This is for anybody. So my district, we're very high into agriculture production, and so we maximize the use of our bio-based materials. As an example, Iowa State Centers for Crop Utilization has worked on projects like creating adhesives and insulation from crops and crop byproducts. These can provide a cost-effective alternative instead of petroleum-based products. Is there a way—or how do we see that we could expand this research or do you think this is a good method that we should be spending our time on in future research?

Mr. HAGERMAN. So if I could answer that, yes, and, right, we see a lot of those types of cellular materials going into the feedstock for our additive manufacturing machines, so I would encourage you to explore, you know, other uses of those materials, too, especially in the advanced construction kind of industry and this 3-D printed world we're about to live in.

Mr. FEENSTRA. All right. Well, thank you so much, Doctors.

Mr. Chair, thank you, and I yield back.

Chairman BOWMAN. Thank you very much. Before we bring the hearing to a close, I want to thank our witnesses for testifying before the Committee today. The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are excused, and the hearing is now brought to a close. We are adjourned.

[Whereupon, at 2:35 p.m., the Subcommittee was adjourned.]

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