THE NEXT MILE: TECHNOLOGY PATHWAYS TO ACCELERATE SUSTAINABILITY WITHIN THE TRANSPORTATION SECTOR

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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C O N T E N T S

September 18, 2019

THE NEXT MILE: TECHNOLOGY PATHWAYS TO ACCELERATE SUSTAINABILITY WITHIN THE TRANSPORTATION SECTOR

WEDNESDAY, SEPTEMBER 18, 2019

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

The Subcommittee met, pursuant to notice, at 2:09 p.m., in room 2318 of the Rayburn House Office Building, Hon. Conor Lamb [Chairman of the Subcommittee] presiding.

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

The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector

Wednesday, September 18, 2019
2:00 PM EST
2318 Rayburn House Office Building, Washington, D.C. 20015

PURPOSE

The purpose of the hearing is to examine the range of research, development, and demonstration (RD&D) activities necessary to advance a new era of sustainable transportation. Improvements in vehicle and fuel technologies are largely responsible for the progress that has been made in reducing various forms of air pollution, and emerging technologies have the potential to significantly reduce greenhouse gas (GHG) emissions from the transportation sector in the years ahead. The desire to further improve energy efficiency and reduce GHG emissions is motivating a transition to new-generation vehicle and advanced fuel technologies, including drop-in biofuels and a broad range of electric vehicles, including plug-in hybrids, battery-, fuel cell-, and roadway-powered vehicles. The hearing will serve to inform the development of legislation that will guide the Department of Energy's (DOE) activities in these and other areas.

WITNESSES

- ***Ms. Ann M. Schlenker****, Director, Center for Transportation Research, Argonne National Laboratory*

  Argonne's Center for Transportation Research (CTR) focuses on solutions to challenges involving fuel efficiency, emissions, durability, safety, design and operating efficiency, petroleum dependence, interoperability, compatibility, and codes/standards compliance and harmonization.[1]

[1] https://www.anl.gov/es/center-for-transportation-research

- ***Mr. James Chen****, Vice President of Public Policy, Rivian Automotive LLC*

  Founded in 2009, Rivian is an American automaker and automotive technology company that develops vehicles, products, and services related to sustainable transportation, and specializes in electric sport utility vehicle (SUV) and pickup trucks.[2]

- ***Mr. Brooke Coleman****, Executive Director, Advanced Biofuels Business Council*

  The Advanced Biofuels Business Council (ABBC) supports efforts to develop and commercialize next generation, advanced biofuels and bio-based products. ABBC members include companies in the advanced biofuel production and technology sectors making low carbon fuels and other bio-based products from feedstocks such as agricultural by-products and sustainable energy crops, municipal and agricultural waste, and algae.[3]

- ***Dr. Claus Daniel****, Director, Sustainable Transportation Program, Oak Ridge National Laboratory*

  ORNL's sustainable transportation researchers identify capabilities for next-generation systems in electrification, engines, and emissions controls; develop new materials for future systems and automated vehicle technologies; provide decision-making tools and intelligent technologies for secure, efficient movement of passengers and freight; and support the development of technologies to improve the energy efficiency of light-, medium-, and heavy-duty vehicles.[4]

- ***Mr. Tim Cortes****, Vice President of Hydrogen Energy Systems, Plug Power Inc.*

  Plug Power is engaged in the design and manufacturing of hydrogen fuel cell systems.[5] The company has delivered hydrogen engines for use in fuel cell-powered electric delivery vans and cargo tuggers used by FedEx at the Albany International Airport[6].

OVERARCHING ISSUES

[2] https://rivian.com/
[3] https://advancedbiofuels.org
[4] https://www.ornl.gov/transportation
[5] https://www.plugpower.com/
[6] https://www.greencarcongress.com/2019/04/20190429-pp.html

- New and expected future transportation advancements, such as on-demand mobility and vehicle automation, and how these may affect net GHG emissions.
- Electric vehicles cost and GHG emission reduction potential for different applications (two, four wheelers, trucks, etc.)
- The role of hydrogen relative to electrification, its relative costs and benefits, and applications where it will have the largest impact
- The role of advanced biofuels for light and heavy-duty transportation, considering costs, availability, and net environmental impacts
- The potential for the various alternative low-carbon technology and fuels in trucking, shipping, rail, and aviation

BACKGROUND

The transportation sector is one of the primary contributors to anthropogenic GHG emissions in the United States. According to the Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2017 (the Inventory), the transportation sector accounted for the largest portion (29%) of total U.S. GHG emissions in 2017. Within the sector, light-duty vehicles (including passenger cars and light-duty trucks, i.e. sport utility vehicles, pickup trucks, and minivans) accounted for the largest category, with 59% of GHG emissions, while medium- and heavy-duty trucks made up the second largest category, with 23% of emissions.[7] The Inventory also showed GHG emissions in the transportation sector increased more in absolute terms than any other sector over the same time period (i.e. electricity generation, industry, agriculture, residential, commercial), due in large part to increased demand for travel.[8]

Petroleum supplies more than 90 percent of the transportation sector's energy, and principally all of the sector's GHG emissions come from the combustion of gasoline, diesel, jet fuel, or other petroleum liquids. Other energy sources like natural gas, ethanol, biofuels, hydrogen, and electricity comprise small fractions of today's transportation energy supply.[9] The majority of GHG emissions from the sector are carbon dioxide (CO_2) emissions resulting from the combustion of petroleum-based products in internal combustion engines. According to the Environmental Protection Agency, "[t]he buildup of CO_2 and other greenhouse gases like methane, nitrous oxide, and hydrofluorocarbons

[7] Fast Facts, U.S. Transportation Sector Greenhouse Gas Emissions, 1990-2017 https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100WUHR.pdf
[8] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
[9] https://www.c2es.org/document/decarbonizing-u-s-transportation/

is causing the Earth's atmosphere to warm, resulting in changes to the climate we are already starting to see today."[10]

There is growing demand for sustainability within the transportation sector due to rising prices of traditional energy sources and expanding mobile connectivity, increasing populations and urbanization, as well as concerns about the environment and global warming. However, adopting sustainable energy technologies, practices, and policies to reduce petroleum consumption and GHG emissions is challenging as rising car ownership, freight movement, and air travel patterns will continue to increase emissions without continued federal R&D direction.[11]

Understanding the most promising technology options at both the micro and macro scale will be necessary to address these challenges. Potential emissions abatement and cost reductions from decreases in vehicle travel, shifts to lower carbon transportation options, and new technology and fuel options require further examination and development. And on a larger scale, a better understanding of the relative roles of these options and how they may interact is also needed. Zero-emission technologies are now coming to the entire transportation sector, and R&D will help determine their various rates of progress.

Light-duty vehicles

Given its large contribution to the transportation sector's GHG emissions (59%), the light-duty vehicle fleet is expected to undergo substantial technological changes in the coming decades. According to a 2015 report by the National Academies entitled *Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles*, new powertrain designs, alternative fuels, advanced materials and significant changes to the vehicle body are being driven by increasingly stringent fuel economy and GHG emission standards.[12] Through continued research, development, and deployment of advanced technologies, new vehicles are projected to be more fuel efficient, lighter, safer, cleaner, but likely more expensive to purchase relative to current vehicles in the near term. Given their increased efficiency, however, these vehicles are also expected to be less expensive to fuel than current conventional vehicles.

The National Academies report noted above projects that though the gasoline-fueled spark ignition engine will continue to be the dominant powertrain configuration through 2030, such vehicles will be equipped with advanced technologies, materials, electronics

[10] EPA, Transportation and Climate Change https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation
[11] https://www.nap.edu/read/18805/chapter/2
[12] https://www.nap.edu/catalog/21744/cost-effectiveness-and-deployment-of-fuel-economy-technologies-for-light-duty-vehicles

and controls, and aerodynamics. And by 2030, the deployment of alternative methods to propel and fuel vehicles and alternative modes of transportation, including autonomous vehicles, will have advanced to greater commercialization.[13]

Mid-Heavy-duty vehicles

Medium- and heavy-duty vehicles account for only 5 percent of vehicles on the road but contribute 20 percent of U.S. transportation emissions.[14] This subsector experienced a 95 percent increase in vehicle miles traveled (VMT) between 1990 and 2015, leading to a 78 percent increase in CO2 emissions.

This category includes tractor-trailers, large pickups and vans, delivery trucks, buses, and garbage trucks. While technological advancements are currently foreseeable for the majority of the vehicles listed, albeit still facing limitation (i.e. electric buses[15,16] and hydrogen medium-duty delivery trucks/vans), emission improvements to heavy duty freight remains stagnant. Barriers to the growth of electric and hydrogen fuel cell heavy-duty commercial freight trucks include limited technology availability, limited economies of scale, long-distance travel requirements, payload mass and volume constraints, and a lack of refueling and recharging infrastructure.

However, as demand for freight transport grows, transitioning the global fleet of on-road freight vehicles to both cleaner and more fuel-efficient will steadily increase in importance to meet emission standards. Most heavy-duty vehicles are powered by diesel engines that, particularly in older models, can emit high levels of particulates, nitrogen oxides, and other pollutants that cause both chronic disease and premature death, especially in urban areas and among the most vulnerable populations. And heavy-duty vehicles are responsible for an increasing proportion of total carbon emissions from the transportation sector, as light-duty vehicles become more fuel efficient. Achieving a cleaner freight transport system will depend not only on a similarly farsighted approach to regulating vehicle emissions and efficiency, but also on developing an effective model for systemic change that includes measures to shift freight to the most sustainable options and optimize supply chain activity.[17]

Barriers to the growth of electric and hydrogen fuel cell heavy-duty commercial freight trucks include limited technology availability, limited economies of scale, long-distance

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[13] https://www.nap.edu/catalog/21744/cost-effectiveness-and-deployment-of-fuel-economy-technologies-for-light-duty-vehicles
[14] https://www.c2es.org/content/regulating-transportation-sector-carbon-emissions/
[15] https://www.wired.com/story/electric-buses-havent-taken-over-world/
[16] https://www.citylab.com/transportation/2019/01/electric-bus-battery-recharge-new-flyer-byd-proterra-beb/577954/
[17] https://theicct.org/heavy-duty-vehicles

travel requirements, payload mass and volume constraints, and a lack of refueling and recharging infrastructure.

Non-road vehicles

Whereas road vehicles are the largest sources of emissions and have received the most attention, one-fourth of transport CO_2 emissions (2.2 gigatonnes) are attributable to non-road transport—maritime, aviation, and rail—a share projected to grow in the coming decades. Maritime and aviation emissions are projected to rise through 2030 as a result of increasing demand and slower efficiency improvements.[18]

Non-road transportation category CO_2 emissions from domestic aviation increased by 8 percent over the same period, while emissions from international flights leaving the U.S. increased by 88.8 percent. By contrast, CO_2 emissions from international shipping from the U.S. have decreased 40.6 percent since 1990.

In addition, non-road vehicles such as agricultural and construction equipment, account for almost three quarters of the fine particulate matter ($PM_{2.5}$) and one quarter of the nitrogen oxides (NO_X) emitted from mobile sources.[19]

The Department of Energy's Sustainable Transportation Programs

DOE's Office of Energy Efficiency and Renewable Energy (EERE) supports U.S. researchers and other partners in efforts to make transportation cleaner and more efficient through its Vehicle, Bioenergy, and Fuel Cell Technologies Offices.

FY 2019 Enacted:	$ 690 million
FY 2020 Budget Request:	$ 157.4 million
FY 2020 House Passed:	$ 770 million
FY 2020 Senate Report:	$ 815 million

Vehicle Technologies Office

DOE's Vehicle Technologies Office supports research and development (R&D) of transportation technologies to improve energy efficiency, fuel economy, and decrease dependency on petroleum. Technology focus areas include advanced batteries and electric drive systems, lightweight materials, advanced combustion engines, alternative fuels, and energy efficient mobility systems.

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[18] https://theicct.org/sites/default/files/publications/Beyond_Road_ZEV_Working_Paper_20180718.pdf
[19] https://theicct.org/publications/managing-emissions-non-road-vehicles

FY 2019 Enacted:	$ 344 million
FY 2020 Budget Request:	$ 73.4 million
FY 2020 House Passed:	$ 370 million
FY 2020 Senate Report:	$ 410 million

Bioenergy Technologies Office

DOE's Bioenergy Technologies Office focuses on research and development to advance bioenergy technologies that are capable of producing price-competitive biofuels, biopower, and bioproducts from various sources of biomass.

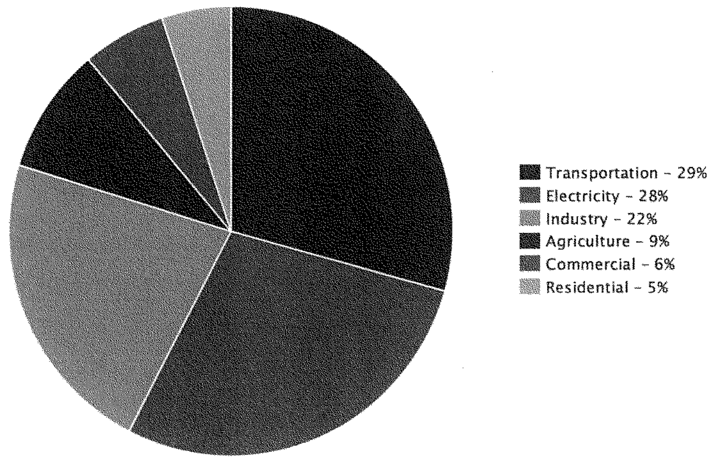
FY 2019 Enacted:	$ 226 million
FY 2020 Budget Request:	$ 40 million
FY 2020 House Passed:	$ 256 million
FY 2020 Senate Report:	$ 245 million

Fuel Cell Technologies Office

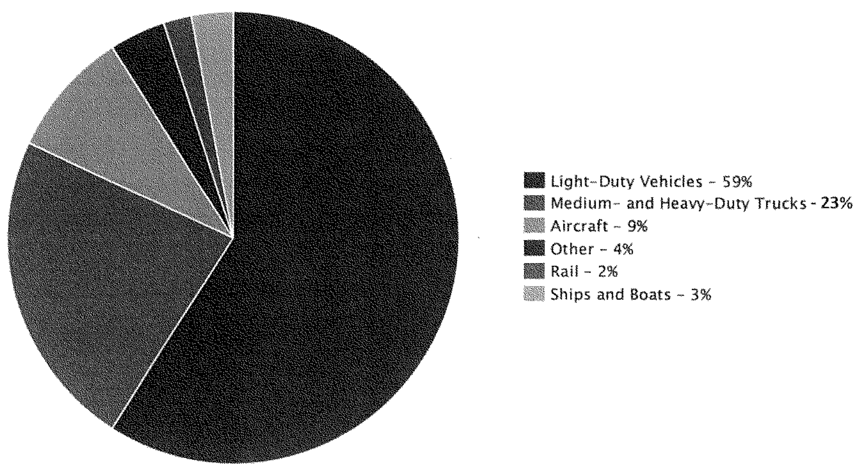
The Fuel Cell Technologies Office supports research to overcome the technological, economic, and institutional barriers to the development and use of hydrogen and fuel cells.

FY 2019 Enacted:	$ 120 million
FY 2020 Budget Request:	$ 44 million
FY 2020 House Passed:	$ 144 million
FY 2020 Senate Report:	$ 160 million

2017 U.S. GHG Emissions by Sector



2017 U.S. Transportation Sector GHG Emissions by Source



Note: Totals may not add to 100% due to rounding. Transportation emissions do not include emissions from non-transportation mobile sources such as agriculture and construction equipment. "Other" sources include buses, motorcycles, pipelines and lubricants.

U.S. Environmental Protection Agency (2019).
Inventory of U.S. Greenhouse Gas Emissions and Sinks; 1990-2017

Chairman LAMB. Hearing will come to order. Without objection, the Chair is authorized to declare recess at any time. Good afternoon. Welcome to today's hearing, called "The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector." I want to thank all of our witnesses for joining us here today. We're obviously discussing a critical topic: How to decarbonize, and make more sustainable, the cars we use every day—the trucks that handle transportation of our manufacturing and other goods all across the country, airplanes, trains, ships. It's clear that all of this stuff is vital to everyday life, but we have to be smarter about it.

In 2017, transportation overtook electricity as the sector of our economy with the highest percentage of greenhouse gas emissions, when it got up to 29 percent, and so finding pathways to reduce these emissions is essential. It's also crucial that we, as leaders, support jobs and industries at the same time, and I think we can do that. The R&D (research and development) that we're going to talk about here today will drive the development of these technologies, improve our economy, create new jobs, make us safer, improve national security, all while improving the climate.

Our labs, universities, business, and research institutions have all worked on these projects for decades. They've had great success, but a lot of the transportation landscape has not budged. Henry Ford first sold the Model T just over a century ago, and a lot of the cars, trucks, and buses on our roads, the vast majority of them still use a similar internal combustion engine. Larger vehicles, airplanes, trains, and ships, become even more complicated, so that's what we're trying to figure out now, is how can we finally drive some serious change in this area?

Scientists have been working hard at it. We've seen huge development in growth of clean electric vehicles (EVs) that can go hundreds of miles on a single charge. We've seen hydrogen vehicles, we've seen hybrid electric, and the demand is continuing to go up and up. In 2018, by our figures, more than 1.7 million plug-in and battery electric vehicles were sold worldwide, which is a 40 percent increase in just 1 year. One point seven million in 2018 alone, so this is a huge market.

The Department of Energy (DOE) is researching other technologies in this sector as well. Bioenergy Technologies Office is working to develop commercially viable biofuels that are compatible with the infrastructure that we already have. There's a variety of feedstocks being talked about waste organic materials, crops grown specifically for this purpose. Some of these fuels, known as drop in fuels, are nearly identical, but they would burn much more cleanly than existing fuels. This means we wouldn't need to make as many changes as we would with a purely electric system, and we're going to go full speed down both tracks.

The Fuel Cell Technology Office at DOE is also working to develop hydrogen fuel cells, and I'll just put in a plug, there's a lot of great work being done at a local university for us in Western Pennsylvania, Carnegie-Mellon, and the Scott Institute, on the future of hydrogen fuel cell technology. All of these things combined will help make our transportation sector more sustainable. Although it is incredibly complex, we think that, with enough investment on our part, in partnership with private sector and nonprofit university partners, we can solve this riddle. And I think we have to, because someone will solve it. There is enough demand at this point worldwide that we know some of our closest competitor nations are doing everything they can to dominate the future of electric vehicles and similar technologies, and I want the United States to win that race. So, very excited to hear from all of you.

[The prepared statement of Chairman Lamb follows:]

Good afternoon and thank you to all our witnesses joining us here today to discuss a topic that is critical for our nation: sustainable transportation. This includes the cars that we use every day to drive to work, the trucks that help us transport goods across the country, the planes that fly all over the world, and the trains and ships that help us get products and people to the places they need to be.

It's clear that transportation is vital to our everyday lives. But we need to be smarter about our investments in technologies that can help reduce emissions from this sector. In 2017, transportation overtook electricity as the sector of the U.S. economy with the highest percentage of greenhouse gas emissions, accounting for 29% of emissions economy-wide. Finding pathways to reduce greenhouse gas emissions from this sector is an essential part of solving our climate challenge. At the same time, it is incumbent on us to ensure that we are leaders in supporting the jobs and industries of the future. The research and development of these innovative technologies improve our economy, our national security, and our climate. That's what we are here to talk about today.

While our labs, universities, businesses and research institutions have worked on these problems for decades - even centuries - much of the transportation landscape remains unchanged. Ford first sold the Model T just over a century ago (1908) and most cars, trucks, and buses on our roads still use an internal combustion engine. And with larger vehicles - think airplanes, trains, and ships - the problem becomes even more complicated.

Scientists have been working hard to come up with solutions that will help these technologies evolve for decades - and we need to ensure they can continue doing so. We have seen the development and growth of clean electric vehicles that can travel hundreds of miles on a single charge, and hybrid electric vehicles that can travel even further. Demand for electric vehicles is projected to increase in the coming years, both worldwide and in the United States and this is already growing rapidly: in 2018, more than 1.7 million plug-in and battery electric vehicles were sold worldwide - a nearly 40% increase over 2017.

The Department of Energy is researching other technologies in this sector as well. For example, the Bioenergy Technologies Office is working to develop commercially viable biofuels that are compatible with our modern transportation infrastructure. These fuels can be made from a variety of feedstocks, including waste organic materials or crops grown specifically for creating energy. Some of these fuels, known as "drop-in" fuels, are nearly identical to the fuels they are designed to replace, but burn much more cleanly than existing fuels. That means we wouldn't need to make any changes to engines, fuel pumps, and other vehicle technologies in order to use these fuels, while still reaping the benefits.

The Fuel Cell Technologies Office at the DOE is working to develop vehicles that run off of hydrogen fuel cells. These fuel cells use hydrogen to produce electricity, which then powers an electric motor, similar to how an electric vehicle operates. Fuel cell vehicles emit zero carbon; in fact the only by-product from these vehicles is water. While hydrogen-powered cars are showing promise, hydrogen can be produced in a variety of ways and scientists are working hard to identify a cost-effective, commercial scale method of production that is also clean, including through the use of renewables and nuclear power.

Making our transportation sector more sustainable is an enormously challenging and complex problem. It requires significant investment on our part and coordination across government, our labs and universities, and the private sector. But it's a must-solve riddle, and I believe it is critical we develop and manufacture the answer - these technologies - here at home. Doing so is a clear win for our economy, national security, and climate.

I am excited to hear from our excellent panel of witnesses assembled here today on their ideas on how to tackle this problem, and I look forward to working with my colleagues across the aisle to advance legislation on this critical and timely topic.

Chairman LAMB. And now I will recognize my friend and colleague, the Ranking Member, Mr. Weber, for an opening statement.

Mr. WEBER. Thank you, Mr. Chairman. I apologize for being a little late. Appreciate you holding today's hearing. I'm looking forward to hearing from our witnesses about innovative transportation technologies, and about DOE's research and development activities in these areas. The United States transportation sector is a critical part of the U.S. economy. Annually in the United States, vehicles transport 11 billion, with a B, tons of freight, equal to 35 billion, with a B, dollars in goods every single day. My District 14 on the Gulf Coast of Texas is the 13th largest exporting district in the country, so the transport of goods for us is huge.

Last year, almost one-third of the United States' energy consumption was used for the transportation of people and goods across the country. Currently this massive energy is met with petroleum products, which account for 92 percent of U.S. transportation energy use. It's clear, and essential, I might add, that we will rely on this incredible resource long into the future, so we need to consider this reality as we seek to reduce emissions, and grow other energy sources. As energy demands increase, American researchers are exploring sustainable technologies that will make fossil fuel consumption cleaner and more efficient. They'll introduce new fuel pathways while maintaining U.S. energy security.

Industry stakeholders are also prioritizing innovation, commercializing electric vehicles, as the Chairman talked about, biofuels, and advanced fuel cell technologies. And this afternoon we'll hear from some of our friends in these successful industries. But although industry is taking advantage of incentives to reduce transportation sector emissions, the Federal Government still has a significant role to play in conducting fundamental research that will, in fact, drive innovation in these technologies.

At the Department of Energy, DOE, sustainable transportation R&D is funded through the Department's Office of Energy Efficiency and Renewable Energy, or EERE, and carried out through its Vehicle Bioenergy and Hydrogen and Fuel Cell Technologies Offices. It bears repeating that the EERE is by far the Department of Energy's largest applied research program. At almost $2.4 billion in annual funding, EERE is bigger today than all of the Department's applied R&D programs combined. Let me repeat that. At $2.4 billion in annual funding, EERE is bigger today than all of the Department's applied R&D programs combined. That's huge. Currently the sustainable transportation portfolio makes up about a third of EERE's budget.

Today's hearing also provides an opportunity for us to discuss potential vehicle technology legislation, H.R. 2170, the *Vehicle Innovation Act of 2019*. This bill would authorize modest growth in funding for DOE's vehicle research activities. It would support a broad range of research efforts to reduce or eliminate vehicle emissions and petroleum usage in the United States. And while it should come as no surprise that I don't agree with everything in this bill, I'm pleased to see that our friends across the aisle are considering a more reasonable approach to funding authorization levels. So I look forward to the discussion on this bill moving forward, and I want to be clear, I support DOE funding for innovative research in transportation technologies.

I'm also supportive of American industry taking the lead, and of the kind of basic research that benefits not just transportation, but all energy technologies. As we all know, the majority of the basic research is carried out in our National Labs, so I'm pleased that we will hear from not one but two Department of Energy labs today about how American researchers are leveraging DOE's unique and unparalleled user facilities to drive innovation and transportation technologies. For example, at Oak Ridge National Laboratory, researchers have access to not only the National Transportation Research Center, NTRC, the Nation's only transportation-focused user facility, but also the lab's Spallation Neutron Source Center for Nanophase Material Science and the Oak Ridge Leadership Computing Facility, which currently houses the world's most powerful supercomputer.

When it comes to vehicle technology research, we need to look at the big picture, and take the long-term approach. Industry simply cannot conduct the fundamental research needed for the next technology breakthrough, but industry can get these technologies out on the road. By prioritizing the basic research capabilities and user facilities that have broad applications, we can still enable the private sector to bring innovative, new transportation technologies to the market, while at the same time advancing science and innovation across this American economy.

Mr. Chairman, I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you, Chairman Lamb, for holding today's subcommittee hearing. I'm looking forward to hearing from our witnesses about innovative transportation technologies, and about DOE's research and development activities in these areas.

The U.S. transportation sector is a critical part of the U.S. economy. Annually, in the United States, vehicles transport 11 billion tons of freight, equal to $35 billion dollars in goods each day. Last year, almost one third of U.S. energy consumption was used for the transportation of people and goods across the country.

Currently, this massive energy need is met with petroleum products, which account for 92 percent of U.S. transportation energy use. It's clear that we will rely on this incredible resource long into the future - so we need to consider this reality as we seek to reduce emissions and grow other energy sources.

As energy demand increases, American researchers are exploring sustainable technologies that will make fossil fuel consumption cleaner and more efficient, introduce new fuel pathways, and maintain U.S. energy security.

Industry stakeholders are also prioritizing innovation, commercializing electric vehicles, biofuels, and advanced fuel cell technologies. And this afternoon, we'll hear from our some of our friends in these successful industries.

But although industry is taking advantage of incentives to reduce transportation sector emissions, the federal government still has a significant role to play in conducting fundamental research that will drive innovation in these technologies.

At the Department of Energy (DOE), sustainable transportation R&D is funded through the Department's Office of Energy Efficiency and Renewable Energy (or EERE) and carried out through its Vehicle, Bioenergy, and Hydrogen and Fuel Cell Technologies Offices.

It bears repeating that EERE is by far DOE's largest applied research program. At almost $2.4 billion in annual funding, EERE is bigger today than the all of the Department's applied R&D programs combined.

And currently, the sustainable transportation portfolio makes up almost a third of EERE's budget.

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When it comes to vehicle technology research, we need to look at the big picture and take the long term approach. Industry simply cannot conduct the fundamental research needed for the next technology breakthrough. But industry can get these technologies out on the road.

By prioritizing basic research capabilities and user facilities that have broad applications, we can still enable the private sector to bring innovative new transportation technologies to the market, while advancing science and innovation across the American economy.

Chairman LAMB. Thank you. Now recognize Chairwoman Johnson for an opening statement.

Chairwoman JOHNSON. Thank you very much, Mr. Chairman, and good afternoon. Let me thank you for holding this timely hearing on how we can best accelerate the sustainability of our Nation's transportation sector. I'd also like to join you in welcoming this distinguished panel of witnesses to the hearing today.

This Committee recently held a hearing where we discussed the need for a national surface transportation agenda. Today's hearing expands upon our commitment to addressing the environmental impacts of transportation in order to mitigate its impacts on climate change and air pollution. While there are many exciting developments in sustainable transportation such as electric cars, alternative fuels, and new concepts of mass transit systems, there are also many barriers to these technologies that we as a country must work to overcome. That's why this hearing is so important.

The transportation sector's carbon emissions are largely attributable to petroleum-based fuels. A transition to a mix of low-carbon fuels and electricity could reduce these emissions by more than 80 percent, and eliminate petroleum use almost entirely. According to the Department of Energy's Vehicle Technologies Office, while researchers believe that this is technically feasible with technologies that already exist today, further R&D will be critical to reducing their cost, and improving their reliability and scalability to meet our economic, environmental, and mobility needs.

As I have stated before, my hometown of Dallas is a hub for air travel and freight—two forms of transportation that are particularly challenged to decarbonize. Those sources of emissions are projected to grow in coming years, as the demand for travel and goods steadily increases. For example, emissions from aviation currently account for almost 3 percent of the total global emissions. However, based on current aviation trends, it could grow to be above 4 percent by 2040, representing 14 percent of the transportation sector emissions. That number may sound inconsequential, but it is significant when you consider the amount of emissions we must reduce to put us on a path to limit global warming in this century.

As I know we'll hear more about from today's panel, several of our National Labs and private companies are dedicated to providing solutions to these very challenges, but Congress must also act and allocate low-carbon R&D funding to further drive innovation within this sector. So I look forward to this discussion, and to working with my colleagues on both sides of the aisle, as we consider ideas to better support the Department of Energy's research and development activities in this crucial area. I thank you, and yield back.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon and thank you, Chairman Lamb, for holding this timely hearing on how we can best accelerate the sustainability of our nation's transportation sector. I also would like to join you in welcoming this distinguished panel of witnesses to today's hearing.

This Committee recently held a hearing where we discussed the need for a national surface transportation agenda. Today's hearing expands upon our commitment to addressing the environmental impacts of transportation in order to mitigate its impacts on climate change and air pollution. While there are many exciting developments in sustainable transportation, such as electric cars, alternative fuels, and new concepts for mass transit systems, there are also many barriers to these technologies that we as a country must work to overcome. That's why this hearing is so important.

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Thank you and I yield back.

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

At this time I'd like to introduce our witnesses. First, Ms. Ann Schlenker is the Director of the Center for Transportation Research at Argonne National Lab. Her responsibilities include evaluating the energy and environmental impacts of advanced technology and new transportation fuels. Ms. Schlenker's portfolio includes light- and heavy-vehicle research, with an emphasis on low-carbon solutions. She also helps to lead the DOE student vehicle competitions for advanced powertrain technologies in connected and automated vehicles. Before her position at Argonne, Ms. Schlenker worked for Chrysler for more than 30 years.

We also have Mr. James Chen, the Vice President of Public Policy at Rivian Automotive, where he oversees policy issues, and is tasked with oversight of regulatory requirements applicable to Rivian's products and facilities. Before his position at Rivian, Mr. Chen worked at the EPA (Environmental Protection Agency), and spent 6 years at Tesla, where he held the position of Vice President of Regulatory Affairs and Deputy General Counsel.

Mr. Brooke Coleman is a co-founder and Executive Director of the Advanced Biofuels Business Council (ABBC), whose membership includes companies in the advanced biofuels and cellulosic ethanol sectors. The ABBC's mission is to support the development and commercialization of the next generation of biofuels and biobased products.

Dr. Claus Daniel is the Director of Sustainable Transportation Program at Oak Ridge National Laboratory. Oak Ridge's sustainable transportation researchers support the development of a range of technologies to improve the energy efficiency of light-, medium-, and heavy-duty vehicles. Dr. Daniel is a materials scientist by training, with over 20 years of experience in the automotive technologies sector.

The Chair now welcomes Mr. Tonko to the Energy Subcommittee for the day, and recognizes him to introduce our last witness, Mr. Cortes. And although it is welcome for the day, sir, you will always be welcome back, and we would even consider you for full admission—based in part on your performance today.

Mr. TONKO. Thank you. Music to my ears. Thank you, Mr. Chair. It is my honor to introduce Tim Cortes, the Vice President of Hydrogen Energy Systems at Plug Power, a leader in commercially viable fuel cell systems based in the Capital Region of New York. With proven hydrogen and fuel cell products, Plug Power replaces lead/acid batteries to power electric industrial vehicles, such as the lift truck customers use in their distribution centers. They're headquartered in the 20th congressional District in Latham, New York, and have facilities in Spokane, Washington; Rochester, New York; Dayton, Ohio; Romeoville, Illinois; and Montreal, Canada.

Tim Cortes joined Plug Power as Vice President of Hydrogen Energy Systems in January 2015. In this role my friend, Mr. Cortes, is responsible for overseeing the gen fuel business, including interactions with customers, partners, and suppliers critical to increasing Plug Power's growing market share within the hydrogen fuel industry. Prior to joining Plug Power, Mr. Cortes served as Chief Technology Officer and Vice President of Engineering at Smith's Power. In these positions, he was responsible for research and development, as well as solutions for global applications. During his tenure at Smith's Power, Mr. Cortes led product line expansion that resulted in a doubling of revenue growth in less than 6 years.

Tim has worked in the development of critical power infrastructures in both the data center and telecommunications markets, including positions with AT&T Bell Labs, GNB/XI Technologies, and Power Distribution, Incorporated. He received his bachelor of science in electrical engineering from New Mexico State University, and he holds several patents in power system architecture. In 2016, *Food Logistics* named him the rock star of the supply chain for his work making it possible for smaller truck fleets to adopt hydrogen fuel cell technology. And I'm proud that our Capital Region's own Plug Power continues to build success as a leader in clean energy in New York, and throughout the country, and thank Tim for his leadership, and welcome him to the panel today. Thank you, Tim. Thank you, Mr. Chair. I yield back.

Chairman LAMB. And thank you. As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in full in the record of the hearing. When you have completed your spoken testimony, we'll start with questions, and each Member will have 5 minutes to question the panel. We will start now with Ms. Schlenker.

TESTIMONY OF ANN M. SCHLENKER,
DIRECTOR, CENTER FOR TRANSPORTATION RESEARCH,
ARGONNE NATIONAL LABORATORY

Ms. SCHLENKER. Chairwoman Johnson, Ranking Member Lucas, Chairman Lamb, Member Weber, and Members of the Subcommittee, thank you for this opportunity today. It is my honor to talk to you about how the U.S. Department of Energy National Laboratories are helping realize the goal of sustainable transportation. I'm Ann Schlenker, and I'm privileged to lead the Argonne Center for Transportation Research just outside of Chicago.

Multiple DOE offices, including the Office of Energy Efficiency and Renewable Energy, fund important research and development at the component, the vehicle, and the transportation system levels. DOE National Laboratories create new knowledge; develop, enhance, and analyze automotive medium-duty and heavy-duty truck technologies; and create new tools. The research spans conventional internal combustion engines, hybrid electric systems, battery electric vehicles, fuel cell electric vehicles, and off highway applications.

At the level of vehicle components, the labs develop and de-risk battery technologies. We test new batter materials, develop scale-up processes for the most promising ones, and ultimately hand that off to industry. Argonne's cell analysis modeling and prototyping camp facility, as an example, has worked with more than 4 dozen industrial partners, from startups to Fortune 500 companies. Our research also encompasses the entire battery lifespan. In February of this year, DOE established a battery recycling center at Argonne with many partners to develop, and reclaim, and recycle critical materials and components from lithium-based battery technology to recover the economic value.

Combustion engines still power the majority of our Nation's vehicles. Laboratory research provides deep insights into our combustion processes so we can achieve predictable and reliable engine performance with the lowest possible environmental footprint. Researchers use sophisticated tools, like the advanced photon source at Argonne, to peer into fuel spray streams to optimize the mixture delivery for cleaner ignition processes. They apply high performance computing capabilities and artificial intelligence techniques to in-house developed computational fluid dynamic codes in order to better understand the combustion variability from cycle to cycle, and then transfer this knowledge to industry.

National Laboratory researchers investigate the complete supply chain of biofuel production, from farm to wheels, to assess the energy consumption and environmental impacts of fuels used in ground transportation, aviation, and the marine sector. This life cycle analysis uses Argonne's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model, which enables this fuel comparisons. Fuel cell and hydrogen technology investigations extend from materials to components in vehicle, and seek to improve performance, durability, and cost. New approaches to renewable hydrogen production as an industrial fuel choice, paired with fuel cell vehicle development, have the potential to create market demand.

National Laboratories research at the vehicle level includes technology to integrate electric vehicles with the grid, and enable faster charging. At the Smart Energy Plaza at Argonne, researchers work to verify the interoperability of chargers in cars. Extreme fast charging and megawatt charging will enable longer distance electric travel, making medium-duty and heavy-duty vehicles more marketable.

Finally, National Laboratories are experts in the vital study of vehicles within a system. The Labs collaborate, and I co-chair, the DOE Systems and Modeling for Accelerated Research in Transportation, or the Smart Mobility Consortia, and we focus on connecting automated vehicles, the built environment, alternative fuel infrastructure, freight and goods delivery, and decision science. We use models and field experiments to study the effects of not only advanced vehicles with the infrastructure technologies, but also the impacts of new business models and modes of transportation. The result is a greater understanding from the vehicle to the city level.

An example of a key insight from this work is really the consumer appetite for e-commerce as a replacement to shopping trips. One might guess that the frequent trips of an Amazon or FedEx delivery truck to your house results in a net energy penalty. However, system analysis shows the inverse is actually true. Avoiding a personal shopping trip in the family car for the average 8-mile trip, as compared to an efficient package delivery system, saves overall vehicle miles traveled and energy used. Combining the DOE National Laboratories computational horsepower with our capabilities in artificial intelligence, Big Data, computation, and predictive analytics gives lab researchers and their partners a scenario-based framework to analyze potential mobility futures.

The National Laboratories and their facilities are America's powerhouses of science, technology, and engineering. They are principle agents of execution in missions of national importance. I am proud to be a member of the National Laboratories sisterhood. Thank you for your time, and I welcome your questions.

[The prepared statement of Ms. Schlenker follows:]

Written Testimony of Ann Schlenker
Director, Center for Transportation Research, Argonne National Laboratory
before the
U.S. House of Representatives Committee on Science, Space, & Technology,
Subcommittee on Energy
September 18, 2019

Chairman Lamb, Ranking Member Weber, and members of the subcommittee, thank you for the opportunity to appear before you. It is my honor to talk about how the U.S. Department of Energy (DOE) national laboratories are helping realize the goal of sustainable transportation and, in so doing, bringing greater prosperity and security to all Americans.

I am Ann Schlenker, director of the Center for Transportation Research at DOE's Argonne National Laboratory, one of America's first and largest multipurpose science and engineering laboratories, located in Lemont, Illinois, near Chicago. Prior to joining Argonne in 2009, I worked for Chrysler, LLC, for more than 30 years, most recently as Director of Advanced Vehicle Engineering and Alliances. During my career in industry, I held a variety of executive engineering positions in research, regulatory development, and frontline product development. My passion for transportation runs deep and long.

As director of the center at Argonne, I am privileged to lead a team of scientists and engineers who collaborate with one another, with colleagues across the national laboratory system, and with industry and other partners. Together we leverage experience and expertise and apply one-of-a-kind scientific tools to address the biggest challenges in transportation.

Systems like transportation impact each of us at multiple levels. The western hemisphere's recent experience with Hurricane Dorian is an example in which preparedness and response could be categorized at the individual, community, and national levels. Individual preparedness constitutes ensuring that we have food, water, medicine, shelter, and energy for ourselves, and for our cars, mobile phones, and generators. Having an adequate, secure, and affordable energy supply is paramount. Communities, on the other hand, prepare by protecting as best they can their local sources of power and light, providing robust public safety and health resources, and supplementing citizens' food and shelter. At the national preparedness level, our continued security and economic prosperity are tied to the availability and cost of energy; here, preparedness encompasses activities such as securing the national electric grid and safeguarding our power sources.

We can translate this individual-community-nation framework to our transportation research. There are levels of study that encompass the components within vehicles, the vehicles themselves, and the wider transportation systems within which vehicles operate. Multiple offices at the DOE, including the Office of Energy Efficiency and Renewable Energy (EERE), fund important research and development at all of these levels. DOE national labs leverage distinguishing capabilities in science and engineering, unique user facilities, and external collaboration networks to execute pioneering research into affordable and sustainable transportation solutions that satisfy consumer demand.

Vehicle Components

At the component level, national laboratories create new knowledge; develop, enhance, and analyze automotive and medium-duty/heavy-duty truck technologies; and create new tools that are applied to conventional internal combustion engines, hybrid electric systems, battery electric vehicles, and fuel cell electric vehicles. We "co-optimize" our technology R&D by coupling it with studies of fuel/energy options including biofuels, hydrogen, and batteries.

Electric vehicles figure prominently in the sustainable transportation conversation. Electrification of the fleet is a critical element of a low-carbon transportation future. Indeed, considerable research is focused on the batteries that power these vehicles and how changes in their chemistry affect their performance, cost, safety, range, and lifespan. The infrastructure of the national laboratories enables researchers to develop and de-risk battery technologies: researchers test their new battery materials for electrodes or cells, develop commercial scale-up processes for the most promising ones, and ultimately hand them off to industry. Argonne's Cell Analysis, Modeling and Prototyping (CAMP) facility, created in 2010 by EERE's Vehicle Technologies Office (VTO) as the nation's first cell fabrication lab, has worked with more than four dozen industry partners, which run the gamut from startups to Fortune 500 companies.

National laboratory research also encompasses battery lifespans. In February 2019, DOE established a battery recycling center at Argonne, where national laboratory, university, private sector, and other scientists develop technologies to reclaim and recycle critical materials from lithium-based battery technology, recovering as much economic value as possible from spent batteries. Accelerating and advancing industry adoption of electric vehicle battery recycling will help meet the VTO goals of reducing the cost of electric vehicle battery packs for consumers, increasing the use of domestic recycled sources of battery materials, and minimizing the nation's reliance on other countries for materials.

Hybrid electric vehicles are powered by an electric battery paired with a gas-powered engine. At the national labs, we ask and seek to answer important questions with implications for market acceptance: When do these cars drive solely under electrical or gas-engine power? How do their unique powertrains affect fuel economy and energy consumption? With knowledge of roads and traffic patterns, how do we optimize battery usage versus use of the combustion engine for a specific trip? These continue to be ripe areas for commercially relevant, impactful research.

The number of electric vehicles on the road continues to increase, but today combustion engines still power the majority of our nation's vehicles. Laboratory research seeks to gain ever deeper insight into the fundamental processes of combustion, thereby yielding predictable and reliable engine performance with the lowest environmental footprint achievable. Researchers use sophisticated tools like the Advanced Photon Source (APS) at Argonne to peer into fuel-spray streams to optimize the mixture delivery for cleaner ignition processes. They apply high-performance computing capabilities and artificial intelligence techniques to in-house developed computational fluid dynamic codes, in order to better understand combustion variability from cycle to cycle. The goal is cleaner, more efficient engines for light-duty and heavy-duty on-road and off-road transportation, as well as applications in national power generation and manufacturing.

National laboratories are constantly on the lookout for partnerships that tap their expertise and facilities. Argonne researchers recently teamed up with computational fluid dynamics company Convergent Science to incorporate an Argonne model into the company's CONVERGE software package, which is used by industry. The partnership has the potential to increase fuel economy and help automakers meet future emissions standards.

In the study of new fuels, we analyze options to diversify our energy supply base while reducing greenhouse gas emissions and other pollutants. In experimental facilities designed to study fundamental fuel kinetics, as well as for engine and vehicle evaluations, specialists collaborate on advanced engine simulations, enabling comprehensive assessment of alternative fuels for a range of applications.

Biofuels, for example, are a complementary element in increasing domestic energy security and improving the environmental profile of transportation fuels. However, questions exist regarding their lifecycle energy and environmental benefits and product costs at scale. National laboratory researchers investigate the complete supply chain of biofuel production, from farm to wheels, to comprehensively assess the energy consumption and environmental impacts of biofuels used in ground transportation, aviation, and the marine sector. We study a wide range of renewable feedstocks—corn stover, switchgrass, woody trees, algae, and waste streams (municipal solid waste, plastics)—and examine the carbon cycle and the above- and below-ground carbon sources and sinks that alter the effects of land-use change. Ancillary valued products created beyond the direct fuel production have the potential to improve the financial robustness of plans to add biofuels to the energy mix.

Scientists and engineers are working worldwide to economically produce low-carbon electro-fuels (e-fuels) by utilizing industrial carbon dioxide (CO_2) and renewable electricity. With the availability of 100 million tons of concentrated sources of CO_2 today from ethanol plants and refineries, approximately 10 billion gallons of e-fuels can be produced annually. E-fuels can play a major role in the sustainability of transportation sectors that cannot be directly electrified, such as marine and aviation, which require high-energy-density liquid hydrocarbons. Argonne leads the sustainability evaluation of e-fuels production, supporting various DOE EERE offices and programs.

Fuel cell and hydrogen technologies are another area of important research. Our fuel cell investigations extend from materials to components and vehicles, and seek to improve performance, durability, and cost. These studies, as is the case with all our transportation research, are enabled by DOE user facilities including those located at Argonne: at the APS, researchers characterize the microstructure of electrodes; at the Argonne Leadership Computing Facility, they simulate the electrochemical transport of reactants and liquid water. Laboratories' hydrogen storage work encompasses onboard and offboard issues, including physical and material-based storage methods and the production, transmission, and dehydrogenation of hydrogen carriers. Finding new approaches to hydrogen production is another area of active research and development. Application of hydrogen as the fuel choice for U.S. industrial processes could be synergistic with fuel cell vehicle development, creating a greater market demand for hydrogen. And, by using renewable wind and solar as the energy source to generate the hydrogen, this is a pathway to a low-carbon future.

As we study new fuels as components of sustainable transportation, we also want to understand the breadth and magnitude of impacts—energy use, greenhouse gas and pollutant emissions, water consumption—produced when on-road vehicles, aircraft, marine vessels, rail, and other forms of transportation are operated using different fuel options. That type of knowledge is the goal of lifecycle analysis. Researchers use EERE-funded models such as Argonne's GREET (Greenhouse Gases, Regulated Emissions, and Energy use in Transportation, with nearly 40,000 registered users) to conduct common, transparent analyses of alternative combinations of vehicle and fuel technologies, for identifying impacts, policy implications, and further needed research.

At the component level, researchers are prioritizing further battery studies, from those at an early technology readiness level to those later in demonstration phases, to enable the electrification of ground transportation and aviation fleets across the supply chain.

Vehicle Research

National laboratories conduct a multitude of studies with implications for the future of sustainable transportation, including examining the various impacts of vehicle electrification. At Argonne's Advanced Mobility Technology Laboratory, engineers use chassis dynamometers and other instrumentation to collect important information on performance, fuel economy, energy consumption, and emissions. These data are critical to the development and commercialization of next-generation vehicles.

Other vehicle-level research analyzes the applications designed to enhance market acceptance of plug-in vehicles and charging infrastructure and bridge the needs of electric vehicle manufacturers and utility companies. R&D in this area includes everything from technology that supports the integration of electric vehicles with the grid and communications (for actively managing vehicle charging loads) to innovations that lower the cost of electric vehicle charging infrastructure and enable faster, more consumer-friendly charging.

In this work, researchers prioritize harmonizing global connectivity standards, with the aim of cleaner, smarter, and more integrated transport and energy worldwide. The Smart Energy Plaza at Argonne houses researchers who work to verify battery charger interoperability in electric vehicle-grid communication field trials and develop technologies such as inexpensive metering devices that can be easily integrated into existing junction boxes. Researchers are designing electric vehicle controllers to communicate and control charging-related power demands from the grid; the next generation of these controllers will support the reverse flow of power, essentially enabling the energy stored in a vehicle to stabilize the grid or to address peak-demand events.

Other innovations with the potential to enhance market acceptance of plug-in vehicles are those that enable fast recharging. Regular charging systems are sufficient for overnight vehicle charging at home or office, but often are not practical for quick recharging in public areas. Extreme fast charging, which can add 60 to 80 miles of range to an electric vehicle in fewer than 20 minutes, is an ambitious goal, but researchers have achieved tangible proof-of-concept demonstrations. Class 4 and class 8 trucks and buses, meanwhile, will require megawatt charging; in the fleets that use these types of vehicles, vehicle up-time is paramount for additional cross-industry R&D.

National laboratories have been leaders in developing tools that enable evaluation of new technology with a model-based system engineering approach, which allows for much more rapid and much less expensive identification and down-selection of vehicle technologies with promising energy consumption and emissions. Now that reliable tools are available, the need no longer exists to build and iterate multiple times in the development process. Argonne's Autonomie vehicle energy evaluation platform toolset works in this "virtual vehicle" design space. The software uses high-performance computing to analyze millions of potential component and vehicle architectures, identifying optimization opportunities, and ultimately leading to more rapid commercialization of new technologies.

At a vehicle level, interactions between electric vehicles, the consumer and the electric grid continue to be ripe areas for expanded research. With medium- and heavy-duty vehicles accounting for about 30% of the energy used for transportation, researchers seek to identify the electrification and alternative fuel best suited to these work applications.

Transportation System

Finally, national laboratories are experts in the vital study of vehicles within systems. In these systems, sustainable transportation results from optimal integration of many rapidly changing facets—connected and automated vehicles, urban science, advanced fueling infrastructure, decision science, and multimodal transportation. The lab collaboration that I co-chair, the Systems and Modeling for Accelerated Research in Transportation, or SMART, Mobility Consortium, focuses on these questions surrounding optimal integration. A VTO initiative, the consortium includes Argonne, Idaho, Lawrence Berkeley, National Renewable Energy, and Oak Ridge national labs. The SMART Mobility Consortium is part of DOE's Energy Efficient Mobility Systems (EEMS) Program, which envisions an affordable, efficient, safe, and accessible transportation future.

With a goal of smart mobility—that is, moving people and goods more affordably and cleanly, with increasing choices and greater mobility access for more travelers—consortium researchers and others use models and field experiments to study the effects of not only advanced vehicle and infrastructure technologies, but also the impacts of new business models and modes of transportation. The result is a greater understanding from the vehicle to the city level. Researchers can tailor assessments of complex mobility systems to desired regional outcomes such as vehicle miles and hours traveled, passenger miles traveled, energy used, costs affected, greenhouse gases emitted, or productivity generated. An example of key insights from this work entail the consumer appetite for e-commerce as a replacement for shopping trips. One might surmise that the frequent trips of an Amazon or a FedEx delivery truck to your house result in a net energy penalty. However, the inverse is true when analyzed as a system. Avoiding a personal shopping trip in the family car for an 8-mile trip, as compared to an efficient package delivery system, saves overall vehicle miles traveled and energy used.

Per-capita increases in vehicle miles traveled, hours lost to congestion, and dollars spent on transportation compel innovation in vehicle components, the vehicle itself, and a connected transportation system where new technologies fit broadly. The aging U.S. population, urbanization, and a shift toward shared transportation are additional drivers for creative thinking and solutions to meet new mobility demands.

In this realm, national laboratory researchers analyze the effects of a range of innovations, from smart parking apps designed to help drivers improve energy use—by reducing the amount of time we drive—to vehicle-to-infrastructure connectivity like smart signal intersections. (It is important to note that this connectivity requires the high-speed 5.9-gigahertz spectrum that has been reserved for vehicle-related safety applications. Without this spectrum, the promise of future mobility technology could be significantly reduced.)

Researchers are studying impacts from a diverse set of solutions designed to increase the efficient movement of people and goods, such as those making ride-hail companies more complementary to mass transit and others that enable seamless intermodal passenger and multimodal freight transportation. Our ability to understand the complex interactions between all of these systems, technologies, business models, and emerging travel modes is paramount to achieving secure and robust smart mobility.

In a current partnership with the Chicago Departments of Aviation and Transportation, the Chicago Metropolitan Agency for Planning, the Chicago Transit Authority, and commercial partner Arity, a subsidiary of the Allstate Corporation, Argonne researchers are using distributed sensors and high-performance computing to develop solutions to reduce traffic congestion and minimize energy consumption and emissions in and around Chicago's O'Hare International Airport. The project will help predict the effects that a proposed major expansion project at O'Hare would have on congestion and energy use. Understanding such effects and applying approved technologies will guide all partners of the consortium in developing strategies to manage transportation.

Combining the DOE national labs computational horsepower—some of the world's fastest supercomputers are located at Argonne and other labs—with our capabilities in artificial intelligence, big data, computation, and predictive analytics gives lab researchers and their partners a scenario-based framework to analyze potential mobility futures, enabling us to guide implementation of new solutions that maximize benefits and minimize harms.

Looking through the lens of smarter mobility, researchers see ever-growing groups of new stakeholders on the horizon. We have strengthened collaborations with the Department of Transportation and other Smart Community research organizations to transfer knowledge and best practices, and to leverage and stretch R&D efforts.

The Next Generation of Transportation Scientists

As the national laboratories work in the present to achieve a sustainable transportation future, we remain cognizant of the need for workforce development to continue our charge. Argonne spearheads the EcoCAR Mobility Challenge program for DOE, which has a 30-year history of managing advanced vehicle technology competitions, representing 20,000 university graduates for a highly skilled domestic workforce over this tenure. Nearly half of the current 4-year program's content is devoted to connected and automated vehicle curriculum, development, and experimentation.

DOE's national laboratories and their facilities are America's powerhouses of science, technology, and engineering. They are principal agents of execution on missions of national importance, including the research, technological innovation, and system integration that comprise a sustainable transportation future. The work of the labs continues, applying expertise and coordinating the myriad of private and public stakeholders to make transportation more efficient, safe, convenient, and sustainable, and in so doing bring prosperity and security to all Americans.

Thank you for your time. I welcome any questions you may have.

Ann M. Schlenker
Director, Center for Transportation Research
Argonne National Laboratory
2019

Ms. Ann Schlenker is the Director for the Center for Transportation Research at Argonne National Laboratory. Ms. Schlenker's applied research area is actively seeking to improve efficiency at a component, vehicle and transportation system level, while preserving transportation consumer choice, affordability and domestic economic growth. Her responsibilities include evaluating the energy and environmental impacts of advanced technologies and new transportation fuels. Her portfolio includes early stage fundamental and applied Light and Heavy Duty vehicle research with an emphasis on low carbon solutions. She directs the transportation system energy modelling for Smart Communities with enhanced mobility offerings. In addition, Ms. Schlenker has responsibility for the DOE Student Vehicle Competitions for advanced powertrain technologies and connected and automated vehicles. Her research is informed by collaborative partnerships which ensure relevance and impact. Schlenker spent more than 30 years with Chrysler Engineering in Product Development, serving in a variety of executive positions.

Chairman LAMB. Thank you. Mr. Chen?

TESTIMONY OF JAMES CHEN, VICE PRESIDENT OF PUBLIC POLICY, RIVIAN AUTOMOTIVE, LLC

Mr. CHEN. Thank you. Good afternoon, Chairwoman Johnson, Chairman Lamb, Ranking Member Weber, Members of the Committee and the Subcommittee. My name is James Chen, and I'm the Vice President of Public Policy for Rivian Automotive. I wish to thank the Committee for the opportunity to testify today on technology pathways to accelerate sustainability in the transportation sector. I've submitted my written testimony, and will summarize the points briefly in this verbal testimony.

Founded in 2009, Rivian is an independent U.S. company dedicated to keeping the world adventurous through the development, production, and distribution of all electric pickup trucks and sport utility vehicles, or SUVs. Scheduled to commence production next year from our Midwest manufacturing facility, the R–1T pickup truck, and the R–1S SUV, will have a number of compelling features, including a range of up to 400 miles on a single charge; quad-motor all wheel drive; a 0 to 60 time of 3 seconds; 11,000 pound towing capability; and the ability to forge through 3-feet of water safely due to the sealed components. These are among many of the other features we have built into the vehicle. Backed by strategic investors that include Amazon, Inc., Ford Motor Company, and most recently Cox Automotive, we employ over 750 people currently at our various U.S. locations in Plymouth, Michigan; Normal, Illinois; and several locations throughout California.

Rivian's products are being developed and released as part of the technology revolution in transportation. In fact, vehicle electrification is the platform that will enable the development, optimization, and introduction of new transportation technologies such as, and including, connectivity and autonomy. The benefits of electrification are numerous, and, the Chairman, you had mentioned quite a few of these: Reducing dependence on foreign oil, promoting use of domestically produced electricity, national security, energy independence, a strong economy, and a cleaner environment.

Of these many benefits, three of the key benefits include the following, that I would like to highlight. First, leadership in technology. Lithium-ion battery technology was invented by an American scientist, now a professor at the University of Texas in Austin. Use of this technologies in cars was pioneered and matured by American companies. The U.S. cannot cede leadership and control of this technology to foreign countries, who are spending billions, literally billions of dollars, to foster and dominate this transportation technology in their own countries.

Second, maintaining this leadership is good for the economy. Using Rivian as an example, we purchased the formerly shuttered Mitsubishi manufacturing plant in Normal, Illinois back in 2017, less than a year after it shut down. We have already spent tens of millions of dollars in equipment and labor to rehabilitate that facility. When all is said and done, we will have spent over $400 million to rehabilitate this former facility. We will create over 1,000 manufacturing jobs, and we'll be producing, with luck, several hundred thousand vehicles out of this facility. Supporting EV technology increases investment in the United States, creating economic opportunity, and jobs in America.

Finally, electric vehicles are good for the environment. Every electric pickup truck and SUV supplants its internal combustion engine-equipped counterpart, lowering the emission of criteria pollutants and greenhouse gases. Minimizing emissions have very real benefits to public health, by lowering the causes of asthma, and other respiratory-related illnesses. Introducing electric vehicles reduces greenhouse gases. With 7 of the last 10 years being the warmest on record globally, we must do more to reduce greenhouse gases, and mitigate the effects of climate change.

While some critics of electric vehicles complain that the technology merely shifts the emissions from the vehicles to power plants at a greater level, this is simply not true. Several studies, including a BloombergNEF study from just last year, shows that, on average, carbon dioxide from battery electric vehicles are about 40 percent lower than their internal combustion engine counterparts, even when including the emissions from power plants providing the electricity for these vehicles. And the vehicle emission profile only becomes cleaner over time as power plants improve emission controls, include a greater mix of generation of sources, including renewables.

In conclusion, the U.S. is best served by robust investment and support of transportation electrification technologies. Congress has a strong role to play in promoting R&D in this technology, and supporting the manufacture and market introduction of this American innovation. Thank you again for this opportunity to testify today. I look forward to your questions.

[The prepared statement of Mr. Chen follows:]

RIVIAN

WRITTEN TESTIMONY BEFORE THE
U.S. HOUSE OF REPRESENTATIVES COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY

HEARING ENTITLED "THE NEXT MILE: TECHNOLOGY PATHWAYS TO ACCELERATE SUSTAINABILITY WITHIN THE TRANSPORTATION SECTOR"

JAMES CHEN
VICE PRESIDENT OF PUBLIC POLICY
RIVIAN AUTOMOTIVE, LLC

September 18, 2019

Chairman Lamb, Ranking Member Weber and distinguished Members of the Subcommittee, thank you for the honor of appearing before you today for this important hearing on ways that the United States can accelerate sustainability in the transportation sector. My name is James Chen and I am the Vice President of Public Policy for Rivian Automotive, LLC.

Founded in 2009 by R.J. Scaringe, a PhD engineering graduate of MIT and a member of MIT's Sloan Automotive Laboratory, Rivian is an independent U.S. company dedicated to the mission of keeping the world adventurous forever, through production and promotion of sustainable transportation. Rivian will be producing two new vehicles next year – a light duty pick-up truck named the R1T and an SUV named the R1S. Both vehicles were unveiled at the L.A. Auto Show in 2018 and have been showcased at various locations throughout the U.S. Both the R1T pick up truck and the R1S SUV will have a range of up to 400 miles on a single charge, quad motor equipped all wheel drive, dynamic air suspension, and a rugged chassis that will enable all-electric, zero emission off-road excursions. In addition, the pick up truck will have seating for five adults, class leading storage in a front truck and side gear tunnel, along with a bed payload capacity of over 1,700 pounds and a rated towing capacity of over 11,000 pounds. The SUV will seat seven adults and have class leading storage through innovations like a front truck, class-leading rear cargo space and folding seats for expanded storage.

Both of these vehicles (as well as future electric adventure vehicle products) were designed and engineered at our Vehicle Design and Engineering Center in Plymouth, Michigan, Representative Haley Steven's district. Both the R1T and R1S will be produced at our 2.6 million square foot production facility in Normal, Illinois, currently under renovation and rehabilitation. In addition to these Midwest facilities, Rivian also has several battery, powertrain, and advanced technology research and development centers in California. Our mission and approach has been validated by strategic partners who have collectively invested over $1.5 billion in Rivian. These strategic investors are leading technology and automobile companies and include Amazon.com, Inc., Ford Motor Company, and most recently, Cox Automotive. Rivian is bringing all electric adventure vehicles and platforms to market to promote zero emissions transportation and to enable exploration of our planet in a manner that is sustainable, safe, and reliable utilizing technology that was developed and built in the United States.

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There can be no question that transportation in the United States is on the verge of a technological revolution. Car-sharing, ride-sharing, and automation are some of the new and exciting technologies promising to transform transportation as we know it. However, no technology shows more potential to provide a wider spectrum of benefits than electrification. In fact, the electric vehicle platform is vital to enable the rest of the aforementioned new transportation technologies to come to market.

Despite the gains made over the past ten years, electric vehicles still only comprise less than 2% of all new car sales in the United States. More must be done to promote this promising American technology. Rivian strongly supports the efforts by this Subcommittee and legislators promoting new transportation technologies such as House Bill 2170, the Vehicle Innovation Act of 2019. This bill would promote research and development in vehicle electrification, support new and improved methods of manufacturing for this technology, and address life cycle uses of electric vehicle batteries and their various components.

The benefits of electrification are numerous. Electrifying transportation in the United States will reduce our dependence on fossil-fuel based sources of energy, lower the total cost of ownership for consumers, promote use of domestically produced electricity, strengthen the grid infrastructure and foster national security, energy independence, a stronger economy and a healthier environment. Of these many advantages, the three that provide the most compelling justification for U.S. investment are our national interests in technology leadership, positive contributions to the economy, and protection of our environment.

More than ever, the United States must lead in the area of new transportation technology. Lithium ion battery technology was invented by U.S. physicist John Goodenough, now a professor at the University of Texas, Austin. Modern use of this battery technology in cars was introduced by the founders of Tesla Motors, Inc., who proved that long-range, highway capable, battery electric vehicles were not only possible, but in many respects, superior to the incumbent technology of internal combustion engines in terms of performance, efficiency and utility. The United States cannot afford to cede leadership in this technology to other countries – a number of whom are spending significant sums to develop and lead in the area of electric vehicle technology. For example, in the last decade alone, China has spent nearly $60 billion dollars to create an industry that builds electric vehicles, while reducing the number of licenses available for gasoline powered cars to increase electric vehicle demand. In addition, becoming the world leader in electric vehicle technology and production is part of China's "Made in China 2025" initiative. The United States simply cannot let the technology invented in the U.S. be dominated by other countries. We have already seen the dangers of allowing foreign countries dominate an industry. For example, 95% of rare earth minerals are produced exclusively in China. In the early part of this decade, China sent world markets roiling when it drastically reduced the allowed export of rare earth minerals. With rare earth minerals used in critical industries as computer memory, rechargeable batteries, cell phones, air pollution control, magnets, fluorescent lighting; and critical defense uses such as precision-guided weapons, night vision goggles, communications equipment, and GPS equipment, restriction of this resource was a substantial threat to the U.S.' security and economy. Such foreign dominance cannot be allowed with it comes to new transportation technology.

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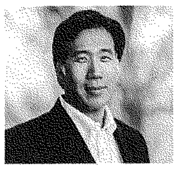
Promoting electric vehicles has very real and tangible economic benefits to the U.S. Using Rivian as an example, the Company acquired the former Mitsubishi production plant in Normal, Illinois in 2017. Originally slated to be torn down and repurposed for mixed use residential and commercial, Rivian will instead, be investing over $400 million into this facility and create over 1,000 direct manufacturing jobs. Rivian has already hired over 130 full time employees at the facility and has already spent millions on equipment and factory rehabilitation. The Company will begin production by the fourth quarter of 2020 and quickly ramp up production in the ensuing years. Ensuring electric transportation technology is supported and promoted in the United States will be instrumental in allowing Rivian to move forward with its investment and create economic opportunity and jobs in America.

Finally, electric vehicles are simply good for the environment. With zero emissions, every electric pick up truck and SUV introduced in the market supplants its gasoline powered counterpart thereby reducing criteria pollutants such as carbon monoxide, nonmethane hydrocarbons, oxides of nitrogen and particulate matter. Minimizing these pollutants is vital to the health of the American public with incidents of childhood asthma and other lung related ailments on the rise. Moreover, every zero emissions vehicle added to the U.S. fleet also reduces the overall greenhouse gas emissions profile of our transportation sector, which accounts for the majority of greenhouse gas emissions in the United States, according to the U.S. Environmental Protection Agency. In fact, reducing our greenhouse gas footprint is not simply desirable, but vital to begin to address the very real threat of climate change. 2019 will soon be recorded as hottest year on record. Not including this year, seven of the last ten years globally have been the hottest on record. According to the Intergovernmental Panel on Climate Change ("IPCC"), global greenhouse gases must drop 55% by2030 to limit the adverse impacts of climate change and limit global warning to only 1.5°C. With total greenhouse gas emissions at around 53.5 gigatons, this means that we need to eliminate 29 gigatons by 2030. Switching our transportation sector to zero emission technology is part of the solution. While some critics of electrification complain that electric vehicles simply shift emissions from the vehicles to the power plant, numerous studies, including a 2015 study by the Union of Concerned Scientists (updated in 2018) and a 2018 study by BloombergNEF, have found carbon dioxide emissions from battery-powered vehicles were about 40% lower than for internal combustion engines, even when accounting for emissions from powerplants. And those vehicles will become even cleaner as the grid continues its current trend of reducing reliance on fossil fuel for electricity generation, providing greater emissions reductions as these vehicles are utilized over time.

In conclusion, the United States is best served by robust investment and support of transportation electrification technologies. Such investment maintains America's leadership in this developing technology, supports and promotes the economy, and improves the environment assuring cleaner air for all Americans. Congress has a strong role to play in promoting research and development in this technology and supporting the manufacture and market introduction of this American innovation.

Chairman Lamb, Ranking Member Weber and distinguished Members of the Subcommittee, thank you again for the opportunity to testify today. I look forward to your questions.

James Chen, Vice President of Public Policy
RIVIAN AUTOMOTIVE, LLC



Serving as Vice President of Public Policy, James "Jim" Chen is responsible for all policy issues and government relations at Rivian Automotive, LLC. He is also tasked with oversight of regulatory requirements applicable to Rivian's products and facilities.

Prior to joining Rivian, Jim spent six years at Tesla, Inc. working first as its Director of Public Policy & Associate General Counsel, and ultimately as Vice President of Regulatory Affairs & Deputy General Counsel. During his tenure at Tesla, Jim utilized his extensive knowledge of international, federal, state and local government relations and policy to further Tesla's mission of catalyzing sustainable energy in the transportation sector during its most formative years (2010 – 2016); as well as providing strategic business development advice and accomplishments on behalf of that company. Between Tesla and Rivian, Jim also spent time as Vice President and General Counsel for two other start up electric vehicle companies, Chanje Energy, Inc. and Faraday Future, Inc., as well as being an independent consultant to other entities in the new transportation arena.

Jim came to the alternative energy and transportation space from nearly fifteen years as a prominent Washington, D.C. attorney – first as a partner in the Environmental Practice of the Washington, D.C. law firm of Hogan & Hartson LLP (now Hogan Lovells LLP) and later as a partner in the Washington D.C. law firm of Crowell & Moring LLP where he was the co-chair of the firm's Product Risk Management Group and a member of the Environment and Natural Resources Group. During his time in the private firm sector, Jim represented a number of established automobile and truck manufacturers, as well as various industry suppliers on environmental and safety regulatory and policy issues affecting the transportation sector. Jim also maintained a lucrative practice in the area of chemical and pesticide regulation, as well as environmental compliance and due diligence. Jim started his legal career as an Honors Hire at the U.S. Environmental Protection Agency's Office of Enforcement.

Jim is a graduate of Case Western Reserve University – School of Law and has a bachelor's degree from the State University of New York at Buffalo.

Chairman LAMB. Thank you. Mr. Coleman?

TESTIMONY OF BROOKE COLEMAN, EXECUTIVE DIRECTOR, ADVANCED BIOFUELS BUSINESS COUNCIL

Mr. COLEMAN. Thank you. Good afternoon, Chairman Lamb, Ranking Member Weber, Members of the Subcommittee. My name is Brooke Coleman. I am the Executive Director of the Advanced Biofuels Business Council. The Council represents worldwide leaders developing and commercializing next-generation advanced and cellulosic biofuels, ranging from cellulosic ethanol made from agricultural residues to advanced biofuels made from sustainable energy crops and municipal solid waste.

Let me start by thanking the Committee and staff for looking at the question of how we are going to make the transportation sector more sustainable. As you know, the transportation sector now emits more carbon than any other in the United States, and yet, take it from the biofuels industry, it is not an easy sector to disrupt. One of the underlying challenges we face on the fuel side is the unfortunate reality that fuel markets are not free markets. They are highly subsidized, vertically integrated, and consolidated. That makes Federal agency engagement, from R&D, to loan guarantees, to vehicle readiness, much more difficult. The corrective policies driving demand for us, like the renewable fuel standard, must move together with front-end technological development and back-end market readiness related to vehicles, pumps, and fuels to be optimized. If one piece falls out, commercial deployment slows, sometimes to a grind.

This is where we find ourselves with many advanced biofuel technologies. DOE, together with USDA (U.S. Department of Agriculture), was instrumental in pushing cellulosic biofuels forward. We are producing commercial volumes now, but we are also grinding on the scaling side, largely because the demand side part of the equation faltered. And I know this isn't an RFS hearing, but EPA did stop enforcing the RFS for 3 years, starting in 2013, then destroyed four billion gallons of policy-driven demand thereafter with the oil refinery waivers you're reading about in the news today. It's just hard to hit milestones when the demand-side policy isn't enforced, and it's hard to expect DOE to absorb 100 percent of that demand risk.

So the question is, where do we go from here? First and foremost, and I'm not just saying this because I'm bookended by them, we need robust support from the National Labs. This is, to set the record straight, what is actually happening type of work essential for emerging industries trying to break through information warfare campaigns designed to impede important change. I cannot tell you the number of times I have cited, and my community has cited, vehicle emissions testing led by NREL (National Renewable Energy Laboratory), carbon modeling led by Argon, and compatibility analysis led by Oak Ridge to set the record straight against industry-funded misinformation campaigns.

Second, programs designed to showcase, perhaps at smaller scale, what can be done in the near term are invaluable. The Co-Optima Program is one example. To my knowledge, ethanol is the only cost-reductive technology available today in the transportation sector to reduce GHG emissions. Optimizing its use leverages a global competitive advantage that we have in agriculture, and supports rural American economies struggling under the weight of trade wars, more extreme weather, and urbanization. We need to harvest ready-made solutions if we're going to harness the full potential of biomass to displace or compete with petroleum.

Demonstrations on the crop side are also valuable. When implemented, the Biomass Research and Development Initiative showcased the degree to which land management practices can reduce carbon emissions, while improving bottom lines. New initiatives could be patterned after the Novozymes Acre Study, which demonstrated the viability of boosting feed, fuel, and energy derived from one acre of corn, while avoiding 1.1 metric tons of CO_2 emissions.

Finally, there's the question of where best to engage, and it's a difficult question, on the commercial deployment side. For many of our companies it's all about deployment. There's a big difference between testing a new enzyme at small scale and throwing it into your main fermenter that you rely on every day to pay the bills. There's a difference between turning a bale of stover into cellulosic ethanol, which we've done many times, and turning a conveyor belt of stover into cellulosic ethanol.

Many of our companies simply don't have the staff, time, and resources to do the planning, engineering, and implementation of plant-scale testing necessary to deploy new technology. The expense of outsourcing stalls the deployment of integrative biorefining technologies that we know to work. That's the sweet spot for expenditure of applied deployment dollars and agency time for us. Of course, excuse me, many staff, including DOE staff, understand this because they ran programs just like this for several years. An important adjustment going forward would be to balance the desire to focus on ultra new technologies, and overly constrained categories like "non-food" with engagement with ready-made solutions at existing plants that could produce transformative results in the immediate term. There are just too many clear benefits of using commercially available and abundant agricultural feed stocks for renewable chemicals, biodegradable plastic, and new fuels, while meeting demand for food and feed.

I will also close with a brief appeal. It's not always about budget. We have American-made, deployment-ready, low-carbon bioenergy solutions unnecessarily parked as we speak. DOE has been very supportive of reviewing testing protocols to determine how much corn fiber cellulosic ethanol conversion we are getting out of our processes. This is a fuel with a 126 percent benefit over petroleum. From a greenhouse gas perspective, a true carbon sink. We don't need technological breakthrough there. We need EPA to cut these technologies loose. And if DOE is qualified, and certainly they are, to engage with us on the testing side, they are more than qualified to engage with EPA, their counterparts, in getting these fuels out the door. Thank you very much. We appreciate the opportunity to be here today.

[The prepared statement of Ms. Coleman follows:]

Written Testimony of:

Mr. Brooke Coleman

Executive Director, Advanced Biofuels Business Council

U.S. House of Representatives Committee on Science, Space and Technology

Subcommittee on Energy

THE NEXT MILE: TECHNOLOGY PATHWAYS TO ACCELERATE SUSTAINABILITY WITHIN THE TRANSPORTATION SECTOR

September 18, 2019

Good morning Chairman Lamb, Ranking Member Weber, and members of the Subcommittee. My name is Brooke Coleman. I am the Executive Director of the Advanced Biofuels Business Council.

The Advanced Biofuels Business Council (ABBC) represents worldwide leaders developing and commercializing next generation, advanced and cellulosic biofuels, ranging from cellulosic ethanol made from agricultural residues to advanced biofuels made from sustainable energy crops and municipal solid waste. Our members include those operating production facilities, those augmenting conventional biofuel plants with "bolt on" or efficiency technologies and those developing and deploying the technologies that make advanced biofuel production a commercial reality, including some of the largest cellulosic ethanol and advanced biofuel enzyme production facilities in the world.

Thank you for the opportunity to be here today to discuss future energy challenges and technology pathways to accelerate sustainability within the transportation sector. The United States must stay vigilant when it comes to developing next generation energy technologies. It is a matter of economic security. It is a matter of national security. And it is imperative for the protection of public health and the environment.

1. The importance of energy innovation to the U.S. economy

Energy innovation has helped drive U.S. economic growth for more than 200 years, and government support has been the catalyst for energy innovation for more than a century.[1] Governmental support drove investment in coal, timber, engine innovations, land settlement for resource extraction and other forms of innovation in the 19th and 20th centuries, and domestic energy consumption and GDP have tracked closely for at least 200 years.[2] Global energy demand rose 2.3 percent in 2018 – its fastest pace in the last decade.[3] From an opportunity perspective: (1) ongoing energy demand growth presents a massive and growing market opportunity for countries willing to seize it; (2) much of the U.S. competitive advantage over the last two centuries has come from our ability to innovate in the energy sector, and "technological innovation is linked to three-quarters of the Nation's post-WWII growth rate, with two innovation-linked factors – capital investment and increased efficiency – representing 2.5 percentage points of the 3.4% average annual growth rate achieved since the 1940's;" and, (3) other countries have made big commitments to energy innovation that are already drawing energy projects away from the United States.[4]

Government support has been critical in the fuel energy sector as well. For example, the shale boom has transformed the United States into one of the world's top oil and gas producers and a leading exporter of fossil fuels. And yet, one of the corporate leaders in the U.S. shale boom credited advantageous federal tax policy as a linchpin to developing the technology: "[w]ithout the current capital provisions in place, we would not have been able to fail over and over again, which is what it took to advance the technology needed to produce the Bakken and numerous other resource plays across America. And it is this technology that allows us to drill two miles down, turn right, go another two miles and hit a target the size of a lapel pin is the technology that has unlocked the resources that make energy independence a reality."[5] And

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[1] See http://www.dblpartners.vc/resource/what-would-jefferson-do/.
[2] *Id.*
[3] https://www.iea.org/newsroom/news/2019/march/global-energy-demand-rose-by-23-in-2018-its-fastest-pace-in-the-last-decade.html
[4] See http://waysandmeans.house.gov/uploadedfiles/colemantestimony922.pdf, referencing U.S. Department of Commerce, *Patent Reform: Unleashing Innovation, Promoting Economic Growth & Producing High-Paying Jobs* (2010).
[5] http://www.finance.senate.gov/imo/media/doc/Hamm%20Testimony1.pdf, p. 2.

much of the technological development occurred in partnership with federal energy agencies. According to the Congressional Research Service, [f]or the period from 1948 through 2012, 11.6% of federal energy agency R&D spending went to renewables, 9.7 % to efficiency, 25% to fossil energy, and 49.3% to nuclear.[6]

This is not just a matter of context. Cellulosic biofuel producers and "tight oil" producers have something in common; they are both endeavoring to supply the country and world markets with what the Energy Information Administration (EIA) terms "unconventional fuel." While facing similar technology risk, cellulosic biofuels (and many other renewable energy types) do not receive equitable federal support as fossil fuels (from the perspective of value or duration). In addition, global oil markets are price-controlled by OPEC and are extremely consolidated and vertically integrated domestically. While not the subject of this committee hearing, it is important to note that the absence of free market forces in the liquid fuel marketplace is a problem for the advanced biofuels industry (and other innovators) because non-competitive marketplaces do not properly facilitate and reward innovation. It is another reason why the federal government must stay engaged when it comes to supporting advanced biotechnologies.

2. The importance of energy innovation to national security

There is little question that the oil shale boom has impacted U.S. policy, causing a general shift in approach from a scarcity mindset to maximizing the economic and energy security benefits of producing and exporting more oil. Some have argued that we do not need renewable fuels in the wake of the shale boom and amidst declining gasoline demand. First and foremost, gasoline demand is increasing, not decreasing. We saw the highest gasoline consumption rate ever recorded in the United States in 2018.[7] Gasoline consumption also

[6] See http://www.fas.org/sgp/crs/misc/RS22858.pdf
[7] See https://www.eia.gov/petroleum/weekly/gasoline.php, June 20, 2018

reached a record high in 2016, breaking the previous record from 2007. Consumption is consistently matching that level and expected to reach another record high in 2019.[8]

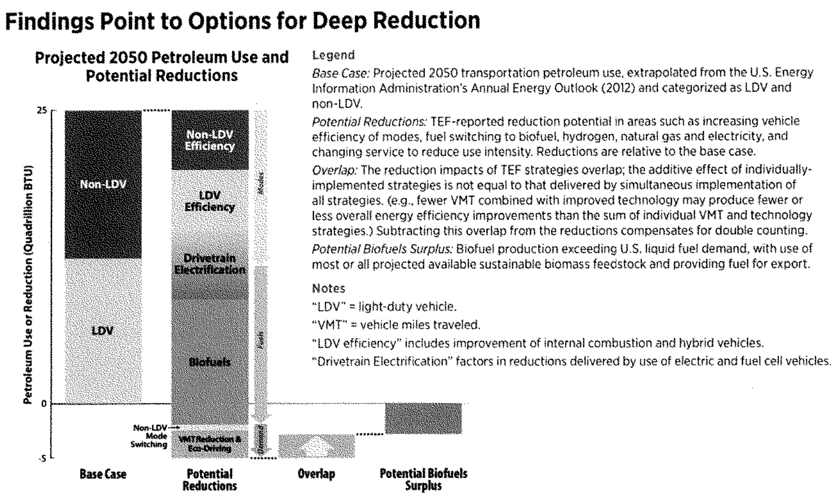
Perhaps more importantly, producing more oil domestically should not be confused with eliminating the national security (and economic) problems associated with remaining dependent on foreign oil. The United States still imports more than 40 billion gallons of foreign oil from OPEC countries alone per year (or ~3M barrels per day).[9] The trade deficit impact of foreign oil imports is now partially recovered by U.S. oil exports – now allowed after the U.S. ban on crude oil exports was repealed in 2015 – but trade deficits do not tell the whole story. American consumers continue to inject OPEC countries with tens of billions of U.S. consumer dollars every year, global oil prices remain vulnerable to natural and human-made supply disruptions, and the U.S. economy is still exposed when it comes to oil price spikes. Just this week, Securing America's Future Energy (SAFE) called the drone attacks in Saudi Arabia "yet another wake-up call to the United States that a disruption in supply anywhere in the world impacts prices everywhere. We must not let our current high domestic production cause complacency in our energy policymaking." In addition, the American taxpayer spends about $81 billion a year to protect oil supplies around the world and keep fossil fuels flowing into U.S. gas stations, according to a 2018 analysis by SAFE.[10]

3. Where we stand in the development of advanced bioenergy systems and products

In 2013, the Department of Energy released the Transportation Energy Futures report – synthesizing the work of multiple national laboratories investigating what is technologically achievable to reduce (carbon) emissions from the transportation sector. The results were encouraging. Looking at the technologies available on the immediate and near horizon, they found that the U.S. could feasibly eliminate petroleum use in the transportation sector by 2050.

[8] See https://www.eia.gov/outlooks/steo/marketreview/petproducts.php; June 20, 2018.
[9] https://www.eia.gov/totalenergy/data/monthly/pdf/sec3_10.pdf
[10] https://www.cnbc.com/2018/09/21/us-spends-81-billion-a-year-to-protect-oil-supplies-report-estimates.html

And the labs detailed a scenario where we could meet our domestic liquid fuel needs and emerge as a net exporter of low-carbon biofuels.[11]



Crucially, this is not a theoretical scenario requiring the invention of a transformative technology or convincing millions of people to change their behavior. This is a "no-sacrifice" scenario – derived from a scientifically-derived picture of what we know can reasonably be achieved – that does not require Americans to give up flying or driving. It is also important to recognize that the biofuels projections are built from the ground up from the Department of Energy Billion Ton Report, which determined that the U.S. could produce one billion tons of biomass every year without adverse effects on either the environment or food markets.[12] Using this conservative production level as a baseline, biomass could replace about 30 percent of our current petroleum use without requiring significant shifts in production agriculture and land use. Even in the most optimistic scenarios, we will need low carbon liquid fuels for air travel,

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[11] https://www.nrel.gov/docs/fy13osti/56269.pdf
[12] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

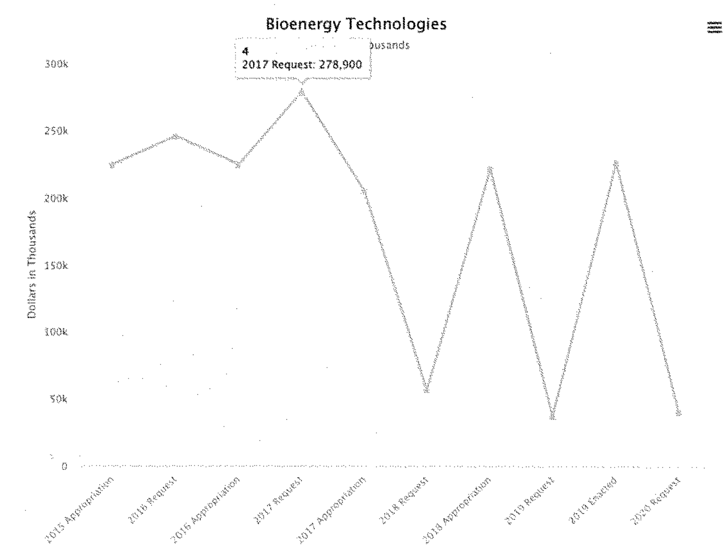
long haul trucking, and oceangoing transport. It is likely that we will need low carbon liquid fuels for light duty vehicles as well.

While it is encouraging to see what is achievable, we are not moving down this path aggressively enough to achieve the stated result of eliminating petroleum use by 2050.

The good news is the United States remains in position in to lead the world in the production of advanced bioenergy technologies. For example, a Bloomberg analysis looked at select regions in the world to assess the potential for next generation ethanol production.[13] The study found that eight regions – Argentina, Australia, Brazil, China, EU-27, India, Mexico and the United States – could displace up to 50 percent of their demand for gasoline by 2030 making cellulosic ethanol from a very small percentage of its each region's agricultural residue supply alone. The industry is embarking on the process of securing efficiencies that can only be achieved via commercialization (i.e. the "experience curve") and economies of scale. When the corn ethanol industry started building plants, their production costs exceeded their feedstock costs by a large margin. However, corn ethanol producers have reduced their production costs by roughly 60 percent since the first commercial plants were built in the 1980s. Likewise, some solar companies have seen a similar 60-70% production cost reduction in just the last ten years, as capacity has increased significantly. Advanced ethanol technology – particularly in the areas of agricultural residues (corn fiber, stover, wood waste, etc.) and municipal solid waste – are at this point. For example, in 2016-2017 EPA staff identified ethanol made from corn fiber as a cellulosic biofuel exceeding commercial expectations and forecasts. Every one of 200+ ethanol bio-refineries in the United States has a natural interest in taking advantage of an under-utilized cellulosic feedstock (corn residues) already at the plant feedstock door. Likewise, regions with high population densities have access to large amounts of municipal solid waste (MSW) – the large majority of which is cellulosic material (paper, cardboard and wood materials).

[13] See http://www.novozymes.com/en/sustainability/benefits-for-the-world/biobased-economy/white-papers-on-biofuels/Documents/Next-Generation%20Ethanol%20Economy_Executive%20Summary.pdf

The bad news is ongoing policy instability creates a ripple effect of investment uncertainty that is slowing down the deployment of advanced biotechnologies. There is tremendous political (and therefore outcome) uncertainty around advanced biotechnology tax provisions, farm bill programs, demand-side policies (e.g. the Renewable Fuel Standard/RFS) and R&D budgets. On the DOE budget side, Congress has pushed back admirably against efforts to de-fund critical advanced bioenergy programs. However, fiscal uncertainty is very difficult for companies to plan against and thereby dampens engagement in these vital programs.



Ironically, Department of Energy (DOE) programs also get ensnared in the policy uncertainty ripple effect. For example, the RFS is designed to break open a motor fuel supply chain largely controlled by the oil industry to provide demand opportunity for both conventional and advanced biofuels. Proper implementation of the RFS would help crack the commercial demand equation for emerging technologies, thereby facilitating success across the vast array of public/private partnerships (including DOE's Title 17 loan guarantee program) deployed by DOE over the years. Unfortunately, the RFS was not enforced in the 2014-2016 timeframe during a critical stage of cellulosic biofuel commercial deployment. The programs designed to facilitate the commercial deployment of advanced bioenergy then get bogged down in risk and politics. Today, many of the emerging RFS fuel pathways for cellulosic biofuels cannot get fuel eligibility registrations from EPA. And the nearly 400 percent increase in Small Refiner Exemptions (SREs) issued by EPA in the 2016-2018 timeframe has wiped out 4 billion gallons of biofuel demand across all biofuel categories (including advanced biofuels). While DOE cannot solve demand-side issues, it can provide more stability in developing technologies.

4. Recommendations

Support Biofuels and Department of Energy Laboratories. As you know, the work of the Department of Energy to advance research, development, demonstration, and commercial application is principally advanced through its Bioenergy Technologies Office (BETO) where it works to advance cost-competitive advanced biofuels from "non-food" biomass resources, including cellulosic biomass, algae, and wet waste. This work has been advanced by a number of the Department of Energy's laboratories including Oak Ridge, Argonne, and the National Renewable Energy Laboratory (NREL). For instance, the Center for Bioenergy Innovation (CBI), led by Oak Ridge National Laboratory, works to develop perennial nonfood crops that thrive in the harsh environment of marginal lands, require less fertilizer and pesticide, and are more easily broken down and converted to advanced biofuels and bioproducts. Argonne National Laboratory, in collaboration with NREL, has conducted valuable research on emerging biomass feedstocks through x-ray absorption spectroscopy that has the promise of delivering better catalyst technologies to the market. Argonne also developed the best carbon accounting model in the world (GREET) that is the model for the California Low Carbon Fuel Standard (LCFS). In an age of industry-funded, asymmetric information warfare – often involving manipulated carbon and land use modeling for bioenergy – it is absolutely critical to maintain independent and objective sources of information (e.g. Argonne, Oak Ridge, NREL, LL, etc.). While there are numerous other examples of biofuels work led by our national laboratories that are worth referencing, it is equally important to note that without a robust funding and direction for offices like the Office of Science and Bioenergy Technologies Office, progress will stagnate. I hope this Committee will continue to prioritize its work on accelerating a cleaner, greener, and more secure transportation future because the leadership you provide is vital.

Reorient the Bioenergy Technologies Office (BETO) with TEF and BT reports. The Transportation Energy Futures and Billion Ton reports concluded that in order to rapidly decarbonize transportation we must aggressively reduce petroleum's role in our economy with biomass as a key player in the effort. BETO would reorient (where necessary) and redouble its efforts (where existing) to produce analysis that supports using biomass to the maximum extent possible with existing infrastructure (and fleets) as well as researching the direct replacement of petroleum-derived products in fuels, chemicals, and products. For example, the current limitations on biofuel use – such E15 limits on pumps or guidelines on vehicles – are generally derived from historical practice rather than scientific analysis. National labs could play a valuable role in sorting out technical fact from fiction regarding how compatible higher blends are with refueling infrastructure and vehicles. However, this will only happen if the agencies are tasked with catalyzing maximum feasible petroleum displacement. National labs also have a key analytical role in the continual improvement of the GHG footprint of biofuels, in addition to correcting the record when necessary, by identifying the most economically efficient ways to widen the gap with fossil fuels throughout the production chain.

Increase funding for Low Carbon Bioenergy R&D. If we are going to take the IPCC report and the global competition to produce clean energy seriously, R&D funding must be commensurate with the scale of the challenge. Key pieces of the transportation economy have no other near-term, climate-friendly solution beyond biomass. R&D efforts should be of sufficient size and focus to deliver viable alternatives in all of these sectors within the next 5-10 years and early market support should be put in place to compete with other nations.

Focus Public-Private Partnerships on Integrated Bio-refining/Applied Research. Like many emerging industries, we have developed promising technologies at smaller scale. The critical next step is further developing these technologies and capturing efficiencies only achievable at larger scale. In addition to restoring funding for previous work on catalysts, feedstocks, and feedstock handling, R&D efforts should return to their emphasis on integrated biorefineries that can maximally extract value from biomass and displace the whole range of products currently produced from fossil fuels. While the 200+ ethanol plants and ~100 biodiesel plants located in the United States are often seen as single-product (i.e. ethanol or biodiesel) biorefineries ineligible for partnerships due to sometimes ineffectual program designations, the reality is these refineries have an eye for the future – in which biofuel producers are managing full-scale integrated biorefineries producing many types of biofuels, feed, biochemicals and materials for biodegradable plastics. The DOE program objective should work backwards from the billion ton report – maximizing displacement of oil in the economy with an ultimate goal of eliminating its use—rather than continuing to pit technologies such and ICE efficiency, electrification, fuel cells, and biofuels against each other for the same market niche. Creative use of existing loan programs, coupled with: (a) production and technical support; and, (b) dependable offtake like past partnerships with the Department of Defense will help break the current bottleneck for advanced (fuel) biotechnology. Public-private partnerships focused on demonstrating integrated biorefining technology would also reenergize many of the programs currently under review. There is no question that the Department of Energy can be a vital catalyst for major partnerships with the private sector with programs properly designed to leverage existing "in-ground" investment and assets.

Support Biofuel Analysis at the Energy Information Administration. While the Energy Information Administration (EIA) is under the purview of a different committee, it is worth noting how critical it is to have access to unbiased statistics. The data that EIA provides to lawmakers and the marketplace helps inform decision-making on a myriad of levels. As the biofuels/bioenergy industry grows, it is important that our primary market surveying agency has the funding and tools to track bioenergy utilization in real-time (and not just as a subset of gasoline/diesel consumption). Ensuring that EIA has the resources it needs is vital, because lag-time between its collection of data and its dissemination to the public can be critical when helping to inform public policy decisions.

Thank you for the opportunity to speak with you today, and I look forward to your questions.

See: Addendum A

ADDENDUM A: Carbon Impact of Bio-Based Fuels

When advanced bioenergy products become disruptive to the status quo – as renewable fuels have in the United States – it is common for incumbents to try to dampen enthusiasm by commissioning countervailing research. In these situations, it is critical to focus on independent research. As such, this addendum is based on analysis conducted by U.S. EPA, the California Air Resources Board (CARB), the U.S. Department of Energy, the U.S. Department of Agriculture and top energy labs such as Argonne and Oak Ridge National Laboratories.

Peer-reviewed analysis coming out of the U.S. Argonne National Laboratory shows that all types of ethanol – even the first-generation ethanol usually scrutinized for its GHG emissions – have significantly lower lifecycle greenhouse gas emissions than petroleum, even with penalties for indirect land use change. It is worth highlighting that the Argonne National Laboratory developed the GREET model, which remains the gold standard for modeling carbon lifecycle emissions from fuels (and is the analytical basis for the California Air Resources Board Low Carbon Fuel Standard as "CA-GREET"). Many of these biofuels are significantly more carbon reductive than technologies often regarded to be the most innovative in the world. Some cellulosic ethanol facilities can deliver fuel to market with more than a 90 percent greenhouse gas emissions reductions.

Well-to-Wheels Greenhouse Gas Emissions Reduction

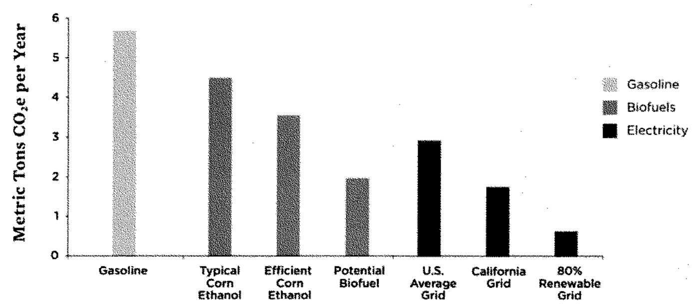
Relative to Average Petroleum Gasoline (including indirect land use change)

WTW GHG emission reductions	Corn	Sugarcane	Corn stover	Switchgrass	Miscanthus
Including LUC emissions	19–48% (34%)	40–62% (51%)	90–103% (96%)	77–97% (88%)	101–115% (108%)
Excluding LUC emissions	29–57% (44%)	66–71% (68%)	89–102% (94%)	79–98% (89%)	88–102% (95%)

Source: Argonne National Laboratory[14]

[14] See http://iopscience.iop.org/1748-9326/7/4/045905/pdf/1748-9326_7_4_045905.pdf

Compared with Gasoline, Alternatives Are Clean and Getting Cleaner



A typical car produces 6.7 metric tons of global warming pollution each year, once emissions from oil extraction and refining are added to tailpipe emissions. Biofuels and electricity are cleaner, and have the potential for dramatic improvements in the future.

Note: The global warming emissions of gasoline represents the metric tons of CO_2e associated with the production and consumption of fuel required to power a typical car (getting 25 miles per gallon, or mpg) for a year (driving 12,000 miles). This is compared with the energy equivalent amount of ethanol. For electricity the emissions represent the production of fuel (e.g., coal, natural gas) and consumption by power plants to generate a quantity of electricity needed for a similar vehicle traveling the same distance, adjusted for electric drive efficiency

SOURCE: CARB 2015A, CARB 2015D; UCS ANALYSIS; NEALER, REICHMUTH, AND ANAIR 2015; HAND ET AL. 2012

The carbon benefits of increasing the use of renewable fuels are even greater when you consider real world conditions – i.e. the fact that renewable fuels replace higher carbon marginal (rather than average) gallons of petroleum. To illustrate, Petrobras chief Jose Sergio Gabrielli has declared that "the era of cheap oil is over." This means that oil companies have shifted to an increasing reliance on more expensive and riskier "unconventional" fuels – including tight/shale oil (e.g. the Bakken), deep water (e.g. Gulf of Mexico, Deep Water Horizon) and Canadian tar sands (e.g. Keystone) – to meet the global demand for fuel energy.[15] Unconventional oil is harder to find and can result in serious ecological problems (earthquakes, drinking water contamination, ecosystem destruction in the case of the Gulf). These fuels are also more carbon intensive than the "average petroleum" often used to compare the carbon value of renewable fuels. There are many recent studies that have looked at the real world "marginal" impact of increasing the use of renewable fuels. One of the more extensive is a 2014 analysis conducted by Life Cycle Associates in California, which concluded that first-generation

[15] See http://www.eia.gov/forecasts/aeo/MT_liquidfuels.cfm#crude_oil

ethanol – assessed by EPA in 2010 to be 21 percent better than 2005 petroleum with regard to lifecycle GHG emissions – is 32 percent better than 2012 average petroleum and 37-40 percent better than petroleum derived from tar sands and fracking. The report recognizes that using less renewable fuel, as would be the case with the current proposal, will increase the use of these unconventional types of oil:

> The majority of unconventional fuel sources emit significantly more GHG emissions than both biofuels and conventional fossil fuel sources ... [t]he biggest future impacts on the U.S. oil slate are expected to come from oil sands and fracking production ... significant quantities of marginal oil would be fed into U.S. refineries, generating corresponding emissions penalties that would be further aggravated in the absence of renewable fuel alternatives." *Source: Life Cycle Associates, January 2014*

These findings are consistent with recent (lower resolution) assessments by federal agencies. For example, a recent report released by the Congressional Research Service (CRS) found that Canadian oil sands are 14-20 percent more carbon intensive than the 2005 EPA baseline.[16] As such, it is an inescapable reality that any proposal to increase renewable fuel blending is a proposal to reduce U.S. consumption of high carbon intensity, unconventional oil. If the high-carbon-intensity marginal gallon of oil is displaced by cellulosic ethanol, the carbon benefits are enormous.

[16] See http://www.fas.org/sgp/crs/misc/R42537.pdf

R. BROOKE COLEMAN

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Brooke Coleman co-founded and serves as the Executive Director of the Advanced Biofuels Business Council (ABBC), a coalition of industry leaders in the advanced biofuels and cellulosic ethanol sectors. Mr. Coleman also advises companies and campaigns in the clean energy sector.

Mr. Coleman has been involved with the energy and environmental sectors at the regulatory and policy levels since 1997. He began his career as the Energy Program Director at Bluewater Network, where he exposed the environmental and public health risks of the gasoline additive MTBE and led a national campaign to ban the chemical in transportation fuels. Mr. Coleman later founded or co-founded several organizations and/or projects, including the Advanced Ethanol Council, the New Fuels Alliance, the California Renewable Fuels Partnership, the Northeast Biofuels Collaborative, the Renewable Energy Action Project (REAP).

Mr. Coleman served as the chief strategist and spokesperson for clean energy advocacy campaigns during the 2008 and 2010 federal election cycles. He has also engaged in several state-level initiatives in recent years. He represented the advanced biofuel industry during the development of the California Low Carbon Fuel Standard (CA LCFS) and spearheaded an initiative in Massachusetts to pass the world's first cellulosic biofuels excise tax exemption.

Mr. Coleman is one of the leading national advocates for advanced biofuels at the state and federal level. He has testified before the U.S. House of Representatives and the U.S. Senate on various issues related to alternative fuels, including performance standards and tax. He has also testified before numerous state legislative committees. He has a deep level of expertise in a number of areas related to energy regulation, including the California Low Carbon Fuel Standard (CA LCFS), carbon lifecycle accounting, the federal Renewable Fuel Standard (RFS), the California and Federal Reformulated Gasoline (RFG) program, energy tax and various other energy-related programs at the federal and state level. He is one of the leading national advocates for advanced biofuels at the state and federal level.

Mr. Coleman is a graduate of Wesleyan University, the Northeastern University School of Law, and is a member of the Massachusetts State Bar. While studying law, he worked on several landmark environmental cases, including the largest ever settlement in Clean Water Act history and a common law climate change lawsuit filed on behalf of eleven state attorneys general.

Chairman LAMB. Thank you. Dr. Daniel?

TESTIMONY OF DR. CLAUS DANIEL, DIRECTOR, SUSTAINABLE TRANSPORTATION PROGRAM, OAK RIDGE NATIONAL LABORATORY

Dr. DANIEL. Chairwoman Johnson, Ranking Member Lucas, Chairman Lamb, Ranking Member Weber, and distinguished Members of the Subcommittee, thank you for the opportunity to appear before you today. I'm Claus Daniel, Sustainable Transportation Program Director for Oak Ridge National Laboratory. Today I will address the important role that the scientific capabilities and expertise of DOE's National Laboratories play in accelerating innovations for an efficient, secure, and sustainable transportation system.

Rapidly advancing technology and increased urbanization are changing mobility in fundamental ways. Growing traffic congestion, higher fatalities, and pollution concerns are some of our greatest challenges. Oak Ridge has a rich portfolio of materials, chemistry, computing, and biological scientists who work closely with DOE's Sustainable Transportation Program to improve energy efficiency and fuel economy for light-, medium-, and heavy-duty vehicles and mobility systems.

Thanks to the Nation's investments, Oak Ridge is home to several facilities that help accelerate our scientific breakthroughs, and I want to thank Ranking Member Weber for recognizing some of them. DOE's largest materials R&D program, supporting scientific user facilities focused on understanding, developing, and advancing materials, such as the Spallation Neutron Source and the Center for Nanophase Material Science. The Oak Ridge Leadership Computing Facility, as you mentioned, which hosts the world's most powerful supercomputer summit, with growing capabilities in artificial intelligence and machine learning. The National Transportation Research Center, the Nation's only transportation-focused user facility, and the Center for Bioenergy Innovation, one of four DOE centers created to lay the scientific groundwork for a biobased economy. Today I'll cite two examples: One on materials and one on mobility, in which we've leveraged these remarkable assets in collaboration with industry, academia, and other National Laboratories to solve problems in the transportation sector.

First, we worked with Fiat-Chrysler and Nemak to develop a new alloy for use in more efficient engines that operate at high temperatures. Using supercomputers, we accelerated the development of the new alloy in only 4 years, versus what normally takes decades. The new alloy is affordable, easy to cast, and can withstand temperatures nearly 100° C higher than traditional aluminum alloys. Our cast engine has surpassed all expectations.

Second, Chattanooga, Tennessee is one of the Nation's busiest traffic corridors, with highly instrumented roadways. Here we're working with collaborators to use our artificial intelligence capabilities to discover ways to ease traffic congestion and cut fuel consumption by at least 20 percent. We're building a digital twin, a real-time living simulation of all traffic.

Moving into the future, we will install Frontier, an exascale computer, able to solve calculations up to 50 times faster than today's top machines, exceeding one quintillion calculations per second, and accommodating much more complex simulations. We believe we can take what we learn in Chattanooga and apply it to solve issues in larger regions, and guide solutions on a national scale, and help hubs, such as Chairwoman Johnson's home airport. Further, we can use artificial intelligence to create simulations of materials and fuels in real-world conditions, analyzing the behavior and actions of millions of atoms under realistic duty cycles. We're also working on a second target station at the Spallation Neutron Source that will offer up to 1,000-times higher performance, with a pulse brightness 25-times greater than currently available. We can probe the structure and function of new complex materials in devices like batteries, ultra-efficient engines, and aircraft turbines at a faster pace.

Our nation has wisely invested resources in developing these unparalleled capabilities to support basic science breakthroughs that translate into real-world results. We look forward to continuing our scientific pursuit in support of a safer, more efficient, and sustainable transportation system for the Nation's prosperity and security. Thank you for this opportunity, and I welcome your questions on this important topic.

[The prepared statement of Dr. Daniel follows:]

Written Testimony of Dr. Claus Daniel
Director, Sustainable Transportation Program
Oak Ridge National Laboratory

Before the
Committee on Science, Space, and Technology
Subcommittee on Energy
U.S. House of Representatives
September 18, 2019

"The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector"

Chairman Lamb, Ranking Member Weber, and distinguished members of the Subcommittee: Thank you for the opportunity to appear before you today. My name is Claus Daniel. I am director of the Sustainable Transportation Program at the U.S. Department of Energy's Oak Ridge National Laboratory in Oak Ridge, Tennessee. I am also founding director of the DOE Battery Manufacturing Facility at ORNL, and I am a materials scientist by education and training, focused on characterization, processing, and manufacturing development for automotive systems. In my career, I have also worked in private industry at companies such as Bosch and Saint Gobain. It is an honor to present this testimony on the important role of the scientific capabilities and expertise of DOE's national laboratories in accelerating innovations for an efficient, secure, and sustainable national transportation system.

INTRODUCTION

Efficient, safe, and sustainable transportation drives our economy and improves our quality of life. It underpins our commerce, enables our work, allows us to access essentials such as food and health care, and enhances our leisure time. In 2018, the U.S. transportation sector accounted for about 28 percent of the nation's total energy use and 69 percent of its petroleum use.[1] The average U.S. household spent roughly 16 percent of its annual expenditures on transportation in 2017, second only to housing expenditures.[2]

At the same time, rapidly advancing technology, increased urbanization, and increasing calls from both the industrial sector and the average consumer for on-demand transport are changing

[1] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office, *Transportation Energy Data Book: Edition 37.2*. Oak Ridge, Tennessee: Oak Ridge National Laboratory, August 2019. https://tedb.ornl.gov/.

[2] U.S Department of Labor, Bureau of Labor Statistics, *Consumer Expenditures—2017*. Washington, D.C., September 2018. https://www.bls.gov/news.release/cesan.nr0.htm.

transportation in fundamental ways. Coupled with growing traffic congestion, rising costs, pollution concerns, and roadway fatalities that have persisted at a rate of some 40,000 for each of the last three years, transportation sector challenges are complex and their resolution is vital.

In a year in which the nation marked the 50th anniversary of the moon landing, it is appropriate to examine how the same spirit of innovation that enabled our space program infuses our country's transportation research today.

We work closely in our transportation-related activities with the DOE Vehicle Technologies Office, whose mission is to enable research, development, and deployment of efficient and sustainable transportation technologies that will improve energy efficiency and fuel economy, with the goal of increasing the nation's energy security, economic vitality, and quality of life.

At Oak Ridge National Laboratory, I am privileged to co-manage one of the largest portfolios of transportation research at DOE's 17 laboratories. From nanoscale materials science for advanced batteries and lightweighting of vehicles and aircraft, to the development and testing of new gaseous fuels and blendstocks, including biofuels, for ultra-clean and efficient combustion engines, to a bi-directional wireless charging system for electric vehicles, to the data behind the decision-making tools at fueleconomy.gov, Oak Ridge touches on nearly every area of transportation science.

For more than 30 years, experts at ORNL have accelerated the pace of research and development for new materials and fuels for next-generation mobility systems, provided decision-making tools for sustainable transportation, and created economic opportunity by improving the energy efficiency of vehicles to support a robust transportation system for people and commerce.

Oak Ridge 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.

Our facilities include:

- 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**, and the **Center for Nanophase Materials Sciences** (CNMS);
- The **Oak Ridge Leadership Computing Facility** (OLCF), which hosts the world's most powerful supercomputer, Summit, as well as growing capabilities in artificial intelligence and machine learning. Training artificial intelligence algorithms requires processors that can handle a massive number of mathematical calculations. Summit links more than 27,000 NVIDIA Volta graphics processing units (GPUs) with more than 9,000 IBM

Power9 CPUs. Each of Summit's 4,608 nodes contains six deep-learning–optimized GPUs packed with more than 21 billion transistors;

- The **National Transportation Research Center** (NTRC), the nation's only transportation-focused user facility with core capabilities in advanced energy storage and electric drive systems, including fast wireless charging, lightweight materials and multi-material structures for harsh environments, advanced combustion engines and biofuels, data science and analysis, and vehicle cybersecurity, vehicle systems integration, and intelligent mobility systems;
- The **Battery Manufacturing Facility** (BMF), the nation's largest open-access battery manufacturing R&D center for studying materials from the atomic level up to 7 Ah pouch cells;
- The **Manufacturing Demonstration Facility** (MDF), the nation's only designated user facility focused on early-stage R&D to improve the energy and materials efficiency, productivity and competitiveness of U.S. manufacturers;
- The **Carbon Fiber Technology Facility** (CFTF), DOE's only designated user facility for carbon fiber innovation to support economic U.S. production of this material of tomorrow for clean energy applications; and
- The **Center for Bioenergy Innovation** (CBI), one of four multi-institutional DOE Bioenergy Research Centers created to lay the scientific groundwork for a new bio-based economy, with a focus on developing sustainable biomass feedstocks, processes to break down and convert plants to specialty biofuels, and valuable bioproducts made from lignin residue.

ACCELERATING INNOVATION WITH BIG SCIENCE CAPABILITIES

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 science tools and expertise to resolve challenges in the transportation sector.

Next-generation materials:

Simulations for a new high-temperature alloy. Working with Fiat-Chrysler (FCA US LLC) and casting manufacturer Nemak, ORNL scientists accelerated the development of a new aluminum-copper alloy ideal for use in advanced, super-efficient engines that operate at high temperatures. The researchers used a quantum mechanics code on Oak Ridge supercomputers to simulate the thermodynamics of alloy materials and determine the best design. Atomic-level characterization tools at the CNMS were used to analyze the new material's function. The alloy was developed in less than four years using these advanced scientific resources, compared with traditional alloy development time of a decade or more. The new ORNL superalloy, known as

ACMZ (aluminum-copper-manganese-zirconium), can withstand temperatures nearly 100 degrees Celsius higher than traditional alloys and is easier to cast than other high-temperature alloys. At Chrysler, an engine made with ACMZ has met or surpassed all expectations in repeated tests.

Accelerating a novel engine design. California-based Pinnacle Engines used the high-performance computing resources at the OLCF to accelerate the design work for its unique internal combustion engine. Pinnacle's opposed-piston engine provides the flexibility needed to optimize energy performance under a wide range of operating conditions. To find the right efficiency and emissions profile among so many variables, the company turned to ORNL's supercomputing resources, simulating key design options for a multi-cylinder gasoline engine for light-duty vehicles. Pinnacle estimated that it would have taken eight times as long to design the engine in-house without using our supercomputers.

The ageless aluminum revolution. Finding an application for cerium, which currently is a waste product when mining the rare earth element neodymium, would enable more economical and secure access to rare earth elements needed for permanent magnets for electric vehicles and other applications. Through DOE's Critical Materials Institute, Oak Ridge scientists worked with Eck Industries, Ames Laboratory and Lawrence Livermore National Laboratory on a unique high-temperature-tolerant alloy that is corrosion-resistant, easier to cast, and does not require expensive heat treatment. To test this aluminum-cerium alloy's performance, ORNL researchers performed a first-of-its-kind experiment on an engine cast with the Al-Ce material—using neutrons at the SNS to investigate the material's performance while the engine was running. The Al-Ce alloy remains stable at temperatures 300 degrees Celsius higher than leading commercial alloys and can withstand 30 percent more load before deforming. By removing the need for energy-intensive heat treatments, scientists estimate that using the new alloy could reduce manufacturing costs as much as 50 to 60 percent. The Al-Ce alloy has been licensed to Eck.

Cobalt-free cathode development and testing. Reducing the use of cobalt in lithium-ion batteries is key to lower costs and less reliance on critical materials. ORNL scientists have developed a nickel-rich cathode using 50 percent less cobalt and tested a water-based manufacturing process at scale. The project achieved 1,000 charging/discharging cycles with pilot pouch cells comprising a nickel-manganese-cobalt, or NMC 811, water-engineered cathode with excellent capacity retention. The results demonstrated that aqueous processing is feasible for nickel-rich cathode materials, which will enable higher energy densities at lower cost and eliminate the need for hazardous solvents in the manufacturing process. The work made use of ORNL's advanced characterization tools as well as the Battery Manufacturing Facility. Oak Ridge is continuing its work in this area, exploring the development of new materials to completely eliminate cobalt in a new type of cathode.

Advancing solid-state batteries. Solid-state batteries that use solid electrolytes have the potential for much higher energy density and safety, but they have traditionally had low ion conductivity and are too expensive for most commercial applications. State-of-the-art microscopy at the CNMS helped identify a feature in a solid electrolyte that is important to increasing the speedy transport of ions. In a similar project, ORNL scientists used scanning transmission electron microscopy and computer simulations to reveal how a two-dimensional ceramic-based material cannibalized itself to form new stable structures ideal for ionic transport such as in solid-state batteries.

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

Additive manufacturing for transportation. Additive manufacturing (AM) is the ability to deposit materials layer by layer to fabricate complex components directly from computer-aided design models. AM technologies give engineers the ability to exploit new materials with custom designs for specific applications, such as lightweighting electric vehicles. Using its Big Area Additive Manufacturing machine at the MDF, ORNL researchers 3D printed a replica of a Shelby Cobra sportscar in 2015 and worked with NTRC to create a "plug-and-play" laboratory on wheels, designed to allow research and development of integrated components to be tested and enhanced in real time, with the goal of improving the use of sustainable, digital manufacturing solutions in the automotive industry. The MDF at ORNL is also being used to help advance the development of novel biomaterials for printing, which in turn supports a healthy bioeconomy that also delivers domestic biofuels.

Safe, Impact-Resistant Electrolyte (SAFIRE). ORNL and collaborators at the University of Rochester developed an electrolyte additive that improves battery safety, transforming liquid electrolyte to a solid upon impact. It blocks contact between electrodes, preventing short circuiting and reducing fire hazards. The SAFIRE electrolyte performs as well as conventional electrolytes while trimming vehicle weight and increasing travel distance. The project leveraged small-angle neutron scattering measurements performed at SNS to characterize materials.

Fuel cell characterization. In support of DOE's fuel cells and hydrogen research, ORNL conducts characterization of fuel cell materials through advanced microscopy, including at the CNMS, to gauge the durability and performance of new technologies. The research has focused on new materials to advance the design and manufacture of catalysts and catalyst supports for hydrogen transportation applications.

DOE lithium-ion battery recycling center. ORNL is participating in the new DOE ReCell Center led by Argonne National Laboratory. Oak Ridge scientists will use state-of-the-art tools at the Battery Manufacturing Facility to develop new methods for separating and reclaiming valuable materials from spent EV batteries. ORNL's role in the ReCell Center will focus on the design of cells to optimize recyclability, including working on the separation of active powders from their collector foils and developing a new method to rejuvenate cathode powers using ionic liquids.

Supercomputing for smarter mobility:

Chattanooga regional mobility project. ORNL is working with several collaborators, including the National Renewable Energy Laboratory (NREL), to improve regional transportation networks, using Chattanooga, Tennessee, as a testbed. Chattanooga, located along one of the nation's busiest traffic corridors, is an ideal testbed since it is a Smart City, equipped with numerous radar detectors on its roadways, cameras to monitor traffic flow, and instrumented intersections with additional sensors. ORNL researchers are working with the city to develop a digital twin, or living model, of the area's transportation network using AI on ORNL supercomputing resources, to enable solutions for smoother traffic patterns and more efficient freight transport. The multi-year project has the potential to reduce energy usage by 20 percent or more in the region.

AI for enhanced autonomous driving agents. Oak Ridge is also teaming with NREL to explore the use of custom machine learning algorithms to enhance the perception and control of autonomous driving agents, including the potential use of ORNL's MENNDL deep learning algorithm. When run on a supercomputer such as Summit, MENNDL can generate a custom neural network very quickly, in a matter of hours as opposed to the months needed to build a conventional artificial intelligence network.

Modeling CAV impact on fuel use, traffic. To study the potential benefits of connected and automated vehicles (CAVs) on roadways, ORNL researchers developed a simulation framework to analyze the impact of partial market penetration of CAVs on fuel consumption, travel time and traffic flow in a merging on-ramp scenario under varying traffic volumes. Research demonstrated that an increased number of CAVs communicating and coordinating driving activity stabilizes traffic flow and, depending on the traffic volume, can reduce fuel use by more than 40 percent.

Machine learning + smart traffic signals for better commuting. ORNL teamed with Knoxville technology firm GRIDSMART to test the use of machine learning algorithms for smoother traffic flow and fuel economy. ORNL scientists developed machine learning algorithms that allowed smart cameras at intersections to recognize various vehicle types in their field of vision and to send signals to traffic lights that decreased the amount of fuel lost to idling and allowed better flow of vehicles through intersections. The project was the first supported by DOE's HPC4Mobility program, which facilitates access to national lab supercomputers and expertise for companies who want to explore energy-efficiency mobility solutions.

Quantum Computing. In the transportation sector, quantum technologies can be leveraged for improved autonomous driving systems, for energy-efficient technologies and for computing at the edge, in which more calculations that enhance automated driving and other mobility solutions are decentralized and still performed in time for proper decision making on board. ORNL scientists are engaged in a lab-wide collaboration that promotes the use of theory, computation, and experiment in the research and development of quantum information technologies. We leverage ORNL capabilities in material fabrication and characterization, high-performance computing, and electrical systems and sensors to develop the ideas and platforms needed for beyond CMOS technologies. The work fosters collaborations between ORNL staff scientists and with external research partners to accelerate development and more quickly realize the benefits from quantum computing.

Fuels, electrification, simulations for next-gen mobility:

Co-Optimizing new fuels, engines for ultimate efficiency. The DOE Co-Optimization of Fuels & Engines Initiative (Co-Optima) led by ORNL is the first program of its kind, leveraging the expertise and resources of eight other national labs and 13 universities to simultaneously tackle fuel and engine R&D for maximized fuel economy and performance. The program leverages high-performance computing facilities at ORNL, NREL, and Argonne, and its researchers have developed algorithms and other computational tools to enable rigorous analysis of potential solutions. Co-Optima recently announced that after three years of research, it has identified 10 blendstocks from four chemical families with the greatest potential to increase boosted spark-ignition engines and to be commercialized for real-world use. These blendstocks can be added to existing fuel to dramatically improve fuel properties and co-optimize performance with engines. Researchers also broadly characterized the fuel properties and engine parameters needed to deliver a path towards 10 percent boost in fuel economy for light-duty vehicles and enhanced engines.

High-powered wireless charging for electric vehicles. Oak Ridge was the first lab to demonstrate a 20-kilowatt bi-directional wireless charging system for passenger electric vehicles (EVs). Just last fall, we demonstrated a 120-kilowatt charging system over a six-inch air gap with 97 percent efficiency, which approaches the convenience of a gas station fill-up. Our next goal is at least 200-kilowatt wireless power transfer for in-motion/dynamic charging and 300 kilowatts for stationary wireless charging. Dynamic wireless charging would allow vehicles to recharge while being driven over roadways equipped with special charging systems. The lab is currently designing and installing a 20-kilowatt bidirectional wireless charging system on a commercial delivery truck with United Parcel Service.

E-fuels: Enabling net-zero carbon fuels while balancing the power grid. Building on our success in such projects as developing new efficient catalysts to convert carbon dioxide to ethanol, ORNL is envisioning how we can leverage supercomputing and materials characterization capabilities for solutions that advance the production of synthetic liquid fuels relying on renewable energy sources. These domestic "e-fuels" would diversify the nation's fuel mix while supporting a more stable and profitable power grid. Liquid fuels production would give a new market to renewable energy generation and help balance the grid, enabling large amounts of energy to be stored, in essence, in the form of synfuels using existing fuels infrastructure. We estimate that the U.S. power grid capacity factor would increase from 44 percent to 96 percent as a result, increasing the grid's profitability and advancing solutions for net-zero carbon transportation fuels.

SuperTruck I and II. DOE's SuperTruck initiatives aim to develop and demonstrate technologies to more than double the freight efficiency of Class 8 trucks, commonly known as 18-wheelers. In our work with Cummins, we are designing a more efficient engine and drivetrain and vehicle technologies. We also used novel diagnostics to enable fuel-efficient engine modeling and design, resulting in 86 percent higher freight efficiency and a 75 percent increase in fuel efficiency. With Daimler, we are making use of leadership capabilities for engine and vehicle simulation, engine and powertrain-in-the-loop experiments, and advanced combustion strategies to improve efficiency and emissions, and emissions characterization and control. The team demonstrated dual-fuel, low-temperature combustion with natural gas and diesel fuel and a 115 percent higher freight efficiency. This doubled the truck's miles per gallon. In our work with Volvo, we helped develop emissions control strategy for the company's advanced engine concepts.

Biofuels: A domestic fuel resource

By supporting biofuels research and development, DOE seeks to advance a domestic, sustainable fuel resource for a modern transportation system that also has the potential to support rural economies. ORNL advances this goal through several initiatives, including:

Center for Bioenergy Innovation. The CBI, which is headquartered at ORNL, engages scientists from across the country who are working to enable viable biofuels and other bioproducts. CBI focuses on developing non-food feedstock crops using genomics and engineering; creating advanced processes to simultaneously break down and convert plants into specialty fuels; and accelerating bioproducts such as chemical feedstocks from lignin residue. CBI scientists are leveraging high-performance computing, high-throughput chemistry, and specialized microscopy to help identify promising microbes and to analyze plant genomes and related traits to advance breakthroughs.

Conversions for biofuels. ORNL researchers are leading a multi-lab consortium developing computational tools and methods to convert biomass into biofuels. These computational models, which extend from the atomic scale all the way to the bioreactor scale, are able to simulate biomass conversion and predict reactor performance. These tools allow the bioreactor to be operated more efficiently, providing lower-cost fuels and greater understanding of how these systems operate in real-world conditions. ORNL also continues to advance new catalysts that can produce bioproducts at lower cost.

Biofuel-to-hydrocarbon technology and scaleup. ORNL invented new catalysts that are able to convert ethanol into different hydrocarbon blendstreams that can be blended with gasoline or jet fuel. The technology is a good means to introduce more renewable fuel into the bioeconomy. This invention offers the advantage of high conversion rates, moderate operating conditions and requires no external hydrogen. The technology was licensed to Vertimass Corporation.

Materials compatibility testing. Our bioproducts program includes compatibility and degradation testing of new biofuels on vehicle technologies and refueling systems, and research examining how biomass conversion technologies may affect biorefinery infrastructure. Our ability to understand materials degradation (such as wear and corrosion) under laboratory conditions allows us to mitigate this damage in the field and is highly valued by our industry stakeholders.

Data for fuel savings:

Fueleconomy.gov. The fueleconomy.gov website, the official U.S. government's source for fuel economy information, is hosted, managed and maintained by ORNL researchers on the Transportation Analysis team at NTRC. The website is DOE's most-visited and provides everything from the latest government fuel economy guides to side-by-side comparisons of cars, trip calculators, and resources to find the cheapest gas by region.

Transportation Data Book. The Transportation Data Book is a comprehensive desktop reference containing detailed data on transportation with an emphasis on energy. It is prepared by ORNL's Transportation Analysis team for DOE's Vehicle Technologies Office. The data book was first published in 1976 and is on its 37th edition.

Freight Analysis Framework. The Freight Analysis Framework, produced by the ORNL Transportation Analysis team through a partnership with the Federal Highway Administration, integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation.

NEW CAPABILITIES TO SUPPORT SUSTAINABLE TRANSPORTATION

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 complex transportation systems.

A new generation of scientific capabilities is being prepared across the DOE lab complex, 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 transportation 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.

Using an exascale system, we can take what we learn in the Chattanooga mobility project, for instance, and **develop regional and even nationwide traffic simulations**. We can include more vehicles and more realistic scenarios with greater complexity, creating a model that can guide us to solutions for congestion and fuel efficiency on a national scale.

Exascale computing can also significantly enhance our **development of new materials, fuels and engines** for better energy efficiency and lower emissions. With an exascale system, we can, for example, perform simulations of a full combustion chamber over a realistic engine duty cycle.

- 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 structure and behavior of **complex items such as batteries, engines, and aerospace parts like turbine blades** in real time at a faster pace without damaging materials. The STS will enable detailed studies of the response of structural materials to manufacturing and extreme conditions.

We are already developing a neutronic engine to use at the SNS that will allow us to measure strain and temperature in a running engine to provide critical insights and important data for simulation. We will for the first time be able to **image inside the cylinder of a running engine** and **analyze injector and spray development in a firing engine**.

VITAL PARTNERSHIPS TO ACCELERATE DEPLOYMENT

The user facilities established by DOE are shared resources, representing large-scale capabilities that private industry and universities cannot afford to build and maintain on their own, but that are essential to maintain U.S. economic competitiveness. The national labs actively seek out collaborators among private industry and academia to ensure our work is targeted and impactful.

ORNL's remarkable capabilities are a nexus for our nearly 4,900 staff. During fiscal year 2018, we also welcomed 3,289 facility users and 1,533 visiting scientists. At the National Transportation Research Center alone, ORNL has partnerships with 137 private companies and

32 universities, and it works with eight other national laboratories on technology solutions with real-world applications.

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 partnerships allow companies to participate in or directly sponsor research across the laboratory system. The results have been significant: At ORNL alone, more than 20 startups have been formed based on lab-developed technologies over the past five years.

CLOSING REMARKS

America's national laboratories and their scientific facilities are powerhouses of science, technology, and engineering. The DOE labs offer one-of-a-kind capabilities with unparalleled scientific capabilities that have real-world results. In collaboration with industry and academic institutions, the labs are advancing projects that will keep the U.S. transportation system at the forefront of innovation.

At ORNL and across the DOE laboratory system, we are open for business: We actively seek and develop partnerships that increase the lab's economic impact, accelerate deployment of lab-developed technologies, and strengthen innovation ecosystems across the nation.

Just as the Apollo program brought together scientists and engineers from multiple institutions to enable successful space missions, the DOE laboratories are eager to collaborate and continue providing early-stage research and development for greater mobility both for commerce and everyday life. We look forward to continuing our scientific pursuits in support of a safer, more efficient, and sustainable transportation system for the nation's prosperity and security.

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

Claus Daniel, PhD
Director, Sustainable Transportation Program
Oak Ridge National Laboratory

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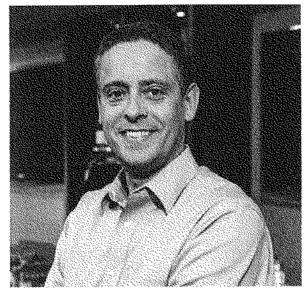

At Oak Ridge National Laboratory (ORNL), Claus Daniel serves as the Director of the Sustainable Transportation Program overseeing ORNL's science portfolio on transportation and mobility technologies.

His responsibility includes relationship management with the Department of Energy Sustainable Transportation Program including the Vehicle Technologies Office, Bioenergy Technologies Office, and Fuel Cell Technologies Office, as well as the U.S. Department of Transportation.

He started at ORNL as a Eugene P. Wigner Fellow in 2005 and held several key positions to build ORNL's energy storage portfolio including the founding director of the Department of Energy Battery Manufacturing R&D Facility at ORNL. He has demonstrated experience in leading large research and proposal teams, including multiple organizations with heavy industry participation.

Dr. Daniel is a materials scientist by training with over 20 years of automotive technologies experience. Before joining ORNL, he worked at Robert Bosch and Saint Gobain and he has collaborated with companies such as Honeywell, Dow, Wieland, Plansee, A123 Systems, and XALT Energy.

He holds a PhD from Saarland University, Germany in collaboration with the Max Planck Institute for Metals Research, and two M.S degrees, one from Saarland University and the other from the Lorraine National Polytechnic Institute, France. He was awarded a number of prizes, including the Carl-Eduard-Schulte-Prize from the German Engineering Society, the Eugene P. Wigner Fellowship Award from ORNL, the Werner Köster Prize from the German Materials Society, and National Academy of Engineering Gilbreth Lectureship Award. Daniel is the editor of the second edition of Wiley-VCH's "Handbook of Battery Materials," has published more than 100 papers in academic journals and holds 21 patents. He also holds a joint faculty appointment with the University of Tennessee's Bredesen Center for Interdisciplinary Research and Graduate Education and the Department of Materials Science and Engineering.

Chairman LAMB. Thank you. And Mr. Cortes?

TESTIMONY OF TIM CORTES, VICE PRESIDENT, HYDROGEN ENERGY SYSTEMS, PLUG POWER, INC.

Mr. CORTES. Good afternoon. Thank you, Chairwoman Johnson, Chairman Lamb, Ranking Member Weber, and the entire Subcommittee, for inviting me to testify before you today regarding sustainable transportation, and the work that is going on in the U.S. Department of Energy's Fuel Cell Technologies Office. I am excited to discuss the role that hydrogen fuel cell technology is playing in sustainable transportation, and share my perspective on how Congress and the Federal Government can enable even greater progress through this pathway.

In our core technology platform, Plug Power replaces lead-acid batteries with fuel cells to power electric industrial vehicles, such as forklifts, that customers use in their distribution centers and warehouses. We have unmatched field experience, with over 28,000 fuel cells in the field, many in your congressional districts. We have installed over 80 hydrogen fueling stations in more than 30 States across the United States. Our CEO, Andy Marsh, is the Chairman of the Fuel Cell and Hydrogen Energy Association, and serves on the Hydrogen and Fuel Cell Technical Advisory Committee, which provides technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts.

Plug Power also participates on the Hydrogen Council, which is a global initiative of 60 leading energy transport and industry companies with the united vision and long-term ambition for hydrogen to foster the energy transition. The council estimates that by 2050, hydrogen can help cut global CO_2 emissions by as much as 20 percent, with substantial reductions coming from the transportation sector. In September 2018, the council adopted a goal to completely decarbonize the production process for hydrogen transportation fuel by 2030. Plug Power looks forward to working with the industry partners, and leveraging support for public sector, to achieve these goals.

The United States has a long history in leadership role in fuel cells. When the Apollo 11 mission put a man on the moon in 1969, the command module's primary source of electricity and drinking water was from fuel cells. Since then, American scientific and industrial ingenuity has ensured that our country became the global leader in hydrogen and fuel cell technologies. This could not have been accomplished without the support and dedication of the U.S. Government, including from this Committee.

Today's Federal support primarily comes from the Fuel Cell Technologies Office housed within the Department of Energy's Office of Energy Efficiency and Renewable Energy. The program leverages the resources of our National Laboratories and partnerships with private sector, including Plug Power, to research, develop, and demonstrate innovative, efficient solutions for advancing fuel cell systems and hydrogen energy. The results speak for themselves, with the United States leading the world in deployments of zero emissions hydrogen fuel cell forklifts and light duty cars. Additionally, the American hydrogen and fuel cell industry continues to push forward with novel applications for these technologies, such as heavy-duty trucking, maritime vessels, port vehicles, drones, military equipment, and more.

Plug Power has been working with the DOE since the company's inception to advance our innovative fuel cell solutions. This started with basic research and development projects, which led to proving the feasibility and utility of powering material handling equipment with hydrogen fuel cells and stationary systems for primary backup power. Once these first-generation systems were ready for deployment, DOE's Market Transformation activities accelerated cost reductions, and promoted customer acceptance for this new alternative energy technology. Thanks to these efforts, Plug Power was able to establish initial relationships with customers, help the company significantly expand, and create an entire new market for hydrogen fuel cell systems.

Today Plug Power continues to work with the DOE to further improve the efficiency of these systems, scale up the production of hydrogen fuel, bring advanced manufacturing processes for our technology from the laboratory to the factory, and introduce hydrogen fuel cells to new markets and applications. Plug Power is very appreciative of DOE's Hydrogen-at-Scale concept, and this program explores the potential for wide scale hydrogen production and utilization in the United States by leveraging resources from the Department, National Labs, and array of diverse domestic industries that can produce and utilize hydrogen fuel. Unfortunately, Plug Power is not currently participating in H2@Scale, but we are hopeful DOE will embrace our priority, since we are the leading user of liquid hydrogen in the United States.

With today's urgent focus to mitigate climate change, industrial countries are recognizing the critical role that hydrogen and fuel cells can play in decarbonization policies across sectors. In just the past few years, other countries, including China, and other developed nations, have put forth and implemented funds and plans worth billions of dollars to accelerate deployment of these technologies, especially in the transportation sector. To ensure the United States does not fall behind in the global leadership in hydrogen and fuel cell technologies, Congress and the Executive Branch must ensure policies and incentives are available to American industry to accelerate further deployment.

America's approach to sustainable mobility needs to incorporate hydrogen fuel and fuel cell systems into our energy strategy. In our written testimony, you can find detailed recommendations supporting the creation of these policies that will allow for scale of infrastructure necessary to facilitate the widespread adoption of fuel cells. Thank you for the opportunity to participate in this hearing, and giving Plug Power the opportunity to talk about sustainability, transportation, fuel cells, and hydrogen technologies.

[The prepared statement of Mr. Cortes follows:]

Testimony of Tim Cortes,
Vice President, Hydrogen Energy Systems

on behalf of
Plug Power Inc.

before the
United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy

Hearing entitled
"The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector"

September 18, 2019

Good afternoon. Thank you to Chairman Lamb, Ranking Member Weber, and the entire Subcommittee for inviting me to testify before you today regarding Sustainable Transportation and the work that is going on in the U.S. Department of Energy's Fuel Cell Technologies Office. I am excited to discuss the role that hydrogen fuel cell technology is playing in sustainable transportation and share my perspective on how Congress and the federal government can enable even greater progress through this pathway.

Background and Introduction:

My name is Tim Cortes. I am the Vice President for Hydrogen Energy Systems at Plug Power, Inc. I have been with the company since early 2015 and I am responsible for overseeing our hydrogen business. I was hired to build a world class hydrogen business and I am proud to say that since I started, we have developed an excellent management team focused on installation, engineering and service of Plug Power's GenFuel hydrogen fueling systems. As I will discuss more later, we have developed, installed and are operating over 80 hydrogen fueling systems across the United States.

Prior to joining Plug Power, I served as the Chief Technology Officer and Vice President of Engineering at Smiths Power. My professional background has been spent in the development of critical power infrastructures in both the data center and telecommunications markets including positions with AT&T Bell Laboratories, GNB/Exide Technologies and Power Distribution Incorporated.

About Plug Power:

Plug Power is the leading manufacturer of hydrogen fuel cell engines and fueling stations serving the broader logistics and transportation market. We have deployed over 28,000 fuel cell systems, many in your congressional districts and states and have unmatched field experience on our technology platform with over 270M hours of customer operation.

Plug Power was founded in 1997 and went public in 1999. We are headquartered in Latham, New York, Congressman Tonko's district, and have facilities in Spokane, Washington, Rochester, NY, Dayton, OH, Romeoville, IL, and Montreal, Canada. We manufacture all of our systems and many of our critical components in Latham, NY and Spokane, WA,

In our core technology platform, Plug Power replaces lead acid batteries to power electric industrial vehicles, such as the lift trucks customers use in their distribution centers and warehouses. We have unmatched field experience, with over 270M hours of customer operation – that's the equivalent to more than 8 billion automotive miles driven. We have installed over 80 hydrogen fueling stations in more than 30 states across the United States. Our customers have completed more than 22 million fills using our hydrogen dispensers. Long-standing relationships with material handling industry leaders forged the path for the company's key accounts, including Walmart, Amazon, Home Depot, Kroger, Wegmans, Honda, BMW, Mercedes Benz and many more.

Plug Power is extending its reach into the on-road electric vehicle market and providing hydrogen solutions for customers. In fact, Plug Power is the only company today that can service the entire logistics and transportation market with our modular hydrogen fuel cell engines and fueling stations as a single-sourced vendor. Earlier this year, we announced our first major on-road customer win. In the second quarter, Plug Power closed a deal with electric vehicle manufacturer StreetScooter, a subsidiary of DHL, the world's largest logistics and mail communications service. With this partnership, StreetScooter will initially deliver 100 hydrogen fuel cell-powered trucks for on-road use to Deutsche Post DHL, starting in 2020. This marks the world's first commercial scale fuel cell engine deployment for the on-road logistics application.

From our leading position as the largest buyer of liquid hydrogen, Plug Power is evaluating strategic priorities for the growing hydrogen business. Our interest is twofold: 1) to provide increasing comfort of hydrogen price and supply stability to our end customers, and 2) to improve margins in our business. Operationally, we remain focused on continuously reducing our product cost, enhancing our technology platform, and increasing overall reliability. These collective activities allow Plug Power to expand the addressable market and continue overall margin improvement.

Plug Power's CEO, Andy Marsh, is the Chairman of the Fuel Cell and Hydrogen Energy Association (FCHEA.) FCHEA represents the leading companies and organizations that are advancing innovative, clean, safe, and reliable energy technologies. Their member organizations represent the full global supply chain for hydrogen and fuel cells, including automakers; material, component, stack and system manufacturers; hydrogen producers and energy companies; trade associations; utilities; and end users. Andy is also a member of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), which was established in the Energy Policy Act of 2005 to provide technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts.

Plug Power also participates on the Hydrogen Council, which is a global initiative of 60 leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition. The council estimates that by 2050 hydrogen can help cut global CO2 emissions by as much as 20%, with substantial reductions coming from the transportation sector.[1] In September 2018, the Council adopted a goal to completely decarbonize the production process for hydrogen transportation fuel by 2030.[2] Plug Power looks forward to working with its industry partners and leveraging support from the public sector to achieve this goal.

Plug Power has been a platinum member of the California Business Council for the last several years. The California Hydrogen Business Council (CHBC) is the leading advocate for the hydrogen and fuel cell industry in Sacramento, California. Its vision is to reinforce California's position as the most advanced clean energy state in the nation, expanding the sustainable use of its precious natural and renewable resources and providing clean air to its citizens, by adopting hydrogen and fuel cell technologies in transportation, power and goods movement markets.

Plug Power sits on the Board of Directors for the Ohio Fuel Cell Coalition. The Coalition was established to ensure Ohio's presence both regionally and nationally in current fuel cell discussions and works to advance the integration of a coordinated, robust fuel cell infrastructure and supply chain, promote public awareness of fuel cell technology, and increase the number of economic opportunities available to Ohio organizations and residents.

About Fuel Cells:

A hydrogen fuel cell (HFC) is an electrochemical power generator that combines hydrogen and oxygen to produce electricity, with water and heat as by-products. Simply put, hydrogen fuel cells form energy that can be used to power anything from commercial vehicles to drones.

HFC technology offers a clean and reliable alternative energy source to customers in a growing number of applications – electric vehicles including forklifts, delivery vans and cars, primary and backup power for a variety of commercial, industrial and residential buildings, and more futuristic-sounding applications like drones and mobile phone recharging.

How does a fuel cell work? A fuel cell is composed of three main components: an anode, a cathode, and an electrolyte membrane. The "magic" of the PEM fuel cell is its proton exchange membrane, which looks like a piece of construction paper. It works by passing hydrogen through the anode side and oxygen through the cathode side. At the anode site, the hydrogen molecules are split into electrons and protons. The protons pass through the electrolyte membrane, while the electrons are forced through a circuit, generating an electric current and excess heat. At the cathode, the protons, electrons, and oxygen combine to produce water molecules.

Fuel cells are very clean, with their only by-products being electricity, a little heat, and water. Additionally, as HFCs do not have any moving parts, they operate very quietly.

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[1] Hydrogen Council, *Hydrogen: scaling up*, November 2017, http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf.

[2] "Our Goal: 100% Decarbonized Hydrogen Fuel in Transport by 2030," *Hydrogen Council*, September 14, 2018, http://hydrogencouncil.com/our-2030-goal/

Advantages & Benefits – 5 things you should know about fuel cells:

1. **Zero Emission Power.** HFCs produce no harmful emissions, eliminating the costs associated with handling and storing toxic materials like battery acid or diesel fuel. In fact, when fueled with pure hydrogen, the only by-products are heat and water, making this a zero-emission sustainable power source. HFCs are a part of many well-planned corporate sustainability programs. Hydrogen fuel cell products utilize environmentally-benign hydrogen as a fuel source, which eliminates the environmental impact of fuel spillage, leaks or air pollution and results in simplified zoning requirements.
2. **Robust Reliability.** HFCs have proven themselves against tough conditions including cold environments as low as -40 degrees F/C, weather environments like hurricanes, deserts and winter storms, and even the hard-working business environments of material handling warehouses.
3. **Improved Efficiency.** According to the U.S. Department of Energy, HFCs are generally between 40–60% energy efficient. This is higher than some other systems for energy generation. For example, the typical internal combustion engine of a car is about 25% energy efficient. In combined heat and power (CHP) systems, the heat produced by the HFC is captured and put to use, increasing the efficiency of the system to up to 85–90%. HFC efficiency is put to work to improve warehouse productivity by up to 15% using fuel cell forklifts; to extend the mileage range for electric vehicles like package delivery vans; and to provide electricity and hot water for hotels and businesses.
4. **Scalability.** The advantages of using a modular product are profound: greater reliability, easier serviceability. But the most important benefit may be scalability – and the savings that feature provides when purchasing and using a fuel cell. These products may be engineered precisely to meet a variety of customer power needs – whether for material handling, stationary power or on-road electric vehicles. Paying for only what you need just makes good business sense.
5. **Lower Operational Costs.** Compared to batteries and internal combustion generators, fuel cells save money. They eliminate the need to change, charge and manage batteries – saving both labor/time and space normally allocated to a battery room. The units run longer than lead-acid batteries and can be fueled in as little as two minutes, substantially reducing vehicle and personnel downtime. Fueling the HFC is as simple as fueling a car. Eliminating a battery charging infrastructure also significantly reduces the peak power demand of a commercial operation. Additionally, simple maintenance and fewer site visits mean up to 84% lower operational costs when compared to combustion generators for stationary power. Robust reliability eliminates the need for quarterly site maintenance visits, keeping site personnel focused on their critical tasks.

United States Leadership in Fuel Cells:

When the Apollo 11 mission put a man on the Moon in 1969, the Command Module's primary source of electricity and drinking water was from a set of three hydrogen fuel cells. In the ensuing decades, American scientific and industrial ingenuity ensured that our country became the global leader in hydrogen and fuel cell technologies. This could not have been accomplished without the support and dedication of the United States Government – including from this Committee.

Today, this support primarily comes from the Fuel Cell Technologies Office (FCTO,) housed within the Department of Energy's Office of Energy Efficiency and Renewable Energy. FCTO leverages the resources of our National Laboratories and partnerships with the private sector, (EERE) including Plug Power, to research, develop, and demonstrate innovative, efficient solutions for advancing fuel cell systems and hydrogen energy.

The results speak for themselves, with the United States leading the world in deployments of zero-emission hydrogen fuel cell forklifts and light-duty cars. There are also more than 550 MW of installed stationary fuel cell capacity nationwide, providing efficient, clean, and resilient energy to power office buildings, data centers, hospitals, universities, manufacturing and logistics facilities, and other stationary end users. Finally, the American hydrogen and fuel cell industry continues to push forward with novel applications for these technologies, such as heavy-duty trucking, maritime vessels, port vehicles, drones, military equipment, municipal and industrial microgrids, energy storage systems, and more.

Working with the Department of Energy (DOE):

Plug Power has been working with the Department of Energy since the company's inception to advance our innovative fuel cell solutions. This started with basic research and development projects in the late 1990s and early 2000s, which led to proving the feasibility and utility of powering material handling equipment with hydrogen fuel cells and stationary systems for prime backup power. Once these first-generation systems were ready for deployment, DOE's Market Transformation activities accelerated cost reductions and promoted consumer acceptance for this new, alternative energy technology.

Thanks to these efforts, Plug Power was able to establish initial relationships with customers, help the company significantly expand, and create an entire new market for hydrogen fuel cell systems. Today, Plug Power continues to work with DOE to further improve the efficiency of these systems, scale up the production of hydrogen fuel, bring advanced manufacturing processes for our technologies from the laboratory to the factory, and introduce hydrogen fuel cells to new markets and applications. For example, through DOE we have conducted a series of successful pilot projects with FedEx to demonstrate the feasibility of our hydrogen fuel cell engines in delivery vans and ground support equipment at the Albany International and Memphis International airports.

Put simply, Plug Power's relationship with DOE is a prime example of "government working right." The company would not have gotten to where it is today without this partnership, and we hope to see its success replicated with other players in the hydrogen fuel cell industry and beyond to accelerate sustainability in the transportation sector.

According to the Department of Energy's website, the mission of its Hydrogen and Fuel Cells Program is to reduce petroleum use, greenhouse gas (GHG) emissions, and air pollution and to contribute to a more diverse and efficient energy infrastructure by enabling the widespread commercialization of hydrogen and fuel cell technologies. The Program's key goals are to advance these technologies—through research, development, and validation efforts—to be competitive with current technologies in cost and performance, and to reduce the institutional and market barriers to their commercialization.

We are pleased to have been part of, what we believe, some of its most successful activities. For example, the American Recovery and Reinvestment Act of 2009 (Recovery Act) was an unprecedented effort by the DOE to jumpstart our economy, create or save millions of jobs, and put a down payment on addressing long-neglected challenges so our country can thrive in the twenty-first century. On April 15, 2009, the Energy Department announced $41.6 million in Recovery Act funding to accelerate the commercialization and deployment of fuel cells; and to build a robust fuel cell manufacturing industry in the United States, with accompanying jobs in fuel cell manufacturing, installation, maintenance, and support services. By the end of December 2011, more than 450 fuel cells for material handling were operational, at customer sites including Sysco Houston, Coca Cola, Kimberly Clark, Sysco Philadelphia, Wegmans and Whole Foods. It was a classic example of how a government program should work. It was a public-private partnership aligning government with industry needs at the exact right time. It allowed customers to demonstrate the technology, "kick the tires," understand technology, validate and get comfortable with hydrogen infrastructure. In the subsequent years, nearly all of these customers have continued or expanded their fuel cell programs, and they provided the basis for many of the expanded list of customers we have today.

Plug Power is very appreciative of DOE's H2@Scale concept. This program explores the potential for wide-scale hydrogen production and utilization in the United States by leveraging resources from the Department, National Labs, and array of diverse domestic industries that can produce and utilize hydrogen fuel. Unfortunately Plug Power is not currently an active participant in H2@Scale, but we are hopeful DOE will embrace our priorities since we are the leading user of liquid hydrogen in the United States. We hope that Congress can maintain support for the concept in future policy authorizations and encourage DOE to work with industry to facilitate partnerships that will be beneficial to all in the industry. For example, we think the program can be utilized to help the fuel cell transportation sector transition to fully decarbonized hydrogen fuel production in the coming years, with the proper policies in place.

Plug Power also appreciates FCTO's continued work on safety, codes, and standards for the fuel cell and hydrogen industry, especially by coordinating with international bodies to ensure the development of one set of global regulations.

A good example of the current, or recently completed, programs Plug Power is working on with DOE that are synergistic with the goals of this committee: **Ground Support Equipment (GSE)**: The GSE program began at the FedEx Hub at the Memphis International Airport in 2015. A total of 15 Charlatte CT5E baggage tractors equipped with Plug Power hydrogen fuel cells were deployed along with an on-site hydrogen delivery system. The initial 2 phases of the program were completed in Memphis At the start of 2019, phase 3 of the program was launched at the Albany International Airport. This phase again supported the freight operation of FedEx, albeit on a different scale than in Memphis.

At the end of June, a decision was made to continue to operate the hydrogen-powered baggage tractors at the Albany Airport to move freight and packages. FedEx and Plug Power will continue to cooperate and support the model established during this program for the foreseeable future.

FedEx Delivery Van Program: Plug Power delivered the first ProGen-powered delivery van to FedEx at the start of 2018 – the vehicle has now delivered packages over more than 18,000 miles in varying weather conditions including ice, snow, rain, and extreme heat. Why is this important? Well, it has proven that the Plug Power design is able to withstand harsh elements with above-average reliability and dependability. The ProGen-powered electric delivery van is one of the first of its kind to operate in a standard commercial environment and deployed on a standard delivery route for FedEx.

The addition of Plug Power's ProGen fuel cell enables the vehicle range to exceed 160 miles per delivery cycle, a 166% increase over standard battery power alone. This is an elite van, operating 11 hours per day (60-100 miles each day) almost immediately upon its deployment. And, since it's delivering Plug Power fuel cell equipment, this truck is carrying some of FedEx's heaviest loads in comparison to its typically delivery van loads.

The FedEx drivers report the vehicle is more responsive with quicker acceleration than the incumbent vehicle. It is also quiet and does not release any diesel odor – since there is no diesel onboard. Pair this with less maintenance from the FedEx crew and we are seeing acceptance from all sides. This project is proving that with hydrogen fuel cells, electric vehicles can be used on all commercial routes as a highly-efficient, highly-sustainable mobility solution.

WSU Program: Plug Power has been working with Washington State University's Hydrogen Properties for Energy Research (HYPER) Labs. This project will result in the implementation of an innovative technology, Heisenberg Vortex Tube (HVT), which will provide more liquid hydrogen to be delivered at scale and allow hydrogen fuel cells to be used in more on-road applications. This partnership focuses on one of the largest logistical issues of delivering hydrogen at scale: efficient transportation. Optimizing the HVT to operate with supercritical hydrogen has the potential to reduce the cost and efficiency of small, distributed hydrogen liquefaction systems as well as aid in low boil-off and heat mitigation challenges relevant to Plug Power and its customers.

The proposed sub-cooling technology will enable improvements to the transportation and storage of liquid hydrogen to fueling stations. It will allow Plug Power's fleet vehicle customers, including material handling lift truck fleets, to achieve lower fuel costs due to lower back-end costs of transportation and storage. In the future, this innovation will improve the operational efficiency of GenFuel liquid hydrogen architecture, which is critical for the high-volume hydrogen fueling needed to support the burgeoning on-road fuel cell electric vehicle market.

Expanding Markets:

As previously mentioned, Plug Power is committed to reducing emissions in the transportation sector by advancing zero-emission hydrogen fuel cell solutions for a variety of mobility applications. We see our technology as complementary to other vehicle electrification technologies, such as batteries. As the United States continues to invest in and scale up deployment of sustainable transportation options, we urge Congress to recognize the unique role hydrogen fuel cells can play in helping to decarbonizing this sector.

For example, according to the Environmental Protection Agency, light-duty vehicles (LDVs) contributed to 59% of transportation GHG emissions in the United States in 2017.[3] The remaining 41% of these emissions came from medium and heavy duty vehicles (23%), aircraft (9%), ships and boats (3%), rail (2%), and other sources such as material handling equipment (4%). While both battery electric and hydrogen fuel cell technologies are important solutions in decarbonizing light-duty transportation, the advantages that the fuel cells provide in range, efficiency, cargo capacity, and refueling times make them a worthwhile option for decarbonizing these other mobility sectors too.

Going forward, Plug Power sees commercial class 5 to class 8 trucks as the next phase in hydrogen fuel cell transportation. We hope that Congress and the federal government can provide the necessary policy and incentive support to get these technologies on the road and start decarbonizing ***all*** transportation applications. This should include further reducing the cost and increasing the availability of hydrogen fuel production, storage, and distribution.

Recommendations:

With today's urgent focus on mitigating climate change, industrialized countries are recognizing the crucial role that hydrogen energy and fuel cells can play in decarbonization policies across all sectors. In just the past few years, China, Germany, Japan, the United Kingdom, France, South Korea, Canada, Australia, and other developed nations have put forth implementation and funding plans worth billions of dollars to accelerate the deployment of these technologies, especially in the transportation sector. To ensure that the United States does not fall behind on global leadership in hydrogen and fuel cell technologies, Congress and the Executive Branch must make sure policies and incentives are available to American industry to accelerate further deployment. America's approach to sustainable mobility on the international community's and incorporate hydrogen fuel and fuel cell systems into our strategy.

Recently FCHEA, with Plug Power's leadership, submitted comments to the House Energy and Commerce Committee on their recently announced plan to achieve a 100% clean economy by 2050. Plug Power supports these recommendations and supports creating policies for scaling up the infrastructure necessary to facilitate the widespread adoption of innovative clean energy technologies, such as fuel cells and hydrogen energy. Ideally, this would include, but not be limited to, updated authorization for the Department of Energy's (DOE) Hydrogen and Fuel Cell Technologies program that focus on:

1. Supporting the development of hydrogen refueling infrastructure nationwide to accelerate the adoption of zero-emission fuel cell transportation.
2. Reducing the cost of hydrogen fuel production, storage, and distribution through the H2@Scale initiative, with an emphasis on obtaining hydrogen from renewable sources.
3. Scaling-up innovative applications of hydrogen fuel cell technology, including medium and heavy-duty transportation, maritime vehicles, port and drayage equipment, microgrids and distributed energy resources, unmanned aerial vehicles, and public safety/resiliency.

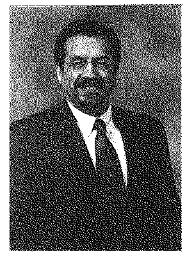
[3] "Fast Facts on Transportation Greenhouse Gas Emissions," *United States Environmental Protection Agency,* June 2019, https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions.

4. Late-state research, development, and technology acceleration programs to further reduce the cost of fuel cell components and systems. This includes mid and late-stage RD&D into fuel cell components such as balance of plant, membrane electrode assemblies, compressors, catalysts, sensors, and storage tanks.
5. Late stage R&D on reducing input costs and improving the performance of light-duty fuel cell vehicles.
6. Promote interagency cooperation between DOE and other federal stakeholders in hydrogen and fuel cell technologies, such as the Department of Transportation, the Department of Defense, the Department of Agriculture, and NASA.
7. Renewed support for DOE's Hydrogen and Fuel Cells Market Acceleration activities that can help deploy novel applications for hydrogen and fuel cell systems, such as in energy storage technologies, steel production, maritime transportation, aviation, and others. The fuel cell industry's early successes today stem from similar activities that were included in the 2009 American Recovery and Reinvestment Act, and as industry develops new approaches to utilizing these technologies, similar initiatives could help the United States scale-up its "hydrogen economy."
8. Including hydrogen fuel cell technologies in any provisions to incentivize the adoption of clean energy solutions across the federal government.
9. Workforce development and training programs to ensure that fuel cell manufacturers and hydrogen fuel suppliers can recruit the talent needed to help the industry thrive.
10. Ensure the policies that govern pipelines for fuel address the needs of transporting gaseous and liquid hydrogen.
11. Renew authorizations for DOE's safety, codes, and standards work to ensure the continued safety and training procedures for utilizing hydrogen fuel.
12. Authorize the EPA to classify hydrogen transportation fuel as an Approved Pathway for its Renewable Fuel Standard and assignment Renewable Identification Numbers.

Funding:

We are thankful to Congress for maintaining robust appropriations for DOE's Hydrogen and Fuel Cell Technologies program in recent years. Plug Power is extremely pleased with the funding levels and report language included in the House and Senate Energy and Water Appropriations for FY 2020, which both direct DOE to maintain a diverse set of early, mid, and late-stage research, development, demonstration, and deployment activities. With continued emphasis of Congressional intent in these reports, we hope DOE will fully align their Hydrogen and Fuel Cell Technologies program with what the industry needs to succeed today including the technology acceleration and H2@Scale programs. Furthermore, while we appreciate EERE's focus on funding the National Labs and research universities, we are hopeful to create more partnerships that will allow for industry to engage on needed priorities. Our goal is to make sure the important research labs and universities are doing is being utilized to create markets and get clean energy technologies in the hands of American tax payers.

Thank you for the opportunity to participate in this hearing and giving us the opportunity to talk about sustainable transportation and fuel cells and hydrogen technologies in a global marketplace, and I look forward to answering your questions.



TIM CORTES

Vice President,
Hydrogen Energy Systems

Tim Cortes joined Plug Power Inc. as Vice President of Hydrogen Energy Systems in January of 2015. In this role, Mr. Cortes is responsible for overseeing the GenFuel business, including interactions with customers, partners and suppliers critical to increasing Plug Power's growing market share within the hydrogen fuel industry.

Prior to joining Plug Power, Mr. Cortes served as Chief Technology Officer and Vice President of Engineering at Smiths Power. In these positions, he was responsible for research and development, as well as solutions for global applications. During his tenure at Smiths Power, Mr. Cortes led product line expansion that resulted in a doubling of revenue growth in less than six years.

Mr. Cortes holds a Bachelor of Science degree in electrical engineering from New Mexico State University. Additionally, he holds several patents covering power system architecture.

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Chairman LAMB. Thank you. We'll now begin with our questions, and I'll take the first round for 5 minutes.

Mr. Chen, I wanted to ask you a little bit about kind of how we got to where your company is today, and the role of government in all that. You know, one of the things we're trying to figure out here is exactly how to spend the research dollars that we have, in addition to how much we have to spend, and you quoted, I think, the figure of what China has spent just on electric vehicles alone, something like $60 billion. So it shows you the overall amount is really important, I think. But are there connections between some of the Federal research and how your company was founded? Was the founder, at MIT, ever supported by Federal research, or can you give us any examples of that?

Mr. CHEN. Yes. So R.J. Scaringe, our founder, as you mentioned, is a Ph.D. mechanical engineer out of MIT. He was a member of the Sloan Automotive Laboratories, so to the extent that there was any government involvement, I am not aware of any direct government involvement, but the investment that is made into DOE to look into these types of technologies certainly is something that raises the entire industry, and awareness of electric and battery technology.

Chairman LAMB. Andit may be as simple as the fact that one of DOE's big investments was in Tesla, which obviously advanced the whole field of battery technology forward, and I'm sure was in some way a side benefit to you all.

On the topic of the lithium-ion battery technology, you rightly raised the fact that China is leading in that area, and I saw some figures from Bloomberg that suggested they could have 3/4 of the world market by 2021, which is not what we want, and we're not feeling optimistic on this side about how we would grow our own market in that. So do you have any ideas or thoughts about what we would do to level that playing field, or create an insurance policy for ourselves against China dominating that area?

Mr. CHEN. Well, I think there are a number of programs that could certainly help in that area. I think H.R. 2170 is a good start. As I reviewed the provisions of that bill, it talked not only about research and development into lithium-ion battery technology, but support of creating manufacturing jobs, or industries that were creating manufacturing jobs in the United States. You mentioned earlier the Tesla loan from the DOE ATVM (Advanced Technology Vehicles Manufacturing) Program. Certainly that was a huge catalyst for Tesla to make a leap forward.

As you noted earlier in my bio, that I was with Tesla at that time, and folks will remember in 2008 the credit markets were completely locked up. There was no place to get money due to the Great Recession, so the DOE loan to Tesla really was the financial impetus that allowed that company to move forward with the Model S, which was the very first ground-up all electric vehicle developed and manufactured in the United States. That led to the Model X, and later to the Model 3, all while driving down the costs of the battery.

So I think there is a number of different areas where government could play in. Incentivizing manufacturing, the DOE ATVM Loan Program, which I understand is still in existence, that can certainly support it, R&D, and then, of course, incentives such as the IRC 30(d) tax credit (Plug-In Electric Drive Vehicle Credit), which I understand is also being considered for expansion. These are all the types of programs that I think can help both drive R&D, manufacturing, and demand and acceptability of these technologies.

Chairman LAMB. Absolutely. Thank you. And, Mr. Coleman, you kind of closed with a point about how it's not all about budget. I think it is largely about that. It's the creation of the market, and the creation of demand, that seems to be the biggest factor for a lot of these things at the end of the day. But could you just kind of use my remaining minute to expand on that point a little bit, involving the struggles with the EPA, and sort of what we could do outside the budget process to help strengthen that demand or market?

Mr. COLEMAN. Yes. I appreciate the question, thank you. So we're at that point, in our industry, where we've been around a little while. We've moved through the R, and then the D, and we're probably on the last D, on the deployment side. And what happens to us often is we get to that point, and people say it's the Valley of Death or whatever. It's the market deployment side of things. And because energy markets are regulated, it's like driving, you've got to show up with a license plate, you've got to have a registration, and you've got to have an inspection sticker. And if you don't have one of those things, and you try to drive around, you're in trouble.

And what happens to us is we often have to navigate the interagency process, and one of those things will hang us up. And so what's happening to us right now on this ultra low-carbon fuel is we have a pathway for corn fiber. And for those of you who don't spend all day on biofuels, corn fiber's just the hard, viscous part of the outside of the corn kernel. That's a cellulose feed stock. It's already at the grain door, and we can produce this stuff commercially. It's hundreds of millions of gallons of ultra low-carbon fuel, and we can't get essentially a registration from EPA to put this out and create a value-added integrated biorefining reality.

DOE is remarkably trained. They look at our stuff all the time, and sometimes it's just a matter of DOE engaging, going over there and saying, hey, we're in charge of energy security, we can literally change this equation overnight, why is this taking so long? And it's a very political process over there, and that's really what I meant.

Chairman LAMB. Thank you. And, with that, I yield to the Ranking Member, Mr. Weber.

Mr. WEBER. Thank you. Dr. Daniel and Ms. Schlenker, in your prepared testimonies, you highlight the importance of sophisticated materials science, enabling those tools like Argonne's Advanced Photon Source, APS, and Oak Ridge's Spallation Neutron Source, SNS, as well as the importance of providing updates, so sometimes the budget does count for a little bit, Mr. Coleman.

So as you know, this Committee has a long, established history of providing strong bipartisan support for these key user facilities. So how critical, and we'll start with you Ms. Schlenker, in your opinion, are these resources to enabling innovative R&D in sustainable transportation?

Ms. SCHLENKER. So I think that user facilities are a real gem of the National Laboratories, to allow access to scientists globally to come in to the facilities, and certainly for the U.S. researchers, and industry, to have access to the experts for those particular user facilities. In transportation, just as an example, for the Advanced Photon Source, we're looking at additive manufacturing as a new technique in transportation for component development.

Mr. WEBER. To make it lighter?

Ms. SCHLENKER. To make it lighter——

Mr. WEBER. Stronger, lighter.

Ms. SCHLENKER [continuing]. But it's really, trialing and putting layer after layer down in deposition, and to understand where the voids, and the fatigue, or the failure modes, might really be. So we've had a longstanding program with various OEMs (original equipment manufacturers) to use that particular facility. We look at fuel spray research from injectors out of an engine to try and reduce the emissions, and to have predictability within that.

So just an example beyond the high-performance computing that we use all the time, and I want to give Claus some time on this, but those are just two big examples that I think of user facilities in transportation that are used on a daily basis.

Mr. WEBER. OK. And, Claus, she's kind of throwing the ball over to you.

Dr. DANIEL. Yes. Thank you, Ann, for that. Thank you, Ranking Member Weber, for the question. I think this is very, very important. The scientific user facilities at the National Labs are really the scientific backbone of our research community, and of the DOE system on there. You made it very clear, you said the APS, and the SNS, right? There's not two of them——

Mr. WEBER. Um-hum.

Dr. DANIEL [continuing]. Right? These are large tools. They require quite some investment to make them the way they are, and you don't repeat those investments as easily.

Mr. WEBER. And to sustain them, to use that sustainability——

Dr. DANIEL. Sustain them is also very expensive, yes. So what we do is we have trained experts who are world-renowned scientists, doing nothing but operating these facilities so they are ready to answer the scientific questions we have, and advance the technology. One example, for example, is here, when we come with an applied problem, where an automotive supplier—this happened in Oak Ridge about 6 years ago, where we had a supplier to Ford come in with—it was a body-supplier, and they——

Mr. WEBER. What kind of supplier?

Dr. DANIEL. A body-supplier. It's a supplier who provides the body shell of the car.

Mr. WEBER. OK.

Dr. DANIEL. And there was a cracking problem at that body—and the automotive company said, we cannot accept these any further. We need to shut down manufacturing lines, and we probably need to have some layoffs if we can't resolve that. Facilities like the user facilities are equipped to go all the way down to the atomic level and understand what is the problem. And we were able, in just 3 days' time, to resolve the issue, understand where it's coming from, and the company was able to then find a solution, and keep their workforce in business.

Mr. WEBER. And that was for Ford?

Dr. DANIEL. This was for a supplier to Ford.

Mr. WEBER. A supplier to Ford? OK. Well, good, that's a great story. Thank you. And a short amount of time left, this is actually for all witnesses, here on the Energy Subcommittee we like to talk about next-generation science and technology discoveries. What are some of the recent technology breakthroughs that could be considered next-generation discoveries in vehicle technologies? And then we'll jump over to hydrogen fuel research after that. But let's start with you, Mr. Cortes. What are some of the recent technology breakthroughs that you would consider next-generation discoveries?

Mr. CORTES. So on the fuel cell side, on a stack level within the fuel cell, advances are being made with regard to the size, and the density, and the power performance of the actual stack, so that's allowing us to make the stacks, and the fuel cells themselves, much smaller, much lighter, and be able to generate more power. So that technology is really going to be crucial in order to improve and go, you know, help with the transportation, in terms of getting the additional power for the distances that you need to travel.

Mr. WEBER. Well, thank you, and I'm actually out of time, but let me jump to you real quick, Mr. Coleman. What do you say?

Mr. COLEMAN. For the record, I am pro-budget. I'm very supportive——

Mr. WEBER. For the record? OK.

Mr. COLEMAN. Very important, yes.

Mr. WEBER. I gave you a chance to redeem yourself.

Mr. COLEMAN. Yes. Thank you. I appreciate——

Mr. WEBER. All right.

Mr. COLEMAN [continuing]. That.

Mr. WEBER. I didn't want that to fuel any controversy.

Mr. COLEMAN. I hear you.

Mr. WEBER. Yes.

Mr. COLEMAN. On our side, we've been focusing on enzyme efficiency, so from a biorefining perspective, when you improve the enzymes, you're producing fuel and feed, you can squeeze more and more of each product out of every bushel of corn, or every whatever——

Mr. WEBER. OK.

Mr. COLEMAN [continuing]. Right? And so that's where we've made a heck of a lot of progress.

Mr. WEBER. Perfect. And I'm out of time, but offline I want to talk to you about why you all can't get—you said—the EPA to give you—was it a permit or designation?

Mr. COLEMAN. A registration.

Mr. WEBER. Registration? Thank you.

Chairman LAMB. Thank you. Recognize Mr. McNerney for 5 minutes.

Mr. MCNERNEY. I thank the Chairman, and I thank the witnesses. An excellent subject, good, interesting information that you're providing.

Mr. Chen, in your testimony you mentioned that Rivian has several battery powered train and advanced technology research and development centers in California. What role do you believe that California's regulations have played in fostering innovation in that State? My State.

Mr. CHEN. I think they played a large role in fostering that, not only from the emission standards, but programs such as the ZEV Mandate, which really encouraged industry to start looking at alternatives like battery electric vehicles. In addition, on a less direct method, by being able to monetize credits from generation and production, and introducing to commerce zero emission vehicles, those types of programs have allowed manufacturers like Tesla, and soon Rivian, to be able to sell those emission credits to traditional manufacturers to help further fund the efforts by those startup manufacturing companies.

Mr. MCNERNEY. OK. What effect, do you think, rolling back the clean air rules for California is going to have on incentives for innovation in California, and in the United States in general?

Mr. CHEN. Frankly speaking, I think it sends absolutely the wrong signal. I think it's a step backward toward our movement toward greater fuel efficiency. Not just alternatives such as battery electric vehicles, but traditional technologies, basically internal combustion-equipped vehicles.

Mr. MCNERNEY. I see it the same way. Ms. Schlenker, you note in your testimony that the application of hydrogen as a fuel choice for U.S. industrial processes could be synergistic with fuel cell development. Could you expand on that a little bit?

Ms. SCHLENKER. I think that some of the very energy-intensive manufacturing processes that we have in the U.S., that could be iron, or——

Mr. MCNERNEY. Is you microphone on?

Ms. SCHLENKER. Thank you. That could be iron, or it could be steel manufacturing, as an example, very energy intensive. And to be able to use hydrogen as a fuel source, expanding beyond natural gas, or other choices in today's market, we think that has some viability to help create that demand for the hydrogen infrastructure. As an example, we have renewable solar and wind today feeding back into the grid. At times, it's actually in surplus to what the grid can take. It goes into secondary battery storage for the grid. It has another use, where it actually could be combined with CO_2 and converted with electrolysis into hydrogen, or other fuel choices. So that's really what we're thinking through, is how to use hydrogen within industrial processes as well to help increase that demand, if you will, for the fuel cell vehicle technologies.

Mr. MCNERNEY. Excellent. Mr. Chen, I've read that rare earth materials will be a significant limitation to large-scale adoption of EV technology. Would you comment on that?

Mr. CHEN. Yes. Interestingly enough, and ironically, rare earth minerals are probably misnamed, because they aren't that rare. Where we really see a problem is supply constraint. Right now roughly 90 percent of all rare earth minerals are produced in a single country, China, and this has given them a near monopoly over the supply chain. There are certainly methods, or policies, that can be put into place to encourage the development of the extraction of these types of resources from places outside of China, including in the United States. To date, I'm aware of only a single operating facility that mines rare earth minerals in the United States. Certainly there is room for policies to encourage greater development here domestically.

Mr. MCNERNEY. Thank you. Whoever wants to answer, how does fuel cell technology compare to simple burning of hydrogen for efficiency?

Mr. CORTES. On the actual fuel cell side, in terms of utilizing hydrogen to generate electricity, the fuel cells are about 50 percent, roughly, efficient, so we can actually create quite a bit of energy from a kilogram of hydrogen. With respect to others, I guess I would leave to somebody else, maybe, on the Committee that might be able to answer that, comparatively speaking.

Mr. MCNERNEY. Burning is going to be less than 35 percent, I can tell you. Thank you. Mr. Daniel, what about AI, artificial intelligence, for easing traffic, and other applications? Has this been proven, or is it still speculation?

Dr. DANIEL. Amongst the National Laboratories, we're working on utilizing artificial intelligence to solve these problems. Traffic problems are inherently complex problems, in which decisions are made by individual players as a small part of a large system. And in that regard, they're very difficult to control, and they're inherently hard to understand. We're using our supercomputing capabilities across the National Labs system to better understand what are the consequences of certain decisions, and how do they play together? We're working on some systems where we can do what we call faster than real-time simulation, where we can do true predictions of a future traffic scenario based on knowledge of a system we have right now, and by doing so, then understand what control mechanisms are needed to really improve traffic, and reduce the chances of accidents happening.

Mr. MCNERNEY. Thank you. I yield back, Mr. Chairman.

Chairman LAMB. Recognize Mr. Biggs for 5 minutes.

Mr. BIGGS. Thank you, Mr. Chairman. I appreciate all of you panelists for being here today. Mr. Chen, when you consider regulations, do you consider that there are regulations that are disincentivizing private industry investment in sustainable transportation R&D?

Mr. CHEN. I'm not aware of any regulation, per se. Do you have a particular example of——

Mr. BIGGS. I'm asking you to see, I mean, you're going to be more familiar than I am. So it's pristine, is what you're indicating?

Mr. CHEN. Well, there certainly are programs out there that encourage the adoption of alternative transportation technologies. And as I mentioned to the other Congressman, with respect to things like rolling back CAFE (Corporate Average Fuel Economy) and the greenhouse gas regulation, those are exactly the wrong signals. Government has always had a role to lead on innovation in areas of technology improvement, whether it be through emissions or safety——

Mr. BIGGS. But what I'm trying to get at is—and if I'm understanding—I'm trying to find out if there's any kind of government regulations that's actually impeding private sector development. And you said no, I think, is what you told me.

Mr. CHEN. Not exactly. There are certain areas of regulation that do have us locked into existing technologies, versus allowing us to foster other developments.

Mr. BIGGS. And that's what I would like to know more about. And before we run out of time, I'd ask if maybe, if that's the case, if you can either get together with me and my staff, or shoot me a memo, or something like that, whatever, in the areas that you think have locked us in.

Mr. CHEN. Yes, absolutely. I can do that.

Mr. BIGGS. OK. I appreciate that. So sustainability within the transportation sector is a reasonable goal, but this issue ought to be, in my opinion, championed by private sector, not the Federal Government, which is why I'm concerned with the legislation we're exploring today.

The *Vehicle Innovation Act* authorizes appropriations of more than $1.6 billion over 5 years for research, development, engineering, demonstration, and commercial application of vehicles, and related technologies in the United States, which, interestingly enough, is roughly the amount of private equity investment in Rivian company, as reported in Mr. Chen's written statement. This sounds like an exciting opportunity for the transportation industry, but we have to be cognizant of the Federal budget constraints facing our country.

And so I just want to cover two quick points before I leave here today. The question that I always ask myself is it appropriate for the government to transfer dollars taken by compulsion—which is what we do. When we tax, we are taking dollars by compulsion. There's nobody here that volunteers to do it. Every time we try to have a volunteer taxation program, it fails miserably, so we have to compel it. Should we take that compulsorily gained taxation and provide it to private companies and entrepreneurs to conduct research and development, even if it might provide an overall good? Now, some economists would argue that such transfers from government to private sector researchers incentivizes inefficiencies, suppresses private equity investment, and creates a path-dependent, or increasing return regime that locks research development industry onto a sub-optimal path that inhibits movement to the most optimal paths of research and development.

Several of you have mentioned today China, and I think we should always respect China has literally spent billions and tens of billions of dollars researching into these areas. But we must also understand, and make no mistake, China is a centralized authoritarian nation. They control the money, they control the economy. The leader of that nation, or if you decide that you think there's oligarchs running that nation, those leaders can seize and divest capital from market-driven priorities into government-sponsored priorities. We are competing with that. I recognize we're competing with that. But we have always believed, in this Nation, that a system of freedom of markets will produce innovation, and that will be a more nimble and quick approach and response, and actually be better in the long run.

So, for me, I look at it, and I say, this is an interesting dilemma that we're always in. Do we take this money away from private individuals and transfer it to researchers and engineers who are on the cutting edge? There's no doubt you're on the cutting edge of technology. That is what I wonder about. I think about that often, and I think you can surmise where I come out. And, with that, my time is expired. Thank you.

Ms. STEVENS [presiding]. The Chair will now recognize Dr. Lipinski for 5 minutes of questions.

Mr. LIPINSKI. Thank you, as we play musical chairs here. I want to thank all the witnesses for your testimony today. I've long been interested, and done a lot of work on autonomous vehicles. I know that's not what we're here to talk about, but I wanted to start out in talking about autonomous vehicles a little bit, because they do have an impact here on sustainability.

First thing, though, in the *FAST Act* (*Fixing America's Surface Transportation Act*) reauthorization, I worked to include a provision to establish an inter-agency working group under DOT (Department of Transportation) to promote autonomous and connected vehicles. Do you believe that there is a need? Is this something that'd be helpful, when we're talking about sustainability, to have a similar inter-agency working group, or is there anything in particular you think—the idea is to have more coordination. Is more coordination needed on the issues of sustainability, or would that be a non-worthwhile—just add another layer of bureaucracy? So does anyone have any thoughts on that? Ms. Schlenker?

Ms. SCHLENKER. So I really welcome the question, thank you, because I think we can strengthen the relationship and the collaboration between the Department of Transportation and the Department of Energy. Typically Department of Energy will do early TRL (technology readiness levels) advanced research and development. DOT, in this space of smart mobility, smart communities, has been funding demonstration and deployment. DOE's doing a little bit of that, but DOT largely plays in that area. So to have a seamless integration and coordination between the two agencies to further the research, everything from data exchanges, data management, what are the ultimate questions we're trying to answer in a cohesive project across the agencies, I think would further all of us, and it would then allow transfer of that knowledge to other areas for best practice learnings. So I would certainly be all in favor of having some sort of formalized strengthened relationship between the two agencies.

Mr. LIPINSKI. Anyone else have any thoughts on that?

Mr. CORTES. Yes. So if you look at the Department of Energy's Hydrogen-at-Scale program, you really look at all the elements that are associated with that, the transportation portion is a key element of that entire ecosystem that's developed there. So having better coordination to help drive some of the projects and programs to be able to push that, and to have the scale that we're looking for, from a hydrogen generation standpoint, I think would really be key.

Mr. LIPINSKI. Thank you. Mr. Chen?

Mr. CHEN. Yes, and I would say that there's certainly a need for coordination, including on the vehicle level. The example that I like to point to is that, under DOT NITSA (National Highway Traffic Safety Administration) regulations, Federal Motor Vehicle Standard 111, you have to actually have rearview mirrors, outside mirrors, and the provisions in the regulation actually use the word mirrors, to be able to provide that rearward view. We have shown in the past, both at Tesla and now Rivian, that, by getting rid of those mirrors, and using streamlined cameras, we can improve the aerodynamic efficiency of that vehicle by as much as 3 percent. However, that is locked into a DOT regulation. Having coordination between DOE and DOT to look at the benefits of modifying that regulation certainly would be helpful at the vehicle level.

Mr. LIPINSKI. Thank you. Mr. Coleman?

Mr. COLEMAN. I want to be mindful of your 5 minutes, but coordination is huge for us because it's not uncommon for our companies to be engaged across multi-agencies, and I think that there's a lot of efficiency to be gained from that as part of the mission for the group.

Mr. LIPINSKI. All right. And, in my last minute here, I want to ask, Ms. Schlenker, at Argonne, has anyone done mild impacts of autonomous vehicles on congestion and emission?

Ms. SCHLENKER. So across the National Laboratories we have a big program on smart mobility, and Argonne co-chairs that. I mentioned that Oak Ridge is a part of it as well, an important player. As we look at automating connected vehicles, we have sophisticated modeling tools, and we can do transportation modeling work to look at potential futures, traffic flow, looking at these new business models like Uber and Lyft coming in, e-bikes, e-scooters, transit, first mile, last mile challenges that we have. So all of that is included into our sophisticated transportation models. Beyond that, we do physical experiments on connected and automated vehicles, and understand what happens with active cruise control, or cooperative active cruise control, what the benefits really are on traffic flow, and congestion, and speed, as an example. So that is very active research for the Vehicle Technologies Office at large, and across the National Labs system.

Mr. LIPINSKI. Thank you. My time's expired, I yield back.

Ms. STEVENS. Thank you. And the Chair now recognizes Dr. Baird for 5 minutes of questioning.

Mr. BAIRD. Thank you, Madam Chair, and thank you, witnesses, for being here. Not sure I'll get to ask each one of you a question, but some of my questions relate to almost every one of you, I think. My ag background stimulates this question. I guess, Dr. Daniel, you may be a part of this, and, Ms. Schlenker, you may also want to respond. But I think the DOE Office of Science funds about four bioenergy research centers, if I'm not mistaken, and they conduct coordinated and geographically diverse research in support of developing a viable and sustainable domestic biofuel and bioproducts industry from dedicated bioenergy crops.

In the biofuels research that is conducted at your labs through the Bioenergy Technologies Office, how often do you feel like you collaborate with or leverage the expertise of the Office of Science, and these bioenergy research centers, and what do you feel that collaboration is like? So how often do you collaborate, and how do you feel that works?

Dr. DANIEL. Thank you for the question. Yes, the Office of Science investments are very, very important for the success of our sustainable transportation program, and our innovations in vehicles and mobility systems. We regularly have interactions with those bioenergy centers. We regularly consult with the scientists in there. We even have scientists who are partially funded through those activities, and partially funded through our applied research facilities. That interaction, from the Office of Science to the Applied Research Program, and handing it off to the private sector, I think is really what makes us so strong, and what is really important for the National Labs system.

Ms. SCHLENKER. A similar response, relative to the Office of Science and our biofuels research that we do at Argonne. In particular we're looking at feedstocks. We're looking at the opportunity, with membrane separations, and agricultural land use, as an example, and those conversion processes, and how you scale that, then, over into industrial and commercial processes, and even into the demonstration phase. So the linkage back to the Office of Science is really important to us, and their expertise in some of these fields is transferred directly over into the applied program.

Mr. BAIRD. Thank you. Mr. Coleman, would you care to elaborate on some of the biofuels, bioenergy crops, that you're looking into, and where that stands?

Mr. COLEMAN. So our industry, as you know, started with corn, because the corn—and by that specifically it's the inside of the kernel, right, because that's what is already fermentable, so the corn does the work of making a corn mash that's already fermentable. What's happening now is the industry is self-interested in feedstock diversity. Obviously they want to be able to not just be tethered to corn prices, but other feed stocks.

Where it's gone in phase two is waste. So 70 percent or so of what's in an urban landfill is wood, paper, and cardboard, and so you have a tremendous amount of cellulosic material there, and then agricultural residues is corn fiber, corn stover, wheat straw, things like that. So the honest answer is, we're working through the waste-side because of the low feedstock costs, and we're at essentially to demonstration phase on the energy crop side. And a lot of that is really applying efficiencies to existing agricultural commodities to squeeze more product out of those products, efficiencies, and obviously better bottom line. Novazymes, for example, is very interested in alternative crops. Some of the miscanthus and the more exciting stuff you hear about on the side.

Mr. BAIRD. Thank you. Mr. Chen, we've got about 48 seconds for two more—any thoughts on that?

Mr. CHEN. No, Congressman, not on those particular thoughts. Rivian's focused on electric vehicles. We're agnostic as to where the electricity comes from.

Mr. BAIRD. Thank you. I didn't think so, but I thought I'd give you a chance. Mr. Cortes, do you have any thoughts, since it's in your DOE——

Mr. CORTES. No, as far as, you know, the electricity from a hydrogen standpoint, that's really more the area that we're most interested, in terms of the generation, and green hydrogen, and having the supply where we need it to be to drive the demand.

Mr. BAIRD. Thank you. My time's up, and I yield back.

Ms. STEVENS. And at this time the Chair would like to recognize Dr. Foster for 5 minutes of questioning.

Mr. FOSTER. Thank you, Madam Chair, and thank you to our witnesses. Let's see, one of the many hats I wear here is co-chair of the National Laboratories Caucus. I'd just like to say that we've been having CODELs (Congressional Delegations) to all of the DOE National Labs, and the reaction that we get from Members when they realize the tremendous amount of intellectual horsepower and technical horsepower there is really, I have to say, gratifying. And we're going to be coming soon to Argonne National Laboratory, and we will, I'm sure, be seeing some of what we're going to be talking about here.

And one of the valuable things National Labs can do, as well as industry, is to look at the costs and the crossover points for different technologies. You know, for example, if you look at batteries, as they descend in cost, they become first viable maybe for automobiles, then later for long-haul trucks, later for—or maybe earlier for things like rail, that may be less weight sensitive, and eventually airplanes, when it all goes well. And so, you know, how much is known about what those crossover points are? You know, at what point are batteries cheap enough that really you sort of give up on the internal combustion engine? And we can try my hometown laboratory, Ms. Schlenker.

Ms. SCHLENKER. So maybe I'll try and bail you out from answering on battery costs. So on electric vehicles, if we just reflect back maybe a decade, and for a 250-mile all-electric-range electric vehicle, maybe that battery pack, and these, again, are estimates, was about $45,000. In a decade, we're down to about $17,000 for that battery pack. Where do we think we need to get for this cost parity crossover question, right? We think that range is really about the $7,000, at a pack level, which then informs DOE's goals on their battery research for their targets as they establish the dollar per kilowatt hour targets.

With that said, though, we have to also remember that it's not just simply a one-component focus. You have to pay attention to that entire vehicle, right? So everything from the cost of gasoline, as compared to electricity, to insurance and repair, and manufacturing costs. All of those other things that play into the total cost of ownership. So we——

Mr. FOSTER. Yes. And Argonne and others have been doing cost estimates for decades on the crossover, and so what we're now able to actually understand is, as you've ramped up electric vehicle production, there have been these cost estimates for how the economies of scale would kick in. And maybe Mr. Chen would be a better person to speak on this, you know, have things gone pretty much as expected? Have there been pleasant or unpleasant surprises for not the battery, but the everything else associated with electric vehicles?

Mr. CHEN. Yes, actually, there has been a substantial amount of progress in that regard. I think if you look back 10 years ago, 2008 is when Tesla introduced the Roadster, and that was a two-seat sports car that had a battery pack that could run roughly 250 miles on a single charge, and that vehicle cost about $130,000. If you go to where we are today, Rivian will be coming out with its R–1T pickup truck, and it starts at a cost of $70,000 for a 105-kilowatt battery pack, so substantially more energy, roughly about the same amount of range as the Roadster back in 2008, but now you've got a vehicle that is substantially larger.

So it's not just the battery cost, as you mentioned, Congressman, but it's also the efficiencies in the motor, it's lightweighting the materials, it's looking at the aerodynamics, and it's the energy density of that battery pack. And, through the entire course of the last 10 years, there has been substantial progress in all of those areas.

Mr. FOSTER. So no disappointments in terms of—has anyone taken the time to look backward at the cost projections that were made a decade ago or two to see if your—because, you know, there's a danger here looking at the proponents' cost estimates, particularly for scaling and quantity.

Mr. CHEN. Yes. Absolutely. I'd say the biggest disappointment is we're not getting there fast enough. And, actually, this hearing is very timely because getting there fast enough is about reducing cost, and is about increasing energy density, and looking at new technologies.

Mr. FOSTER. Yes. And, Mr. Cortes, how do fuel cells fit into this landscape of, you know, cost and performance?

Mr. CORTES. Yes, it's really more about performance. So if you look at—and we think about things as not as an either/or, it's an and. There are very good places where—and applications where batteries work really well. When you talk about long haul, or range and distance, at some point, when you have a battery, in order to increase the distance, you have to add more batteries. When you add more batteries, you're adding more weight. And at some point it becomes difficult.

And, for us, there's a crossover point from a performance standpoint, where fuel cells provides that additional range without that additional burden of the weight. It's more of can you add a larger tank to house the additional hydrogen needed to be able to do that? So there's applications that are really well-suited for batteries, and then there's applications that are really well-suited for long haul, and delivery vans and things like that where now the payload becomes a critical aspect.

Mr. FOSTER. All right. Thank you, and I guess my time is up at this point.

Ms. STEVENS. And now, also from the great State of Illinois, the Chair would like to recognize Mr. Casten for 5 minutes of questioning.

Mr. CASTEN. Thank you. Technically it's the greatest State, especially with so many folks from Illinois here. So thank you very much. Thank you all for coming. A couple questions, and the first is a question that just always puzzled me a little bit. My first car was an 1984 Honda Civic, super nice car. It had an AM/FM radio. I think it had a tape deck. I know it had a rear defroster, and it had headlights. I'm not sure what other electric loads were on that car. And, you know, to buy a new car today you've got, you know, GPS, you know, XM satellite radio, heated front and rear seats, maybe a heads up display on the dashboard, all the new stuff that's coming out. Drive by wire auto parking, you know, automatic driving. Can you just help me understand, Dr. Daniel, I'm curious, number one, you know, I know we've gone from 12-volt batteries to 24-volt batteries, and—alternators. What is happening to the onboard electric loads in the vehicle, and is there any reason to believe that that trend is saturating, or is that just continuing in perpetuity?

Dr. DANIEL. Yes, thank you for that question. I think that's a very timely question. When we look at the changes happening in the mobility segment there, I believe that current vehicles, vehicles that have an operator, and where a driver is doing most of the work, those auxiliary loads are not quite as critical, unless it is in an area like an electric vehicle, where every electron counts, right? That's something we really have to look for, and the Department of Energy is looking particularly at research—how can I reduce those loads? But where it really changes the game is when we look at connecting automated vehicles, vehicles that drive themselves, potentially, vehicles that need to make decisions based on perception around them. We believe that the auxiliary loads at that point will go through the roof. And that's something where we have no technical solutions right now for, and we need to dramatically reduce the energy consumed by sensors and processing units for those vehicles.

Mr. CASTEN. So without asking you to guess on a time, is it reasonable to conclude that at some point just the features that consumers want on a car is going to make electrification substantially inevitable?

Dr. DANIEL. I don't know if I can draw that conclusion inherently, but energy efficiency of those components becomes very, very critical. We're seeing very high demands. Some people estimate that in a connected automated vehicle we're having, like, 3 kilowatts of usage for sensors and computing.

Mr. CASTEN. Um-hum.

Dr. DANIEL. Some people put that number as high as 5 or 7 kilowatts.

Mr. CASTEN. OK. Can I at least conclude that getting to some level of plug-in electrification is going to be inevitable, just given the voltage and the efforts that we made on cars?

Dr. DANIEL. I believe some electrification will certainly be helping there, but I think there are other reasons why we would want to electrify, not necessarily just the——

Mr. CASTEN. Sure.

Dr. DANIEL [continuing]. The autonomous——

Mr. CASTEN. Yes, of course.

Dr. DANIEL [continuing]. Side of it.

Mr. CASTEN. Of course.

Dr. DANIEL. Absolutely. Yes.

Mr. CASTEN. So then I get the question, and this is for, you know, I guess for Mr. Chen in the first instance, there was this political article, I think last week, about the oil companies working very hard behind the scenes to slow—essentially deployment of charging infrastructure. What are you seeing, and what are the specific concerns you have that we should be watching for? Because if, in fact, for all the reasons, whether consumer driven or environmental driven, you know, the reasons you mentioned, if we know we're going to need that charging infrastructure, what are the barriers that you see that we should be thinking about, even beyond the scope of this Committee, to make sure that we get that charging infrastructure out there, given that the oil companies seem to be working hard to prevent it from happening?

Mr. CHEN. Yes. I did read that article, and, to be honest, I was a little bit annoyed by that article, because they continued to cite a study, I believe it may have been out of the UK, but that study has been long debunked. It basically was the conclusion that electric vehicles were less efficient than gasoline-powered vehicles. And, again, that study has been thoroughly debunked by scientists.

In answer to your question, I think what the Committee should be looking out for is the accuracy of this type of information, and the interests of those who oppose the deployment of electric vehicles in fostering American innovation. What are the goals behind that? Why are they really coming at this angle? As we look toward how we invest American taxpayer dollars into technology, this Committee needs to make sure that those dollars are invested wisely, and based on solid information, and sound science.

Mr. CASTEN. OK. Well, I'm out of time, but if you have any information specifically about the charging infrastructure, of where we should be looking, I'd very much appreciate it.

Mr. CHEN. Absolutely.

Mr. CASTEN. Thank you. I yield back.

Ms. STEVENS. The Chair now recognizes Mr. Tonko for 5 minutes of questioning.

Mr. TONKO. I get to go ahead of the sitting Chair. Thank you. Thank you. Wow, I like it here, you know? So thank you, Madam Chair, and thank you to the Subcommittee for holding this hearing, and thank you to our witnesses for the expert testimony that you provide so we can discuss sustainable transportation. I hope the Federal Government can play a positive role in moving the research and the field forward.

As I mentioned earlier, I am so proud to represent the Capital Region of New York, which is home to many innovative companies, including Plug Power. Plug Power continues to be a leader in the innovation economy. Last month, indeed, I had the opportunity to join them in celebrating the partnership amongst Plug Power, the United States Department of Energy, FedEx, and Charlotte, and Albany Airport to power highly efficient fuel cell-powered ground support equipment through a DOE-funded program, a great feat. So, Tim, congratulations again on that success.

In your written testimony, you talk about the DOE market transformation being a key to your success. Can you tell us a little more about how it was successful, and how it is leading to additional sustainable transportation technology developments with project partners?

Mr. CORTES. Yes. Thank you for the question. Yes, in 2008 we were awarded the program that allowed us to deliver several hundred fuel cells to customers. At the time it was really good timing for the program to come to us, because it was at the point where we were just about to introduce that product to the marketplace. And what it really did was—it allowed Plug to seed several units with customers to get them to be able to have an understanding of the technology, understand how to use it, understand the value that it brought to them, and their organization, and their operations, and the ability to actually take advantage of that in the application to make sure they understand all of the performance aspects, any safety concerns that they had, and it really was, you know, a program that allowed them to do trials, if you will, without having to spend significant amount of money for infrastructure, and to, you know, to make a huge commitment on theirs. So it really provided them the avenue to test the technology, and prove it in within their own operations.

Mr. TONKO. Thank you for that. And what do you think the DOE could do to better strengthen the partnership with the industry? How do we make sure that the U.S. keeps our leadership in hydrogen and fuel cells in the global marketplace?

Mr. CORTES. That's a really good question. I think the DOE does a really good job when it comes to the pure R&D, and the funding for the labs, and the great work that they're doing. I think some of the areas that could really help with bringing some of these technologies to market, and driving the growth with regard to these technologies, both for fuel cells and hydrogen, is ensuring that there's an appropriate amount of funding and programs for some advanced demonstrations.

I mean, at some point you have to take the hard work, and all the findings from the lab that was done, and determine how do you scale, how do you take it to practice to then be able to implement it on a commercial standpoint? So there's a chasm there that exists that would really be good if there was a certain percentage of the DOE dollars not just for the hard research and the R&D, but also to be able to bridge those gaps.

Mr. TONKO. Thank you. Can you speak to the current supply and demand for hydrogen, and how it affects hydrogen fuel cell integration into the commercial market?

Mr. CORTES. Yes. So supply of hydrogen, as it relates to the hydrogen that can be used by fuel cells, has been very flat over several years, and the demand that we've seen, both from our marketplace, as well as light-duty retail vehicles, has really started to go up. So the concern that we have is at some point that demand is going to, if things aren't done differently, outstrip some of the supply. And what that does is it creates a scenario for the application and the market to be very concerned about, if I'm going to go and invest in these technologies, and I'm going to spend money, what's going to happen if I don't have that supply of hydrogen to be able to continue to use my products?

It's like—when you and I go buy a car, we don't worry about, you know, where the gasoline's going to come from. It's ubiquitous, it's everywhere, and so it's not a care for us. But if you're worried about supply, and it's not readily available, it makes you think twice, and then the adoption rate then becomes a difficult factor.

Mr. TONKO. And you state in your testimony that Plug Power participates on the Hydrogen Council, a global hydrogen fuel initiative, which estimates that hydrogen could help cute global CO_2 emissions by as much as 20 percent by 2050. Can you just explain quickly how hydrogen fuel technology adaptation could help achieve this goal?

Mr. CORTES. Yes, absolutely. So, you know, a byproduct of fuel cells is basically electricity, but there's also a small amount of heat and water. There's no emissions, so it's not like a combustion engine that's putting out emissions. And if you couple that with fuel from hydrogen that could be generated from hydroelectric, wind, solar, then you've got, you know, a clean source of hydrogen going into the unit, and you've got a generation of electricity powering equipment with no emissions and no byproducts.

Mr. TONKO. Wonderful. Thank you so much. Madam Chair, you have been generous. Thank you. I yield back.

Ms. STEVENS. And the Chair would now like to recognize herself for 5 minutes of questioning.

Mr. Chen, in your testimony, you specifically mention rare earth minerals. My colleague, Mr. McNerney, also talked about this in his questioning to you as an area where battery technology developers in the United States are sort of at the mercy of China, and an example of how foreign dominance is an impediment to the development of electric vehicle technology. In addition to the availability of rare earth minerals, and potentially dovetailing from some of the line of questioning that my colleague, Mr. Tonko, was asking of Mr. Cortes, what are some of the other long-term impediments you see to electric vehicle adoption in the U.S. market?

Mr. CHEN. Thank you for the question. That's actually a pretty broad question, and I would have a long laundry list of things that could certainly hamper deployment of electric vehicles. I think I have to go back and look at the demand side of this, and say that there are still concerns amongst consumers about understanding electric vehicles. The cost, the charging infrastructure, the maintenance requirements. I really think a lot of the impediment is education to the public and the infrastructure.

Ms. STEVENS. So why does a company like yours exist?

Mr. CHEN. Well, without trying to sound glib, I mean, it's simply the right thing to do. A company like Rivian exists because our founder, and every member of our company, believes in this technology, in the fact that, you know, our mission is to or allow the world to continue to be adventurous. It does not make sense to go out into these pristine areas of the world and do so in a vehicle that is spewing criteria pollutants and creating greenhouse gas emissions. So, quite simply, we believe humanity should be out there and enjoying the world, and everything it has to offer, but minimizing that footprint as much as possible.

Ms. STEVENS. Well, and certainly others agree with you, given the continued investments being made from outside investors in your company. I am so delighted that you're located in Plymouth, in the old Boroughs plant, and it is certainly an exciting and vibrant atmosphere that I think is speaking to the demand that exists not only here in the United States, but around the world.

And, I was wondering, could you shed any light in terms of some of the global competitiveness that you see that we have here in the United States, as compared to countries who maybe are making some more prominent and pronounced investments in electric vehicle technology, and where does that leave our consumer base, versus what we're seeing internationally?

Mr. CHEN. Sure. So, as you mentioned accurately, there is a high demand for our products. We've had several events where we've had folks come out and see the vehicles, and generate a lot of excitement and a lot of buzz. That all said, I think the United States has a long way to go still on electric vehicle technology investment. What was mentioned earlier in my testimony, and through a line of questionings, about other countries, China in particular was mentioned as investing $60 billion a year into electric vehicles not just to seed the market, but for manufacturing and technology. So I certainly think there is a role for the U.S. Government to play in investment, and certainly looking at how to foster this technology.

Ms. STEVENS. Yes. And, with that, I'd love for our labs to chime in here as well, and maybe talk a little bit more, in addition to what was so pronounced in your testimony, but how you see yourself interacting with companies like Rivian, and the technology demand today, and in the future, and what would be required of us to continue to support you and your lab efforts? Ms. Schlenker, if you would like to start, we'd love to hear from you.

Ms. SCHLENKER. So as we think about electric vehicles, and of course, the infrastructure has to come along with it, but it's really a dance, where you have to have good utilization of that infrastructure at the same time the market is there for the consumer pull of the vehicle. And lots of different models available now in electric vehicles. It's wonderful to satisfy that market, but really addressing some of those infrastructure challenges still. Everything from faster charging, as I talked about, medium duty, heavy duty at a megawatt. We are seeing successes with mass transit buses now, when you stop to think about the big 40 passenger bus, and they're being electrified. Chicago, New York, many other cities as well. That's a real win, where all of a sudden that technology is cost competitive to what previously was a natural gas or other biofuel vehicle.

Dr. DANIEL. Yes, thank you for the question on that. I'm actually really excited to hear about some of the anxieties about the rare earth materials because I believe we can provide technical solutions on there, that maybe those might not be needed as much as they currently are in the future anymore.

So, as an example, we have developed motor technology in the National Labs system at Oak Ridge National Laboratory with ferrite magnets in them. They don't need rare earth materials in them. Those are potential solutions. In order to solve some of the problems of rare earth supply, some of those issues in the United States is that waste processing is a big problem. So if you mine neodymium, for example, 90 percent of what comes out of that mine is cerium. We have developed a use for cerium in a new alloy which can be utilized, and, therefore, with the potential application of that waste product, the cost of providing neodymium has the opportunity to drop.

And my last comment on that is we're working with two other National Laboratories together in an electric drive technologies consortium, where we have the goal by 2025 to reduce the combined size of the power electronics and electric machinery component for an electric vehicle, to reduce that by a factor of eight compared to what's currently in vehicles in there. All of those technology developments will have a dramatic positive impact.

Ms. STEVENS. And, with that, I yield back the remainder of my time, and would maybe like to pass this over to our—OK. Well, we'll say this, that this hearing is absolutely essential, and we thank our partners from the labs who have joined as members of the audience today, and we also thank our industry partners, as well as our consortium partners in a topic that is most assuredly going to continue to evolve and capture the imagination of our country.

And in regions like where I represent, I think the big question around the moon shot for the next 50 years is couched within our ability to get to electric vehicles, and get to zero emissions, and how we do that, and why we do that, continues to drive us forward. So know that the history of today's hearing, the great leadership that we have from Chairman Lamb, and the incredible colleagues that I have the privilege of serving on this Committee with will continue to carry the ball forward, and develop legislation that will advance the work of our labs, and assist the charge to bring electric vehicles, and the infrastructure, to proliferate them into the marketplace as part of our legislative portfolio. So thank you all so much for being here.

The record will remain open for 2 weeks for additional statements from Members, or for any additional questions that Committee Members may have of the witnesses. At this time the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 3:53 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ms. Ann M. Schlenker

U.S. House of Representatives Committee on Science, Space, & Technology,
Subcommittee on Energy
September 18, 2019, Hearing
The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector
Questions for the Record Submitted to Ann Schlenker

Questions from Representative Bernice Johnson, Chairwoman,
Committee on Science, Space and Technology

Question 1. *In your written testimony, you discuss the interactions between electric vehicles, the consumer and the electric grid.*

a. *What are the primary limiting factors to widespread adoption of electric vehicles? Are the solutions to those limiting factors found primarily in economic, technological or systemic changes?*

Electric vehicle adoption in the U.S. has steadily grown but market penetration remains low. There are indeed many car models available for consumer choice, however, the marketplace pull has been less than many desire. The component technology cost, i.e., battery packs, does remain a barrier to matching the price of an internal combustion engine (ICE) conventional vehicle. Additionally, people remain uncertain about battery life in varying use profiles. Providing an all-electric range of at least 200 miles for light duty (LD) vehicles appears to offer users security and comfort, with home, work, and public charging options. Early adopters are pivotal in demonstrating to the market that the technology is safe, robust, and reliable and satisfies household mobility needs. This social connection and interactive learning of new technology is paramount to achieving the technology adoption curve whereby purchasers become comfortable with a new technology.

b. *In your opinion, what future research is required to accelerate the commercialization of the EVs of the future?*

Reducing the cost of battery packs, extending useful life and lessening dependence on rare and precious metals requires fundamental scientific research into new materials beyond the lithium ion technology most common today. The pipeline from discovery to product incorporation frequently spans 15-20 years; the time is now to accelerate this R&D. Battery recycling plans—critical to reducing U.S. dependence on anode and cathode materials—are in early R&D stages and planning for secondary usage and end-of-life disposal and recovery are prime environmental and security issues. Moreover, the consumer is accustomed to an 11 gal/min gasoline fuel rate, for a 3-4 minute fueling station stop. Equivalent electric vehicle charging time is not foreseeable but consumers will likely accept a 15-20-minute fast charging experience, which can serve as a real and perceived safety net, avoiding the risk of the electric vehicle being stranded. However, fast charging has been observed to negatively affect battery life, meaning additional research is needed on fast charging, extreme fast charging (XFC) and vehicle and grid interactions. Finally, infrastructure build-out, in the form of residential and commercial building requirements, workplace charging installations, and public charging availability, will prepare the transition to an electric vehicle future. As most charging occurs at home and work, programs supporting charging station deployment at these locations will be beneficial.

c. *What differences are there between the research needed to develop medium- and heavy-duty electric vehicles for trucking and shipping and the research needed for light-duty electric vehicles for consumers?*

Medium duty/heavy duty (MD/HD) trucking and goods shipment present a great electrification opportunity along with some unique challenges. Electric buses within a city are an early demonstration of achieving environmental stewardship while simultaneously fulfilling up-time requirements as a service provider. Total cost of ownership analyses have encouraged this application. In addition, electrifying MD/HD trucks requires us to address factors such as varying and heavy payloads, numerous work applications and differing daily driving distances and duty cycles. Diverse business models are a factor as well—some businesses may lease or own their trucks for a limited amount of time before reselling, while others keep their truck fleet for a period sufficient to recoup their initial investment.

This electric MD/HD segment requires a larger battery pack than the LD segment (e.g., a transit bus at 220-660 kWh, compared to a LD application at 60 kWh) and charging-related time out of service significantly hinders an efficient business operation. Megawatt (MW)-level XFC is needed; impacts to the grid, vehicle, battery pack, cycle life are all areas ripe for research. Charging at depots and yards must be complemented with public XFC. Use pattern predictability may open doors to synergistic benefits as well, such as using school bus batteries to offset excess solar power when the buses are not used.

As goods delivery business models change and e-commerce increases, the daily distance traveled by trucks has decreased. This trend favors electrification in component sizing and charging requirements. E-commerce and new mobility technologies may accelerate the market penetration and demand of PEVs (plug-in electric vehicles). Quantifying this opportunity is another ripe research area.

Question 2. *In your written testimony, you draw important connections between advancing vehicle transportation and emergency preparedness and security.*

a. *Could you expand on the importance of improving vehicle efficiency, whether light-weighting or improved equipment efficiency, to U.S. citizen's day-to-day lives?*

Family transportation expenses, second only to those for housing, represent a large part of the household budget. We require mobility to access our job, doctor, school, and grocery store, whether using a personally owned vehicle, bus, or transportation network company provider. Our movement is seldom fully discretionary for a Monday-Friday life; transportation affordability impacts the household. Improving fuel economy in new vehicles, with a ripple effect into the used car market, helps families save money. The numerous fuel efficient technologies in our vehicles include engine combustion enhancements, transmission gear speeds, light weighting, improved tire compositions, start-stop features, and more. Steady year-over-year improvements continue. This fuel efficiency progression, with simultaneous tremendous technological improvements in vehicle safety, clearly achieves a societal benefit while remaining cognizant of new vehicle purchase affordability. The U.S. continues this positive efficiency trajectory to improve citizen's lives.

Question 3. *While electric vehicles and hybrids have the potential to decarbonize light-duty vehicles, and to a lesser extent mid- to heavy –duty vehicles, off-road vehicles are much different.*

a. *Could you please explain how Argonne's work, such as in "e-fuels", is helping to decarbonize difficult aspects of transportation like aviation?*

Non-road transportation applications such as aircrafts, marine vessels, and railway locomotives require onboard energy sources of high volumetric and gravimetric density to propel engines moving extremely large payloads over thousands of miles. Such high onboard energy density is feasible today only with liquid hydrocarbon fuels. Sustainable pathways for using liquid hydrocarbon fuels in these high energy demand applications include both biofuels and e-fuels. E-fuels are attractive because they enable a more flexible and balanced grid, especially with larger penetrations of intermittent renewable power (e.g., solar and wind) in various markets while utilizing existing CO_2 sources, thus achieving the near zero-carbon target for the non-road applications. Sustainability of e-fuels production and use depends on a number of factors: the purity of CO_2 sources; the energy used for capture, compression and transport; the cost and environmental footprint of electricity source; the utilization and energy efficiency of converting electricity and CO_2 to e-fuels; and the amount of carbon in CO_2 that can be locked in the hydrocarbon e-fuel.

Argonne evaluates the sustainability of various pathways for producing e-fuels through chemical engineering process modeling and environmental life cycle analysis. In conducting such sustainability analyses, Argonne has engaged energy and auto industries, national laboratories, and electric utilities through various DOE-industry partnerships and sponsored projects. Other government agencies such as the Federal Aviation Administration help identify e-fuel pathways of interest, disseminate the key research findings, and inform R&D decisions.

b. *Which low-carbon technologies are particularly well suited for uses other than on-road vehicles?*

Low-carbon technologies applicable to non-road vehicles are those producing "drop-in" or "blendstock" liquid hydrocarbon fuels that leverage both existing infrastructure and end-use applications. In particular, low-carbon biofuels and renewable e-fuels that can replace or blend with existing distillate fuel streams (e.g., diesel, jet and marine fuels) are strongly suited to these non-road applications. One known technology that produces different streams of low-carbon e- fuels utilizes Fischer-Tropsch (FT), a process synthesizing straight chains of liquid hydrocarbons from synthetic gas (syngas), which is commonly produced from renewable hydrogen and CO_2 in a reverse water-gas shift reaction. The renewable hydrogen is produced from renewable and low-carbon electricity via the low-temperature or high-temperature water electrolysis technologies. The availability of the FT and electrolysis technologies and regional availability of renewable/low-carbon electricity and high-purity CO_2 sources, along with various policy drivers, enhance the value proposition of introducing e-fuels into the non-road transportation sector.

Question 4. *Based on investment decisions by large car manufacturers, it appears R&D efforts are focused on battery electric vehicles and plug-in hybrid electric vehicles rather than hybrids.*

a. *Can you explain if, and why, hybrid-engine R&D is still important and how it might be able to serve a unique function in the wider transportation sector?*

Large car manufacturers are making R&D and product investments on a wide range of technologies from hybrid vehicles and plug-in hybrids to battery electric vehicles and fuel cell vehicles. Hybrid technologies might not make daily headlines, but this propulsion option remains an important element of the industry's product portfolio. Researchers remain committed to creating new science, fundamental knowledge, and tools and technology even in a domain as "mature" as the internal combustion engine invented 140 years ago, with lower emissions, greater efficiency and shorter design cycles as a result."

Hybrid vehicle technology was introduced into the U.S. market nearly 20 years ago; this provides a significant inflection point in vehicle fuel economy. Yet, market adoption remains low and R&D is needed to reduce costs and ready this technology for a fuel economy play. Some manufacturers consider this technology as an interim actor, whereby a plug-in vehicle (PEV) is an end-state for greenhouse gas (GHG) and regulatory and legislative considerations. We are still considerably far from that end-state, and hybrids still have room to advance. For example, vehicle-to-vehicle and vehicle-to-infrastructure connectivity and situational awareness suggest new R&D for powertrain controls, and driver information to gain fuel economy benefits of eco-driving and routing, including a pairing based on vehicle technologies. The fuel economy gains strategy needs to remain an all-in game.

Question 5. *In the light-duty vehicle industry there is a tremendous amount of investments in electric vehicles and autonomous vehicles, such as Ford Motor's and Amazon's partnership with Rivian.*

a. *Even with this high private sector investment, why is it important that Oak Ridge and Argonne maintain, if not expand, its applied R&D capabilities and work?*

The Department of Energy national laboratories possess broad transportation portfolios and are stewards in creating new insights, technology, and tools with unbiased scientific data and analyses that are publically presented, commercialized, or transferred to industry for U.S. competiveness. Argonne conducts research for the DOE Vehicle Technology Office of the Office of Energy Efficiency & Renewable Energy, among other program offices, at the vehicle component level, the vehicle level and the transportation system level. We create new materials, manufacturing processes, and scientific knowledge by leveraging tools and user facilities like the Argonne Leadership Computing Facility and the Advanced Photon Source. We convene myriad stakeholders to address challenges from natural gas and off-road technologies to XFC performance requirements and urban life hurdles. This connection with stakeholders shapes national laboratories' R&D as relevant, impactful and timely. A wide industry perspective enables us to ascertain research necessary to engage in the pre-competitive arena for big reach. This early stage research can fill gaps, depending on the market participants and their internal capabilities. Being a "neutral party" in a technology debate and providing sound scientific data and methodologies benefits society at large, as well as government and regulatory entities. Ultimately, the goal is a safe, secure, efficient, and affordable mobility future. The national laboratories help shape that outcome.

Question 6. *Biofuels are regarded as one of the most significant options for reduction of CO_2 emissions in the transportation sector. However, conventional plant-based biofuels' share of total transportation-fuel consumption in 2018 was only 5%, due to challenges such as shortage of raw materials the so-called regulatory 'blend wall" that has prevented the blending of higher volumes of biofuel with conventional fuel.*

a. *Advanced biofuels, for example drop-in fuels and fuels from microalgae, are considered by many experts to be a promising solution, but what are the current barriers preventing wide-scale deployment of these fuels?*

The so-called first generation biofuels, including corn ethanol, biodiesel, and renewable diesel from crop oils and waste oils, have reached production of nearly 20 billion gallons a year in the U.S., with encouragement from biofuel policies such as the Renewable Fuel Standard and low-carbon fuel standards in Oregon and California. Farming and biofuel conversion improvements in the past two decades have resulted in more than 30% reductions in GHG emissions from corn ethanol and more than 65% reductions from soybean oil-based biodiesel. Biodiesel and renewable diesel from waste oils such as animal fats and used cooking oil achieve even higher GHG reductions. Further, modeling the type and magnitude of land use changes induced by biofuel production has advanced in the past 10 years with simulated GHG emissions trending downward.

The E10 blending wall has been a bottleneck in expanding ethanol use in the gasoline pool. Recently, the U.S. Environmental Protection Agency (EPA) has taken action to permit E15 use nationwide to overcome the blending wall.

R&D efforts are underway to advance technologies for next-generation biofuels including cellulosic ethanol, drop-in biofuels and algae-based biofuels. These advancements have reduced costs and improved environmental performance of these fuels, though they are not yet produced at commercial scale. Cellulosic biomass-based biofuels, feedstock quality, logistics, and pretreatment presently still encounter cost and technical challenges, whereby DOE has made extensive R&D investments to help overcome the impediments. Research on algae-based biofuels has focused on increasing algae yields and new strains, harvest and logistics of algae biomass and conversion of the whole biomass—beyond lipids in algae—to biofuels. In addition to the so-called micro-algae, macro-algae (sea weed growth in oceans) offers great potential for significant biofuel production without confronting the challenges of land and water requirements for micro-algae growth.

b. What should be the focus of federal government research in this area?

The federal government has supported biofuels R&D for over 30 years. This effort has resulted in lower cost biofuel production and increased energy and environmental performance from biofuels. Moreover, support has been aligned to R&D efforts for efficient biofuel use in motor vehicles and to establish needed biofuel distribution and refueling infrastructure. Beyond R&D support, biofuel policies have had an impact on biofuel deployment in the transportation sector.

c. What is the role of advanced biofuels for light and heavy-duty transportation, considering costs, availability, and net environmental impacts?

Biofuels, with significant energy and environmental benefits, will continue to help reduce the environmental footprint of ICE technologies in the transportation sector. ICE technologies will continue as an important propulsion technology for the medium time frame; expanded biofuels with low-carbon footprints and better performance attributes (such as high octane number) will enable improved outcomes for ICE sustainability. This is especially important in transportation modes where electrification could be more challenging, such as long-haul heavy trucks, air transportation, and marine applications.

Question 7. *There are still questions about the life-time environmental impact of biofuels, as you note in your testimony.*

a. How does Argonne's research of biofuels examine the lifetime emissions and environmental impact of producing these fuels?

Argonne has been conducting life-cycle analysis (LCA) on a variety of vehicle technologies and transportation fuels, including conventional petroleum fuels, biofuels, electricity, and hydrogen, for more than 20 years. Argonne has developed the Greenhouse Gases, Regulated Emissions and Energy Use in Transport Model (GREET) LCA model to consistently evaluate the energy and environmental effects of these technologies and fuels. There are currently nearly 40,000 registered GREET users, including governmental agencies, industries, universities, and research institutions, globally. The GREET model has been used by the EPA, National Highway Traffic Safety Administration, California Air Resources Board and the state of Oregon.

With annual data updates in farming and biofuel conversion, the GREET model shows GHG emission reductions of 30% from corn ethanol and 65% from soybean diesel as compared to petroleum gasoline and diesel, respectively. Next-generation biofuels will demonstrate even larger GHG reductions, while reducing fossil energy use. As part of its LCA efforts, Argonne, in collaboration with several universities, has simulated biofuel-related land use changes. This research has been informative, as simulated GHG emissions related to land use changes are much lower than estimated 10 years ago. For example, corn ethanol GHG emissions from land use changes are now simulated to be less than 15 grams per megajoule (MJ) of ethanol, versus more than 100 grams per MJ simulated in 2008.

Question 8. *In your testimony, you state that "fuel cell and hydrogen technologies are another important area of research."*

a. *Can you describe the applications in which fuel cell research might have the largest impact?*

Fuel cells are particularly attractive for zero-emission vehicles (ZEV) requiring large amount of onboard energy storage, such as medium-duty and heavy-duty vehicle applications (delivery vans, transit buses, drayage trucks, and other vocational vehicles) that carry significant payload and travel over 100 miles each day. Deploying such zero-emission vehicles is particularly critical in areas with high nitrogen oxide (NOx) and other pollutant emission concerns, and with high population densities exposed to these emissions. Onboard hydrogen storage can carry a large amount of energy, which along with the high efficiency of fuel cells can satisfy these vehicles' daily duty cycle. With a large amount of low-cost onboard hydrogen energy storage, the fuel cell becomes a small overhead to the total vehicle cost, and the cost of fuel cell vehicles can become more competitive with other ZEV technologies.

b. *What are some of the barriers to wide scale adoption of hydrogen fuel cell technology?*

The main barrier to large-scale fuel cell vehicle adoption is the availability and cost of hydrogen fueling infrastructure and the cost of hydrogen, especially from renewable sources. The fueling cost is high in the early fuel cell vehicle adoption phase, due to the small scale and lack of utilization of such infrastructure (in this "chicken and egg" situation, the value proposition of vehicle and infrastructure is dependent on the market penetration of the other). Public support for the initial network of fueling stations and partnership of the hydrogen producers and fuel cell vehicle makers can address this situation.

Attractive early market applications with high hydrogen fueling demand and utilization include captive fleets, such as transit bus and drayage truck applications that return to base for fueling each day. Our research and analysis show the cost of fueling hydrogen fuel cell vehicles can compete with the cost of fueling conventional internal combustion engine vehicles for both light-duty and heavy-duty vehicle applications in the future, due to learning and economies of scale, as the demand for hydrogen fueling grows with the increased market demand for ZEV.

Responses by Mr. James Chen

RIVIAN

October 29, 2019

The Honorable Conor Lamb, Chairman
Subcommittee on Energy
Committee on Science, Space and Technology
U.S. House of Representatives
2321 Rayburn House Office Building
Washington, D.C. 20515-6301

Subject: Follow Up to September 18, 2019 hearing titled "The Next Mile: Technology Pathways to Accelerate Sustainably within the Transportation Sector."

Dear Chairman Lamb:

On behalf of Rivian Automotive, LLC, I am in receipt of your letter of October 15, 2019 thanking me for appearing and testifying at the above captioned hearing. It was my pleasure and an honor to appear before the you and the members of the Committee. In addition, this letter also provides you with responses to your inquiries in follow up to the hearing. Your questions have been reproduced in italics below and our responses immediately follow.

Ql: *In your written testimony, you noted that electrifying transportation in the U.S. will "strengthen the grid infrastructure and foster national security."*

a. Will you please expand on your statement?

There are numerous benefits to the advent of electric drive in the transportation sector. As mentioned during the hearing, among those are environmental benefits as well as strengthening grid infrastructure and fostering national security. With respect to grid infrastructure, an increase in the number of electric vehicles in the U.S. fleet will drive demand for electricity. In discussions with various utilities, Rivian is aware that utilities are making investments to support the growing and anticipated demand. Such improvements include new power lines and upgraded transformers, which increase carrying capacity for all rate payers – not simply those with electric vehicles. These investments are unlikely but for the anticipated growth in demand projected to be generated by electric vehicles.

Moreover, as more customers adopt electric vehicles, vehicle-to-grid services could help even out electricity supply and demand. This option may be especially useful in cities that have adopted larger fleet based electric vehicles. For example, cities that utilize electric buses for public transportation or districts that utilize electric school buses with limited hours of operation could utilize these fleets to provide electricity to the grid when not in use, decreasing costs for the city and customers. Rivian's battery technology is designed to provide vehicle to grid as well as grid to vehicle flow. Even the more sporadic or distributed use in individual consumer applications can have positive impacts. Specifically, utilities are planning to use distributed resources, such as renewable energy production, storage and demand response, to partially control charging impacts of electric vehicles. Smart grid technologies such as advanced metering infrastructure could prove helpful not only in managing the charging of electric vehicles, but better predicting and providing power to all utility users. In addition, such devices allow charging stations to be integrated with time-based rates that encourage off-peak charging, thus better utilizing power generation when utilities have concerns with excess power production. They also allow utilities to analyze charging station usage and charging behaviors to inform investment decisions. All these factors help provide a more efficient and robust utility infrastructure, thus strengthening the overall grid through improvements, better utilization and modernization.

With respect to the national security advantages, despite the increase in domestic production of oil, the United States remains dependent on petroleum produced in other countries for transportation fuel – particularly petroleum from the Middle East. Because of the outsized influence of that region in oil production, the United States is subject to price fluctuations, supply disruptions and other geopolitical events that negatively impact the price and availability of petroleum. Electric vehicles do not rely on a single source of electricity generation but can utilize domestically produced energy from a variety of sources, including traditional generation means such as coal, natural gas, and nuclear power, but also renewable sources such as hydro, wind, solar and geothermal electricity, which have inherent additional benefits as well. Shifting our dependence away from foreign oil to a variety of domestic energy sources strengthens the U.S.'s energy security and protects the nation from the adverse impacts of oil embargos, oil shortages, high prices, and other fluctuations. Simply put, while petroleum access is not a guarantee, domestic supplies of electricity are more certain.

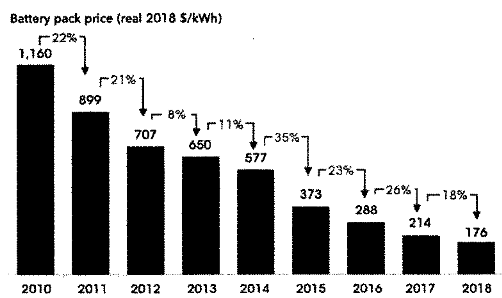
In addition, climate change, driven by the burning of fossil fuels, itself poses a national security threat. The adverse effects of climate change are being felt worldwide. These impacts, which include rising sea levels, droughts, crop failure, and other agricultural disasters, will only increase with continued unchecked carbon dioxide emissions. Such impacts will place more and more pressures on world resources leading to wars, famine, disease and other negative results, which will challenge the safety and security of U.S. interests at home and abroad.

Finally, on national security, oil drives the U.S. economy and the military. With respect to the military, shortages or price increases in oil adversely impact the military's budget and divert funds from other readiness and operational expenditures. Oil shortages can literally prevent the military from functioning given the strong reliance on petroleum as fuel for equipment such as tanks, Humvees, troop carriers, essentially any military hardware on wheels. With respect to the economy, oil shortages can cause economic shock due to the cost of oil in delivery of goods and services, use in air travel and shipping, and even consumers ability to commute, operation of critical infrastructure (banks, supermarkets, hospitals, schools, pharmacies). Shifting dependence away from oil would limit those shocks and provide greater resilience from adverse impacts to the military and the economy. While electric vehicles are not a panacea, they can substantially shift the transportation sector away from its dependence on the single source of petroleum as its only fuel and enhance national security.

b. *What are the primary limiting factors to widespread adoption of electric vehicles? Are the solutions to those limiting factors found primarily in economic, technological, or systemic changes?*

Widespread adoption of electric vehicles is currently hindered by several major factors. These include: availability, cost, and consumer awareness. With respect to availability, the current selection of long-range, all electric vehicles are extremely limited with only a single automaker, Tesla, producing vehicles at volume that are capable of 300 miles or range or better. Rivian has specifically targeted a line of electric pick up trucks and sport utility vehicles ("SUVs") that will have maximum range of 400 miles. Until more automakers commit to making longer range electric vehicles (i.e., at least 300 miles) in a variety of configurations demanded by consumers, the market will remain limited. With respect to cost, electric vehicles remain on the higher end of the price spectrum for new vehicles. This is necessarily due to the higher costs of the energy storage system – namely the batteries. However, as research and development continue and demand grows, maturity of the technology, new chemistries and the coming economies of scale will drive down cost, which will, in turn, lower prices. In a 2019 report, BloombergNEF demonstrated that the cost of lithium ion battery costs has dropped dramatically over the past nine years. The graph below (available at: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/) shows the rate of cost reductions in battery pack prices per kilowatt hour (kWh). As costs dip below $100 kWh, battery electric vehicles will get closer to parity with the cost of their gasoline powered counterparts and potentially surpass gasoline powered vehicles in terms of lower cost at retail.

Lithium-ion battery price survey results: volume-weighted average



Source: BloombergNEF

The third limiting factor is consumer awareness. Consumers are still leery of electric vehicles with concerns about lack of variety, range anxiety and general unfamiliarity with the technology.

Fortunately, the solutions to all these hurdles are solvable. A very large part of this will be support from the federal government in terms of programs and policies that promote electric vehicle and electric vehicle technology proliferation, research and development into batteries and battery chemistry, and a strong signal that the government supports this domestic technology. More specifically, the federal government can and should look to programs that incentivize purchase of qualified electric vehicles such as expansion of the federal tax credit for purchase of eligible electric vehicles (i.e., the Driving America Forward Act, S.1094). Conversely, efforts to levy additional taxes or fees on electric vehicles in lieu of gas taxes to support infrastructure are a red herring and should be avoided, at least at the present. Electric vehicles make up less than 1% of the entire U.S. fleet currently. They do not have an appreciable negative impact to roads or other highway infrastructure. Moreover, the infrastructure funding issue goes beyond simply the gas taxes not paid by electric vehicles. As ALL vehicles have gotten more and more efficient (thanks in large part to strong regulatory programs such as the U.S. Environmental Protection Agency's ("EPA's") greenhouse gas ("GHG") regulation and National Highway Traffic Safety Administration's ("NHTSA's") Corporate Average Fuel Economy ("CAFÉ") requirements from the past several years), manufacturers have increased the efficiency of their vehicles. The federal government should not mandate efforts in one direction only to penalize that success in another way. Rivian agrees that ALL road users must pay their fair share to support critical infrastructure. However, this is a fleet wide issue and not one unique to electric vehicles. Mandating a punitive and market-discouraging fee sends the wrong signal about electric vehicles.

If anything, the federal government should be implementing additional subsidies and programs that encourage electric vehicle technology, including point of sale rebates, nationwide access to High Occupancy Vehicle lanes, and other tangible benefits to electric vehicle purchase and ownership. Such other programs could include grants to states and cities to build charging stations and incentives for utilities and other private enterprises to support broader rollout of electric vehicle charging stations. The proliferation of charging stations can help alleviate current consumer concerns around range anxiety and provide a point from which consumers can gain better understanding and knowledge about the benefits and conveniences of all electric mobility. To encourage domestic production, the federal government could also provide grants to private industry to retool existing manufacturing plants or provide monies to entities reopening or revitalizing shuttered assembly facilities. Those grants could also incentivize the domestic siting of battery and cell manufacturing or research and development activities for the public and private sector. With nearly 100% of battery cell and pack production occurring overseas, the U.S. can support bringing that production back to the United States to supply manufacturers such as Rivian, who is looking for those domestic sources of high-quality cells in large volume. Additional incentives can be focused on job creation, new plants and factories focused on electric vehicles, batteries, charging stations and charging solutions, and other electrification technology. In sum, the federal government can help tip the scales and support electric vehicles by directly addressing the hurdles of cost and incentivizing greater production, which would lead to more availability and greater public awareness.

c. *In your opinion, what future research is required to accelerate the commercialization of the EVs of thefuture?*

Future research that can accelerate the commercialization of the electric vehicles of the future can and should focus on methods to increase energy density and capacity, recharging robustness and capability, and efficiencies to lower costs. Such activities are already occurring in the private sector, but public support of such research and development can help support the industry as a whole, versus a single manufacturer.

Q2: *In your written testimony, you state that the U.S. must lead in the area of new transportation technology or we may "cede leadership in these technologies to othercountries."*

a. *In your opinion, how should the U.S accelerate the pace of research to keep up with technological change, and move proven innovations into practice, codes, and standards more quickly to compete globally?*

U.S. leadership must take the form of unified and bipartisan support for electric vehicle technology. As noted in my written and oral testimony, the technology of lithium ion batteries was invented in the United States; and it was a U.S. company that pioneered the use of this technology to power the current generation of electric vehicles being developed and produced in the United States. Not only must the U.S. continue its leadership role in terms of research and development, but as noted in the response to question 1b, the federal government must take a proactive role in sending a signal of support for this industry to continue to grow and thrive in the United States. This includes robust policies and regulation mandating electrification through such programs as stringent GHG standards for motor vehicles and CAFE requirements. The federal government should also consider other methods of regulation such as a carbon tax where carbon dioxide emissions can be treated as not only a regulated pollutant, but a method to generate credits for those industries and companies who reduce their emissions and the emissions of their products below a threshold level. For motor vehicles, this means credits generated from zero emission vehicles can be commoditized under the EPA and NHTSA programs.

The federal government should also consider support of programs pioneered by states like California with a zero emissions vehicle ("ZEV") mandate – a program that has been so successful that versions of this regulation were adopted overseas as well (including recent adopting in China). Other programs can offset the costs of such new programs – for example, reducing or eliminating the billions in subsidies provided to the oil and gas industry. Based on a U.S. Treasury Office of Tax Analysis review from October 2018, the oil and gas industry will receive tax benefits of $27 billion over the next ten years from tax preference programs such as expensing exploration and development costs ($8.8 billion), percentage depletion ($6.4 billion), short term amortization of geological and geophysical expenses ($2.4 billion) and enhanced oil recovery and marginal wells credits ($9 billion). Shifting these expenditures can fund a number of programs to support transportation electrification. As industry leaders such as Rivian show the capability of electric adventure vehicles, thus triggering a competitive response from others, government can and should play the vital role of pushing such technologies forward through regulatory mandates, minimum goals and a shift in support to electrification.

Q4: *Argonne National Laboratory's ReCell Center, the Department of Energy's first lithium-ion battery recycling center, is focused on finding ways to advance recycling technologies along the entire battery life-cycle for current and future battery chemistries.*

a. What is Rivian's life-cycle strategy for the electric batteries and the various components the company will employ in its automobiles?

As a company dedicated to zero emission vehicles and sustainability, Rivian has devised a long-term plan for addressing lithium ion battery use and end of life. First, lithium ion batteries utilized in electric vehicles already have a long expected useful life (defined as the ability to retain 80% of capacity). Operational viability in electric vehicles is ten (10) years or longer. Once a vehicle battery is no longer suitable for transportation use, that battery can be put directly into a second life application. We have already initiated a pilot program with the Honnold Foundation, a charitable organization seeking to provide solar power and battery backup to impoverished and underserved populations in the world, where our second life batteries from research and development vehicles are donated to that organization's cause. In fact, the Rivian battery packs are designed from the outset to be removed from the vehicle and installed directly into second life stationary applications without the need for extensive retooling or refurbishing. In this application, these batteries will supply another decade (or more) of service before eventually being recycled. Recycling is the third and final step of the battery life management plan.

Rivian's current plan gives the Company maximum flexibility, because the value of a scrap lithium ion battery is unknown currently. This uncertainty is driven by two factors. First, the cost of raw materials remains in flux. Specifically, prices of minerals such as cobalt, nickel, and copper are increasing driven by the increased demand for lithium ion batteries. Continued increases in prices will likely drive a market for recycling these batteries where the value of those minerals will exceed the cost of extraction during the recycling process. Second, the state of lithium ion battery recycling is not yet mature. Until that industry better develops, a strategy that allows Rivian to have the majority of first life batteries going into second life use allows time for the recycling market and technology to develop.

With respect to current recycling activities, R&D batteries that are not donated to causes like the Honnold Foundation are currently recycled. Currently, Rivian pays a recycler a base amount by weight to recycle its batteries. That base amount is then reduced depending upon the composition of the lithium ion battery and the value the recycler can extract from that battery. The general approach to recycling is to remove the printed circuit boards for separate recycling for copper and possibly other elements, and removal of other easily uninstalled parts of the battery. The remaining components are then put through an industrial shredder. The resulting material is called black mass and is chemically processed to recover the materials of interest. For some recyclers, selling black mass to third party processors is the end of their own involvement, and others are more integrated, and do the processing themselves. This processing does not appear to be optimized yet, industry-wide, and the processes vary depending on the type of lithium ion battery chemical in question. Rivian will continue to track the development of the recycling industry and is committed to working with that industry to find the most appropriate and sustainable means of ensuring full battery useful life and subsequent element recovery.

Q5: *In the light-duty vehicle industry there is a tremendous amount of investments in electric vehicles and autonomous vehicles, such as Ford Motor's and Amazon's partnership with Rivian.*

a. Even with this high private sector investment, why is it important for National labs such as Oak Ridge and Argonne to maintain, if not expand, its applied R&D capabilities and work?

While the private sector can and does play an important role in leading technology for electrification of transportation, the public sector has an important role as well. In addition to regulatory mandates and minimum goals as discussed in the responses to questions 1c and 2, research and develop activities benefit the entire electrification industry. Accordingly, it is important that the public sector also participate and lead in these broad application areas.

* * *

Thank you again for the opportunity to appear at the Committee on Science, Space and Technology, Subcommittee on Energy. It was my honor and I hope the foregoing responses are helpful to you. Should you or other members of the Committee have any additional questions or would like to engage in further dialogue, please feel free to contact me.

Sincerely,

James C. Chen, Vice President of Public Policy

Responses by Mr. Brooke Coleman

HOUSE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

"The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector"

Mr. Brooke Coleman, Executive Director, Advanced Biofuels Business Council

Questions submitted by Representative Eddie Bernice Johnson, Chairwoman
Committee on Science, Space, and Technology

Q1: Biofuels are regarded as one of the most significant options for reduction of CO2 emissions in the transportation sector. However, conventional plant-based biofuels' share of total transportation-fuel consumption in 2018 was only 5%, due to challenges such as shortage of raw materials the so-called regulatory "blend wall" that has prevented the blending of higher volumes of biofuel with conventional fuel.

ANSWER: Respectfully, we do not agree with the premise of the question.

- The biofuels industry is the largest renewable energy sector – by employment – in the United States. Roughly 10 percent of the market for gasoline is made up of domestically-produced, renewable ethanol. Biodiesel and renewable diesel constitute a smaller but significant percentage of the diesel fuel marketplace. The biofuels industry ramped up commercially very quickly, and should be considered an example of what can happen when environmental, national security, economic and political interests are aligned.

- There is no shortage of raw materials to make first-generation biofuels. In fact, it's just the opposite. The United States is suffering from corn and soybean oversupply, and the resultant problem of low prices. Trade disputes are part of the problem, as export markets have dried up during the Trump Administration's trade war with China. However, U.S. EPA has also wiped out roughly 4 billion gallons of biofuel demand by issuing an unprecedented number of small refinery exemptions (SREs) under the Renewable Fuel Standard (RFS). The U.S. farming trend line is increased production of agricultural commodities from declining acreage (due to sharp yield-per-acre increases and other efficiencies). The issue is not feedstock supply, it's undependable policy implementation in a non-competitive, policy-driven marketplace. In other words, global fuel markets are not free markets. As such, renewable fuel producers rely on corrective policy like the Renewable Fuel Standard (RFS) to drive demand. When the policy is not implemented as prescribed by Congress, demand dries up and the market over-supplies. Inconsistent policy implementation also undercuts complementary government programs, including well-designed ones at DOE.

- The 10 percent "blend wall" does not exist. More than 30 states broke through the so-called "blend wall" in 2016. E15 blends (15% ethanol) are certified for use in most of the vehicles on the road today, and are being approved in some of the largest gasoline markets in the country. Biodiesel and renewable diesel do not face "blend wall" issues either. The challenge is the recalcitrance of incumbents. Higher biofuel blends would see much stronger growth with proper RFS implementation.

a. Advanced biofuels, for example drop-in fuels and fuels from microalgae, are considered by many experts to be a promising solution, but what are the current barriers preventing the wide-scale deployment of these fuels?

ANSWER: Drop-in fuels and fuels from microalgae are part of the solution to carbon emissions in the transportation sector. However, we would caution policymakers against considering them a solution to a problem (the "blend wall") that does not exist. Drop-in fuels should be considered an important part of the integrated biorefining product portfolio. In other words, the cheapest biofuel to produce is ethanol, most suitable for on-road travel. Ethanol is also a drop-in fuel, as it is splash blended with gasoline. Drop-in fuels – i.e. defined as biofuels more closely resembling hydrocarbon-based fuels – are more energy dense and are easier to transport via pipeline when commingled with fossil fuels. However, they are more expensive to produce due to the additional processing requirements. We do not view drop-in biofuels as an alternative to conventional biofuels, or vice-versa. If a biorefinery has an off-take partner seeking to maximize energy density – such as a commercial aviation company – it can tailor its technology and processing facility to produce (e.g.) bio-jet fuel. If the off-take partner values cost over energy-density for on-road travel where refueling infrastructure is widely available, ethanol is usually the preferred option. The Biofuel A vs. Biofuel B narrative is designed for politics rather than business modeling.

b. Where should the federal government be focusing on research in this area?

In my written testimony, I recommended that that the DOE should work backwards from the billion ton report – maximizing displacement of oil in the economy with an ultimate goal of eliminating its use – rather than (inadvertently) pitting technologies such and ICE efficiency, electrification, fuel cells, and biofuels against each other for the same market niche. As such, we recommend the same things for "drop-in" biofuels as we do for advanced "splash-blended" biofuels. First, using DOE researchers to level-set the misinformation being made against biofuels – whether related to land use, vehicle compatibility or similar – is hugely valuable. Second, we recommend that DOE leverage "in ground" investments and assets, effectively maximizing the government investment to push existing projects over the finish line. Creative use of existing loan programs, coupled with: (a) production and technical support; and, (b) dependable offtake like past partnerships with the Department of Defense will help break the current bottleneck for advanced (fuel) biotechnology. Public-private partnerships focused on demonstrating integrated biorefining technology would also reenergize many of the programs currently under review. New biofuels of different types face many of the same hurdles.

c. What is the role of advanced biofuels for light and heavy-duty transportation, considering costs, availability, and net environmental impacts?

The role of advanced biofuels for light, medium and heavy duty transportation is significant. The medium and heavy-duty transportation sector alone is a substantial market with large greenhouse gas (GHG) emissions. Tractor-trailers, buses, commercial trucks, and other heavy vehicles account for approximately 22 percent of energy use by U.S. transportation. Rapid decarbonization will depend to a large degree on the availability of off-the-shelf, low carbon solutions that can be used with current technology. Biofuels are at the top of the list when it comes to medium and heavy duty transport and aviation (which is important because electric drive is unlikely to dent these markets in the near to intermediate term). Biodiesel and renewable diesel are already being blended with on-road diesel to reduce carbon emissions. And cellulosic ethanol can be used in heavy-duty trucking, reducing carbon emissions by 90 percent or more.

Q2: There are still questions about the life-time environmental impact of biofuels, as Ms. Schlenker noted in her written testimony.

a. How does your industry respond to the life-time emissions and environmental impact of producing biofuels?

ANSWER: Biofuels are arguably the most environmentally researched fuel in the world. As noted by the question, there are two primary research areas:

- Lifecycle Carbon Emissions. The Argonne National Laboratory maintains the gold standard carbon lifecycle model in the world (GREET). According to GREET, first generation ethanol reduces GHG emissions by between 39 and 43 percent – including both direct and indirect land use change impacts – and second generation ethanol (cellulosic) reduces GHG emissions by between 70 and 126 percent. RFS-eligible biodiesel reduces GHG emissions by 50 percent or more. GREET is also the go-to model for state policymakers. For example, when the State of California designed the first-ever Low carbon Fuel Standard (LCFS), it started by building a California-specific carbon lifecycle model based on the GREET model – now called CA-GREET. California is already taking advantage of emissions reductions from biofuels as part of its implementation of the Low Carbon Fuel Standard (LCFS). Biodiesel, renewable diesel, and ethanol generate more than 70 percent of the state's LCFS credits.

- Lifecycle Environmental Impact. The lifecycle environmental impact of biofuels usually breaks down into two categories: tailpipe emissions and non-carbon land use impacts (as carbon-related land use impacts are included in carbon lifecycle accounting). The tailpipe emissions impact of ethanol and biodiesel blending is well-researched, in part because these fuels are in-use. Generally, ethanol displaces some of the most toxic chemicals in gasoline (octane boosting compounds like aromatics/benzene). Biodiesel is known to significantly reduce diesel particulate emissions. Air quality regulators have generally concluded that both biodiesel and ethanol reduce tailpipe emissions in several important categories: toxics, particulate matter, total hydrocarbons and carbon monoxide. The question with biofuels has always been its impact on NOx emissions – a known contributor to ground level ozone (smog) formation together with hydrocarbons and carbon monoxide. Even assuming slight increases in NOx emissions, most biofuels have a net positive (reducing) impact on smog formation. However, a 2018 study comparing actual vehicle tests with different blends concluded that newer vehicles better capture the benefits of ethanol blending without increasing NOx. Either way, the question of biofuel blending as it pertains to tailpipe emissions is largely a regulatory one regarding State Implementation Plans (SIPs) as biofuel blending generally reduces cumulative human exposure to toxics and smog. There is also data showing that biofuels reduce emissions of lesser known but dangerous pollutants (e.g. PAHs). On the non-carbon land use side, there is concern that biofuels are leading to agricultural land use intensification that could damage pristine lands. However, growth in U.S. biofuels production over the last two decades has not increased total cropland, nor has it changed the normal acreage cycling that occurs as a result of crop shifting (see below). In addition, while oil gets dirtier and dirtier, farm inputs are going down. For example, corn growers have increased production while reducing use of primary nutrients (nitrogen, phosphorous, and potassium). Farmers produced 6.64 billion bushels of corn in 1980 using 3.2 pounds of primary nutrients per bushel. By 2014, farmers more than doubled production while cutting nutrient use in half, producing 14.2 billion bushels using 1.38 pounds of nutrients per bushel.

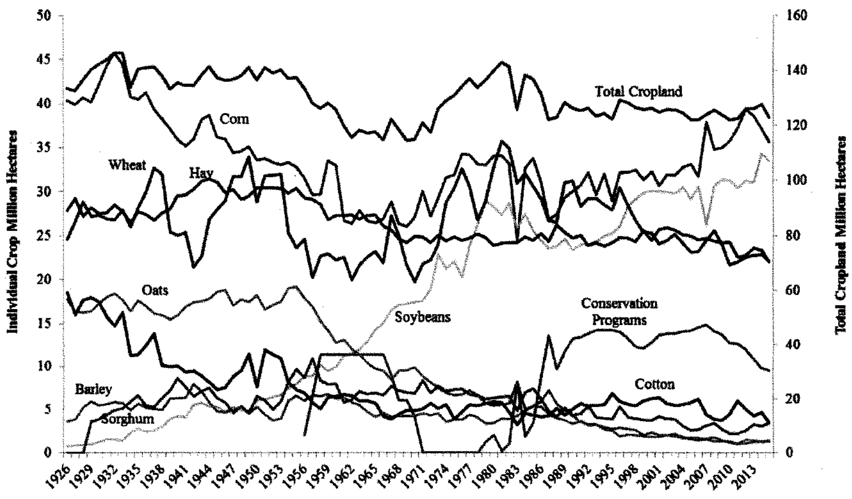


Figure 1. Total cropland hectares and individual crop hectares from 1926 to 2015.[9]

Q3: In your testimony, you note that existing ethanol bio-refineries and regions with high amounts of municipal solid waste present ideal opportunities for the development of biofuels.

a. **What barriers currently exist that prevent these refineries from using these resources?**

   ANSWER: The challenges for MSW-to-ethanol (or biogas or other types of biofuel) are largely the same as faced by other types of cellulosic biofuels. The primary challenge is investment risk brought on by policy uncertainty and regulatory instability against the backdrop of a marketplace not driven by price (i.e. a largely non-competitive market dominated by oil companies). For example, the RFS was not enforced between 2013-2016. Shortly thereafter, the current administration wiped out 4 billion gallons of RFS biofuel demand from 2016-2018 with Small Refinery Exemptions (SREs) offered to some of the largest oil companies in the world (e.g. Exxon, Chevron). SRE over-issuance not only destroyed market growth for all types of biofuels, but also slashed D3 (cellulosic) RIN credit prices (which provide the economic incentive for incumbents to invest in and purchase cellulosic biofuels). MSW itself is not unique when it comes to barriers. The biggest barrier is investment risk brought on by inconsistent and undependable policy implementation.

b. **What kinds of R&D is necessary to adapt these existing infrastructures and resources to produce sustainable biofuels?**

   ANSWER: Early movers in the MSW-to-biofuels sector are facing off-take issues – stemming from policy/demand uncertainty – more than any other issue (including those related to R&D). For DOE, in the context of MSW, it is more a matter of securing deeper support for existing and historic programs than it is about doing something new. Put another way, DOE has been focused in the right places. Properly implemented, the Renewable Fuel Standard (RFS) drives off-take and mitigates technology risk. The DOE loan guarantee program – when implemented – further reduced investment risk. As is the case for other cellulosic biofuels, we recommend that DOE leverage "in ground" investments and assets, effectively maximizing the government investment to push existing projects over the finish line. Creative use of existing loan programs, coupled with: (a) production and technical support; and, (b) dependable offtake like past partnerships with the Department of Defense will help break the current bottleneck for advanced (fuel) biotechnology. Public-private partnerships focused on demonstrating integrated biorefining technology would also reenergize many of the programs currently under review. New biofuels of different types face many of the same hurdles.

Q4: In your written testimony, you discuss some of the current biofuels related research at DOE national labs, including, for example, the development of crops that are able to thrive in harsh environments and the analysis of carbon accounting models that can help determine levels of net greenhouse gas emissions.

a. How effective are the DOE national labs in targeting their efforts and expertise to solve research problems on biofuels that support, and don't duplicate, industry efforts in this field?

ANSWER: As discussed in written testimony, the analytical work conducted by the national labs is well-targeted and essential. We believe BETO should reorient and redouble its efforts to produce analysis that supports using biomass to the maximum extent possible with existing infrastructure (and fleets) as well as researching the direct replacement of petroleum-derived products in fuels, chemicals, and products. For example, the current limitations on biofuel use – such as E15 limits on pumps or guidelines on vehicles – are generally derived from historical practice rather than scientific analysis. National labs could play a valuable role, as they have in many cases already, in sorting out technical fact from fiction regarding how compatible higher blends are with refueling infrastructure and vehicles. However, this will only happen if the agencies are tasked with catalyzing maximum feasible petroleum displacement. National labs also have a key analytical role in the continual improvement of the GHG footprint of biofuels, in addition to correcting the record when necessary, by identifying the most economically efficient ways to widen the gap with fossil fuels throughout the production chain. Our industry prefers public/private partnerships with an eye toward leveraging in-ground investment and assets over the early stage development of new technologies (especially when framed as alternatives to other new bioenergy technologies). As discussed, to achieve rapid decarbonization DOE must target maximum feasibly disruption using existing or proximate technology together with its existing (and important) focus on ultra-low carbon energy and fuels.

b. What do you think the appropriate role of the labs should be in biofuels research – should they be focused exclusively on early stage research, or is there a role for the labs to play in later stage demonstration projects as well?

ANSWER: As discussed, we encourage creative use of existing loan programs, coupled with: (a) production and technical support, particularly front end; and, (b) dependable offtake like past partnerships with the Department of Defense will help break the current bottleneck for advanced (fuel) biotechnology. Public-private partnerships focused on demonstrating integrated biorefining technology would also reenergize many of the programs currently under review. Like many emerging industries, we have developed promising technologies at smaller scale. The critical next step is further developing these technologies and capturing efficiencies only achievable at larger scale. In addition to restoring funding for previous work on catalysts, feedstocks, and feedstock handling, R&D efforts should return to their emphasis on integrated biorefineries that can maximally extract value from biomass and displace the whole range of products currently produced from fossil fuels. While the 200+ ethanol plants and ~100 biodiesel plants located in the United States are often seen as single-product (i.e. ethanol or biodiesel) biorefineries ineligible for partnerships due to sometimes ineffectual program designations, the reality is these refineries have an eye for the future – in which biofuel producers are managing full-scale integrated biorefineries producing many types of biofuels, feed, biochemicals and materials for biodegradable plastics.

Responses by Dr. Claus Daniel

House Committee on Science, Space, and Technology
Subcommittee on Energy
Hearing entitled, "The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector"
September 18, 2019
Questions for the Record for Dr. Claus Daniel, Oak Ridge National Laboratory

Questions from Rep. Eddie Bernice Johnson, Chairwoman, Committee on Science, Space, and Technology:

Question 1:
In the light-duty vehicle industry there is a tremendous amount of investment in electric vehicles and autonomous vehicles, such as Ford Motor's and Amazon's partnership with Rivian.

a. *Even with this high private sector investment, why is it important that Oak Ridge and Argonne maintain, if not expand, its applied R&D capabilities and work?*

Answer:

Even with private sector investment in transportation, there are fundamental science and early-stage research questions that inhibit technology readiness and adoption of scientific advancements. The U.S. Department of Energy's (DOE) laboratories such as Oak Ridge National Laboratory (ORNL) and Argonne National Laboratory are focused on resolving those questions to enable industry to adopt advanced technologies, thereby increasing the competitiveness of the U.S. manufacturing sector.

At Oak Ridge, our nine scientific user facilities focus on multi-disciplinary research ranging from: molecular-level materials science; machine learning and artificial intelligence with the world's fastest supercomputer; electric drive systems, energy storage and advanced fuels and engines at our transportation research center; as well as advancements at our battery manufacturing, carbon-fiber technology and advanced manufacturing demonstration facilities. We're also accelerating scientific solutions for sustainable, economically viable biofuels production.

This broad spectrum of scientific tools can be leveraged not only to basic science questions, but also to solve early-stage applied problems for the benefit of the nation. The designated user facilities at DOE's laboratories are available to all scientific users—large or small, from private industry, the public sector, and academic institutions—to accelerate solutions and help democratize these advancements for the greatest societal impact.

Question 2:
Whenever we discuss consumer products, especially products like cars with high-accident potential, safety is a critical factor.

a. *Could you discuss some of Oak Ridge's technology validation projects and capabilities that help prove a technology's safety and effectiveness?*

Answer:

While DOE's primary focus is on energy efficiency, our research and development efforts also benefit advances in the safety of new technologies.

ORNL's modeling and simulation work optimizing merging traffic and intersection control is aimed at easing traffic congestion, which will result in fuel savings and also reduce vehicle accidents. An example is our modeling of the potential benefits of connected and automated vehicles (CAVs) on roadways. Our work demonstrated that an increased number of CAVs communicating with each other and coordinating driving activity stabilizes traffic flow while reducing fuel use. In another project, ORNL developed custom algorithms to help guide smart cameras at intersections, decreasing the amount of fuel lost to idling while easing congestion.

Another prime example for materials development which results in safety benefits is the development of electrolytes and separators for batteries. The separator in lithium-ion batteries prevents internal short circuits and uncontrolled electricity flow while allowing for the flow of ions. ORNL developed an additive for lithium-ion batteries that transforms the liquid electrolyte to a solid upon impact, reinforcing the separator's mechanical stability. By blocking contact between the battery's electrodes, the Safe Impact Resistant Electrolyte, SAFIRE, can prevent short circuiting and a potential fire during vehicle accidents. Similarly, our ongoing research in the development of solid-state batteries that use solid electrolytes enable concurrent advancements in energy density and safety.

Essential to these innovations are our premier facilities enabling an atomic-level examination of the properties and behaviors of materials and alloys, including the Center for Nanophase Materials Science, the Spallation Neutron Source, and the Center for Nanophase Materials Sciences, as well as our unique capabilities in transportation systems research, advanced manufacturing, and supercomputing for materials behavior modeling and mobility systems analysis.

Question 3:
When discussing light-duty vehicle efficiency, we've seen arguments presented that suggest there is a trade-off between vehicle weight, which is often associated with efficiency, and safety.

a. *Given Oak Ridge's work on vehicle light-weighting at the Carbon Fiber Technology Facility, for example, could you expand on the perceived tradeoffs between vehicle light-weighting, efficiency, and safety?*

Answer:

At the DOE Carbon Fiber Technology Facility at ORNL, we are working on methods for low-cost carbon fiber production at scale to support composite materials that have the potential to dramatically reduce vehicle weight. As a rule of thumb, it is commonly accepted that a 10% reduction in vehicle weight results in roughly 6% lower fuel consumption. Thus, lightweighting of electric vehicles has a direct impact on extending drivable range.

While there are perceptions of a tradeoff between the lightweighting of vehicles and passenger safety, in fact that is not the case. Due to the development of new materials and active safety advancements, compact modern cars are safer in many respects than the large, heavy vehicles of the past.

Thanks to the work of the U.S. Department of Transportation and its National Highway Traffic Safety Administration (NHTSA) and automakers, we have such advancements as modern seatbelt technologies, advanced airbags, and steering wheels that retract during accidents. A greater understanding of the mechanical deformation of materials has enabled chassis materials that absorb maximum energy during an accident while protecting the passenger zone. Thanks to these rigorous efforts, our cars and trucks are safer than ever before.

Question 4:
Given the scale and complexity of decarbonizing the transportation sector, such as the consumer preferences involved with light-duty vehicles sales, why is it particularly important for advancing sustainable transportation that DOE researchers such as yourself coordinate closely with industry and academia??

Answer:

In the United States, we place a high value on personal freedom and consumer choice. We do not prescribe which vehicles consumers will buy. Our research instead focuses on advancing energy technologies to the point where a vehicle is energy-efficient and as convenient for consumers as possible.

For example, we have worked with Ames National Laboratory, Lawrence Livermore National Laboratory, and a Wisconsin company, Eck Industries, to develop a new high-performance aluminum alloy. The automotive industry is interested in aluminum alloys that can operate at high temperatures because of their potential for use in lightweight engine components, which would increase efficiency and fuel economy. To assess the performance of the new material under real-world operating conditions, we used the resources of the Manufacturing Demonstration Facility and the National Transportation Research Center to cast a cylinder head made of this alloy, using sand molds created by 3D printing. We retrofitted this component to a gasoline-powered engine designed to operate at the Spallation Neutron Source's engineering diffractometer to assess the performance of the running engine. This experiment confirmed that the new alloy outperforms other aluminum alloys under realistic operating conditions. It also demonstrated the benefits of coupling fundamental science with early-stage R&D on new materials and technologies.

Coordinating with industry is essential to understanding which technology integration and research focus areas will yield the most promising results for consumer adoption. And by collaborating with academia, we have the opportunity to help advance individual basic research ideas and concepts into early-stage applied research opportunities.

<u>Question 5:</u>
Biofuels are regarded as an option for reduction of CO2 emissions in the transportation sector. However, conventional plant-based biofuels' share of total transportation-fuel consumption in 2018 was only 5%, due to challenges such as shortage of raw materials, the so-called regulatory "blend wall" that has prevented the blending of higher volumes of biofuel with conventional fuel.

<u>a.</u> *Advanced biofuels, for example drop-in fuels and fuels from microalgae, are considered by many experts to be a promising solution, but what are the current barriers preventing the wide-scale deployment of these fuels?*

<u>Answer:</u>

Advanced biofuels encompass several different potential fuels beyond the current first-generation corn starch to ethanol and come from a variety of feedstocks, including lignocellulosic materials.

The largest current barriers to widespread deployment include the cost of feedstock production and unproven conversion at multiple scales. These barriers have constrained the advanced biofuels industry (i.e., beyond first-generation biofuels) to relatively small advancements and niche markets. The formation of an advanced biofuel industry will require disruptive but viable changes in technology that would facilitate retrenchment and pursuit of higher value products along with sustainable advanced biofuels.

Based on numerous analytic evaluations we believe that there is the potential for the United States to produce sufficient feedstocks (e.g., agricultural residues, dedicated biomass feedstock, waste materials) to supply a robust advanced biofuels industry Technology resolutions such as the upgrading of alcohols into hydrocarbon fuels would support the move past the ethanol "blend wall."

Finally, supply chain issues are another barrier to widespread deployment. Each new feedstock and each new advanced biofuel will require some modification to existing infrastructure from the farm to the conversion facility to distribution avenues.

b. *What should be the focus of federal government research in this area?*

Answer:

A major need and focus for federal investment in overcoming technical barriers through early-stage research and development.

Federal R&D can explore, develop and offer a variety of solutions. These solutions should be both technical in nature —i.e., to lower costs across the bioenergy supply chain—and to explore and assess the impact of the technical solutions. Due to the variety of productive lands and climates in the United States, we will need to develop a portfolio of diverse feedstocks, including cellulosic biomass. We will need to invest in multiple conversion technologies to produce a flexible and resilient mix of fuels, products and power.

In order to reach the full potential of sustainable advanced biofuels, barriers must be addressed across the bioeconomy supply chain. While a combination of a number of incremental technical improvements may ultimately get us there, transformative R&D should be initiated that accelerates our chances to offer viable solutions in a reasonable timeframe. This will require a sustained and broad research effort.

R&D in the energy bioeconomy should exploit modern biotechnology, including AI-based data-mining of systems biology and utilization of synthetic biology, development and confirmation of sustainable practices, and taking gene-to-ecosystem approaches into the overall bioeconomy supply chain.

De-risking for farmers and landowners of new feedstocks and practices will require more trials and data-gathering for better predictive deployment, along with the development of policies related to crop insurance and landowner education. Similarly, on the conversion side, there is a need for de-risking investments for biorefineries.

c. *What is the role of advanced biofuels for light- and heavy-duty transportation, considering costs, availability, and net environmental impacts?*

Answer:

We believe that current research and assessment show that biofuels can be produced sustainably with net positive environmental impacts and that this sustainability can be improved further. However, research assessments are needed to correct misperceptions of sustainability and to guide practices during deployment. The United Nation's IPCC reports consider biofuels as a part of the overall energy solution.

In light-duty applications, advanced biofuels can be deployed in parallel with electrification and will offer environmental benefits such as a reduced carbon footprint during the transition to full electric.

For heavy-duty applications that are not as conducive to electrification, alternative liquid fuels can play a key role in reducing emissions. Biofuels, including the upgrading of biofuels (alcohols, pyrolysis liquids, biogas or biodiesel) into drop-in hydrocarbon blendstocks, will be needed to meet this challenge. Aviation and marine applications will require liquid fuels for the foreseeable future. Advanced liquid biofuels are a feasible, sustainable solution for these sectors.

Question 6:
In Mr. Coleman's written testimony, he discussed current biofuels related research at DOE national labs, including, for example, the development of crops that are able to thrive in harsh environments and the analysis of carbon accounting models that can help determine levels of net greenhouse gas emissions.

a. *How effective are the DOE national labs in targeting their efforts and expertise to solve research problems on biofuels that support, and don't duplicate, industry efforts in this field?*

Answer:

National labs are particularly effective at using multidisciplinary teams to attack problems across the technology development cycle.

Early and mid-stage research are clear examples of the types of research the national lab system effectively and efficiently conducts. Multiple technologies developed at the national labs have been licensed to industry to assist the bioeconomy. For example, the four DOE Office of Science Bioenergy Research Centers have accumulated more than 500 patent application with 176 patents awarded, and more than 240 licenses or options of their technology.

We have provided multiple avenues to engage industry in tech transfer and collaborative research and development agreements. Our DOE user facilities provide mechanisms for labs to assist industry with solutions and capabilities. In the bioeconomy, these have included Lawrence Berkeley National Laboratory's Joint Genome Institute, the National Renewable Energy Laboratory's Integrated Biorefinery Research Facility, and the ORNL's Manufacturing Demonstration Facility.

b: *In your opinion, what should be the role of the labs in biofuels research—should they be focused exclusively on early stage research, or is there a role for the labs to play in later stage demonstration projects as well?*

Answer:

The DOE national laboratory system is focused on early-stage research. Sometimes, a large-scale demonstration is still affected by early-stage research questions as the process is scaled up. Particularly with varying feedstock properties, at-scale demonstration is a core part of early-stage research barriers to be overcome.

Pre-commercial demonstrations facilitate interactions between DOE's laboratories and industry to leverage the capabilities of the national labs as part of the industry's risk assessment effort.

Question 7:
In your written testimony, you note Oak Ridge's immense computing power, through the supercomputer "Summit" and soon to be built "Frontier," that can enable tools like artificial intelligence for sustainable transportation R&D.

a. *Could you explain how AI can transform the scale and potential of your research?*

Answer:
The artificial intelligence capabilities of Summit and the move toward exascale computing with the Frontier system will enable groundbreaking research across fields, answering previously intractable questions and accelerating our research and development efforts.

In the sustainable transportation sector we will be able to, for instance:

- Model the complete combustion process of an engine, greatly enhancing our understanding of the process and presenting new fuel efficiency and engine design opportunities;
- Model a material in an automotive application on a real-world scale to understand its potential and its limitations; and
- Model a mobility system on a city, regional or even national scale to understand its complexities and predict issues such as traffic congestion and accident potential, enabling the development of control solutions.

The benefits of the Frontier exascale computing system will extend beyond DOE to other federal agencies and to U.S. industry. Researchers in the United States will have access not only to physical computing systems with the requisite power, but also to an exascale ecosystem with the applications, software, hardware technologies, architectures and other tools needed to deliver breakthroughs critical to a strong economy, scientific discovery, and national security.

Responses by Mr. Tim Cortes

U.S. House of Representatives Committee on Science, Space, & Technology,
Subcommittee on Energy
September 18, 2019, Hearing
The Next Mile: Technology Pathways to Accelerate Sustainability within the Transportation Sector
Questions for the Record Submitted to Tim Cortes

Q1: In Ms. Schlenker's written testimony, she states that "fuel cell and hydrogen technologies are another important area of research."

a) Can you describe the applications in which fuel cell research might have the largest impact?
   a. I agree wholeheartedly fuel cells remain an area where increased research is needed. Here are some areas in which increased attention would prove to be fruitful:
      i. Scaling-up innovative applications of hydrogen fuel cell technology, including medium and heavy-duty transportation, trains, maritime vehicles, port and drayage equipment, microgrids and distributed energy resources, unmanned aerial vehicles, and public safety/resiliency.
      ii. Late-state research, development, and deployment programs to further reduce the cost of fuel cell components and systems. This includes mid and late-stage RD&D into fuel cell components including:
         1. balance of plant,
         2. long duration, low cost membrane electrode assemblies,
         3. compressors,
         4. catalysts,
         5. sensors, and
         6. low cost, low pressure, high density storage.
   b. Also important is increased research, development, demonstration and deployment of hydrogen technologies and infrastructure:
      i. Supporting the development of hydrogen refueling infrastructure nationwide to accelerate the deployment of zero-emission fuel cell technologies
      ii. Reducing the cost of hydrogen fuel production, storage, and distribution, with an emphasis on obtaining hydrogen from renewable sources aiding in decarbonization

b) What are some of the barriers to widespread adoption of hydrogen fuel cell technology?
   a. Availability of hydrogen
      i. Supply of availably hydrogen at scale. Currently one of the main issues today is the limited availability of hydrogen for use in fuel cells and getting hydrogen to customers with economics that are predictable.
      ii. There are limited locations that customers can access hydrogen including limited numbers of hydrogen fueling stations.
   b. Despite the promising potential of renewable-sourced hydrogen, the technology to produce it is still in its nascent stages of deployment due to higher input costs.
   c. Regulatory barriers and appropriate codes and standards need to be addressed to enable large scale commercialization and a robust, reliable supply chain

c) Can you compare costs and benefits of fuel cell vehicles with that of other sustainable transportation options? Do you think these technologies will be complementary or competitors?

   a. Complimentary. The future of transportation is going to include a range of options including battery electric vehicles (BEV) and fuel cell electric vehicles (FCV). BEVs are well suited for smaller passenger vehicles going short distances including in city driving. FCVs show great value in larger vehicles including passenger vehicles, commercial fleet vehicles including delivery vans, busses and medium and heavy-duty trucking. FEVs are scalable in size, have quick refueling and replicate the current driver experience which is incredibly important to consumers.
   b. We believe that fuel cell engines coupled with batteries provide an optimal solution for broader logistics applications for class 3-8 engines requiring high asset utilization, payload requirements, long range and fast fueling. According to research report published by Oppenheimer and Co, total cost of ownership for fuel cell engines are almost 50% lower than full BEV for the last mile delivery applications. As the overall system cost for fuel cell engines continue to come down the cost curve, the value proposition and TCO will only continue to improve in multiple end market applications.

d) Can you provide insight on the current supply and demand for hydrogen and how it affects hydrogen fuel cell integration into the commercial market?

   a. The supply of hydrogen as a fuel for fuel cell utilization has been relatively flat to date while the demand for hydrogen within the material handling market as well as light duty retail vehicles has increase significantly within the last five years. This mismatch has caused concerns for customers that want to enter the market. They are concerned about where is the supply going to come from in the future and what is going to happen to the price of hydrogen if the demand continues to outpace supply. The situation has caused the adoption rate of fuel cells in many applications to slow. By contrast, if the market supply of hydrogen would escalate and scale, the price and availability would stimulate growth in the fuel cell market.

Q2: You state in your testimony that Plug Power participates on the Hydrogen Council, a global hydrogen fuel initiative, which estimates that hydrogen can help cut global CO2 emissions by as much as 20% by 2050.

a. Can you explain how hydrogen fuel cell technology adaptation could help achieve this goal?
   a. The hydrogen molecule is a zero-carbon energy carrier in that it does not contain carbon.
   b. It can be used to store energy over long periods of time and transport energy over large geographies.
   c. Hydrogen fuel cell electric vehicles, whether heavy duty, light duty or material handling vehicles, have no tailpipe emissions.
   d. Hydrogen can be produced with near-zero carbon emitted, even on a life-cycle basis.
   e. More applications and sectors are looking to utilize hydrogen due to the attributes described above.

b. How long can a hydrogen fuel cell operate and how are they disposed of or recycled?
   a. Typically, 20K to 25K operating hours is a good estimate for the "economic" life of a fuel cell. In theory, fuel cells, like engines or generators, can have the wear items including Membrane Electrode Assembly (MEA) and compressors replaced to continue to extend the operating life. With the pace of technology, and improving scale driving lower costs in the industry, there is a point at which it is cheaper to purchase a new fuel cell than the low volume legacy parts and technician labor to extend the life of an older system.

b. First, the fuel cell is a "green item, that can be recycled in its entirety. From a Plug Power perspective, we provide a "cradle to grave" service for our customers with respect to fuel cell systems. We have two scenarios:
    i. Scenario One -- End of useful life
        1. Customer returns to Plug
        2. Plug defuels, tears down unit
        3. Tanks are drilled to prevent reuse
        4. Metal parts (Castings, Brackets, Tanks, Housings, Fasteners) are recycled
        5. Plastics are separated and sent for recycling
        6. Where appropriate; critical parts (control boards, compressors, stacks etc) are remanufactured for use in servicing legacy units in the field.
        7. MEA's are recycled for platinum, precious metals
        8. Lithium ion cells are sent to recycling
        9. Money received from scrap value/recycling effectively offsets tear down costs.
    ii. Scenario Two: Equipment renewal/refresh (equipment still has useful life)
        1. Plug Power would typically offer a trade in value on the equipment
        2. Product will be reconditioned/tested and placed into a rental fleet for customers or made available for sale.
        3. If no aftermarket demand for model, scenario one would apply.

Q3: You state in your testimony that Plug Power wouldn't have gotten to where it is today without its partnership with DOE because of the Department's commitment to reach and development projects for hydrogen and fuel cell technologies.

a. How critical is it that DOE continue to play a role past the fundamental research stage to help bring these technologies to market?
    a. DOE does a really good job when it comes to funding pure R & D, and the funding for the labs, and the great work that they're doing. Areas that could really help with bringing some of these technologies to market, and driving the growth with regard to these technologies, both for fuel cells and hydrogen, is ensuring that there is an appropriate amount of funding and programs for advanced demonstrations. At some point you have to take the findings from the lab and determine how do to scale, how to reduce it to practice and be able to implement it on a commercial standpoint. There seems to be a chasm that exists that would really benefit a certain percentage of the DOE dollars not just for the hard R & D, but also to be able to bridge those gaps.

Q4: You mention in your testimony that Plug Power is not currently an active participant in the H2@Scale program at DOE. The goal of this program is to explore the potential for wide-spread hydrogen production and utilization in the Unite States by leveraging a variety of resources here in the United States.

a. Can you elaborate on why Plug Power is not participating in the program?
    a. As a leader in fuel cell technologies and fueling infrastructure deployments, Plug Power continues to provide initial project submissions to DOE H2@Scale FOAs but continuesto have the submissions "discouraged" by program examiners from providing final project submissions.
b. Is the U.S. equipped to transport and provide hydrogen to supply fuel cells on a large scale? What would need to be done to get there?

  a. Currently there are limitations with regard to supply and economic transport to many parts of the U.S.
  b. There needs to be significant expansion in both the production of hydrogen and the diversification of locations where hydrogen is generated in order to ensure that hydrogen is economically available to more parts of the county. Future hydrogen generation facilities also need to be integrated with renewable sources of energy to facility low carbon hydrogen as well as drive down the cost of hydrogen fuel to end users.

c. Do you have any recommendations to improve existing R&D programs or to establish any new activities within the Department of Energy's Hydrogen and Fuel Cell Technologies office?
  a. It is imperative that DOE activities allow for early, mid, and late-stage research, development, demonstrations and deployment of all fuel cell and hydrogen technologies including infrastructure. We are concerned the Department remains focused on early stage research and is not fully coordinating with industry to determine what is needed, isn't redundant and focuses on maximizes taxpayer investment.
  b. We would like to see renewed support for DOE's Hydrogen and Fuel Cells Market Transformation (AKA technology acceleration) activities that can help deploy novel applications for hydrogen and fuel cell systems, such as in energy storage technologies and decarbonization.
  c. Education and worker training programs