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THE ROAD TO TOMORROW: ENERGY INNOVATION IN AUTOMOTIVE TECHNOLOGIES

FIELD HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

TO

EXAMINE THE OPPORTUNITIES AND CHALLENGES FACING VEHICLE TECHNOLOGIES, ESPECIALLY ENERGY-RELEVANT TECHNOLOGIES

JANUARY 25, 2018

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THE ROAD TO TOMORROW: ENERGY INNOVATION IN AUTOMOTIVE TECHNOLOGIES

THURSDAY, JANUARY 25, 2018

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 10:10 a.m. at the Washington Convention Center, West Salon Room, 801 Mount Vernon Place NW, Washington, DC, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

The CHAIRMAN. Good morning. The Committee will come to order.

It is a little bit unusual to be here at the convention center for an energy hearing, but I think it is certainly appropriate given the subject matter that we are discussing today.

I certainly did not mind the short commute over here, and it is a great setting to be at the Auto Show surrounded by the latest and the greatest the auto industry has to offer.

I am joined this morning by Senator Stabenow, from the great State of Michigan, and she has encouraged me that while the Washington Auto Show is good, the Detroit Auto Show is great.

[Laughter.]

So that might be the locale for our next field hearing——

Senator STABENOW. That's right.

The CHAIRMAN. ——next year on this same subject.

I appreciate you standing in or sitting in here this morning for Senator Cantwell, our Ranking Member on the Committee.

I understand that Senator Manchin will also be with us, but he is enjoying the Auto Show right now and he will be here as soon as he can peel himself away from some of the latest and the greatest.

I do want to thank the City of Washington for hosting us. I also want to thank the Washington Area New Auto Dealers Association, which puts on this Auto Show every year, for helping us coordinate the hearing.

I really do think that this is an exciting time for the automotive sector, a host of new technologies that have emerged in the recent years. Lightweight materials like carbon fiber, titanium, aluminum and composites are increasing vehicle efficiency while boosting performance.

At the same time, advanced manufacturing technologies, like 3D printing, are decreasing the time and the cost of bringing new concepts to market. This has increased the productivity of our automotive suppliers, allowing U.S. manufacturers to thrive in a hypercompetitive global market. Lithium-ion battery prices are falling precipitously and a new generation of batteries is powering today's electric vehicles, like the Chevy Bolt and Tesla's Model 3. Meanwhile, sales and consumer adoption have increased for other alternative fuel vehicles, including the hydrogen-powered Toyota Mirai.

While technologies are changing, so, too, are policies, in many countries across the map. In the past year a number of nations have issued new targets, mandates and regulations. India, for instance, has committed to banning petroleum-powered vehicles by the year 2030. France has made that same commitment by 2040. China, which has the world's largest automotive market, has mandated that 10 percent of the vehicles sold by an automaker be electric by the year 2019, with annual target increases after that. Here in the United States, I think we are going to do what we do best, probably better than anyone in the world, and that is innovate.

I am particularly interested in hearing from our witnesses this morning about the status of their efforts, whether at private companies or national laboratories, and how research across the technology readiness spectrum can be brought to market.

As we think about new automotive technologies, I think it is important that we ensure that our federal policies are modern, that they are neutral and that they are working as intended. We also need to make this a holistic determination by considering how electric and hydrogen vehicles will affect, and be affected by, our energy system.

I was mentioning as we were gathering in the back just before this, that in Alaska, in our capital city of Juneau, which is on an island, we have a burgeoning electric vehicle market. The local utility provides nearly 100 percent renewable power to its customers by way of five hydroelectric plants, and it is engaged in a pretty successful demand response program to incentivize charging at specific times during the day. These efforts are cutting costs and emissions and the result that we are seeing in Juneau is one new EV registration per week which in a smaller community, it is about 35,000 people there in our capital, that is meaningful. That is meaningful, and it is really kind of exciting.

Many of our remote communities up in the state are completely disconnected from a traditional grid, and yet we are innovating in some ways that are pretty unique, bringing local resources together to decrease costs in very high cost rural areas.

Last year, we held a field hearing, Senator Cantwell was able to join us. We were in Cordova, a little fishing village in southcentral Alaska, not connected by road to anywhere else—not a transportation grid and not an electric grid. We focused on hybrid microgrids. Now Cordova's innovators are working with the national labs, with the University of Alaska and industry to further test the bounds of their microgrids. One of their next steps will be installing four EV chargers at their city center and studying how

EV charging can benefit their microgrid. So we are testing applications even in the furthest north of this country.

This morning, I am happy to welcome a distinguished panel of witnesses to tell us about the next generation of advanced vehicle technologies. We have representation from across the automotive sector and across multiple technology development stages, from research to suppliers to automakers.

We have considerable opportunities in front of us, but we also have a lot of work to do to realize them, whether it is moving our most promising concepts from the lab benchtop to the dealership lot and out onto the road; or whether it is addressing lesser recognized challenges, such as our mineral security, which could make or break entire technologies. We cannot allow that to worsen as advanced vehicle technologies are increasingly adopted.

So again, I thank our witnesses in advance of your testimonies for being here this morning and all who helped make the hearing possible.

I will now turn to Senator Stabenow for any comments that you wish to make, and I am pleased that you are with us this morning.

STATEMENT OF HON. DEBBIE STABENOW, U.S. SENATOR FROM MICHIGAN

Senator STABENOW. Well, thank you so much, Madam Chair, for holding the field hearing today. I really appreciate your focus on this very exciting area of automation and transportation and energy. We look forward to having you at some point in Detroit. We would welcome you there as well. I also want to thank all of the witnesses. I have to tell you that I am very proud that of our five witnesses, three are from Michigan. Michigan is in the house here today.

[Laughter.]

There is a good reason for that. It is because that is where the action is on these issues.

So I want to welcome all of you, particularly Britta Gross of Detroit, who is the Director of Advanced Vehicle Commercialization Policy for General Motors; Carla Bailo of Ann Arbor, who is the CEO of the Center for Automotive Research; and Dr. Mihai Dorobantu from Eaton and Galesburg, Michigan.

We thank all of you for being here and for our witnesses not from Michigan, you are welcome to move to Michigan.

[Laughter.]

We would love to have you.

You know, I have often said that Michigan's workers can outbuild, out-innovate and out-imagine anyone, and we are proud of that. A lot of that building, innovating and imagining is centering around automobiles and transportation. That has been true for 100 years or more, and it is very true today.

One out of every five vehicles manufactured is manufactured in Michigan, and our state's 944,000 auto-related jobs account for about 20 percent out of our total workforce.

We used to say this isn't your father's Oldsmobile. I actually grew up on an Oldsmobile car lot in Northern Michigan, but we don't do Oldsmobiles anymore. But I will say it is also not your grandfather's Chevy or Ford.

We know that mobility and transportation is rapidly evolving. I think more than we even realize that things are moving very quickly, both here in the United States and around the globe.

That is why we are proud that Michigan is the home of the American Center for Mobility, focusing on all of these issues. I had a chance to see some of that great evolution just last week at the North American Auto Show—from the emergence of new engines powered by electricity or hydrogen rather than oil.

Did you buy a car, Joe?

[Laughter.]

Did you buy one? I want to know.

Senator MANCHIN. I am still negotiating.

Senator STABENOW. Alright, alright.

To the new lightweight materials and designs to rapidly evolving autonomous technologies, these breakthroughs will change the way we take our kids to school, go to work and get the products that we make to market. Best of all, they have the potential to dramatically improve safety and cut the amount of carbon we are emitting.

However, we know that leadership is not a given. If the United States does not continue to invest in new automotive technologies, we will be left idling in a cloud of dust while the rest of the world speeds ahead of us.

We can't let that happen. To stay in the lead, we need strong partnerships between industry and our scientists at the Department of Energy and research institutions and all of us together. That is why I appreciate the Chair's support for the bipartisan Vehicle Innovation Act that Senators Peters, Alexander and I introduced in the past, and have reintroduced. It is part of the Energy bill on the Floor of the Senate, which I strongly support moving forward on. So I want to thank you for that.

I look forward to hearing from our partners today about the new research, the new technologies and the new approaches that are driving us forward.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator Stabenow.

I have an opportunity to engage in just fascinating discussion as we have hearings before the Energy Committee. I think some of the subjects that we deal with are the most captivating of our time.

My husband and I have raised two sons. They are in their mid- to early-20s right now, and they look at their mother's job sometimes with, oh, gosh, how do you sit through all that? This is one hearing that caused them to actually say, she's got a pretty good job.

[Laughter.]

Senator Manchin, would you care to make any opening comments before we turn to our witnesses?

STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

Senator MANCHIN. Thank you, Madam Chairman. It is a pleasure to be here with both of you.

I want to thank Lisa for setting this up here—the most appropriate place for us to be and also for Debbie, our Ranking Member, to be here also from Detroit City.

Senator STABENOW. That is right. That is right.

[Laughter.]

Senator MANCHIN. I am an old gearhead, so I am a little bit late because I was admiring all the new products.

[Laughter.]

I have owned everything from General Motors, to Ford, to Chrysler, to Toyota. If you make it, I will buy it.

[Laughter.]

I really do. I just appreciate it, and I think you all are so lucky to be in this industry. They say, if you find a job that you love, you never work a day of your life. If you are in the auto industry, I think that is true.

So I want to thank the Committee for hosting this hearing.

I want us to talk a little bit about West Virginia University (WVU). As you know, my alma mater has been competing in advanced vehicle technology competitions since 1988, beginning with the Methanol Marathon. WVU is actually one of the 16 universities chosen to compete in the latest advanced vehicle technology challenge, EcoCAR 3. We have over 60 undergraduate, graduate and Ph.D. students working on this project. The multiyear project aims to create a hybrid electric Chevy Camaro that reduces the environmental impact but still delivers performance. A very exciting project to be discussing, especially at this year's Auto Show. I am happy to see Toyota represented on the panel.

I just did a little interview live that was going to go back to our Buffalo plant in Buffalo, West Virginia, where they make the drivetrain. Now they make the engines they start up, the four-cylinder engine, 25 years ago.

The whole thing about the evolution of the Toyota plant in West Virginia, Dr. Toyota. I met him when I was Governor—I had gone to Nagoya, Japan, with then-Senator Rockefeller. Dr. Toyota was so excited to tell me that against all of the advice of all of his high-powered engineers and his business consultants, who recommended do not put an engine plant there. He was determined to do it, and he put that engine plant in Buffalo, West Virginia. Not only has the engine plant become a success, it has become a model for Toyota manufacturing. It has now grown, and some of the most sophisticated engines in the world are made there. Then they went into the drivetrains.

I was standing by a Highlander, and I said I want you to see this beautiful vehicle. Without West Virginia labor, it would not move. I said, this thing would not move without the engine you put in it and without the drivetrain that you made for it. I was very proud of that. We are proud of the Buffalo plant and manufacturers of the engines and transmissions.

Toyota employs 1,900 workers in West Virginia, approximately 1,300 in this plant and over 600 at 13 Toyota dealerships across the state. Investment by Toyota Motor Manufacturing through West Virginia totals more than $1.2 billion, producing over 697,000 engines and 537,000 transmissions. Toyota also supports 900 jobs of our automotive suppliers. Their contribution to West Virginia's economy is vital, and I am glad they are part of our great state. I want to thank all of you from Toyota for what you have enabled us to do, and all your help for the people of West Virginia.

I look forward to working with all of you and all of the industry. It is very important and so goes the auto industry, so goes us. We do not move without you. We are very proud to be here, and I look forward to participating until they call us and make us go back to the Hill. All three of us would rather be right here——

Senator STABENOW. That is right.

Senator MANCHIN. ——than on the Hill.

[Laughter.]

The CHAIRMAN. Thank you, Senator Manchin.

With that, we will now turn to our witnesses. I will introduce each of you. We will go down the line, beginning with Dr. Khaleel.

I would ask that you try to keep your comments to about five minutes. Your full statements will be included as part of the record. That will allow us plenty of opportunity to make inquiry, provide for questions and answers, going back and forth and, hopefully, good dialogue this morning.

Joining us on this morning's important panel is Dr. Mohammad Khaleel. He is the Associate Laboratory Director for the Energy and Environmental Sciences Directorate at Oak Ridge National Laboratory (ORNL). We appreciate the good work that comes from our many national labs around the country. It is good to have you this morning.

Ms. Carla Bailo, who is the President and CEO at the Center for Automotive Research, has already been acknowledged by Senator Stabenow. Nice to meet you and to have you here.

Dr. Mihai Dorobantu, who is the Director for the Technology Planning and Government Affairs at Eaton Vehicle Group. Again, a Michiganer, and is that right?

Senator STABENOW. Michigander.

The CHAIRMAN. Michigander, okay.

Senator STABENOW. Yes.

The CHAIRMAN. Okay, I have to get that right.

Ms. Britta Gross, also a Michigander, Director, Advanced Vehicles Commercialization at General Motors. Nice to have you with us.

And Mr. Robert Wimmer is the Director for the Energy and Environmental Research with Toyota. It is good to have the full panel with us.

Dr. Khaleel, if you would like to start off this morning, and we welcome you.

STATEMENT OF DR. MOHAMMAD A. KHALEEL, ASSOCIATE LABORATORY DIRECTOR FOR ENERGY AND ENVIRONMENTAL SCIENCES, OAK RIDGE NATIONAL LABORATORY

Dr. KHALEEL. Thank you, Senator.

Chairman Murkowski and members of the Committee, thank you for the opportunity to appear before you today with this distinguished panel.

Today, I want to discuss the challenges and opportunities we see in the nation's transportation sector. The rapid increase in vehicle electrification and the introduction of autonomous vehicles is revolutionizing the transportation. These technologies will forever change personal mobility, the movement of goods and the society in fundamental ways. A smooth transition to this future requires scientific innovations.

At Oak Ridge National Lab our scientists and engineers work with the industry and other partners to produce breakthroughs for most efficient and cleanest forms of transportation. For example, our staff enable to innovate in the area of safer, high energy, density vehicle batteries. We have increased the battery energy content fivefold while lowering the cost by a factor of five. We co-optimized engines and fuels with ultra-low emissions and ultra-high efficiencies. An electric motor made with low cost domestic materials—that generates significantly more power than the electric motor that uses rare earth elements that we use today.

It was at the ORNL's National Transportation Research Center, DOE's only transportation facility, that we developed the world's first wireless vehicle charging system capable of transferring 34 kilowatts of energy. We are now on the way to delivering 100 kilowatt system. Bidirectional, wireless charging can make recharging much easier while ensuring that an electrified transportation system is a benefit and not a burden to the nation's power grid.

ORNL's AMIEs project demonstrate how a hybrid electric vehicle can wirelessly transfer power to and from a home that is generating energy using solar panels. The benefits are multiple folds: energy reliability for the homeowner, more flexibility for the electric grid operator and the ability to use the vehicle battery for energy storage.

ORNL's supercomputers, especially Titan and the upcoming system, Summit, resources are being leveraged to model and simulate the behavior of advanced vehicles and engine systems. These resources, including the next generation Summit supercomputer, funded by the DOE Office of Science, is expected to be the world's most powerful, when it comes online this year, enabling the artificial intelligence systems needed to control and integrate autonomous and connected vehicles.

Even as we look to the future of electrified vehicles, the internal combustion engine is still the workhorse of the transportation sector. ORNL and other national labs are leading DOE's co-optima initiative focused on combining fuels and combustion research to maximize vehicle fuel economy and performance.

The labs are researching breakthroughs for vehicles powered by hydrogen fuel cells, focus on lowering cost, improving onboard storage and supporting hydrogen infrastructure through H2@Scale program.

At ORNL we are also using capabilities of the manufacturing demonstration facility and the carbon fiber technology facility to come up with breakthroughs in low cost carbon fibers, composite materials and 3D printing of tools and dies for faster and cheaper production methods to improve the global competitiveness of the American automakers.

Partnerships with the industry and academia are crucial for sharpening the research activities and efforts of the national labs, guiding the way to the most impactful scientific results for real world success.

We are a co-founder of the Institute for Advanced Composite Manufacturing Innovation, IACMI, bringing together over 160 members from the private and public sector to move carbon and other fiber composites into the automotive market.

Just last month, ORNL joined 19 other private companies and universities and state agencies in a new initiative called TennSMART to accelerate the development and the deployment of mobility innovation in Tennessee.

In conclusion, ORNL and other national labs stand ready to work with the public and private partners to develop and demonstrate breakthroughs in science and fundamentals, bringing them to the road.

I thank you again for the opportunity to provide this briefing, and I would welcome your questions.

[The prepared statement of Dr. Khaleel follows:]

The Road to Tomorrow: Energy Innovation in Automotive Technologies

Statement of Mohammad A. Khaleel, Ph.D.
Associate Laboratory Director
Oak Ridge National Laboratory

Before the
Committee on Energy and Natural Resources
United States Senate
January 25, 2018

Thank you, Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee. I am Dr. Mohammad Khaleel, Associate Laboratory Director for Energy and Environmental Sciences at the U.S. Department of Energy's Oak Ridge National Laboratory in Oak Ridge, Tennessee. It is an honor to participate in this hearing with this distinguished panel today.

INTRODUCTION

Oak Ridge National Laboratory (ORNL) is the largest Department of Energy (DOE) science and energy laboratory, conducting basic and applied research to deliver transformative solutions to compelling problems in energy and security. ORNL's diverse capabilities span a broad range of scientific and engineering disciplines, enabling the Laboratory to explore fundamental science challenges and to carry out the research needed to accelerate the delivery of solutions to the marketplace.

DOE's scientific and technical capabilities are rooted in its system of national laboratories—17 world-class institutions that constitute the most comprehensive research and development network of its kind. The laboratories work as a network with academia, industry, and other federal agencies to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

ORNL is actively engaged in helping address these compelling national energy challenges, and we are partnering with other laboratories, industry, and academia to enable the rapid innovation that will be required. ORNL supports DOE's national missions of:

- Scientific discovery—We assemble teams of experts from multiple disciplines, equip them with powerful instruments and research facilities, and address compelling national problems;

- Clean energy—We deliver technology solutions for energy sources such as nuclear fission/fusion, fossil energy, solar photovoltaics, geothermal, hydropower, and biofuels, as well as energy-efficient transportation, buildings, and manufacturing;

- Security—We develop and deploy "first-of-a-kind" science-based security technologies to make the United States, its critical infrastructure, and the world a safer place.

ORNL supports these missions through leadership in four major areas of science and technology:

- Computing—We accelerate scientific discovery and the technology development cycle through modeling and simulation on powerful supercomputers, including Titan, the nation's most powerful system for open scientific computing, advance data-intensive science, and sustain U.S. leadership in high-performance computing;

- Materials—We integrate basic and applied research to develop advanced materials for energy applications. The latest frontier in materials research is at the nanoscale—designing materials atom by atom —and we leverage ORNL assets such as Titan and the Center for Nanophase Materials Science for breakthrough materials research;

- Neutrons—We operate two of the world's leading neutron sources that enable scientists and engineers to gain new insights into materials and biological systems;

- Nuclear—We advance the scientific basis for 21st century nuclear fission and fusion technologies and systems, and we produce isotopes for research, industry, and medicine.

As Associate Laboratory Director at ORNL, I am privileged to lead a talented group of scientists and engineers as we address scientific challenges to advance America's clean energy future. Our researchers work with many of America's best innovators and businesses to pursue scientific breakthroughs in areas such as sustainable, efficient transportation technologies, including intelligent mobility solutions, extreme fast charging and wireless charging, automated vehicle technologies and vehicle cybersecurity, advanced materials, fuels, engines, and emissions research, and big data for decision-making. We also deliver solutions for energy efficiency for manufacturing, homes, and buildings; electric grid resiliency and security; and the advancement of domestic energy sources such as fossil energy and bio-derived fuels and feedstocks.

Our discoveries fuel the growth of science as well as local, regional, and national economies. In partnership with industry, academic institutions, and other DOE national laboratories, ORNL is well positioned to achieve scientific breakthroughs and develop innovative technologies that will meet our nation's clean energy needs for the next generation.

The DOE's Office of Energy Efficiency & Renewable Energy (EERE) is the primary sponsor of vehicle technology research at the national laboratories. EERE's Vehicle Technologies Office leads research on batteries, charging and EVs; energy-efficient mobility systems; advanced combustion systems and fuels; lightweight and propulsion materials, and technology integration. EERE's Fuel Cell Technologies Office supports new fuel cell propulsion system research; its Advanced Manufacturing Office supports research into more efficient production processes, including additive manufacturing of tooling; and its Bioenergy Technologies Office supports work on new fuels for advanced combustion.

The unique combination of scientific tools and expertise at our national laboratories provide a powerful resource to foster U.S. technical and economic competitiveness, particularly when working alongside American companies to identify and more rapidly develop superior, affordable materials solutions.

The national laboratory system addresses energy efficiency challenges through technology breakthroughs in partnership with the academic and private sectors. DOE ensures that scientific and technical advances can move beyond the national laboratories to increase the economic impact of the intellectual property developed as a result of federally funded research and development. The laboratories are encouraged to work with the private sector to find and implement new approaches for translating early-stage innovations to viable market options. These efforts leverage traditional funding streams and programs focused on early-stage research with private-sector investment and market knowledge that provide a pathway to create new businesses, product lines, and jobs.

THE FUTURE OF TRANSPORTATION SYSTEMS

Efficient, affordable, and secure transportation is essential to the nation's economy and to our standard of living. Some 269 million vehicles traversed America's roadways in 2016, according to the Department of Transportation.[1] The transportation sector consumed 27.9 quadrillion Btus of energy that year.[2] Petroleum has accounted for more than 90% of transportation energy consumption since the mid-1950s.

However, the transportation system of the future is likely to look very different than today. The rapid increase in vehicle electrification and the introduction of autonomous vehicles is revolutionizing the mobility industry not only on-road but also in the areas of air, marine, and off-road. These technologies will forever change personal mobility, the movement of goods, and society in fundamental ways.

Vehicle electrification includes both all-electric and hybrid-electric vehicle architectures. Hybrid-electric systems provide an opportunity to combine the best characteristics of combustion and electric-drive technologies as well as to enable the use of clean, high-efficiency technologies that may not be able to meet vehicle transient power demands on their own. Examples include alternative architecture combustion engines and gas turbines.

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[1] U.S. Department of Transportation Bureau of Transportation Statistics, "Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances."
[2] U.S. Department of Transportation Bureau of Transportation Statistics, "U.S. Energy Consumption by the Transportation Sector."

Very important to the success of electrification and autonomous vehicles is driving range. We envision a future where vehicle refueling is easy, fast, and convenient—more of a maintenance interval or happening without driver interaction or knowledge. This will be very important for truly autonomous vehicles. DOE's national laboratories have strong research programs for extending vehicle range through better onboard energy storage, wireless charging, extreme fast charging, reduced vehicle weight, and improved fuel efficiency of onboard power generation.

Electric vehicle (EV) adoption is on the rise. Sales of new battery-driven or hybrid plug-in vehicles are likely to have reached nearly 200,000 for 2017 in the United States, up nearly 26% from the year prior, according to DOE estimates.[3]

The International Energy Agency (IEA) in its *Global Electric Vehicle 2017* report found that electric vehicles nearly doubled worldwide in 2016 to more than 2 million vehicles. With research and development leading to cheaper batteries with higher energy density, and with global policies favoring EVs, the IEA predicts that global EV inventories will rise to between 9 million and 20 million by 2020, and between 40 million and 70 million by the year 2025.[4]

China is the largest market for EVs, accounting for more than 40% of the electric cars sold in the world and more than double the number sold in the United States in 2016, IEA notes. Norway has the highest market share, with 29% of its vehicles running at least partly on electricity as of 2016. That is followed by the Netherlands with 6.4%, Sweden with 3.4%, and China, France, and the United Kingdom with electric car market shares close to 1.5%.

Volvo Cars has stated that beginning in 2019, it will no longer sell cars containing just an internal combustion engine. Its vehicles will all contain an electric motor, whether fully electrified or a hybrid. Supporting the future of EVs globally is the news that officials in Great Britain, France, Norway, India, and China have said they will propose a ban on vehicles running solely on fossil fuels in some regions as early as 2040 in an effort to improve environmental quality.

Battery manufacturers are key players in the EV space. Lithium ion battery technology was first commercialized by Sony in Japan in 1991. Other major companies in Japan are Panasonic, the current supplier of Tesla batteries, and Toshiba, typically producing batteries for electric grid applications. Japan fully dominated the battery consumer market for a decade until we began seeing a shift to Korea in the early 2000s, with the rise of Samsung SDI and LG in battery manufacturing.

China entered the battery market with the establishment of Amperex Technology (ATL), mostly as a prismatic cells supplier for phones and tablets, and BYD Company, supplying batteries for EVs and the grid. With these two companies, China has become a hub for battery manufacturing.

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[3] Argonne National Laboratory/DOE, "Light Duty Electric Drive Vehicles Monthly Sales Updates," (accessed January 16, 2018).

[4] International Energy Agency, *Global EV Electric Outlook 2017.*

Companies in Japan and Korea are shifting production to China. The world market is mainly shared between Japan, Korea and China, with a forecasted advantage to China. Europe has limited lithium ion battery manufacturing.

In the United States, the Tesla-Panasonic Gigafactory venture ramping up production now is expected to position our country as a major producer in the battery space. Tesla is targeting annual battery production capacity of 35 gigawatt hours at the facility—nearly as much as the entire world's current battery production combined.

In Japan, the focus has been on hydrogen fuel cell vehicles. Japan's automakers now have two hydrogen powered vehicles on the market, and they are teaming with energy suppliers to expand the hydrogen fueling network. The Japanese government has said it wants 900 hydrogen fueling stations and 800,000 fuel cell cars on the road by the year 2030.

While the outlook for these vehicles is promising, significant research and development challenges and opportunities remain. Solutions are needed in the EV space, for instance, to make the vehicles cheaper and more energy efficient, to increase their range and the number of charging options, and to integrate EVs into our daily lives in a way that makes them a benefit to the nation's power grid rather than a burden.

MOBILITY AND CONNECTIVITY

The goals of next generation transportation systems are to alleviate congestion, reduce energy use and emissions, and improve safety. Core disruptive technologies for such transportation systems include vehicle connectivity, vehicle automation, and the notion of shared personalized infrastructure enabled by mobility on demand systems, which today have their genesis in ride-hailing services. The central challenge is to develop more efficient transportation systems to connect communities and increase access, without also increasing the negative consequences of transportation (e.g., emissions, energy consumption, and congestion).

Scientists at the national laboratories are tackling the challenges for intelligent, ultra-efficient and connected mobility, and the fundamental changes to technology and infrastructure needed to arrive at that future.

National Transportation Research Center

The National Transportation Research Center (NTRC) at ORNL is DOE's only transportation user facility. At the center, we are focused on helping shape a more energy efficient future with foundational research for new materials such as high-temperature aluminum alloys for engines and low-cost carbon fiber for lighter, stronger car bodies and more efficient, low-cost engine components; new battery designs with higher energy density at lower cost; advanced high-efficiency, low-cost power electronics that use wide bandgap semiconductors; cheaper, more efficient catalysts for emission controls; novel materials for fuel cells; new combustion modes for more efficient hybridization solutions; and breakthroughs to enable advanced biofuels.

The NTRC provides an interdisciplinary ecosystem that is critical to driving innovation and scientific breakthroughs to application in these fast-emerging areas. More specifically, this ecosystem has demonstrated success in bridging high performance computing, materials science, and neutron science with the transportation and manufacturing programs to develop and demonstrate new technologies from the fundamentals to the road.

Connected and Autonomous Vehicles

ORNL is leading autonomous vehicle research with an interdisciplinary research strategy that bridges artificial intelligence, machine learning, sensors, electrification, and advanced manufacturing. This includes the use of the fastest open science computer in the United States—Titan—to greatly accelerate the interpretation and use of big data from vehicles and complex mobility systems.

In addition to Titan, ORNL is deploying a new system, called Summit, which may well be the world's most powerful supercomputer, operating at least five times faster than Titan when it comes online later this year. Summit will also be an exceptional resource for artificial intelligence applications, with the potential to address challenging data analytics problems utilizing deep learning in a number of scientific domains.

High Performance Computing (HPC) for the Big Data Era

To help design the transportation system of the future, industry is entering the big data realm. Autonomous vehicles are already generating terabytes of data that can be used to better understand vehicle miles traveled, driving behavior, traffic congestion, and other factors. Expertise and capabilities such as the high-performance computing assets at ORNL allow scientists to develop neural networks to parse that data for the creation of new controls and software to ensure the most efficient use of energy as we move toward a more autonomous and connected transportation system.

DOE's recently announced HPC4Mobility program will support companies, cities, and transportation system operators who seek access to the supercomputing capabilities and data science expertise of the national labs to discover opportunities for energy efficiency increases in mobility systems. First-year projects under HPC4Mobility include: 1) ORNL working with GRIDSMART Technologies on reinforcement of learning-based traffic control approaches to optimize energy usage and traffic efficiency; and 2) Lawrence Berkeley National Laboratory working with the Los Angeles County Metropolitan Transportation Authority on HPC-enabled computation of demand models at scale to predict the energy impacts of emerging mobility solutions. Applications include modeling the impact of autonomous vehicles on transportation energy use and the hour-by-hour impact of ride hailing services on traffic congestion.

Omnidirectional, Autonomous Vehicle Testbed

Our researchers have developed a one-of-a-kind omnidirectional autonomous mobile vehicle, which is used as a testbed for ORNL-developed technologies and complex control systems. It only took two days to rapid prototype the structure of this vehicle at DOE's Manufacturing

Demonstration Facility at ORNL, using large-scale additive manufacturing technology developed at the laboratory and now licensed to Cincinnati Incorporated and Strangpresse.

Control Technologies for Connected and Automated Vehicles
ORNL scientists are helping develop novel control technologies for connected and automated vehicles with the goal of achieving a 20% improvement in vehicle energy efficiency. The work is targeting improvements in optical routing to bypass traffic congestion; accelerating and decelerating based on traffic conditions and the state of surrounding roads; and optimizing onboard powertrain efficiency. Leveraging the connectivity of automated vehicles is a key concept in the project.

Vehicle Cybersecurity
As vehicles get smarter, the technologies that will keep them connected to each other and to central systems also make them vulnerable to cyberintrusion. Our challenge is to produce solutions to better protect vehicle communications and controls while continuing to advance the efficiency and other benefits of intelligent mobility.

At ORNL, our Vehicle Security Center brings together researchers from across the lab with unique transportation, sensors and controls, computational science, and cyber expertise to address this challenge. The center's Vehicle Security Laboratory places cyber experts and advanced software analysis tools in close association with vehicle and manufacturing researchers. The focus is predictive assessment—identifying threats and building in security features to neutralize them. One such tool is Hyperion, developed by an ORNL cybersecurity team to analyze code and identify threats, eliminating them proactively.

ELECTRIFICATION

The national laboratories are creating breakthroughs for electric vehicles as well as ultra-efficient internal combustion engines to support advanced hybrid and full-electric vehicles.

Better Batteries
The national labs are working on new battery technologies that extend battery lifetime, increase energy and power density, reduce battery size and cost, and improve safety for America's drivers. Scientists are concentrating their expertise in electrochemical engineering, materials characterization, material and chemical processing, and materials and systems simulations to identify battery performance limitations and develop revolutionary technologies and manufacturing processes for next-generation batteries. The highest payoff is in the development of advanced cathode materials, since they determine the energy content and lifespan of a battery.

DOE's **Battery500 Consortium** led by Pacific Northwest National Laboratory (PNNL), for instance, brings together the expertise and capabilities of DOE national laboratories, universities, and industry to develop smaller, lighter, and less expensive vehicle batteries. The consortium's goal is to develop lithium-metal batteries with nearly triple energy density than batteries in today's EVs—specifically with 500 watt-hours per kilogram compared with then 170-200 watt-hours per kilogram found in current batteries. Other members of the consortium include Brookhaven National Laboratory, Idaho National Laboratory (INL), SLAC National Accelerator Laboratory, Binghamton University, Stanford University, University of California-San Diego, University of Texas-Austin, University of Washington, and IBM as an advisory board member.

DOE's **Battery Manufacturing R&D Facility**, housed at ORNL, is the nation's largest and most comprehensive R&D facility for this purpose. Here, our scientists are studying battery materials from the atomic level up to industrially relevant scales, including roll-to-roll manufacturing techniques in which battery components are printed on flexible substrates, resulting in a faster, more efficient process.

ORNL research has resulted in improvements that reduced the cost of lithium ion batteries cost by five-fold, while simultaneously increasing gravimetric energy density by five-fold.

ORNL battery manufacturing has been critical to the nation's recent advancements in the following areas:

- Battery cost reduction by inventing and implementing an industrial high-speed water based process to replace the costly organic and heavy infrastructure electrode fabrication process.
- Energy density improvement by increasing cathode and anode materials loading densities beyond current industry limits while achieving excellent cycle life (700-plus cycles).
- Performance improvement by incubating unique electrode architecture design, formation cycle protocols, and down selecting best matching electrochemical couples.

Quick Coatings for Lithium-Ion Batteries
In one recent project, scientists at ORNL used the precision of an electron beam to instantly adhere cathode coatings for lithium-ion batteries as the components roll down a production line. The process saves energy, reduces production and capital costs, and eliminates the use of toxic solvents. Typical curing processes can require drying machinery the length of a football field and expensive equipment to recover solvents. This new approach presents a faster, energy-efficient manufacturing process for high-performance, low-cost lithium-ion batteries.

ORNL is also advancing scientific breakthroughs for general battery safety under DOE's Advanced Research Projects Agency-Energy (ARPA-E) program. We are exploring innovative technologies to provide robust batteries where the overall system weight and cost can be reduced because the batteries are more durable and require less protection in the event of a collision.

SAFIRE — Safe Impact Electrolyte
ORNL is also improving the safety of EV batteries by developing a shear thickening colloid as the electrolyte in a project called SAFIRE, or Safe Impact Electrolyte, improving the safety of EV batteries by developing a shear thickening colloid as the electrolyte. This electrolyte transforms from liquid to solid upon impact, preventing the formation of short circuits and a potential fire. SAFIRE performs as well as conventional electrolytes under normal conditions

and can significantly reduce electric vehicle weight and increase travel distance by reducing the need for extra materials to shield batteries. A second innovation, Safety Foil current collectors, provides for breakage of large area electrodes into smaller fragments upon impact. This electrically isolates any damaged regions of the electrodes, such that thermal runaway is avoided, and the undamaged areas continue to function.

Convenient, Fast Recharging & Infrastructure

Keeping pace with the growth of EVs, charging infrastructure is on the rise. There are now more than 17,000 EV public charging stations in the U.S., and more than 47,000 individual charging outlets, according to DOE's Alternative Fuels Data Center.[5] The national labs are innovating this infrastructure as well, with development of wireless charging technology, concepts for extreme fast charging solutions, and better planning tools for infrastructure developers.

Recently, a report issued by INL, Argonne National Laboratory, and the National Renewable Energy Laboratory (NREL) identified technical gaps to implementing an extreme fast charging network in the United States.[6] The aim of this DOE/national lab consortium is to develop charging stations with 400 kWh capability—which would recharge a battery-powered EV in less than 10 minutes. The report addressed challenges in three key areas: better batteries with higher energy density, extended lifetimes, and lower cost; vehicle improvements to handle the higher voltage through advanced power electronics, including solving the tradeoff between driving range and recharge time; and infrastructure challenges such as standardization of vehicle systems and recharging stations, careful planning of station siting, and efforts to limit impacts to the larger power grid.

Bi-directional Wireless Charging

ORNL researchers developed and demonstrated a 34-kilowatt wireless vehicle charging system that can charge passenger vehicles five times faster than conventional plug-in systems at the same efficiency as a wired connection, and are targeting 100 kilowatts for next year on the way to an ultimate 350 to 400-kilowatt system. In partnership with Toyota, Cisco Systems, Evatran and Clemson University, our scientists installed the system on several electric production vehicles, including a Toyota RAV4. We are currently working with United Parcel Service to develop a bidirectional wireless charging system with higher ground clearance for the company's delivery trucks. Evatran has since developed a commercial wireless EV charging system based on this breakthrough, "Plugless," which it plans to roll out as automakers introduce vehicles with wireless charging technology.

Recharging Station Planning Tool

ORNL has extensive expertise in developing and applying spatial decision support systems to traffic forecasting and associated infrastructure investment studies. Recently, ORNL scientists in collaboration with Clemson University developed a novel method to anticipate the demand for

[5] U.S. DOE, "Alternative Fuels Data Center Fueling Station Locator" (accessed January 16, 2018).
[6] U.S. DOE, "Enabling Extreme Fast Charging: A Technology Gas Assessment," October 2017.

electric vehicle charging stations and to assist communities with infrastructure planning for intercity travel. The data-driven method, developed with input from the California Department of Transportation, considers electric vehicle volume and random timing of vehicles arriving at charging stations to determine the optimal number of chargers needed in the near- and long-term.

Integrating EVs into the Power Grid

As we look to an electrified transportation system of the future, questions arise about impacts on the overall power grid and on electricity demand in general. The fastest, commercially available charging stations can deliver about 50kW to electric vehicles. The impact of this growing demand and how the grid may benefit from EVs is the subject of ongoing research at the national laboratories

INTEGRATE — Integrated Network Testbed for Energy Grid Research and Technology Experimentation

In the INTEGRATE project led by NREL as part of DOE's Grid Modernization Initiative, scientists are looking for ways to enable sustainable transportation technologies, renewable power, and energy efficiency to increase the capacity, efficiency, and stability of the grid. A key premise of the research in the program is that vehicle-to-grid technology makes it possible to store surplus electricity generated from intermittent solar sources, for instance, in EV batteries during non-peak periods, and to feed that power back into the grid when needed, thus enhancing grid stability and reducing electricity costs at peak times.

AMIE — Additive Manufacturing + Integrated Energy

With the AMIE project, ORNL demonstrated a future in which an additively manufactured home equipped with its own power generation—in this case a 3.2-kilowatt solar panel system—can produce, store, and consume renewable energy. The house's energy system can wirelessly charge a hybrid electric vehicle, whose chassis was also 3D-printed, and in turn the energy stored in the vehicle's batteries can wirelessly supplement power to the house as needed. A home and vehicle that can store electricity and transfer that power back and forth provide key advantages: occupants maintain electricity during outages; there's less stress on the utility grid if the home can use its own power during peak times; and the EV can function as an energy storage resource. To accomplish this, ORNL developed breakthroughs in several key areas, not the least of which was the ability to wirelessly transfer a large amount of power in both directions.

ALTERNATIVE PROPULSION SYSTEMS

While we look to the future of an electrified transportation system, our researchers are also innovating fuels, engines, and emissions technologies to support conventional and hybrid gasoline vehicles in pursuit of lower petroleum imports, energy efficiency, and a robust economy. ORNL conducts research and development focused on the interrelated areas of advanced combustion engines, lubricants, fuels, and emissions controls.

Co-Optima

ORNL is co-leading with NREL, PNNL, and Sandia National Laboratories and participation by other national labs, universities, and industry on the Co-Optimization of Fuels & Engines (Co-Optima) initiative. This first-of-its-kind effort is focused on combining fuels and combustion R&D, building on decades of advances in both fuels and engines. This effort brings together diverse expertise to simultaneously tackle fuel and engine research and development to maximize light-, medium-, and heavy-duty vehicle fuel economy and performance while mapping lower-cost pathways to reduce emissions, leveraging diverse domestic fuel resources, boosting U.S. economic productivity, and enhancing national energy security.

ACMZ cast aluminum superalloys

ORNL and partners Fiat Chrysler Automobiles and Nemak USA developed a new class of affordable, lightweight aluminum, copper, manganese, zirconium (ACMZ) superalloys capable of withstanding temperatures nearly 100 degrees Celsius greater than current commercial alloys while providing exceptional thermomechanical performance and hot tear resistance. The new alloys are easy to cast and ideal for the next generation of high-efficiency combustion engines.

HPC, Neutrons for Efficiency Improvements

In another project, ORNL researchers are collaborating with General Motors, Convergent Science, Lawrence Livermore National Laboratory, and the Oak Ridge Leadership Computing Facility on virtual engine design and calibration. Researchers are using supercomputers to increase simulation detail and accuracy while accelerating throughput. The team also collaborated with Ford Motor Company and Convergent Science to use supercomputing to identify factors that promote combustion instability in spark-ignition engines, with the aim of improving fuel efficiency and reducing emissions. In another activity, researchers made use of the ORNL High Flux Isotope Reactor and neutron imaging to improve fuel injectors, and ultimately increase engine efficiency.

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. These trucks haul some 80% of the nation's goods, and use about 28 billion gallons of fuel per year, accounting for 22% of total transportation energy usage. 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% higher freight efficiency and a 75% 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. We demonstrated dual-fuel, low-temperature combustion with natural gas and diesel fuel for 115% higher freight efficiency and doubled the truck's miles per gallon. In our work with Volvo, ORNL helped develop emissions control strategy for their advanced engine concepts.

Hydrogen and Fuel Cell Technologies

Fuel cells could be a gamechanger for the electric vehicle industry, promising clean and efficient production of electricity. These cells use the chemical energy of hydrogen or another fuel to produce electricity. If hydrogen is the fuel, electricity, water, and heat are the only products; there are no emissions of carbon dioxide or air pollutants.

H2@Scale

DOE has begun exploring the potential for wide-scale hydrogen production and utilization in the United States to enable resiliency of the power generation and transmission sectors, while also aligning diverse, multibillion-dollar domestic industries. The H2@Scale concept aims to develop transformational technologies that reduce the cost of hydrogen production and distribution, diversify the feedstock available for economic hydrogen production, enhance the flexibility of the power grid, reduce emissions through novel uses of low-cost hydrogen, generate jobs, and provide global technology leadership for export of next-generation energy solutions.

Hydrogen is mostly produced in the United States by reforming natural gas. Switching to clean, low-cost hydrogen would take advantage of increased domestic natural gas supplies and technological advances in carbon capture and sequestration, enabling truly zero emissions for transportation and other applications.

DOE and its national laboratories have hosted three H2@Scale workshops to identify R&D concepts and bring together stakeholders to examine needs of the industry, as well as identifying regulatory, policy, and safety issues. The department has selected 26 collaborative research and development projects in which the national laboratories will work alongside industry with funds from industry going directly to the laboratories for accessing their capabilities. Access to the national laboratories is a key enabler for advancing the technology and the availability of hydrogen and fuel cells throughout the nation.

Nanoscale Materials Characterization and Component Development

ORNL is DOE's leading resource for characterization of hydrogen fuel cell electrode materials through electron microscopy and X-ray photoelectron spectroscopy. ORNL scientists are using atomic-level imaging of catalysts to develop better-performing, lower-cost fuel cell technologies. Fuel cells typically rely on costly platinum to convert chemical energy into electricity. Researchers are using advanced microscopy to aid the design of custom alloys of platinum and cheaper metals such as cobalt, and to take the next step to develop catalysts that are precious metal-free.

LIGHTWEIGHT MATERIALS AND ADVANCED MANUFACTURING

Materials Research

New, lightweight, domestically sourced materials are essential to lowering the cost and increasing the efficiency and driving range of the next generation of vehicles. It takes less energy to accelerate a lighter object than a heavier one; a 10% reduction in vehicle weight, for instance, can result in a 6-8% increase in fuel economy. By using lightweight structural materials, cars can carry additional advance emissions control systems without increasing the overall weight of the vehicle.

But development of new and improved materials, particularly aluminum alloys and carbon fiber composites, is slow, difficult, and very expensive. Modern materials research tools, staffed by a team of dedicated materials scientists, are extremely costly to purchase and maintain. Consequently, today many firms in the transportation sector possess limited capability to effectively develop superior new materials that will lead future technology. Here is where the national labs can step in with unique capabilities and expertise in atomic-level imaging using advanced microscopy, spectroscopy and neutrons, and with high performance computing to develop a new generation of materials.

Carbon Fiber and Composites

ORNL is leading the nation in developing low-cost carbon fiber to reduce vehicle weight. Estimates show that carbon fiber composites have the potential to reduce vehicle weight by 40% or more.

ORNL is home to DOE's Carbon Fiber Technology Facility (CFTF)—a 42,000 sq. ft. innovative technology facility. The CFTF offers a highly flexible, highly instrumented carbon fiber line for demonstrating advanced technology scalability and producing market-development volumes of prototypical carbon fibers, and serves as the last step before commercial production scale.

Low-Cost Precursor

The CFTF has made available for licensing a new method of producing carbon fibers from multipurpose commercial fiber precursor—such as fibers used in carpeting or clothing. The technology has the potential to reduce carbon fiber production costs by more than 50%. In addition, the method reduces energy consumption by as much as 60% and has applications across the aerospace, transportation, energy, and infrastructure industries. LeMond Composites was the first company to license the acrylic fiber method, with plans to take the technology to market.

Bio-Derived Materials

ORNL is leveraging its expertise in advanced and composite materials and additive manufacturing in partnership with the University of Maine and its Advanced Structures and Composites Center to develop new methods and uses for forest-based biomaterials, including for automotive and other industrial applications—a partnership supported by EERE's Advanced Manufacturing Office.

IACMI — Institute for Advanced Composites Manufacturing Innovation

ORNL is a founding partner of the Institute for Advanced Composites Manufacturing Innovation, one of the Manufacturing USA centers for innovation. IACMI, the Composites Institute, has assembled a consortium of almost 160 members committed to moving carbon and other advanced fiber composites into mainstream use in strategic application areas for the United States, including vehicles and transportation. IACMI, working with ORNL and other innovation partners are working with leading automakers Ford, Fiat Chrysler Automobiles, and others as they team with partners in their supply chains such as Dow, Faurecia, DuPont, BASF, and PPG to develop and demonstrate new materials and processes on the path to large scale deployment.

IACMI in conjunction with LIFT (Lightweight Innovations for Tomorrow) have opened a manufacturing scale-up facility at Corktown in Detroit, Michigan, where industry and institute members can conduct research and development in lightweight metals and advanced composite materials. ORNL, for instance, is collaborating on a project at Corktown to develop new, lighter materials for EV battery shielding.

Novel Electric Motor

In work supported by the Critical Materials Institute, ORNL researchers designed and demonstrated a novel electric vehicle motor that achieves 75% higher power than commercial electric motors of the same size at a lower cost. The motor makes use of permanent magnets made from common, domestic ferrite material rather than the imported rare earth materials typically used now to manufacture magnets for electric motors. In testing, the motor achieved peak power of 103 kilowatts and exceeded DOE targets for power, efficiency, and cost. That's compared to the 60-kilowatt motor typically found in many hybrid EVs.

Joining Breakthrough

Incorporating new, lightweight materials into vehicle components is very difficult using conventional methods like welding. PNNL has developed a breakthrough method to resolve these issues. PNNL's "Friction Stir Scribe Process for Joining Dissimilar Materials" joins dissimilar materials with drastically different melting points in a continuous, linear, or curved manner without the need for additional adhesives, bolts, and rivets.

Advanced Manufacturing

Advanced manufacturing at the national labs involves working hand-in-hand with industry to enhance the global competitiveness of the American manufacturing sector and to bring manufacturing jobs back to U.S. shores. At DOE's Manufacturing Demonstration Facility (MDF) at ORNL, we are collaborating with automakers to create lightweight, complex components for the transportation industry. Some of our most high-impact research in this space revolves around advances in the tool and die industry—creating custom molds, for instance, for new vehicle designs quickly and at a much lower cost than in conventional manufacturing practice.

Composite Tooling

ORNL is working with Ford and Volkswagen to produce low volume composite tooling out of high temperature thermoplastic materials via additive manufacturing. We are also collaborating with American automotive tooling companies to produce high-volume stamping dies via large-scale metal additive manufacturing.

World's First 3D-Printed Cars
ORNL collaborated with Local Motors to develop materials processes for 3D-printing the chassis of the world's first 3D-printed car—the Strati—using the big-area additive manufacturing (BAAM) machine developed by ORNL and Cincinnati Incorporated. Building on that success, the laboratory 3D-printed the Shelby Cobra electric sports car, used as a living laboratory for integrating advanced vehicle technologies, at the MDF using the BAAM system. Local Motors leveraged the same technology to additively manufacture the chassis for its Olli autonomous shuttle bus. ORNL is working with Local Motors to install its wireless power transfer technology on the Olli.

These remarkable breakthroughs would be difficult if not impossible for industry to solve alone. The national laboratories bring together world-class facilities and experts across a wide spectrum of disciplines to tackle scientific challenges from a vehicle's smallest component to solutions for efficient vast transportation networks, in collaboration with partners from industry, academic, and public institutions who help guide our research for the greatest impact.

CLOSING REMARKS

A robust transportation system utilizing efficient vehicles is essential to lowering consumer fuel costs, supporting our domestic economy, increasing energy security, and minimizing pollution. DOE works through its national laboratories and their industry and academic partners to support research, development, and deployment of efficient, sustainable transportation technologies that will improve energy efficiency, fuel economy, and enable America to use less petroleum and to reduce energy imports. These technologies will increase America's energy security, economic vitality, and quality of life.

The national laboratories are a remarkable asset for the nation. Over the past 75 years, they have consistently provided the science and technology needed to address compelling national problems, and they offer an extraordinary set of resources for sustaining and advancing the national, economic, and energy security of the United States in the 21st century.

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

APPENDIX

ORNL TRANSPORTATION RESEARCH FACILITIES

National Transportation Research Center

The National Transportation Research Center (NTRC) at ORNL is DOE's only transportation user facility. The facility contains several highly sophisticated, experimental research laboratories and leverages unique science expertise and facilities in high performance computing, material sciences, and neutron sciences. NTRC offers industry, academia, and other agencies the opportunity to access state-of-the-art technologies, equipment and instrumentation, and computational resources to advance transportation technologies. In its more than 55,000 square feet of research laboratory space, NTRC contains:

- DOE's largest open access Battery Manufacturing Facility
- Fuels, Engines, and Emissions Research Laboratory
- Power Electronics and Electric Machinery Laboratory
- Vehicle Integration Laboratory
- Transportation Analysis and Visualization Laboratory
- Access to ORNL world-class supercomputing, visualization, and materials science capabilities
- Uninterrupted power backup for entire laboratory
- Transportation data analysis
- 80,000-pound pit reference scale
- Engine and chassis dynamometers
- Analytical chemistry laboratory
- Catalysis function laboratory
- Fuel cell laboratory with evaluation capabilities for cells up to 3 kW
- Unique diagnostic tools for in situ chemical speciation and catalysis surface analysis
- Wide bandgap device evaluation facility
- Co-located with ORNL's Manufacturing Demonstration Facility

Carbon Fiber Technology Facility

Carbon fiber is a strong, stiff, lightweight enabling material for improved performance in many applications, including vehicles. DOE's Carbon Fiber Technology Facility (CFTF) at ORNL is the nation's only open-access, semi-production scale facility for testing new methods of carbon fiber manufacturing. The facility offers two carbon fiber processing lines to test conventional thermal conversion as well as melt-spinning. A third line under development will explore microwave- and plasma-based processing technologies. Backed by ORNL's world-class materials research program, the CFTF aims to reduce carbon fiber production costs and accelerate the adoption of lightweight, strong, and efficient composite materials by US manufacturers.

The 42,000 square-foot facility offers a highly flexible, highly instrumented carbon fiber line for demonstrating advanced technology scalability and producing market-development volumes of prototypical carbon fibers, and serves as the last step before commercial production scale. The facility, with its 390-ft. long processing line, is capable of custom unit operation configuration and has a capacity of up to 25 tons per year, allowing industry to validate conversion of their carbon fiber precursors at semi-production scale.

Manufacturing Demonstration Facility
DOE's Manufacturing Demonstration Facility (MDF), established at ORNL, helps industry adopt new manufacturing technologies to reduce life-cycle energy and greenhouse gas emissions, lower production cost, and create new products and opportunities for high-paying jobs.
At the MDF, we are collaborating with equipment manufacturers and end users to advance state-of-the-art technologies and revolutionize the way products are designed and built using additive manufacturing (AM) technology. Drawing on its close ties with industry and world-leading capabilities in materials development, characterization, and processing, ORNL is creating an unmatched environment for breakthroughs in additive manufacturing.

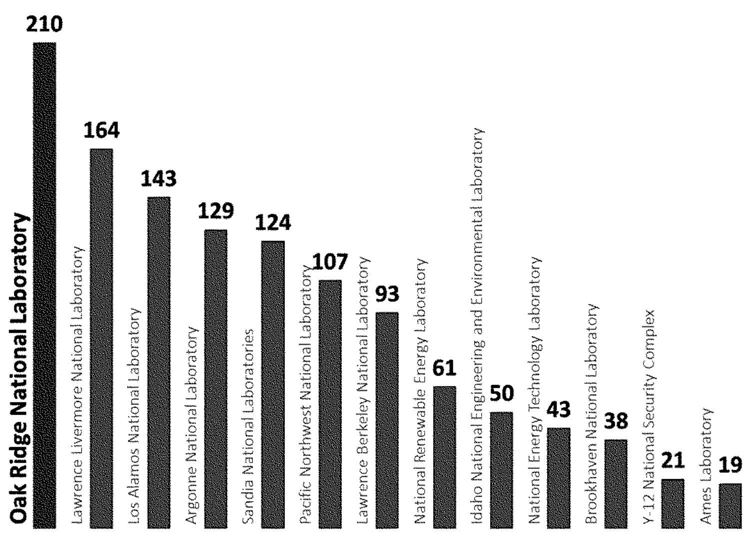
We are creating metal components and new super alloys by melting metal powder or wire to form the part directly from a computer-generated design file. Metal additive manufacturing can significantly improve energy efficiency by increasing material utilization and minimizing scrap material associated with component fabrication. Elimination of geometrical constraints associated with conventional manufacturing technologies such as casting and machining can result in components that fulfill all of the functional requirements but weigh significantly less than those of conventional design.

We are also engaged in polymer additive manufacturing, which can enable the rapid manufacture of lightweight, complex components and impact a broad spectrum of manufacturing industries. Examples include the tool and die industry (rapid, low-cost tooling), lightweight components for the transportation industry (automotive and aerospace), and low-cost components for the energy industry. Current objectives are focused on developing composite materials, process monitoring and closed loop feedback control systems to increase the mechanical properties and production quality of fused deposition modeling (FDM) components.

R&D 100 AWARDS
ORNL has earned 210 R&D 100 Awards since their inception in 1963, more than any other single organization. ORNL was recognized with nine total awards in 2017, with six of those coming from DOE EERE, and two specifically supported by EERE's Vehicle Technologies Office:

- *ACMZ Cast Aluminum Alloys* – a new class of affordable, lightweight superalloys capable of withstanding temperatures of almost 100-degree Celsius more than current commercial alloys while providing exceptional thermomechanical performance and hot tear resistance. Supported by DOE's Office of Vehicle Technologies.
- *Filler Materials for Welding and 3D Printing* – innovative filler materials that counterbalance how much the materials expand and shrink and control the residual stress and distortion of high-strength steel structures. The filler materials also do not require the costly, labor-intensive heat treatments normally needed to avoid cracking and material embrittlement, providing significant economic benefits while improving the stability and durability of welded and 3D printed structures. Supported by DOE's Office of Vehicle Technologies and Office of Fuel Cell Technologies.

Total R&D 100 Awards by the National Laboratories



Source: ORNL

PARTNERSHIP SUCCESSES

ORNL actively engages industrial and public-sector partners to guide its research efforts for the most impactful results. Some examples:

Aluminum-Cerium alloy — Eck Industries
As part of DOE's Critical Materials Institute, researchers at ORNL worked with Ames Laboratory, Lawrence Livermore National Laboratory, and Eck Industries to develop a new high-performance aluminum alloy. 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 their new alloy under real-world operating conditions, the research team used the resources of MDF and NTRC to cast a cylinder head made of this alloy, using sand molds created by 3D-printing. They retrofitted this component to a gasoline-powered engine designed to operate on the VULCAN instrument at SNS and used neutron diffraction 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.

GRIDSMART Technologies
ORNL is collaborating with GRIDSMART, a company advancing smart traffic management systems for local communities. Their focus is a camera-based system that controls traffic lights in response to actual roadway conditions, thereby preventing lane closures, improving worker safety, and reducing costs. The system provides data on vehicle volume, turning movements, and other points to remotely control traffic systems. The technology has been installed in more than 3,000 locations worldwide, and plans are to integrate the system into autonomous vehicle technologies in the future.

TennSMART
ORNL is a member of the newly launched TennSMART Consortium, consisting of 20 public and private partners working to accelerate the development and deployment of intelligent mobility innovations in Tennessee. The group establishes a regional ecosystem focused on connected and automated vehicles, heavy-duty trucking and freight efficiency, vehicle cybersecurity, electric vehicles, and multimodal commuting. Other members include: Bridgestone Americas, Cummins Filtration, Inc., DENSO Manufacturing Tennessee, FedEx Corporation, GRIDSMART Technologies, Inc., Local Motors, Lyft, Miovision, Nissan North America, Stantec Consulting Services Inc., the Tennessee Department of Environment and Conservation, Tennessee Department of Labor and Workforce Development, Tennessee Department of Transportation, Tennessee Tech University, Tennessee Valley Authority, Top Five Inc., University of Memphis, The University of Tennessee, and Vanderbilt University.

Grid Modernization
ORNL works with several utilities on grid modernization and security innovations, including the Chattanooga Electric Power Board (EPB), Dominion, Duke Energy, Southern Company, Georgia Power, and Tennessee Valley Authority.

For instance, ORNL and DOE have enjoyed a productive working relationship with the Chattanooga EPB. These efforts support America's technological leadership, national security, and the goal to create a new, more reliable, and affordable electric utility service for the Internet Age. The EPB smart grid and advanced communications network also make a living laboratory to test new technology developed by ORNL and other labs.

Another example demonstrates *Neighborhoods of the Future* with partners like Southern Company and its subsidiaries Alabama Power and Georgia Power. The energy for Smart Neighborhood will be provided by the existing electric grid, as well as a community-scale power system called a "microgrid," which is composed of solar panels, battery storage, and backup generation. The Georgia development will include "EV-ready" townhouses allowing homeowners the ability to add the charging technology later.

The CHAIRMAN. Thank you, Dr. Khaleel.

Ms. Bailo, welcome.

STATEMENT OF CARLA BAILO, PRESIDENT AND CEO, CENTER FOR AUTOMOTIVE RESEARCH

Ms. BAILO. Thank you very much.

I'd like to thank Chairman Murkowski and also Senator Stabenow, Senator Manchin, for the opportunity to address you today.

I'm Carla Bailo. I'm President and CEO of the Center for Automotive Research in Ann Arbor, Michigan. We do, we are a non-profit, independent, unbiased research facility that brings together stakeholders for discussions and really trying to solve and do the research for some of the issues that are facing the automotive industry.

For a little bit of a personal background, I was born and raised in Michigan. I have cars in my blood. I had 35 years in the automotive industry, prior to two and a half years in academia where I led smart mobility and smart city research and now am fully into the non-profit research side of the business.

When we look at the automotive industry today, it's really in a critical period of disruption. On the one side, sales are booming, even though we had a slight drop-off in this past fiscal year, and we're seeing high profit models, SUVs, crossovers, full-size pickup trucks that are providing profitability at levels that we have not seen in some time. On the other side, there's a strong need for technology and powertrains and electrification combined with autonomous connected vehicle technology that are really stretching the limits in terms of talent and dollars.

Really, in order to provide the vast array of technologies required to meet the global standards because our automakers are all global, for CO2, et cetera, the portfolios that are required are very diverse and challenging. To remain competitive, the automakers must comply with all the regulatory environments including those that are most aggressive globally.

We've seen nearly all the automakers announcing electrification goals. It runs the gamut from start/stop technologies all the way through full electrification.

The dichotomy that exists today is, and we talked about this a little bit before the panel began, is we can't make the customers buy what they don't want. And our research indicates, today, that the internal combustion engine will still comprise about 90 percent of global vehicle volume by 2030 and over 95 percent for North America in 2025.

The good news is that battery technology is continuing to get better quickly driving costs down and improving the range. It's difficult, really, to predict, but if this continues the proliferation throughout the marketplace could increase significantly.

Throughout the U.S. the percentage of electric vehicles varies greatly depending on the infrastructure and the initiatives. And on a global level, we see a very similar trend. The main drawback that we hear from customers about purchasing an electric vehicle is range and the lacking of charging infrastructure going along with that as well as purchase cost. Although, if we look at the pure economics, the total cost of ownership, including serviceability and refueling that product, it will break even in a certain amount of time. So a lot has to do with informing the customers of the true facts of EV ownership.

We can solve a lot of these issues through technology, supply/demand and clarity on the charging infrastructure which also includes the hydrogen infrastructure.

I'd be remiss if I did not mention that the electric used to supply the EV power must be from a renewable source. EVs utilizing coal-powered electricity have a greater carbon footprint, end-to-end, than a very efficient internal combustion engine.

My last point is really about technology leadership and talent. This is a strong passion of mine. And really, if the U.S. wants to continue leadership in the electrification race, we need to be a hub for this kind of development in the automotive industry.

The countries who create the high standards will drive the innovation and grow the talent, and we would really like for that to be here in the U.S.

Thank you for your time.

[The prepared statement of Ms. Bailo follows:]

Statement of Carla Bailo
President and CEO
Center for Automotive Research, Ann Arbor Michigan
Before The
Senate Committee on Energy and Natural Resources
On The Road to Tomorrow: Energy Innovation in Automotive Technologies
January 25, 2018

I would like to thank Chairman Murkowski, Ranking Member Cantwell, and the Members of the Committee for this opportunity to address the committee regarding the opportunities and challenges before the U.S. automotive industry related to energy-relevant vehicle technologies. I am Carla Bailo, the President, and CEO of the Center for Automotive Research (CAR). CAR is an independent, non-profit 501(c)3 organization based in Ann Arbor, Michigan that produces research and fosters multi-stakeholder forums on critical issues facing the automotive industry and its impact on the U.S. economy and society.

We are in a critical period for the U.S. automotive industry. U.S. light vehicle sales grew to a record 17.5 million units in 2016 and closed 2017 slightly below that at 17.2 million units.[1] Sales are plateauing at a very high level and include a rich mix of pickup trucks, SUVs, and CUVs that are highly profitable. In fact, these popular vehicles dominated the main show floor at the North American International Auto Show in Detroit last week. Despite all the shiny new metal on the show floor, everyone was talking about connected and autonomous technologies, new mobility service models, and advanced powertrain solutions. These are the technologies in which automakers and suppliers are investing billions of dollars to secure their competitive position in the future of our industry.

Investing in advanced technologies is not only costly but also brings considerable risk. In all things related to automotive technology, consumer acceptance is critical. Regulatory technology mandates can mitigate the risks, but the auto industry operates in many different regulatory environments and must meet many different sets of targets. Even while the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) are completing work on the Mid-Term Evaluation, automakers and suppliers are aggressively pursuing electrification to meet requirements and CO_2 emissions reduction targets set across Europe, Asia, and South America. In North America, Canada and Mexico have signed agreements to align their regulatory frameworks with that of the California Air Resources Board.[2] All of this means that automakers and suppliers—nearly all of which are large multi-national companies—must keep up with the most aggressive regulatory environments if they wish to remain globally competitive.

When you do not know exactly where you are going, it helps to have a map—and many associations, academics, consultants, and research organizations have produced advanced technology roadmaps that can help guide the automotive industry and key stakeholders to what the future may hold. New outlooks and forecasts come across my desk nearly every week. With support from the Government of Canada, CAR recently undertook an effort to make sense of the future of automotive technologies. Our researchers reviewed over 100 automotive technology roadmaps, synthesized the documents into one

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[1] IHS|Markit

[2] Memorandum of Understanding to Enhance Cooperation on Climate Change and the Environment Between the State of California of the United States of America and the Ministry of Environment and Natural Resources and the National Forestry Commission of the United Mexican States, 28 July 2014, https://www.gov.ca.gov/docs/7.28_Climate_MOU_Eng.pdf

document, and validated the resulting roadmap with key automaker and supplier leaders. The result is CAR's 2017 *Technology Roadmaps: Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light Duty Vehicle Propulsion* summary report that I would like to submit as an addendum to my statement here today.[3] While there are synergies between each of these technology areas (e.g., electrification and connected and automated vehicle technologies or lightweighting and advanced powertrains), I will provide a brief overview of CAR's light-duty vehicle propulsion technology outlook as this area is most relevant to this committee.

While CAR researchers found general agreement on the direction of changes in the area of light-duty vehicle propulsion, there is tremendous uncertainty regarding the timeframe of specific changes, and each manufacturer is following its unique technology pathway. Automakers need to balance the needs of their customers with the corporation's need to comply with a wide array of government regulations. Suppliers that have developed new powertrain technologies are eager to have stricter fuel economy and emissions targets that create demand for their products.

Automakers are investing heavily and making significant commitments to advanced propulsion and vehicle electrification[4]:

- BMW plans to offer 12 fully-electric vehicles by 2025.
- Daimler plans to sell 100,000 electrified vehicles by 2020.
- FCA is planning to offer half of all Maseratis as EVs by 2022.
- Ford is spending $11B and plans to offer 40 electrified vehicles by 2022.
- GM will offer 20 all-electric models by 2023.
- Honda announced two electric vehicles in 2017 and plans to have two-thirds of its lineup electrified by 2030.
- Mercedes is planning an electrified version of every model it sells.
- Renault-Nissan has sold nearly 500,000 Leafs—the highest volume of EVs of any automaker—and expects to have zero-emission vehicles make up 20 percent of its sales by 2020.
- Tesla is planning to build 500,000 all-electric Model 3s annually by 2020—which would be six times the total number of EVs sold in 2016.
- Toyota plans to offer all zero-emission vehicles by 2050.
- VW is investing $11.8B to roll-out 80 new electric models across all of its brands by 2025.
- Volvo announced it would only launch electrified vehicles after 2019.

From both a cost- and performance-perspective the internal combustion engine (ICE) remains a challenging target to beat. There is a proliferation of technologies that can boost ICE efficiencies—

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[3] Smith, Brett, Adela Spulber, Shashank Modi, and Terni Fiorelli. (2017). Technology Roadmaps: Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light-Duty Vehicle Propulsion. Center for Automotive Research, Ann Arbor, MI. http://www.cargroup.org/wp-content/uploads/2018/01/Technology_Roadmap_Combined_23JAN18.pdf

[4] Reuters Staff. (2017, November 17). "Factbox: Automakers get serious about electric cars." Reuters. https://www.reuters.com/article/us-autos-electric-factbox/factbox-automakers-get-serious-about-electric-cars-idUSKBN1DH28A; Edward, T., & Preisinger, I. (2017, September 7). "BMW gears up to mass produce electric cars by 2020." Reuters. https://www.reuters.com/article/us-autoshow-frankfurt/bmw-gears-up-to-mass-produce-electric-cars-by-2020-idUSKCN1BI1LM; Carey, N., & White, J. (2018, January 14). "Ford plans $11 billion investment, 40 electrified vehicles by 2022." Reuters. https://www.reuters.com/article/us-autoshow-detroit-ford-motor/ford-plans-11-billion-investment-40-electrified-vehicles-by-2022-idUSKBN1F30YZ; Tajitsu, N. (2017, June 8). "Honda says its self-driving cars will hit the streets in 2025 — but that could be too late." Business Insider. https://www.businessinsider.com/r-honda-to-focus-on-self-driving-cars-robotics-evs-through-2030-2017-6 ; Welch, D. (2017, October 2). "GM Plans 20 All-Electric Models by 2023." Bloomberg. https://www.bloomberg.com/news/articles/2017-10-02/gm-pledges-electric-future-with-20-all-electric-models-by-2023

including gasoline direct injection that is expected to exceed 75 percent market penetration by 2025, mechanical turbocharging that could be on more than three of every five vehicles sold by 2025, and 12-volt stop-start that could be on half of the vehicles sold by 2025.[5] Fewer vehicles will have Atkinson cycle engines or engines that use variable compression ratios or homogeneous charge compression ignitions—all essential technologies that improve the efficiency of the ICE. Globally, diesel engines will remain part of the mix, but these engines will face headwinds from increasingly stringent NOx and particulate regulations, as well as consumer acceptance in the wake of several widely-publicized testing scandals.

Countries including China, France, Germany, Great Britain, India, Norway have announced plans to phase out gasoline and diesel-powered engines. Also, Austria, Denmark, Ireland, Japan, the Netherlands, Portugal, Korea and Spain have set government targets for EV sales.[6] Despite these headlines that countries and companies are moving away from conventional engines, ICEs remain the dominant propulsion globally and in North America. The CAR roadmap shows ICE engines will still be in over 90 percent of all new light vehicles sold globally in 2030 and over 95 percent of new light vehicles sold in North American by 2025. In roughly 20 percent of those vehicles with ICE, the engine will be part of a hybrid system—be it a plug-in hybrid electric (PHEV), hybrid electric (HEV), or mild hybrid (MHEV or 48-volt systems). The point is, electrification does not always mean full battery-electric (BEV).[7]

HEVs have been in the market since the mid-1990s, but in 2017 electrified vehicles of any type have only achieved a 3.3 percent market share.[8] The cost of having two propulsion systems hinders HEV cost-competitiveness. BEVs face an even higher cost-competitiveness hurdle, as well as lagging market acceptance due to performance (range, recharge time). Fuel cell vehicles (FCEVs) offer another alternative that several manufacturers are pursuing, but these vehicles have cost, hydrogen production, distribution infrastructure, and onboard storage challenges.

Battery costs are rapidly declining, and performance is increasing. The current cost of lithium-ion battery packs is estimated to be approximately $275 per kilowatt-hour (kWh).[9] Lithium-ion battery development continues at a rapid pace and is expected to achieve even better performance and lower costs. Beyond lithium-ion, there are battery chemistries such as solid-state lithium metal and lithium air that could reach theoretical densities much greater than current lithium-ion technology. Battery technology developments are difficult to forecast, but could drastically change the BEV equation, and must be carefully watched.

As of today, there are vast differences between regional generation emission of CO_2 in the United States. For example, a PHEV or BEV charged from the grid in Alaska, California, and Washington emits far less CO_2 than one charged using the grid mix that exists in states like Colorado, Michigan, West Virgina.[10] The United States must continue to develop and implement low CO_2 and renewable energy electricity

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[5] Smith, Spulber, Modi, Fiorelli, *op.cit.*

[6] Petroff, A. (2017, September 11). "These countries want to ban gas and diesel cars." CNN Money. https://money.cnn.com/2017/09/11/autos/countries-banning-diesel-gas-cars/index.html

[7] Smith, Spulber, Modi, Fiorelli, *op.cit.*

[8] Center for Automotive Research analysis of data from Ward's Automotive Reports and HybridCars.com

[9] Smith, Brett, Adela Spulber, Shashank Modi, and Terni Fiorelli. (2017). Technology Roadmaps: Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light-Duty Vehicle Propulsion. Center for Automotive Research, Ann Arbor, MI. http://www.cargroup.org/wp-content/uploads/2018/01/Technology_Roadmap_Combined_23JAN18.pdf

[10] Sivak, Michael and Brandon Schoettle. (2017). Fuel Sources for Electricity in the Individual Countries of the World and the Consequent Emissions from Driving Electric Vehicles. University of Michigan Transportation Research Institute, Ann Arbor, MI. http://www.umich.edu/~umtriswt/PDF/SWT-2017-18_Abstract_English.pdf

generation capacity to assure the PHEVs and BEVs reduce, and not merely shift, the country's carbon footprint.

Widespread implementation of PHEVs and BEVs has implications for electricity generation investment. Electric utilities have shown the ability to encourage off-peak vehicle charging to smooth daily and seasonal peaks and valleys in demand. These demand shift strategies can lead to higher utilization rates for the established generation portfolio, and even lessen future investment in new generation capacity.

While EV range and cost are critical, the robustness and reliability of the electrical grid is also a factor for PHEV and BEV penetration, especially for home charging. One day without electrical power is challenging for any household, but even more so if they rely on electricity to power their vehicle. Early experiences indicate there has been relatively little initial impact on current neighborhood grid infrastructure in areas where PHEVs and BEVs have clustered.[11] However, as these vehicles become more prevalent, there is need to monitor both the local and regional grid capacities and capabilities.

Consumers are unlikely to buy a vehicle without a developed refueling infrastructure, and the private sector is not likely to build the infrastructure before there is a critical mass of EVs in-use. VW's diesel settlement may provide some funding for infrastructure development. Investment in grid balancing strategies and the development of microgrids can help reduce the risk of overburdening the U.S. electrical grid. The United States should consider a range of solutions to this challenge: direct public development, public-private partnerships, bonds, and zoning/building code mandates for new construction (e.g., new houses and multi-use developments must have 240V circuits available).

The automotive world is inching ever closer to an electrification tipping point, and automakers and suppliers will develop these technologies for—and in—those countries and markets that provide both the carrot (infrastructure and incentives) and the stick (regulatory mandates). The location of automotive R&D investment and technology manufacturing could shift outside of North America, which would have implications not only for the nation's engineering and skilled talent development institutions but also for the overall technological leadership of the United States.

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[11] Allison, Avi and Melissa Whited. (2017). Electric Vehicles Are Not Crashing the Grid: Lessons from California. Natural Resources Defense Council, Synapse Energy Economics, Cambridge, MA. http://www.synapse-energy.com/sites/default/files/EVs-Not-Crashing-Grid-17-025_0.pdf

Appendix to Statement of Carla Bailo

President and CEO

Center for Automotive Research, Ann Arbor Michigan

Before The

Senate Committee on Energy and Natural Resources

On The Road to Tomorrow: Energy Innovation in Automotive Technologies

January 25, 2018

June
2017

Technology Roadmaps:

Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light Duty Vehicle Propulsion

CAR
CENTER FOR AUTOMOTIVE RESEARCH

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The Center for Automotive Research, a nonprofit automotive research organization, has performed detailed studies of the contribution of the automotive industry and its value chain in the U.S. economy for more than 35 years.

CAR's mission is to conduct independent research and analysis to educate, inform and advise stakeholders, policy makers, and the general public on critical issues facing the automotive industry, and the industry's impact on the U.S. economy and society.

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Introduction

Major technological advances to both products and manufacturing processes are accelerating innovation throughout the automotive industry. To capture the scope of these technologies, the Center for Automotive Research (CAR) was called upon by Innovation, Science and Economic Development Canada (ISED) to develop and validate a technology roadmap for the automotive sector. This roadmap provides a broad understanding of technology trends throughout the industry from current year to beyond 2030.

CAR identified and reviewed over a hundred existing roadmaps published by consulting firms, independent think tanks, trade journals, and CAR's own research. CAR also conducted literature searches and reviewed announcements at key industry events to identify any emerging technologies that were not covered in existing roadmaps. Based on the information gathered, CAR synthesized the research and existing roadmaps into three groups: Intelligent Mobility Technology; Materials and Manufacturing Processes; and Light Duty Vehicle Propulsion. Once these synthesized technology roadmaps were developed, CAR convened a roundtable of 25 experts from each of the technology groups to validate the findings.

This whitepaper synthesizes the results from the technology roadmap project conducted for ISED and adds further interpretation of the challenges and concerns related to the projected technology and manufacturing trends.

Intelligent Mobility Technologies

Advances in connectivity, automation, and new mobility services are powerful agents of change affecting the automotive industry, the larger transportation sector, and beyond. To better assess the potential and likely directions and magnitude of change, the Center for Automotive Research (CAR) developed a "technology roadmap" that reflects input from a wide array of industry experts. This roadmap is the result of CAR's in-house research, completed by a critical analysis of reports from leading consulting firms, investment banks, and universities and validated by select industry leaders and stakeholders. While there is an overall consensus on the direction and nature of changes through which the industry is going, a great deal of uncertainty remains in predicting specific timeframes.

The World We Know

Vehicle automation, connectivity, and mobility encompass trends in technology and business models that have been in motion for decades; however, in the last five to 10 years, the transportation sector has witnessed an acceleration in technology development and strategy decisions. In this period, automated vehicle systems that influence the lateral or longitudinal (or both) motion of a vehicle, including applications such as automated park assist, adaptive cruise control, and automated emergency braking, have become available on an increasing number of new vehicles. Eventually, this trend is expected to culminate in fully automated (i.e., SAE Level 5[1]) vehicles. In a parallel evolutionary track, numerous advanced driver assistance systems (ADAS) that warn, aid, and assist drivers were introduced

[1] SAE International, a global association of engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries, has defined six levels of levels of automation for on-road motor vehicles that are detailed in the J3016 standard. Level 5, Full Automation, is defined as "the full-time performance by an Automated Driving System of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver."

in 2000-2010 on higher-end vehicles. ADAS serve to automate specific vehicle systems for improved safety and better driving, though a human driver remains in command.

Vehicle connectivity covers a wide variety of functional systems, from telematics and infotainment to vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications focused on cooperative, active safety. In recent years, great progress has been made developing and testing V2V and V2I equipment and applications, and regulatory rule-making has us on the brink of a V2V mandate.

New mobility services (NMS) provide entirely new business models or reshape existing models with technology, such as ridehailing linked to for-hire vehicles or ridesharing linked with carpooling. Generally, NMS are enabled by emerging technology platforms and wireless connectivity that allow for more convenient, efficient, and flexible travel. Their beginnings can be placed roughly in the 1990s. Real growth occurred in the 2010s when the number of different concepts (or business models) and companies increased substantially; NMS are especially appealing in dense urban areas.

Drivers of Change, Technological and Otherwise

Intelligent mobility technologies are enabled by several recent technology innovations, including digital cellular networks, powerful computer processors, various sensors (including GPS), data fusion, and machine learning. Automotive manufacturers are always on the look-out for innovative technologies to differentiate their products. Intelligent mobility technologies will be increasingly important in the marketing of new vehicles, as well as nurturing relationships with consumers. Automotive manufacturers and tech companies big and small have engaged in a race towards the development of these technologies, and automakers are now competing with new players in the emerging mobility industry to remain relevant and innovative. Automakers are particularly interested in connectivity, automation, and ADAS, because they offer car buyers new solutions for safety and convenience, and such features can increase the profit margin of vehicle sales and offer new revenue streams.

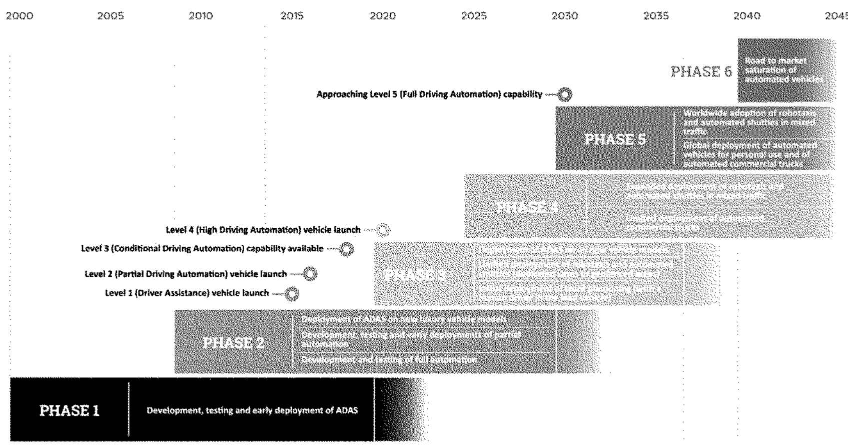
Consumers' desire for seamless, reliable, and convenient transportation has been crucial for the rapid growth of ridehailing, but this same desire also underpins new mobility services such as carsharing, ridesharing, and microtransit. Ridehailing and carsharing companies are disrupting the transportation sector by providing more ways to have access to vehicles without ownership. Automakers are hedging their bets against these disruptors by testing new business models themselves, seeking to go beyond the old models of selling cars to individuals and developing new mobility services in-house.

The World on the Horizon

North American, European, Israeli, and Japanese companies are leading the development of automated vehicles, but Chinese companies are accelerating their efforts and quickly catching up. Furthermore, tech companies and startups are disrupting traditional supply chains by developing software, chipsets, and sensors for automated vehicles. In turn, many automakers are developing driving automation technologies in-house to assure their companies remain relevant and profitable in a future in which software, data, and connectivity are more valuable than the mechanical elements of a vehicle.

ADAS features will be increasingly common in the coming decades (see Figures 1 and 2). Some of those features likely will be mandated or included in safety-rating systems, such as the New Car Assessment Program (NCAP). Fully automated vehicles likely will be first launched as low-speed automated shuttles; pilot tests for automated shuttles are already in progress. Many experts predict that driverless taxi services will be available in select urban areas as soon as 2020, while automated vehicles for personal use will be available in 2030 or later.

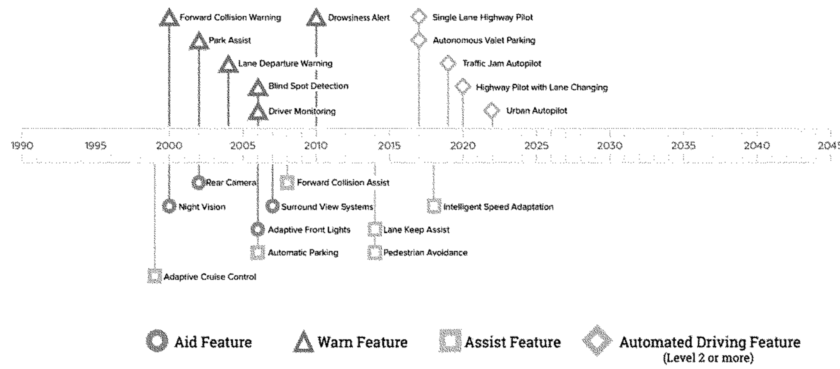
Figure 1: Roadmap for Advanced Driver Assistance Systems and Vehicle Automation Technologies



Source: CAR Research

Many automotive manufacturers are developing vehicles with automated driving systems, and several have pledged to introduce conditional automation (SAE J3016 Level 3), such as automated highway operation, within the next year or two. Other automakers indicate that such conditionally-automated systems are too complicated from a human-factors perspective and intend to skip to higher levels of automation that do not require a human driver at all. There is no consensus in terms of strategy among automakers and suppliers on this point. Finally, it is too soon to predict whether it will be possible to produce fully automated vehicles (SAE Level 5), capable of operating anywhere and in all situations.

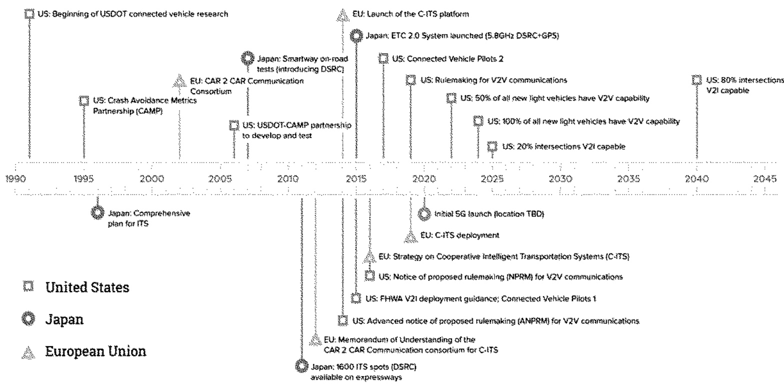
Figure 2: Timeline for Launches of Advanced Driver Assistance Systems and Automated Driving Features



Source: CAR Research, BCG

Clearly, connectivity will play an increasing role in the auto and mobility sectors in the coming years (see Figure 3), but it is less clear what specific communication technologies will be most pertinent and prevalent. The United States likely will have a leading role in the large-scale deployment of V2V and V2I safety applications if the mandate for V2V-capability on light-duty vehicles proposed in December 2016 is issued. Automotive and tech companies, as well as governments, have pledged to make substantial efforts for the deployment of V2V and V2I applications based on Dedicated Short-Range Communication (DSRC) in the 2020s, both on the infrastructure and vehicle side; however, the exact timeline is highly dependent on the priorities of the new U.S. administration, which currently has not appointed a new administrator to lead the National Highway Traffic Safety Administration (NHTSA). European countries and Japan also have expressed commitments to create the legal framework needed, invest in V2I infrastructure, and support the development of V2V applications. Progress will not be limited to DSRC-based connectivity. The launches of first 5G mobile networks, the next telecommunications standards beyond the current 4G LTE standards, will occur around 2020, and 5G is expected to enable a variety of commercial- and convenience-oriented applications. Whether or not 5G can support cooperative, active safety, however remains an open question.

Figure 3: Timeline for Vehicle Connectivity Technologies

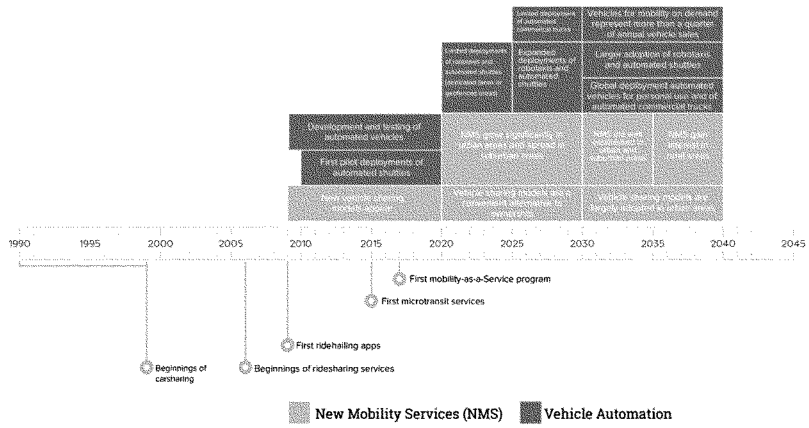


Note: The exact year when all new U.S. light vehicles will have V2V capability is dependent on having a V2V mandate in FMVSS and on the specific phase-in period required.

Source: CAR Research

New mobility services are expected to diversify and grow significantly in cities and to spread beyond urban areas in the 2020s and 2030s, benefitting from the convergence with vehicle automation (see Figure 4). In the 2020s, sharing models will become a convenient alternative to vehicle ownership for an increasing share of the world's population. By 2030, ridehailing/taxi rides will represent almost a quarter of miles traveled worldwide (see Figure 5). After 2030, vehicle-sharing models will be largely adopted in cities and viable NMS models will be introduced in rural areas.

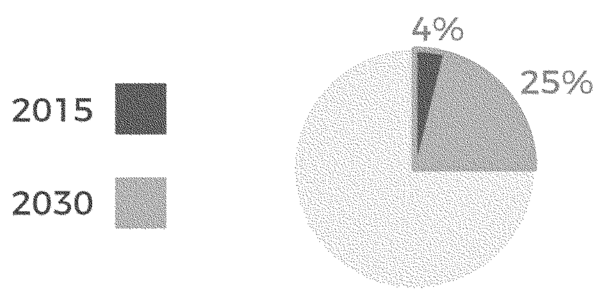
Figure 4: Roadmap for New Mobility Services and Vehicle Automation Technologies



Source: CAR Research

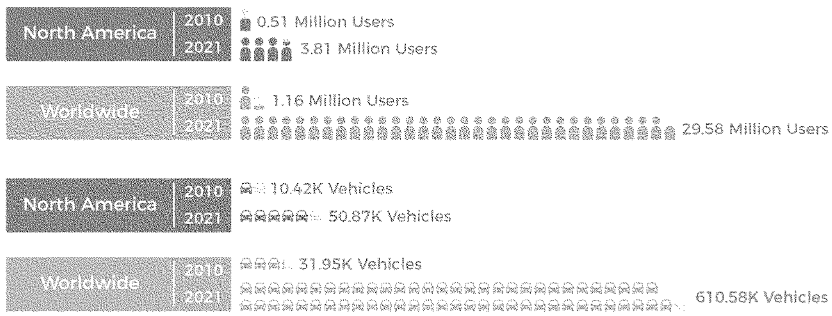
Figure 5: Growth Projections for Carsharing and Ridehailing

Growth of ridehailing/taxi services in the United States and worldwide (percent of annual vehicle miles traveled that will be made by ridehailing services, taxis, and robotaxis)



Source: Morgan Stanley

Growth of Carsharing Programs



Source: CAR Research

Enablers and Threats

These forecasts and timelines (see Figure 6 for an overall view) could well be affected by related developments. For example, faster development of key enabling technologies (such as in the area of artificial intelligence) could hasten the market availability of full automaton, and lack of consumer acceptance could delay it.

Enablers

The range of potential enablers is broad and dependent on the precise technology. The deployment of automated vehicles is dependent on the improvement of key enabling technologies, such as human-machine interface, driver monitoring, object recognition, artificial intelligence, sensors (miniaturization and cost reduction), cloud computing, cybersecurity, and 3D high definition maps. Substantial public and private investment in V2I and 5G infrastructure would facilitate the rollout of connectivity applications. The growth of new mobility services will be boosted with increased development of dense and walkable urban areas, where these services are most successful. The use of NMS will also increase with integration of different transportation modes through mobility-as-a-service systems and the convergence with vehicle automation and connectivity.

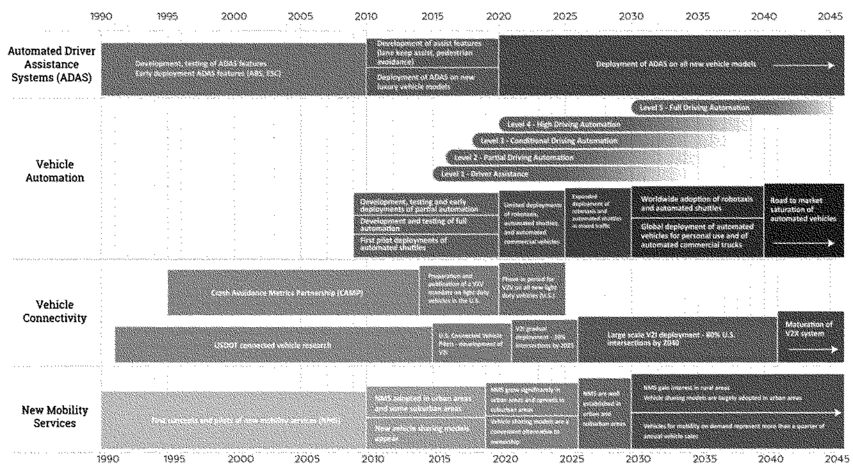
Threats

Threats and potential delays also can come from several different directions, and ultimately sales of connected and automated vehicles, as well as the use of new mobility services, will depend on consumer acceptance and this could change dramatically in the aftermath of a major connected and automated vehicle crash, recall, or cybersecurity attack. Cost is an important concern; if these vehicles remain too expensive for the average consumer, then sales will suffer. For new mobility services, the main limitation is a lack of appeal beyond dense urban cores. Insufficient public investment could delay deployment of V2I infrastructure for decades, and a lack of rigorous communication standards will limit interoperability. Given current travel behavior patterns related to length and duration of work commute trips, as well as current pricing schemes for NMS, these services remain an expensive option compared to public transit. Nonetheless, even at current prices, some NMS such as ridehailing services often operate at a loss, an unsustainable strategy in the long term if the service is completely dependent on market forces.

Monitoring the Future

Industry stakeholders are well advised to closely monitor how these enablers and threats are evolving. This includes attention to technical breakthroughs (e.g., progress on solid-state Lidar, a sensing method that measures distance to a target by illuminating that target with a laser light), regulatory and legislative efforts in North America and beyond, mergers and acquisitions, and more. Specifically, stakeholders should monitor future legislation on automated vehicles and data protection in countries across the world, as well as mandates, like the proposed one for V2V on all light vehicles sold in the United States. Legislation and regulation could hinder the development of connected and automated vehicle technology and new mobility services, depending on national and local policy positions. The latter likely will not be favorable if the observed safety or traffic congestion benefits will be lower than expected.

Figure 6: Global General Timeline



Source: CAR Research

Materials and Manufacturing Technologies

New materials with better performance characteristics are introduced into vehicles for various reasons, but primarily for improving crashworthiness, noise and vibration, overall cost, and fuel economy. The regulatory pressure to improve fuel economy is expected to accelerate the evolutionary rate of the introduction of lightweight materials into the vehicles.

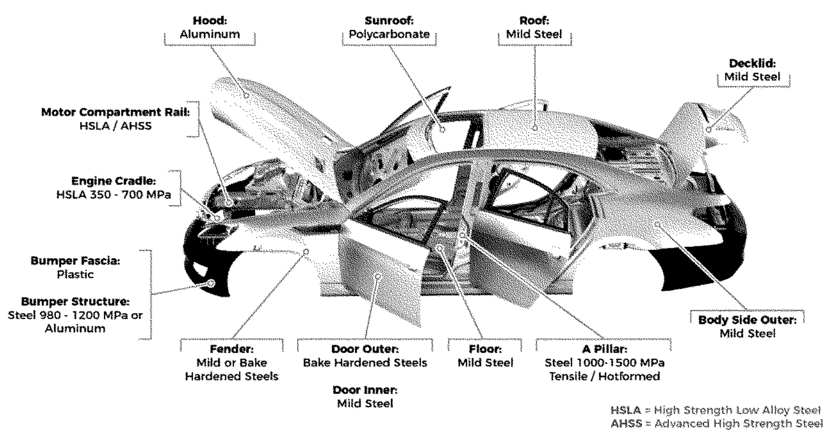
In order to understand the current material technology in the vehicles and future material trends, this whitepaper presents material and manufacturing technology roadmaps identified by extensive cross-company research and inputs from various industry experts along with primary research from the Center for Automotive Research (CAR) of survey data from nine automakers. This survey data includes 42 model year 2015/2016 vehicles, covering four vehicle segments (cars, CUV, SUV, light trucks). These 42 models represent approximately 50 percent of the U.S. light-duty vehicle sales. The survey requested detailed data on current materials used, forming technology, and joining technology on 20 components from every vehicle surveyed. Automaker opinions on material technology usage in the selected components for 5, 10 and 15 percent vehicle mass reduction were also queried. CAR published the results of this study in 2016.[2] To validate the results, material experts from different companies and organizations with more than 150 years of combined work experience were invited for a half-day roundtable discussion.

The World We Know

Current Industry

Product engineers try to work on the philosophy of the right material at the right place. Figure 7, shows the current most commonly used materials for major structure components. Theoretically, a material can be used to make vehicle parts if it is commercially available, can be manufactured with an available technology, and meets the performance requirements.

Figure 7: Materials Used Most Commonly for Major Vehicle Structure Components in the Current Fleet

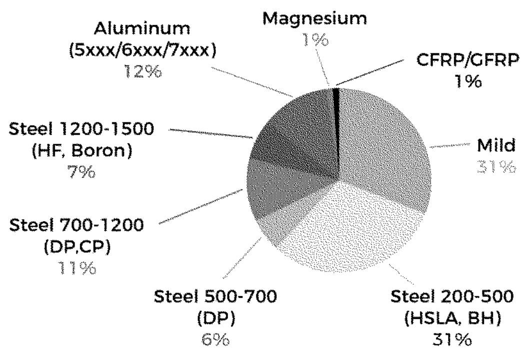


Source: CAR Research

However, designers cannot use every available material because they are constrained by practical day-to-day difficulties such as supply-chain, infrastructure, cost, reparability, environment, etc. Figure 8 shows the current material mix in 14 major vehicle components from the body structure and closures.

[2] Baron, J., and Modi, S. Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles. September, 2016,

Figure 8: Current Vehicle Material Mix Based Upon 14 Major Components from 42 Mass Produced Vehicles



Components:

A Pillar
B Pillar
Front Bumper Strucuture
Roof Panel
Engine Cradle
IP Beam
Floor
Lower Control Arm□Streering
Knuckle
Fender
Front Door Inner
Front Door Outer
Hood
Decklid

Source: CAR Research

Vehicles today are predominantly steel structures with some use of aluminum. The grades of steel range from mild (270 Mega Pascal (Mpa) tensile strength) to hot-formed boron (1500 MPa plus tensile strength). Magnesium and polymer composites are used in some components mostly on higher end vehicles.

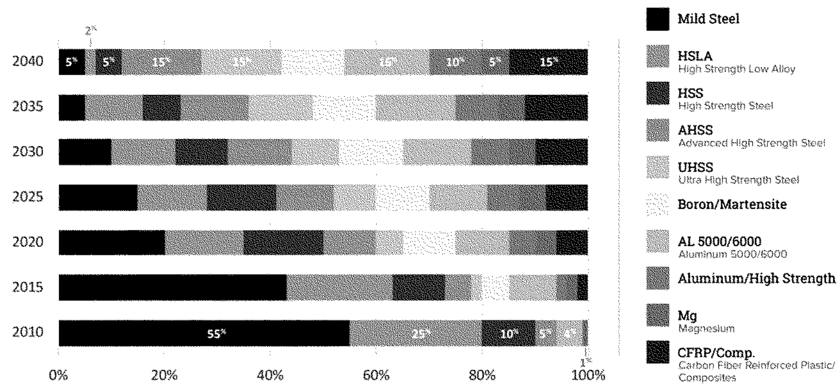
The predominant manufacturing technology today is cold stamping, but higher strength steels are difficult to cold form. The use of hot stamping is increasing as the heat increases the ductility of the material which helps in forming complex shapes without cracking. For plastics and carbon fiber composite parts, injection molding and resin transfer molding are currently the most common production technologies respectively.

The World on the Horizon

The regulatory pressure to reduce carbon emissions and the race to improve performance are drivers for change to the material mix in the vehicles. Automakers are looking for materials with higher strength-to-weight ratio which reduces weight, while improving performance. CAR research indicates the U.S. fleet will achieve a five percent curb weight reduction by 2025 through greater use of aluminum predominantly in the closures and body-structure. Interiors are also a recent focus for lightweighting as it is considered dead weight.

Figure 9 shows the change in material mix in the U.S. fleet between 2010-2040. Experts agree that no single material wins in the race to lightweighting. A weight and performance optimized vehicle will have a mixed-material body structure. The industry is already experiencing this shift in recently introduced vehicles which use materials customized for each area of the car to simultaneously advance driving dynamics, fuel economy, and cabin quietness.

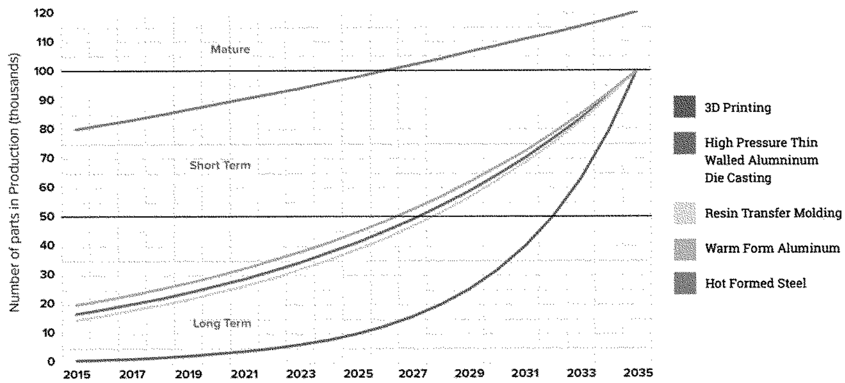
Figure 9: Material Distribution in the U.S. Fleet (Body-in-White Plus Closures), 2010 to 2040



Source: CAR Research

New manufacturing technologies are also advancing to achieve the speed and cost effectiveness required for mass production. Hot forming of steels is already used in high production parts and will reach maturity by 2025 as the need for ultra-high strength steels increases (see Figure 10). Maturity of a technology is a subjective term which depends on the vehicle program. In broad terms, a mature technology can be used in mass-produced vehicles (volume over 100,000 units a year), has multiple product applications, and is available from multiple suppliers with a global supply capability. Additive manufacturing, also called 3D printing, is a revolutionary technology with the potential to change the tool and die business but is not yet suited for mass production in terms of cost or cycle time.

Figure 10: Emerging Manufacturing Processes and Enablers for Growth, 2015 to 2035

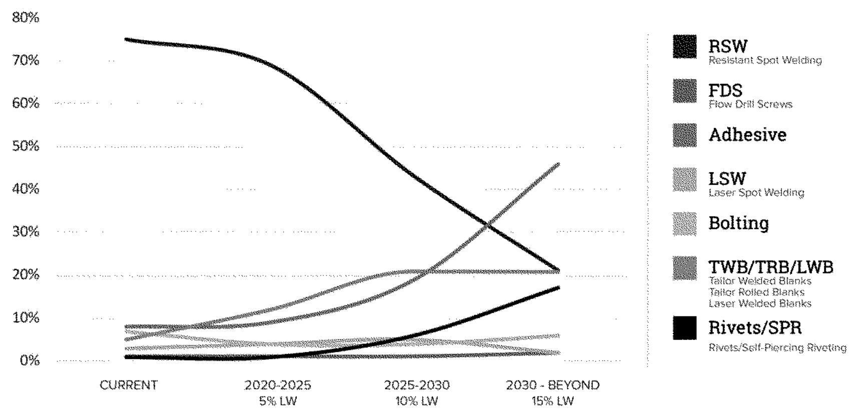


Enablers for Growth	3D Printing	High Pressure Thin Walled Aluminum Die Casting	Resin Transfer Molding	Warm Form Aluminum	Hot Formed Steel
	Reduce Cycle Time	More R&D Needed	Reduce Cycle Time	More R&D Needed	Increase Equipment Capacity
	Reduce Equipment Cost	Increase Equipment Capacity	Standardization of Operating Barometers	Increase Equipment Capacity	Reduce Cycle Time
			Develop Supply Chain for CFRP		

Source: NHTSA; CAR Research

With new materials come new challenges. Joining dissimilar materials is not easy, and is sometimes impossible to do using traditional resistance spot welding due to differences in melting point. Joining technologies–such as adhesives and advanced fasteners–will play an important role in achieving the optimized mixed-material architecture, since they have the ability to join any combination of dissimilar materials (Figure 11).

Figure 11: Trends in Joining Processes, Current Year to Beyond 2030



Note: LW= Lightweighting
Source: CAR Research, Lucintel

Enablers and Threats

Enablers

Heavier vehicles require more power to move the vehicle. To produce more power, engines burn more fuel. Thus, a lighter vehicle derives better fuel economy from the need for smaller propulsion packages. Lower fuel consumption also corresponds to lower exhaust emissions. Across the globe, governments are imposing regulations to control vehicle emissions to address climate change. This is the primary driver for increased usage of lightweight materials. To stay competitive, automakers add content to the vehicles every model year – such as improved infotainment features, driver assist sensors, increased leg and cargo space, etc. CAR's research indicates that by 2025, around five percent of the curb weight of the U.S. fleet will be added to every vehicle for safety and performance improvements (Figure 12). For example, an additional 200 to 300 pounds per vehicle will be added for automated driving features.

Figure 12: Drivers for Material Technology Change

- **Fuel Economy**
- **Autonomous Vehicles**
- **Performance Improvement**
- **Vehicle Emission Reduction**
- **Electric Powertrain**
- **Added Content**

Source: CAR Research

To maintain or improve performance and fuel economy, the weight added for the additional consumer and safety content needs to be offset elsewhere. Also, with increasing trends towards electrified powertrain, the weight differential between an internal combustion engine (ICE) and battery packages affects vehicle weight targets. In fact, battery electric vehicles (BEV) need to be much lighter than their ICE counterparts to get adequate driving range. The regulatory push towards BEVs coupled with rising customer expectations will increase the pace of introduction of lightweight materials into the vehicles.

Threats

Working with multiple materials in a manufacturing environment is not an easy task. Apart from joining, galvanic corrosion and thermal management are two major issues engineers face while designing vehicles with mixed-material body structures. While engineers worry more about the technical challenges, purchasing and manufacturing executives are more concerned about the cost of new materials and potential supply-chain risks. Newer manufacturing technologies such as additive manufacturing, resin transfer molding, thin walled die casting, etc. are not yet mature processes. These technologies have longer cycle times, as well as quality issues that need to be resolved for use in mass production across-the-board. Figure 13 lists major challenges the auto-industry is facing with new materials and mixed-material assemblies.

Figure 13: Challenges to Address for Faster Introduction of New Materials

Mixed-Material Joining	Difference in melting point between materials
Corrosion	Relative placement in the galvanic series and exposure to moisture
Thermal Expansion	Differences in coefficient of linear expansion (CLTE) cause materials to expand differently in the paint oven
Cycle Time	Automotive industry needs process cycle times to match line speed which is approximately one unit a minute for mass production
Cost	Cost of newer materials like carbon fiber is very high compared to steels. Carbon fiber for automotive costs $10 to $12 a pound, compared to less than a dollar for steel.
Supply Chain	Automakers are shifting towards global platforms. The availability of material across the world from multiple suppliers is critical.
End-of-life Recycling	Most materials used in automobiles should be easily recyclable for environmental reasons and to meet regulatory requirements
Repair	A hard to repair vehicle will have increased insurance cost and in turn will affect sales
Talent Gap	Engineers and plant workers need to be retrained to work with new materials and processes

Source: CAR Research

Monitoring the Future

Automated Vehicles	3D Printing	Low Temp. Fast Cure Adhesives	Aluminum to Steel Welding	Fuel Prices	Fuel Economy Regulations	Cost of Carbon Fiber	BEV Sales

Automakers, as well as new players in the Silicon Valley, are investing in automated vehicle technology. Automated vehicles may lead to new business models, insurance structures, and new mobility models that will affect vehicle design and hence the materials mix. The National Highway Traffic Safety Administration (NHTSA) estimated that in 94 percent (±2.2 percent) of the crashes the critical reason was the driver.[3] If human drivers can be replaced by automation, many of the crashes can be prevented and traffic deaths avoided. This will give vehicle designers flexibility to downsize vehicle crash structure

[3] Singh, S. (2015, February). Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. (Traffic Safety Facts Crash Stats. Report No. DOT HS 812 115). Washington, DC: National Highway Traffic Safety Administration.

and use lighter materials. However, at this moment the future of automated vehicles and safety regulations are uncertain.

Another technology to monitor is 3D printing, which is currently used primarily for rapid production of prototype parts, but the future looks bright if the cycle time and equipment cost can be reduced. In materials, the steel industry is investing in developing high strength steels which also have high elongation. These "gen-3 steels" can limit the use of other lightweight materials due to potential cost differences, and because automakers are more invested in working with steel.

Other uncertainties include cost of polymer composites, innovations around dissimilar bonding technologies, and fuel prices which can change the roadmaps presented in this whitepaper.

Light Duty Vehicle Propulsion

Shaped by emissions and fuel economy regulations, and driven by customer expectations, light duty vehicle propulsion systems have evolved rapidly in recent years. However, many believe the industry may be on the verge of truly revolutionary change. The Center for Automotive Research (CAR) developed a roadmap to provide a better understanding of key propulsion system trends through 2030. This technology roadmap reflects a synthesis of stakeholder expectations and is the result of CAR's in-house research, completed by a critical analysis of publically available reports from leading consulting firms, research organizations, investment banks, and universities, and validated by select industry leaders and stakeholders. While there is general agreement on the direction of change, a great deal of uncertainty remains in predicting specific timeframes and technology pathways.

The World We Know

Current Industry

Manufacturers are investing in a wide range of propulsion technologies. The fact that they plan to do so for many years suggests great uncertainty. While regulations arguably drive light-duty vehicle advanced propulsion technology implementation, the success of many alternative propulsion technologies is ultimately determined by the customer. In a highly competitive market, vehicle performance and purchase price are critical. Manufacturers must balance regulatory and consumer requirements while developing and delivering solutions. Contrary to some reports, the answers are not necessarily clear.

For over a century, the dominant propulsion for light-duty vehicle has been the internal combustion engine (ICE), and in North America, the spark-ignited (gasoline) ICE. In that time, and specifically since the introduction of computer controls, the ICE has undergone a dramatic evolution. Yet, many believe the industry is on the verge of a propulsion revolution; they believe that the industry has in fact reached the electrification tipping point.

The World on the Horizon

Forecasts for future propulsion technology penetrations vary greatly. The following points are worth considering:

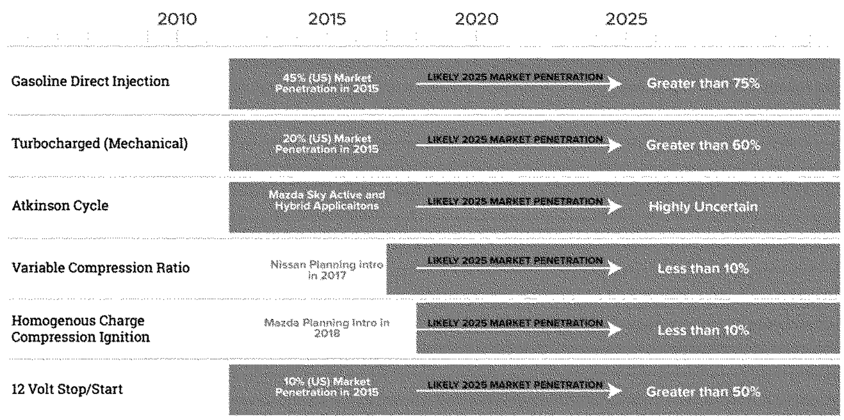
- First, the automotive industry appears to be at or near an inflection point in propulsion technology. Advanced battery development, further enabled by increasingly stringent emission regulations, has created expectations of a shift to electrification;
- Second, regional regulation differences and local market characteristics will create differing mixes of ICE, electrification and even fuel cells between regions. In many instances, more developed markets will likely be able to support more advanced propulsion technologies, while less advanced markets may take longer to accept these costlier higher-tech solutions;
- Third, at least in the mid-term (4-10 years) some governments may choose a technology solution, leading to a higher than (global) average penetration rate for that country. Conversely, other countries may choose to delay or minimize regulatory policy, thus decreasing the implementation of advanced propulsion technologies in those markets.

Globally as well as within North America, the ICE is likely to remain the most cost competitive mass market propulsion system through 2025. The automotive industry—suppliers and manufacturers—are masters of evolutionary change. There continues to be disagreement over how long ICE will be able to meet future standards. However, the industry will continue to refine, and add technology to make the spark-ignited engine even more efficient.

Gasoline direct injection and turbocharging for gasoline engines are expected to continue to increase penetration globally. These technologies have been integral to recent efficiency increases, and will continue to be tools for future gains. Atkinson cycle engines have recently been promoted by some U.S. regulators as a likely contributing technology, and is commonly used in hybrid vehicles. However, many manufacturers appear to have reservations about its effectiveness in non-hybrid applications. Variable compression ratio (VCR) and homogenous charge compression ignition (HCCI) are expected to see very early market introduction, but are likely to remain niche applications. 12-volt stop/start technology offers opportunity for reduced fuel consumption and greenhouse gas emissions, and will likely be widely implemented. Stop/start can be a relatively cost-effective means of reducing emissions, and could be key in many developing markets where cost is a significant barrier for new technology. (Figure 14).

Globally, diesel engines will continue to be part of the propulsion technology mix. However, diesel will face increasingly significant headwinds in many key markets as governments increasingly tighten NOx and particulate emissions regulation and focus on more rigorous testing. In recent years, diesel technology has lost share in Europe, and faces challenges from urban local emissions regulations in several regions

Figure 14: Internal Combustion Engine (ICE) Technologies



Source: CAR Research, USEPA/NHTSA Technical Assessment Report; Various media publications

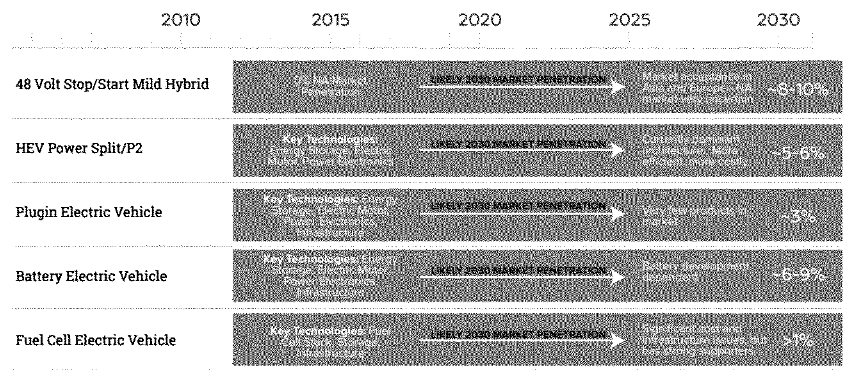
Clearly, the electrification of light-duty vehicle propulsion is underway. However, the timing for mass market acceptance and the type of electrification remains uncertain. Hybrid electric vehicles (HEV) were introduced in the mid-1990s, and have struggled to gain consumer acceptance in most markets. While offering efficiency gains, the cost of two propulsion systems will continue to hinder HEV cost competitiveness. Plugin hybrid electric vehicles (PHEV) offer opportunity for zero emissions over short distances, and this may help with some local emissions challenges. However, PHEVs still incur the cost of two propulsion systems, plus added cost for a larger battery. While viewed by some as transitional technologies, HEVs and PHEVs will be an important part of the market through at least 2030.

Currently, 48-volt hybrids (mild hybrids) have gained initial penetration in Europe and China, but not in the North American market. These 48-volt hybrids appear to present opportunity as a transitional technology for luxury vehicles and possibly for pick-up trucks in North America.

Battery electric vehicles (BEV) may present opportunity for wider market acceptance in the coming decade. Regulations, and a strong commitment to BEV by proponents are driving increased expectations for the technology. However, market acceptance lags behind these expectations. BEV performance (range, recharge time, etc.) still does not meet most consumer requirements. In time, many of these issues may be resolved—or at least greatly minimized. If costs are significantly reduced, the 200 mile-plus range BEV with fast-charge capabilities could become an important part of the advanced propulsion equation.

It is important to note that even with the current enthusiasm for BEV, many major vehicle manufacturers continue to develop fuel cell electric vehicles (FCEV) as yet another alternative. Although significant cost, hydrogen production, distribution infrastructure, and onboard storage challenges greatly limit FCEV penetration over the next decade, FCEVs do offer short-term low-volume compliance opportunities. Also, the amount of investment by key players indicates the technology may present a viable long-term solution, and a defensive strategy against battery development delays (Figure 15).

Figure 15: Electrified Vehicle Technology Pathways

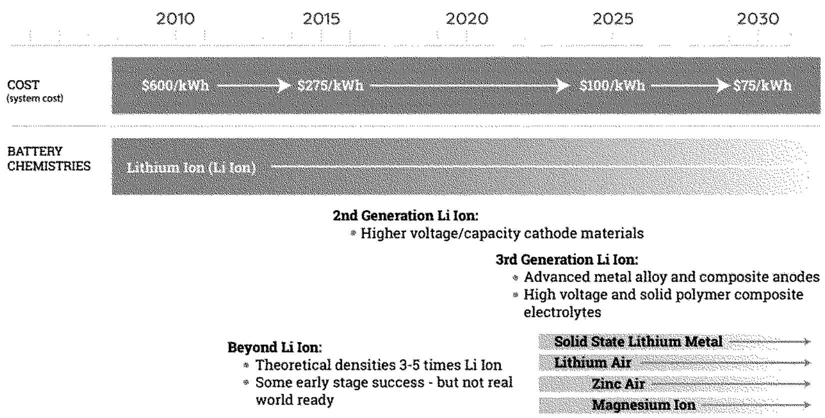


Source: CAR Research, summary of various media publications

Advanced energy storage development is the single most critical enabler for reaching the electrification tipping point. Advanced battery development continues to track at an impressive rate. Battery cost estimates are very difficult to verify, with some published estimates being overly optimistic for marketing purposes, and others overly pessimistic. However, it is clear that costs are rapidly declining while performance is increasing. Second generation lithium ion battery packs costs are likely at or below $275 per kilowatt-hour (kWh). The battery packs are expected to decrease rapidly in the coming decade with $75 per kWh possible by 2035. And, as costs are reduced, energy and power are increasing. Third generation lithium ion battery technology—possibly reaching market after 2020—is expected to greatly improve performance characteristics and lower costs (Figure 16).

There are several battery technologies in early development stages that may replace lithium ion, but they appear to be at least a decade away from real world application—and likely much farther from mass market automotive use.

Figure 16: Advanced Battery Development Trends

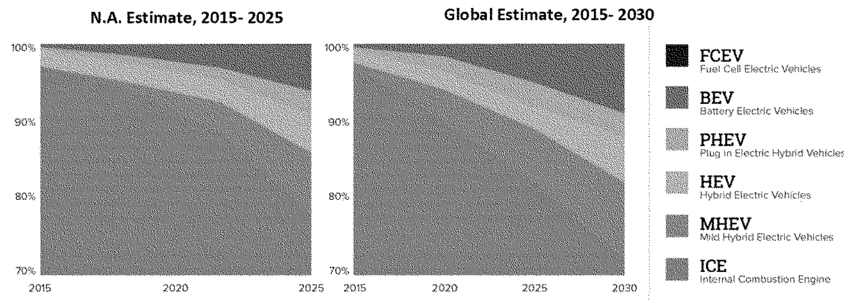


Source: CAR Research, summary of various media publications

As noted earlier, published forecasts for future propulsion technology penetrations vary greatly. Broadly, there are indications the global light-duty vehicle propulsion market may be at a technology tipping point, with significant change coming over the next 15 years. Electrification is happening, and BEVs, long a niche player in the market, appear to be developing rapidly. HEV and PHEV technology will be required to meet future emission standards. Yet the rapidity and completeness of this transition is far from certain.

It is likely at least 20 percent of the North American market, and nearly 30 percent of the global market will include some form of electrification by 2030. It is also likely electrification in some major markets may exceed these estimates. However, the internal combustion engine will continue to present a very strong cost/efficiency target for the consumer. Clearly regulation will drive this change, what remains uncertain is whether the consumer is willing to accept this revolution (Figure 17).

Figure 17: North American and Global Light Duty Vehicle Propulsion Technology Market Penetration 2015-2030



Source: CAR Research; USEPA/NHTSA Technical Assessment Report; Global EV Outlook 2016, International Energy Agency; Joining Forces to Tackle Road Transport CO2 Challenge, European Automobile Manufacturers Association; various others

Enablers and Threats

Enablers

Increasingly stringent emissions regulations will require increased application of advanced propulsion technologies, and even may open the door to an electrification revolution. Advanced battery development will be the important enabler in expediting significantly increased light-duty vehicle electrification. Cost reductions, combined with improved chemistries and more effective thermal management will increase battery capabilities and likely decrease charge time, making electrification more enticing to consumers. Two hundred-plus mile range, combined with quicker charge times, may also reduce charging infrastructure requirements.

The advancement of connected and automated vehicle technology is in many ways symbiotic with increased electrification for light-duty vehicle propulsion systems. As vehicles become more highly automated, they will quickly over-tax the twelve-volt system. Forty-eight-volt systems or greater may be required to supply power to automated technologies.

Threats

Consumer acceptance is possibly the most daunting threat to advanced propulsion technology. Low (and relatively stable) energy prices in the United States will continue to make market acceptance of advanced propulsion systems challenging. Even if battery costs continue to plummet as forecasted, ICE will present a difficult cost target with which to compete. Also, many consumers are cautious with new technologies. Backlash by the consumer is possible if future BEV (or FCEV) technology does not meet consumer expectations and this could occur either in the form of refusal to purchase the technology, or pressure on regulators to reduce regulations.

Monitoring the Future

Industry stakeholders need to monitor several key trends. Emissions and fuel economy regulation will be critical. Those countries that have the ability to implement top down regulation, or those where there is strong public support for environmental issues will likely have the ability to implement more stringent regulation. In countries where there is less central control or where consumers may not place a high value on environmental issues, implementing more stringent emissions regulation will be more challenging. However, globally, advancement will continue to happen.

Technology development will also play a pivotal role. Battery development is proceeding rapidly, but still needs improvement before the electric vehicle is perceived as a replacement for ICE. And, the industry will continue to refine the ICE.

These forecasts should be considered a guideline. There are many uncertainties driving light-duty vehicle propulsion. It is possible these forecasts underestimate the success of electrification over the next 15 years. However, proponents of vehicle electrification have been declaring the end of internal combustion for decades —yet ICE still accounts for approximately 98 percent of vehicles sold globally.

Conclusion

Among the three technology sections, there are several factors that could potentially impact the future advancement of technology in the automotive industry. They include, consumer acceptance; cost reduction and uncertainty; cross-sector communication; and policy and regulation.

The more accepting consumers are of new materials, technologies, or new mobility services—the more likely these technologies will advance. The market determines the success of a vehicle, not regulators or technology advancements. Consumers are concerned with safety, privacy and security issues, environmental impacts, efficiency, and cost. Governments can nudge consumers on a certain path, but in the end will not overpower consumer acceptance.

Relative cost competitiveness is another influential factor. Automakers and suppliers are cost-constrained, and make decisions on which advancements to pursue based on those that will not add significantly to the cost of the vehicle. The path of technology development and the pace of cost reductions are uncertain. Key examples include Industry 4.0, Additive Manufacturing/3D Printing, and New Mobility Business Models.

Increased cross-sector communication and communication between automakers and their suppliers, as well as within the supply chain is required to effectively incorporate technology changes into a product. As technology advances, cross-industry collaboration among the automotive industry as well as other industries will significantly increase due to the sophistication of technologies. This is evident in several partnerships and mergers among technology companies, startups, automakers, and suppliers. A breakdown in communication can lead to several inefficiencies including increased cost and waste of materials.

Long-term agreements on the regulatory future can also enable technology advancements. Automakers and suppliers are risk-adverse, and desire certainty in the direction set by governments. Uncertainty in public policy or the regulatory environment can be a barrier to technology advancement. If one government sets lower regulatory standards, overall global OEMs will continue to advance technologies to meet standards set in other countries, but may not be able to amortize those development costs over the entire global fleet when one large market differs substantially from the rest.

The CHAIRMAN. Thank you.
Dr. Dorobantu, welcome.

STATEMENT OF DR. MIHAI DOROBANTU, DIRECTOR, TECHNOLOGY PLANNING AND GOVERNMENT AFFAIRS, EATON – VEHICLE GROUP

Dr. DOROBANTU. Good morning. Chairman Murkowski, Senators Stabenow and Manchin, thank you for the opportunity to testify in front of your Committee.

The industry is in a period of rapid change and it's enabled by automation, electrification and connectivity. This Committee has correctly identified these trends as enormous opportunities as we move into the next generation of commercial and passenger vehicles.

Eaton is a leading Tier 1 supplier with 20,000 associates in more than 110 facilities across the United States, and our vehicle group employs nearly 3,000 associates in manufacturing, research and development in Georgia, Indiana, Nebraska, North Carolina and, of course, Michigan.

As an independent supplier, Eaton's innovations are incorporating a large number of vehicles, delivering significant fuel consumption improvements both in the U.S. and worldwide.

Regulatory pressure, technology innovation and customer expectations are driving the adoption of clean and intelligent products, creating exceptional growth opportunities for well-positioned companies.

At the vehicle level, the need to simultaneously reduce carbon dioxide and nitrous oxide emissions is driving advances in internal combustion engines and powertrain electrification, both as a means to improve efficiency.

At the transportation systems level, connectivity and better electronics and controls enable step changes in efficient utilization of these vehicles.

Eaton recognized early that the vehicle sector was on a trajectory of increased CO2 emissions and petroleum-based fuel burn, so we positioned our entire vast R&D portfolio to address vehicle energy efficiency allowing the following three directions: To first improve the efficiency of the vehicle power creation both conventional and electrical, then to efficiently distribute that power from its creation all the way to the wheels, and finally to optimize the use of that power in an increasingly diversified set of needs.

So over a decade we have worked closely with several government agencies that are also pursuing advanced energy use in vehicles. Our public-private collaborations with national labs, such as Oak Ridge in Tennessee or the National Renewable Energy Lab in Colorado, accelerate innovation and promote U.S. competitiveness. Eaton benefits from access to leading edge talent and capabilities such as high-performance computing or vehicle testing equipment as well as precompetitive results. But at the same time, we contribute expertise, research direction, materials and funding. The result is that working together we create and demonstrate new technologies and join in the vast state-of-the-art and enhance our competitiveness.

We also work closely with the Department of Energy through its Vehicle Technologies Office and Advanced Manufacturing Program. In partnership with the DOE, we successfully developed the fundamentals of advanced technologies that are now becoming essential elements of new products.

From the perspective of the vehicle programs at the DOE, these play a vital role in maintaining the U.S. technology leadership in global markets.

And especially important is the public-private partnership model. These partnerships accelerate innovation several ways. They foster collaboration across the industry in ways that are not easily achieved with separate commercial entities that are acting independently. And thus, we create new opportunities and new products. They also connect basic research capabilities in universities and national labs with their industrial R&D counterpart organizations thus accelerating the pace of introduction of innovation. The partnerships also connect technology startups, where new concepts are developed, to industrial players that have manufacturing capabilities and scale. And finally, they also demonstrate the potential of new technologies and thus enable product development investments that otherwise could not be made in what is, essentially, a conservative industry.

The vehicle programs at the Department of Energy and national labs are key to maintaining the U.S. industry's leadership position at all the levels of the supply chain. The public-private partnership model is proving particularly effective in guiding investments in areas that have a promise of high impact or perhaps too early, too broad or too unproven for industry to pursue alone.

It is essential that the investments are balanced between fundamental research and funding technology demonstration programs. In my experience, it is easy to recognize fundamental science and that's typically the domain of public investment. And it is also easy to recognize new product development which is typically the industry's job. However, the transition between these two areas is nontrivial. It is at this juncture in the innovation process, the public-private partnerships are most effective.

In closing, I would like to thank you again for the opportunity to testify. As we can see by the automotive innovation that surrounds us here today, the industry is moving forward at a rapid pace and we applaud your efforts to understand the emerging trends and support American innovation in the field.

Thank you.

[The prepared statement of Dr. Dorobantu follows:]

Testimony for the hearing,

"The Road to Tomorrow: Energy Innovation in Automotive Technologies"

Before the

Senate Committee on Energy and Natural Resources

Offered by
Dr. Mihai Dorobantu
Director, Technology Planning and Government Affairs
Eaton - Vehicle Group

January 25, 2018

Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee, thank you for inviting me to share Eaton's experience with innovation in the automotive industry. The U.S. and global automotive industry are in a period of rapid change and development, which this Committee has correctly identified as an enormous opportunity, as we move into the next generation of truck and passenger vehicles. At the same time, these rapid changes in the industry also present challenges. I look forward to discussing both the opportunities and challenges that Eaton sees with the Committee.

Eaton is a leading Tier 1 supplier that competes in the global market by consistently driving technology innovation. For over 100 years, Eaton has helped our customers grow their business profitably through innovation that drives results. With 10,800 patents, Eaton is focused on developing technology solutions for our customers' toughest power management challenges. We have 28,000 associates in more than 110 facilities throughout the United States. Eaton's Vehicle Group employs nearly 3,000 associates in manufacturing and research and development centers of excellence in Georgia, Indiana, Nebraska, North Carolina and Michigan.

We are part of a motor vehicle parts manufacturing industry that is a driving force in transforming mobility through innovation and technology, while leading greater environmental improvements through sustainability around the global economy. Motor vehicle component manufacturers are the nation's largest direct employer of manufacturing jobs in the U.S., employing over 871,000 workers in all 50 states. Together with indirect and employment-induced jobs, the total U.S. employment impact of the supplier industry is 4.26 million jobs. The total jobs in the supplier industry saw nearly 19 percent growth between 2012 and 2015.

As an independent supplier, Eaton's technology innovations are incorporated into a large number of vehicles, delivering significant fuel consumption improvements in the U.S. and world-wide. Light-duty suppliers alone account for 30 percent of total automotive investment in research and development and continue to take on a greater role in the design, testing, and engineering of new vehicle parts and systems in the United States. Motor vehicles suppliers provide the technologies and components that make up more than 77 percent of the value of a new vehicle. Development and manufacturing of these advanced products have also provided a robust domestic supply base that generates jobs and investment while boosting U.S. competiveness.

Regulatory pressure, technological innovation, and customer expectations are driving adoption of clean and intelligent products, challenging traditional notions of mobility and creating exceptional growth opportunities for well-positioned companies.

Eaton's advanced products help customers increase energy efficiency through a portfolio of solutions dedicated to enabling sustainable businesses. Whether a vehicle covers 50 or 500 miles a day, or makes five or 500 stops, it needs to be safe, reliable, and efficient. Our technology solutions offer improved fuel efficiency, enhanced vehicle productivity and performance, and safety and comfort enhancements that protect vehicle operators, the environment, and our customers' business investment. Our technologies also enable businesses to meet regulatory requirements and performance goals, ensure reliability and uptime, and lower fleet operational costs. Our experience tells us that new product developments will only succeed when all of these customer expectations are met. Our approach to innovation begins and ends with these requirements.

At the vehicle level, the need to simultaneously reduce carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions drives advanced internal combustion technologies and powertrain electrification as a means to improve efficiency. Light-weighting and aerodynamic solutions are also applied to reduce vehicle energy demand.

The vehicle transportation industry will continue to seek clean and intelligent solutions. Vehicle electrification will play a key role in reduced emissions and improved fuel economy -- with 12% of global passenger cars projected to be battery electric by 2030. Eaton will provide original equipment manufacturers with innovative power management, distribution and protection technologies for electrified vehicles. Emerging markets for fuel cell vehicles also provide additional opportunities for zero-emission mobility solutions in the transportation sector.

We will also continue to improve the efficiency and fuel emissions of internal combustion engines through an extensive portfolio of powertrain solutions. At the transportation systems level, connectivity and embedded electronics and controls enable step-changes in the utilization of vehicles, including levels of autonomy ranging from driver assistance to full autonomy, optimized routing and platooning, enhanced fleet management, and increased productivity.

Eaton recognized early that the vehicle sector was on a trajectory of increased CO_2 emissions and petroleum-based fuel burn, and that market, societal and regulatory forces will need to come together to reverse that trend. We positioned our entire advanced research and technology portfolio to address vehicle energy efficiency, along the following three directions:

- Improving the efficiency of vehicle power creation, both conventional and electrical;
- Efficiently distributing that power from creation to the wheels, and
- Optimizing the power usage for increasingly diversified needs.

The key technologies we invest in are engine air management and controls, through variable valve actuation and precise air flow control; efficient transmissions and torque control devices, including electrified powertrains; automation and deep integration of powertrains, as well as power electronics systems for charging, conversion, distribution and protection.

For example, Eaton led the global market in introducing hybrid electrical systems for heavy duty commercial vehicles in North America, followed by exports world-wide. Recently, we found ways of improving the efficiency of electric commercial vehicles, helping customers reduce battery sizes and extend range. Technology innovation in air management systems improves fuel consumption by increasing heavy duty diesel engine efficiency and enabling novel highly efficient combustion cycles for passenger cars, such as gasoline compression ignition. We introduced the first commercial vehicle dual clutch transmission, as well as heavy duty high efficiency automated transmissions deeply integrated with diesel engines. These advanced products reduce fuel consumption and vehicle down-time, while increasing performance and safety.

Working with the National Laboratories and the Department of Energy

In the past decade, we have worked closely with several government agencies that also are pursuing advances in vehicle energy use. Our public-private collaborations, with National Laboratories, such as Oak Ridge National Laboratory in Tennessee and the National Renewable Energy Laboratory in Colorado, accelerate innovation and promote U.S. competitiveness.

Eaton benefits from access to leading edge facilities, such as high-performance computing or vehicle testing equipment, as well as pre-competitive results, such as agency research on new battery technologies. These benefits enhance our global competitiveness. At the same time, we contribute our expertise and research direction, materials, and funding, to the Labs' efforts. The result is that, working together, we create and demonstrate new technologies and jointly advance state of the art technologies and enhance American competitiveness.

We also work closely with the Department of Energy, through its Vehicle Technologies Office and Advanced Manufacturing Program. In partnership with the Department of Energy, we successfully developed the fundamentals of new technologies that have become essential elements of advanced products. For example, the SuperTruck programs became testbeds for multiple technologies that are now entering the heavy duty market and are enabling U.S. manufacturers and suppliers, for the first time, to take the lead in efficient trucks over our European competitors.

From our perspective, the vehicle programs play a vital role in maintaining U.S. technology leadership in global markets, especially through private-public partnerships. These partnerships accelerate innovation in several ways:

1. Public private partnerships foster collaboration across the industry in a way that is not easily achieved with separate commercial entities acting independently, thus creating new opportunities and new products. As an example, engines and transmissions are traditionally designed by different organizations that aim to maximize generic pairings. SuperTruck allowed Cummins and Eaton to consider the engine and transmission as an optimized and deeply integrated powertrain, resulting in significant fuel consumption reduction, and ultimately a new product line: the SmartAdvantage powertrain.
2. They connect basic research capabilities in universities and National Laboratories with industrial research and development organizations, accelerating the pace of innovation. As an example, battery life extension methodologies developed by NREL were integrated with optimized hybrid powertrain controllers, resulting in reduced battery needs for hybrid buses.
3. Public private partnerships connect technology start-ups developing new ideas to industrial players that have manufacturing capabilities and scale. As an example, advanced air breathing technologies enable novel 2-stroke opposed piston engine concepts with a promise for both low fuel and low emissions breakthroughs in diesel technology.
4. They also demonstrate the potential of new technologies, enabling product development investment decisions that otherwise would not be made in a conservative industry. As an example, the benefits of multi-speed transmissions for electrical trucks and buses are enabling a shift towards commercialization by significantly reducing motor and battery needs.

The vehicle industry is facing significant challenges. As it is very capital intensive, the industry has historically been relatively conservative in investment. However, the technology landscape is changing rapidly and forward-looking investment is imperative. The industry is responding to the challenge of reducing fuel burn, which adds cost and complexity throughout the supply chain. Evolving markets are also creating industry challenges as we face increased technology competition from Europe and pressure from emerging markets. Vertical integration is putting additional pressure on independent manufacturers.

Our successful response to these challenges lies in our commitment to innovation and to the quality and vitality of the U.S. vehicle technologies and workforce. The vehicle programs at the Department of Energy and National Labs are key to maintaining U.S. industry's leadership position at all levels of the supply chain. The public-private partnership model is proving particularly effective in guiding investments in areas that have the promise of high impact in the market but are perhaps are too early, too broad or too unproven for industry alone to pursue.

We work continuously with government agencies to identify critical areas for technology investments that are potential game-changers. In our case, that means advances that can significantly reduce transportation energy consumption and costs, and at the same time increase the competitiveness of U.S. manufacturers.

It is essential that those investments are balanced between growing the fundamental research capabilities of the nation and funding technology demonstration programs. Without proper support for demonstration, particularly through various forms of public-private partnerships, the potential breakthroughs identified by basic research can be lost. I have witnessed technologies, which were successfully developed, only to be trapped in the so-called "Valley of Death." The technologies failed to gain a sustainable market - not due to lack of merit, but rather due to insufficient attention in demonstrating value to the stakeholders who are responsible for much larger product development investment decisions.

In my experience, it is easy to recognize fundamental science, typically the domain of public investment, and new product introduction, which is typically the job of industry. However, the challenges of transitioning between these areas are not trivial. It is at this juncture of innovation that public-private partnerships are most effective.

In closing, I would like to thank you again for the opportunity to testify on this important topic. As we can see by the automotive innovation that surrounds us here today, the industry is moving forward at a rapid pace. We applaud your efforts to understand these emerging trends and to support American innovation in this field.

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The CHAIRMAN. Thank you, Dr. Dorobantu.

Ms. Gross, welcome.

STATEMENT OF BRITTA GROSS, DIRECTOR, ADVANCED VEHICLE COMMERCIALIZATION POLICY, GENERAL MOTORS COMPANY

Ms. GROSS. Good morning. My name is Britta Gross, and I am General Motors' Director of Advanced Vehicle Communication Policy. I want to thank Chairman Murkowski, Senator Stabenow and Senator Manchin for inviting me here today to talk about some of the opportunities and challenges General Motors sees facing advanced vehicle technologies, particularly electric, or zero emission, vehicles.

If I may first offer you a perspective about how quickly the world is changing. In 2010, when General Motors introduced the plug-in Chevrolet Volt, we were one of consumers' first experiences with a plug-in vehicle. However, last year Americans purchased nearly 200,000 electrified vehicles, including battery electrics, plug-in hybrid electrics and fuel cell electric vehicles from more than a dozen manufacturers. Our own ground-breaking Chevrolet Volt, Chevrolet Bolt EV and Cadillac CT6 Plug-in accounted for nearly one-quarter of those vehicles. While this sounds like an incredible growth in electric vehicle interest, it's nothing compared to what is coming.

You may have heard General Motors recently announced our zero, zero, zero vision: that is, our belief in a future world with zero crashes, zero emissions and zero congestion. This vision represents the convergence of our work in connectivity, electric vehicles, autonomous vehicles and car-sharing in an effort to move humanity forward. And as part of that vision, we announced our plans to bring at least 20 new all-electric vehicles to the market by 2023, our next step in moving to a zero emissions world.

We know we are not alone in our optimism. As electric vehicles become cheaper, as batteries improve on performance and price and as manufacturers reach scale, we will see exceptional growth in EV adoption.

Electric vehicles bring enormous societal, economic and technological opportunities. Not only are electric vehicles cleaner and quieter to operate, they are also fun to drive thanks to the instant torque electric motors provide.

Because of electric vehicles, General Motors is making major financial investments in manufacturing facilities, as well as research and development facilities here in the United States. We are innovating around battery design and we're increasing hiring in areas not always associated with the auto sector, like computer science and software design.

With all the benefits electric vehicles bring, there are challenges too. Consumer acceptance of electric vehicles has steadily increased, but we still have a long way to go.

I want to focus on two areas where your Committee could help sustain continued growth. The first is consumer adoption, and the second is aiding with charging infrastructure build-out.

The Federal Electric Vehicle Tax Credit, worth up to $7,500, has been an important incentive for EV buyers and is without a doubt responsible for helping to fuel EV adoption. We appreciate the Senate's role in keeping this customer incentive in place as tax reform passed last year. This federal incentive sends a particularly powerful signal about the importance of vehicle electrification to consumers in all 50 states.

Right now, when we are on the cusp of attracting more mainstream consumers to EVs, is when we need to continue and strengthen this positive signal the most. It is a valuable tool to allow consumers greater access to EVs.

On infrastructure, this Committee has a unique opportunity to lay the foundation for the future. Mass-adoption of electric vehicles represents a large, smart and flexible load that is unlike any other load on the electric grid.

If we do this right and if we plan for smart-charging of EVs late at night and in the early morning hours, EVs can act as storage devices that make use of under-utilized power plants at night and take advantage of intermittent renewables. Thus, EVs can lead to a more balanced grid load.

But all the benefits to the grid can't happen unless the United States reaches true scale with EVs. We need EV charging stations that are highly visible to consumers and that drive consumer confidence in the ability to drive EVs anywhere at any time.

EV charging infrastructure today has grown from non-existent to over 17,000 public stations, but more is required. This market will become more viable and competitive over time, but we have a long way to go. This early market currently requires continued partnership between electric utilities, station operators, vehicle manufacturers and support by federal, state and municipal government to establish charging stations at the same scale as the 168,000 gas stations across the country.

I would also like to thank the Committee for their support for the Vehicle Innovation Act, bipartisan legislation introduced by Senators Stabenow, Alexander and Peters, that would support the development of new technologies in the automotive space, including electric vehicle charging. This is important legislation we hope the Congress will pass this year.

EV infrastructure is not only key to removing the barriers to acceptance of electric vehicles, but is also an imperative for other innovative and advanced mobility solutions, such as car-sharing, ride-hailing and self-driving vehicles. The speed with which EV charging infrastructure and EV adoption grow will determine the future of mobility in the United States and set the stage for even more advanced transportation technologies, and leading in these technologies here in the United States means we can take these technologies to global markets and that's good for all of us.

Thank you for your time today, and I look forward to answering any questions that the Committee members might have.

[The prepared statement of Ms. Gross follows:]

Statement to U.S. Senate Energy and Natural Resources Committee
Britta Gross
Director, Advanced Vehicle Commercialization Policy
General Motors Company
January 25, 2018

Good morning.

My name is Britta Gross and I am General Motors' director of advanced vehicle commercialization policy. I want to thank Chairman Murkowski, Ranking Member Cantwell, and the other committee members for inviting me here today to talk about some of the opportunities and challenges General Motors sees facing advanced vehicle technologies, particularly electric, or zero emission, vehicles.

If I may first offer you a perspective about how quickly the world is changing. In 2010, when General Motors introduced the plug-in Chevrolet Volt, we were one of consumers' first experiences with a plug-in vehicle. However last year, Americans purchased nearly 200,000 electrified vehicles including battery electrics, plug-in hybrid electrics, and fuel cell electric vehicles from more than a dozen manufacturers. Our own ground-breaking Chevrolet Volt, Chevrolet Bolt EV and Cadillac CT6 Plug-in accounted for nearly one-quarter of those vehicles. While this sounds like an incredible growth in electric vehicle interest, it's nothing compared to what is coming.

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Electric vehicles bring enormous societal, economic and technological opportunities. Not only are electric vehicles cleaner and quieter to operate, they are also fun to drive thanks to the instant torque electric motors provide. Because of electric vehicles, General Motors is making major financial investments in manufacturing facilities, as well as research and development facilities in the U.S. We are innovating around battery design and we're increasing hiring in areas not always associated with the auto sector, like computer science and software design.

With all the benefits electric vehicles bring, there are challenges too. Consumer acceptance of electric vehicles has steadily increased, but we still have a long way to go. I want to focus on two areas where your committee could help sustain continued growth: the first is consumer adoption and the second is aiding with charging infrastructure build-out.

The Federal Electric Vehicle Tax Credit, worth up to $7,500, has been an important incentive for EV buyers and is without a doubt responsible for helping to fuel EV adoption. We appreciate the Senate's role in keeping this customer incentive in place as tax reform passed last year. This federal incentive sends a particularly powerful signal about the importance of vehicle electrification to consumers in all 50 states. Right now, when we are on the cusp of attracting more mainstream consumers to EVs, is when we need to continue and strengthen this positive signal the most. It is a valuable tool to allow consumers greater access to EVs.

On infrastructure, this committee has a unique opportunity to lay the foundation for the future. Mass-adoption of electric vehicles represents a large, smart, and flexible load that is unlike any other load on the electric grid. If we do this right, and plan for the smart-charging of EVs – late at night and in the early morning hours – EVs can act as storage devices that make use of under-utilized power plants at night and take advantage of intermittent renewables. Thus, EVs can lead to a more balanced grid load.

But all the benefits to the grid can't happen, unless the United States reaches true scale with EVs. We need EV charging stations that are highly visible to consumers and that drive consumer-confidence in the ability to drive EVs anywhere at any time.

EV charging infrastructure today has grown from non-existent to over 17,000 public stations, but more is required. This market will become more viable and competitive over time, but we have a long way to go. This early market currently requires continued partnership between electric utilities, station operators, vehicle manufacturers and support by federal, state and municipal government to establish charging stations at the same scale as the 168,000+ gas stations across the country.

EV infrastructure is not only key to removing the barriers to acceptance of electric vehicles, but is also an imperative for other innovative and advanced mobility solutions, such as car-sharing, ride-hailing, and self-driving vehicles. The speed with which EV charging infrastructure and EV adoption grow will determine the future of mobility in the U.S., and set the stage for even more advanced transportation technologies. And leading in these technologies here in the U.S. means we can take these technologies to global markets – and that's good for all of us.

Thank you for your time today and I look forward to answering any questions that the members of the committee might have.

The CHAIRMAN. Thank you, Ms. Gross.

Mr. Wimmer, welcome.

STATEMENT OF ROBERT WIMMER, DIRECTOR, ENERGY & ENVIRONMENTAL RESEARCH, TOYOTA MOTOR NORTH AMERICA, INC.

Mr. WIMMER. Chairman Murkowski, Senator Stabenow, Senator Manchin and members of the Committee, Toyota appreciates the opportunity to testify before the Committee today on energy innovation in automotive technologies.

Toyota believes there is no one solution to addressing our energy and environmental challenges. That's why we're developing a portfolio of technologies from advanced gasoline and diesel engines to more efficient transmissions, to lighter weight materials, hybrid and plug-in hybrid drive systems, as well as our zero emission, battery electric, and hydrogen fuel cell vehicles.

It is our hydrogen fuel cell technology that I'm pleased to discuss today. Fuel cells are not new. In fact, they were developed in the 1800s and provided electricity and drinking water for our Apollo and space shuttle astronauts. Systems for on-road vehicles combine hydrogen gas stored in onboard carbon fiber tanks with oxygen from the air to produce electricity that powers the vehicle. A fuel cell vehicle's only emission is a small amount of water vapor from the tailpipe.

For Toyota, hydrogen fuel cells are an integral part of our zero emission vehicle strategy. What differentiates fuel cell vehicles from other zero emission technologies is their long driving range, typically over 300 miles on a fill of hydrogen; their ability to refuel quickly, usually under five minutes; and scalability of fuel cell systems to virtually any size vehicle. Toyota believes retaining key attributes of the internal combustion engine allows hydrogen fuel cell vehicles to appeal to the broadest range of buyers, ultimately leading to greater zero emission vehicle sales.

Toyota introduced its first retail fuel cell vehicle, the Mirai, in 2015. Since its introduction, over 3,000 have been sold in California and over 5,000 globally. The Mirai has an EPA estimated range of 312 miles on a tank of hydrogen and a fuel economy rating of 67 miles per gasoline gallon equivalent, about twice that of a standard mid-size sedan.

Scalability is another important aspect of fuel cell technology like adding more cylinders to an engine, more cells can be added to a fuel cell stack to increase system power. This makes fuel cells the perfect zero emission technology for SUVs and trucks which accounted for over 65 percent of new vehicle sales in the U.S. in 2017.

Scaling the technology further, Toyota has developed fuel cell systems for both transit buses and tractor trailers. We recently announced that Toyota will build 100 second generation fuel cell buses for athlete transport during the 2020 Tokyo Olympics.

In the U.S. we have begun testing a proof of concept drayage tractor trailer hauling cargo containers from the ports of Los Angeles and Long Beach to local destinations and rail yards. This tractor trailer has a range of 200 miles per tank and has a gross vehicle weight of 80,000 pounds. If successful, fuel cell drayage trucks could provide an opportunity to eliminate emissions and noise from often highly-polluted and underprivileged port areas.

A great advantage of hydrogen is its ability to be produced in a variety of ways from different fuels. Toyota will demonstrate one approach with the world's first megawatt scale carbonate fuel cell power generation plant and hydrogen fueling facility that we are building at the Port of Long Beach to fuel our port operations. The Tri-Gen facilities will use renewable bio-waste to generate water, electricity and hydrogen.

Toyota believes the greatest challenge to fuel cell vehicle success is not vehicle price nor consumer acceptance, but hydrogen refueling infrastructure. California is the leader in infrastructure in the U.S., having committed $200 million to co-fund 100 hydrogen fueling stations. To date, there are 31 stations open to the public with potentially another 12 expected to open this year.

While impressive, other countries with strong federal policy and financial support are outpacing California. There are 91 operational hydrogen stations in Japan, 44 in Germany and about 20 in Korea. To ensure the U.S. remains competitive in the emerging hydrogen economy, the Federal Government needs to take a more proactive approach to growing both hydrogen infrastructure and fuel cell vehicle sales.

Finally, Toyota wants to recognize the Department of Energy for their ongoing support of hydrogen and fuel cell research, development and commercialization. Their investment of over $1 billion for R&D has accelerated commercialization of the technology to the benefit of all. Recently, it's ongoing engagement with state and regional authorities to address technical questions related to tunnels and bridges and to alleviate any concerns about the safety of the technology has been highly beneficial. DOE's continued support in these areas is critical to eliminating regulatory barriers that will slow the roll out of the Toyota technology.

Toyota strongly believes that a portfolio of advanced technologies, highly efficient engines and a range of electric drive options are required to meet the sometimes divergent needs of customers, regulators and society. With their longer range and ability to refuel quickly and scalability, we believe hydrogen fuel cell vehicles can fulfill many of those needs.

We appreciate the opportunity to testify before the Committee and we'd be happy to answer any questions.

[The prepared statement of Mr. Wimmer follows:]

Testimony of Robert Wimmer

Director, Energy & Environmental Research, Toyota Motor North America, Inc.

Hearing on The Road to Tomorrow: Energy Innovation in Automotive Technologies

Committee on Energy and Natural Resources

United States Senate

January 25, 2018

Chairman Murkowski, Ranking Member Cantwell and members of the committee, Toyota Motor North America appreciates the opportunity to testify before the Senate Energy Committee today.

Toyota has been doing business in the US for over 60 years. Over that time, we've directly invested over $24 billion, which we've used to build 10 manufacturing plants that produce nine different models, in addition to sales distribution and R & D centers. And just this month we announced a joint-venture plant with Mazda in Huntsville, AL, which will employ 4,000 associates. These jobs will add to the 136,000 Toyota/Lexus[1] jobs in the US.

Toyota is developing a portfolio of technologies to address energy and climate challenges, while also meeting the needs of customers. These technologies include advanced gasoline and diesel engines, more efficient transmissions, lighter weight materials, hybrid drive, plug-in hybrids and a number of Zero Emission Vehicle (ZEV) technologies such as battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs). This past December, Toyota announced our intent to sell more than 5.5 million electrified vehicles per year globally by 2030, with 1 million of those being BEVs and FCEVs. Toyota also plans to introduce 10 new BEVs globally by the early 2020s and have electrified vehicles across our entire model lineup by around 2025.

While all these options will likely be needed across global markets, much of the public and policy attention over the past 10-years has focused largely on BEVs, and to a lesser

[1] Includes Toyota manufacturing, supporting operations and dealerships

extent, PHEVs, especially here in the US. For Toyota, an integral part of our zero-emission strategy – in addition to battery electric and plug-in hybrid electric vehicles – are fuel cell vehicles. What differentiates FCEVs from other zero emission technologies is their long driving range (typically over 300 miles on a "fill" of hydrogen), their ability to quickly refuel (usually less than five minutes) and the scalability of fuel cell systems to virtually any size vehicle. Toyota believes retaining key consumer attributes of the internal combustion engine allows hydrogen fuel cell vehicles to appeal to the broadest range of buyers, ultimately leading to greater zero emission vehicle sales.

Fuel cells are not new. In fact, they were developed in the 1800s and provided electricity and drinking water for the Apollo and Space Shuttle astronauts. There are several different types of fuel cells, but those used to power on-road vehicles all function essentially the same way. They combine hydrogen gas, stored on-board in carbon fiber tanks, with oxygen from the ambient air, to produce electricity that powers the vehicle. A fuel cell's only emission is a small amount of water vapor from the tailpipe.

Toyota introduced its first retail fuel cell vehicle, the Mirai, or "future" in Japanese, in 2015. It is a mid-sized sedan that represents the culmination of over two decades of R&D that started before the introduction of the first hybrid electric Prius or RAV4 EV. This extensive R&D allowed engineers to design the entire fuel cell powerplant and much of its assembly tooling in-house. Toyota even took advantage of its extensive knowledge of high-speed textile looms[2] to develop a significantly faster and more precise machine for winding carbon fiber around the hydrogen fuel tanks. This new tool optimizes tank design, while

[2] Toyota was founded in 1926 as **Toyoda Automatic Loom Works, Ltd.** producing a series of manual and machine-powered textile looms.

maximizing strength. The result is a lighter tank that takes less energy to manufacture, while meeting all US and global safety requirements for high-pressure tanks.

The “final exam” for this massive engineering effort and investment was the construction and real-world testing of over a hundred fuel cell vehicle prototypes. The objective was to ensure the technology’s, durability, performance and safety in all operating conditions and climates. The success of this multiyear test program allowed us to move forward with the Mirai production program.

Since its introduction in 2015, over 3,000 Mirai have been sold in California and 5000 globally. The vehicle has an EPA-estimated range of 312 miles on a tank of hydrogen and a fuel economy rating of 67 mile per gasoline-gallon equivalent (mpgge), about twice that of a standard mid-size sedan. The Mirai has a Manufacturer’s Suggested Retail Price (MSRP) of $57,500 (before government and/or manufacturer incentives) or can be leased for $349/month. Either way, customers receive three years of free fuel, maintenance and roadside assistance. Like Prius, the Mirai is a hybrid with a small battery pack that recovers energy while braking and aids in acceleration. In addition to great low-speed acceleration, like all fully electric vehicles, the Mirai cruises effortlessly at highway speeds. Along with Toyota, Honda and Hyundai are currently delivering fuel cell vehicles to customers in California. The State’s ZEV regulations, combined with its strong commitment to the success of fuel cell technology, made it the logical place to start.

The Mirai joins Toyota’s portfolio of 14 hybrid electric and plug-in hybrid electric vehicles offered in the US. Globally, Toyota has sold over 11 million electric drive vehicles ranging from sub-compacts to shuttle buses, which are estimated to have saved over 8.7 billion gallons of fuel and reduced CO2 emissions by 85 million metric tons.

Another important aspect of fuel cell technology is its scalability. Like adding more cylinders to an engine, more cells can be added to a fuel cell stack to increase system power. In the same way, a larger hydrogen fuel tank can be added to increase range. This makes fuel cells the perfect zero emission technology for SUVs and trucks, which accounted for over 65% of the new vehicle sales in the U.S. in 2017.

Toyota currently is testing hydrogen fuel cells in transit buses and trucks. Over a decade ago, Toyota operated a small fleet of fuel cell buses at the Achi Expo in Japan. Since then, our fuel cell buses have been used to shuttle passengers at the Nagoya airport and on regular routes in Toyota City, and we recently announced that Toyota will build 100 second-generation hydrogen fuel cell buses for athlete transport during the 2020 Tokyo Olympics.

In the US, a small group of Toyota engineers in Southern California and Michigan have taken two Mirai fuel cell systems and integrated them into a Class 8 drayage truck (tractor trailer). This proof of concept truck has a range of 200 miles per tank and has a gross vehicle weight of 80,000 pounds. It is currently undergoing real-world testing by hauling cargo containers from Los Angeles/Long Beach ports to local destinations and rail yards. Our objective is to demonstrate how zero emission fuel cell technology can meet the performance needs of drayage operators, while eliminating all emissions from the vehicle. If successful, fuel cell drayage trucks could provide an opportunity to eliminate emissions and noise from often highly polluted and underprivileged port areas.

At the other end of the scalability spectrum, hydrogen fuel cells are being used to power nearly 20,000 fork lift trucks at warehouses around the country. Companies like Walmart and Amazon have embraced the technology for its superior performance and warehouse efficiency relative to battery powered fork trucks.

It is important to consider upstream greenhouse gas generation from fuel production when assessing the overall benefit of any zero-emission vehicle. Like electricity, hydrogen can be produced in a variety ways. Today, most hydrogen is efficiently produced from abundant domestic natural gas. Using hydrogen produced from natural gas, fuel cell vehicles generate about 50% of the greenhouse gases per mile of a conventional gasoline vehicle on a well-to-wheels basis. Hydrogen also can be produced renewably using electrolysis from wind, solar or hydropower, or using bio-methane captured at landfills and sewage treatment plants. Toyota currently is constructing the world's first megawatt-scale carbonate fuel cell power generation plant with a hydrogen fueling station at the Port of Long Beach to fuel our port operations. The Tri-Gen facility will use bio-waste sourced from California agricultural waste to generate water, electricity and hydrogen. When it comes online in 2020, Tri-Gen will generate approximately 2.35 megawatts of electricity and 1.2 tons of hydrogen per day. In addition to generating hydrogen and electricity, this process prevents these bio-methane gases from being released to the atmosphere. Ultimately, hydrogen will be produced by a combination of sources based on the region of the country, availability, price of the feedstock, and regulatory requirements.

Hydrogen is relatively simple to store and transport. Where electricity requires a battery for storage, hydrogen can be stored as a gas for extended period in tanks. This ability is the cornerstone of the DOE H2@Scale project and the Hydrogen Society concept. Both envision the generation and storage of low-cost hydrogen from excess wind or solar power. This would help to decarbonize the energy sector as renewable hydrogen could be used for vehicles, for industrial processes, or even turned back into the electricity grid in an emergency. Hydrogen generation can take place near where the renewable electricity is generated or hundreds of miles away off the grid. Likewise, the generated hydrogen can be transported and used elsewhere. As part of the Hydrogen Council, an international multi-industry organization, Toyota is exploring these concepts and promoting ways to transition hydrogen into the energy sector to help decarbonize society.

Toyota believes the greatest challenge to fuel cell vehicle success is not vehicle price nor consumer acceptance, but hydrogen refueling infrastructure. California is the leader in infrastructure in the US, having committed $200 million to co-fund 100 hydrogen fueling stations. To date, there are 31 stations open to the public with potentially another 12 expected to open later this year. Most stations are in the Los Angeles and San Francisco metropolitan areas. The remainder are connector stations that allow fuel cell vehicle drivers to travel between metro areas. While impressive, the station roll-out in CA has been slower than expected.

To accelerate station construction, Toyota has partnerships with several companies. In CA, we have partnered with First Element Fuel (FEF) on 19 stations and recently announced two additional partnerships, one with Shell to add refueling capabilities to seven stations in Northern CA and another with FEF for eight additional stations. In the Northeast, we have partnered with Air Liquide, an industrial gas supplier, on the development of 12 hydrogen stations in NY, NJ, MA, RI and CT. These states were selected for their large metro areas, customer demographics, contiguous proximity, and requirement that automakers sell zero emission vehicles. Most stations will be in the Boston and New York City metro areas, with a few connector stations to allow convenient travel between the two cities. Most stations will be completed this year, with vehicle deployment starting when a sufficient number of stations are operational to meet customer needs.

To insure the US remains competitive in this space, the federal government needs to take a much more proactive role supporting hydrogen infrastructure growth. In Japan, Korea, Germany and Scandinavia, the federal governments provide strong policy and financial support for both fuel cell vehicles and infrastructure. This has resulted in 91 operational hydrogen stations in Japan, 44 in Germany, and about 20 in Korea. Without robust federal support for hydrogen infrastructure, possibly part of a national infrastructure program, the numbers of fuel cell vehicles on our roads will remain modest.

The federal government can also help by assuring all zero emission vehicles are treated equally when it comes to vehicle and infrastructure incentives. Currently, zero emission battery electric vehicles are eligible for a consumer tax credit, which we support. But zero emission fuel cell vehicles are not. The fuel cell tax credit expired prior to any meaningful number of vehicles being on the road. The credit needs to be reinstated. We were pleased to see it included in Chairman Hatch's tax extender package, but would encourage members to support a longer extension of the credit, so that both the industry and consumers can have greater cost certainty. Reinstatement of the credit also is important to reestablish parity among zero emission vehicles.

Toyota also supports the alternative fuel vehicle infrastructure tax credit, which, like the vehicle tax credit, has expired. Hydrogen stations are multi-million dollar investments. For the tax credit to be meaningful it needs to increase (from its current $30,000 cap) to a level that makes hydrogen infrastructure investment viable. These actions would send a signal to industry and the States that the federal government supports fuel cell and hydrogen technology, while addressing a primary concern of many investors.

We appreciate that the Committee does not have jurisdiction over tax policy, but thought it important to highlight government policies that would have a major impact on getting hydrogen fuel cell technology out into the market in the shortest time possible.

Finally, Toyota wants to recognize the Department of Energy for their ongoing support of hydrogen and fuel cell research, development and commercialization. Their investment of over a billion dollars for R&D has accelerated commercialization of the technology to the benefit of all. DOE supported Toyota's initial Cooperative Research and Development Agreement (CRADA) with a national lab and a real-world range test of our fuel cell prototype vehicle, the FCHV-adv in 2009. The vehicle demonstrated a range of over 430 miles on single fill of hydrogen. More recently, DOE's support of codes and standards development is benefiting station developers and automakers alike. Similarly, it's ongoing engagement with state and regional authorities to address technical questions related to tunnels and bridges, and to alleviate any concerns about the safety of the technology has been highly beneficial. DOE's continued support in these areas is critical to eliminating regulatory barriers that will slow rollout of the technology.

Toyota strongly believes that a portfolio of advanced technologies, highly efficient engines and a range of electric drive options are required to meet the sometimes-divergent needs of customers, regulators and society. With their longer range, ability to refuel quickly and scalability, hydrogen fuel cell electric vehicles are an important part of Toyota's portfolio.

We appreciate the opportunity to testify before the Committee today and would be happy to answer any questions.

The CHAIRMAN. Thank you, Mr. Wimmer.

I was just sitting here thinking, I can't remember what year it was that President Bush, in his State of the Union, made the statement that a child that was born that year, when he or she turned 16, they would be driving a car that was a hydrogen-powered vehicle. What year was that?

Mr. WIMMER. I believe it was 2000.

The CHAIRMAN. Yes, I think so.

Mr. WIMMER. I believe it was 2000. So, we're right there, yes.

The CHAIRMAN. Okay, well, we are now in 2018.

[Laughter.]

Okay, get moving.

Senator STABENOW. That's right.

The CHAIRMAN. But very interesting updates from each of you. I appreciate that.

The focus on the innovation and the advancements that we have made, how we can move to not only higher safety standards, but greatly decreased emissions. I see some in the audience here. The Moms Clean Air Force, focusing on how we can do a better job, an important job, of reducing emissions when it comes to our transportation fleet.

So thank you for what we have heard today.

Here in the nation's capital and up on the Hill, there is a lot of discussion about infrastructure and what an infrastructure package might look like that we could work to advance. I would be curious to know, several of you have hit upon it. Mr. Wimmer, you certainly spoke to the need for infrastructure as it relates to hydrogen stations. Ms. Gross, you spoke to the need for charging stations for EVs. But what else is out there in terms of energy-related infrastructure challenges that we are seeing right now with regards to advanced vehicle technologies? If we are putting together a package that could help advance these technologies and start making a difference, what else is out there other than charging stations? And you can amplify, if you want, but I would be curious to hear from each one of you.

Let's begin with Dr. Khaleel.

Dr. KHALEEL. Thank you, Senator.

So clearly, like you said, charging stations will be needed. Other infrastructure for producing hydrogen will be needed, but a lot of these depend on, really, electricity either from the main grid or from a microgrid.

So I think the big thing that we really need is to make sure our electrical grid is resilient and reliable through the introduction of things like microgrids and also energy storage in various ways. I think that would be the backbone to all of the items you discussed there.

The CHAIRMAN. Very important.

Ms. Bailo.

Ms. BAILO. Thank you.

I fully support the need to have the correct infrastructure, both in charging stations and in hydrogen. Hydrogen and fuel cells are one of the powertrains that will have the greatest impact on full-size trucks and/or commercial vehicles. And with the burgeoning

E-commerce load that we're seeing today, it makes a lot of sense to propel that technology.

When we think about the burden that it will have on the grid to reinforce it, microgrids are very essential. We need to start trialing those in various areas.

We also need to look at grid balance and the appropriate positioning of where we put those charging stations. It may not be equally distributed. You really have to look at the demographics of usage.

We also need to get the private sector involved. Companies have to put in charging stations for their employees. All new multi-unit dwellings, all new homes should at least have a charging station plumbed in as part of its code. Fundamentally, same as you, you know, you plumb in it for a dryer today. It should be there. It should be ready. Doesn't mean you need to put the expense of a charging station, but it's easier to do it in the beginning than in the end.

We also need to focus, as I mentioned before, on renewables, making sure that we have a clean energy supply coming into that grid.

Dr. DOROBANTU. So I'll reinforce the point about the electric grid and especially the electrical grid modernization. We have a number of issues, challenges, facing us in the form of grid stability, incorporating renewables. People talked about microgrids and that is a significant change to our infrastructure. But also, things like smart grid management in the overall control and distribution, geographically, of the electrical grid.

The CHAIRMAN. Ms. Gross.

Ms. GROSS. Yeah, a couple things come to mind.

First of all, I just echo everything that Carla talked about, the public charging, the workplace charging and the building codes that would ensure that housing, single family homes, multi-dwelling user unit homes, that everything is just building in codes that require just a simple dedicated circuit when you move into this home so that it's ready to charge a vehicle when you move into the home. So I think that's really important.

But beyond that I would say one thing that's really tough right now in this early market and why there's a lack of investment in EV infrastructure is that it's a really tough business case. There just isn't the scale. There isn't the utilization of these stations. And so, a business case is very, very tough which means there's just not that competition out there, which means there's just not the investment.

One of the likely parties that you can turn to is the utility industry. They are experts at deploying electrical systems, at maintaining, at operating, they're reliable. They do a fantastic job in that industry. But if you look at the 3,000 utilities in this country, then the 50 state regulators for most of those utilities, you start to recognize there's nothing that knits them together so that the infrastructure they put in, sort of, is adapted to the utility next door and the next utility so that we end up with a semblance of some national strategy. So coordinating the utility industry and the state regulators to participate together is really important.

And maybe I'll, sort of, just touch on the smart charging area of vehicles. It's really important to take advantage of this big load coming and do it right by smart charging, you know, charge the vehicles in the early morning hours when there's low—when the wind is blowing or in the daytime at work, when the sun is shining and there's excess electricity on the grid.

Utilities being prepared today with APIs on their front end to talk to telematic systems, like our OnStar system, mean that utilities could talk to OnStar, talk to all of our vehicle drivers and say hey, would you like to take advantage of hydroelectric power on the grid right now, we've got access. We'll drop your rate a couple pennies. And here you go, charge up tonight. You don't care as long as the vehicle is charged by six o'clock in the morning.

So, those kinds of, sort of, forward looking, system views of how, what the utility's role is in EV infrastructure and the smart charging of this load is going to be really, really powerful going forward.

The CHAIRMAN. Mr. Wimmer, final words?

Mr. WIMMER. Final words.

[Laughter.]

I agree with what many of the other panel members said, but on hydrogen, I think we can look at, from the infrastructure standpoint, the needs to have some standardized codes and standards from the different cities and states. In California, it's been fairly straightforward because we're dealing with, primarily, one entity. But in the Northeast when we look at expanding infrastructure to other states you're dealing with each individual state and each individual city, and their regulatory process is very different. There's a long education that goes, or involved education process that the industry has to do with each regulator.

Then also, the hydrogen production, as I mentioned. We're looking at one approach, unique approach, to hydrogen production. I think there's many other ways. One is DOE's hydrogen at scale approach where you're looking at using excess renewable or grid energy to produce the hydrogen in a very clean and efficient way. To be able to look at other options for hydrogen production and transport to the stations would be helpful.

The CHAIRMAN. Thank you all very much, very helpful.

Senator Stabenow.

Senator STABENOW. Well, Madam Chair, Senator Manchin has indicated he is going to have to leave shortly, so I will yield——

The CHAIRMAN. He is going to go buy a car.

[Laughter.]

Senator STABENOW. He has to go buy a car, so, I will yield to him and then I will reclaim my time after.

The CHAIRMAN. Great, great.

Senator STABENOW. Thank you.

Senator MANCHIN. I wish.

Let me just say, first of all, thank you all for your presentations.

I want to remind everybody that 76 percent of all the electricity produced in America comes from coal and natural gas, and West Virginia is proud to produce 76 percent of your energy. We are an all-in energy state. Water, hydro, solar, wind, we love it all. But the fact is, if you want 24/7 reliability, you have to go with baseload. So don't ever forget that right now. We are still trying to move through the new technologies, but you have to remember what has us at the dance right now.

I understand a major challenge of the grade of manufacturing, and this is from the manufacturing, okay, adoption of electric vehicles is access to critical minerals, also known as rare earth minerals or rare earth elements. China's monopoly in this space is concerning, extremely concerning, to me from both the economic and national security perspectives. This Committee examined the issue last year and we continue to have discussions around how to ensure the U.S. consumers and manufacturers have access to these materials, including the recreation of a domestic supply chain.

I find it interesting that the largest global adopter of electric vehicles in 2016 was China at 40 percent of global demand for these vehicles.

So my question would be, in light of the use of critical minerals and lithium-ion batteries and other components of these vehicles, how concerned are you and your company about access to critical minerals? It could be shut down at any time. You could be choked off at any time.

So we need you to engage. I think I have three people I know it hits directly and everybody can respond.

On top of that, I needed to finish up on that and rare earth elements, so that you will know. We don't mine any rare earth elements in the United States of America at all. We do not produce one ounce anymore. We are relying on another foreign country to produce where you all want to go and where the American consumer might want to go, but you have to be realistic. We are not prepared to do it. And you are putting billions and billions of dollars in investment that could shut you down overnight.

So, again, my little State of West Virginia, we have a lot of rare earth minerals that come from the mining of the coal, even from some of our waste, it has to be that we are trying to contain for the climate which is our mine drainage. We can produce and we are working on that, 45,000 tons per year. Forty-five thousand tons per year of rare earth elements just from the waste in the mining of what we do for the country.

But it is going to take an investment from the Department of Energy working with us. We have our friends here with the Department of Energy, and I am glad they are here. We want to make sure that you are all aware of that because we are going to need your help.

So, if you could tell me how this could affect you?

Yes, sir, Mr. Khaleel.

Dr. KHALEEL. So, Senator, I think, a few points.

On coal, one should look at coal to products and one of these products, actually, is rare earth, but there are a lot of other things one can do with coal.

Senator MANCHIN. Sure.

Dr. KHALEEL. Including, you know, you can produce carbon fiber.

Senator MANCHIN. We do.

Dr. KHALEEL. When it comes to rare earth, we need also to look at substitutes, other substitutes, for example, making magnets without any rare earth.

There is an initiative and an institute funded by the Department of Energy, and actually the National Energy Technology Lab is part of that, called the Critical Material Institute led by Ames National Lab and Oak Ridge is a participant in that.

Senator MANCHIN. Right.

Dr. KHALEEL. And we've been able to produce electric motors with no rare earth elements in them with much higher efficiency than existing——

Senator MANCHIN. Are you doing that on a commercial scale right now?

Dr. KHALEEL. No.

Senator MANCHIN. Or just basically in the production, I mean, into the——

Dr. KHALEEL. But I think they can move into that easily.

Senator MANCHIN. Into commercial.

Dr. KHALEEL. The other thing is when it comes to batteries, yes, there are a lot of critical elements like lithium, manganese, cobalt, nickel. And you know, clearly, when it comes to lithium, for example, we in the United States don't have that production. Although we have the resources in North Carolina with the——

Senator MANCHIN. We're not buying any of it.

Dr. KHALEEL. Right.

And I think that's a challenge. Today we get it from Chile——

Senator MANCHIN. I think what I am asking is are you all concerned about your supply chain because of our trade differences or our trade, maybe, disagreements that you could be harmed if something happens in our relationships?

Dr. KHALEEL. I could speak from the research point of view, I think, and the innovation.

I think we need to really invest in the research and the innovation.

Senator MANCHIN. Okay.

Dr. KHALEEL. To make sure we can produce things at cost.

Senator MANCHIN. So right now you are saying you are not concerned at all.

Dr. KHALEEL. No, I am.

Senator MANCHIN. Oh, okay. That is all I need to know.

[Laughter.]

Who would like to speak next?

I know, but all of you can, if you have time, Madam Chairman? All of you can really just respond to this, I'm sorry.

Mr. WIMMER. Well, as a large manufacturer of batteries, clearly any interruption in our supply chain materials, we would be concerned with, but——

Senator MANCHIN. Is that part of your strategic planning and thinking?

Mr. WIMMER. Exactly.

And we are looking at, as was mentioned by my colleague, of technologies, materials that can either substitute in——

Senator MANCHIN. Gotcha.

Mr. WIMMER. ——our electronics, our motors, our batteries or diversifications.

For example, our hybrid batteries, most are nickel metal hydride with only a few as lithium-ion. So with diversification if there's a shortage in one type of material, it might not affect all of our vehicles, but just some.

It's a concern, but the diversification and moving toward——

Senator MANCHIN. Well right now, as most of your products that you use, as far as your product you manufacture, does that come from China? Are you all buying from China?

Mr. WIMMER. I don't happen to know that.

Senator MANCHIN. You don't know that, okay.

Mr. WIMMER. We can get back to you on that.

Senator MANCHIN. We know you are because they are the ones. They have most of the——

[Laughter.]

We already knew the answer before we asked you.

[Laughter.]

But they have the global control of rare earth energy and elements.

I am sorry, Ms. Bailo.

Ms. BAILO. Thank you.

Most of the automakers, fundamentally, have a diversification of supply. As much as possible they try to mitigate that risk. Now if there's only a single source, of course, that's a risk too that has to be tackled.

What each company does is hedge that and look at the costs associated with that. When we look at what's happening globally for the cost of some of those rare earth materials, as well as aluminum and steel——

Senator MANCHIN. Sure.

Ms. BAILO. ——we are seeing significant increases recently. So all of that needs to be hedged and put into the future plans and it goes into the design optimization process.

The one thing that really needs to be focused on is the reduction of some of those rare earth elements, and that can only happen through the technological breakthroughs in research that is required. And it needs to be supported, not only within the industry, but also within academia and international——

Senator MANCHIN. Let me ask one question.

What time period are you talking about before this evolution comes to these new alternative rare earth elements that you do not need anymore?

Ms. BAILO. Well, we've already seen a significant reduction, even in the very basics that exist today in catalytic converters.

Senator MANCHIN. Okay.

Ms. BAILO. Probably up to 60 percent has been reduced. And again, as we keep finding breakthroughs and better chemical equations in the battery technology, et cetera——

Senator MANCHIN. Sure.

Ms. BAILO. ——that number will continue to come down. If it's ever going to become zero is anybody's guess.

The other thing I wanted to add on the coal front is I don't think we can negate the fact that in some coal plants producing energy, if you put in the right catalytic converters and others, you can have a pretty efficient plant.

So, we can also look at——

Senator MANCHIN. Not when we had an Administration that tried to shut us down completely eight years ago.

Horrible. Okay.

Mr. Dorobantu.

Dr. DOROBANTU. Eaton, in its vehicle business, is not really a player in the battery, on the battery side of the business.

Senator MANCHIN. Okay.

Dr. DOROBANTU. So we're not directly affected.

I can go back and ask about our other industries——

Senator MANCHIN. Yes.

Dr. DOROBANTU. ——and get back to you.

[The information requested had not been received as of the date of printing.]

Senator MANCHIN. Thank you.

Ms. Gross.

Ms. GROSS. Yeah, and just to add a couple nuances from our perspective.

Yes, we care about the sources. We have teams of people that look around the world and make sure that we know how to source these materials.

One thing that's of interest, though, is that some of these, not— a lot of these materials are also not just in automotive in our batteries, they're also across all of electronics, laptops, cell phones and so on. So, it isn't just us tugging on these resources. That's important.

What also comes back to us is, sort of, the cost of these materials. More recently there's been an issue with cobalt. Prices increasing. Of course, that just drives prices on our side as well and that's a problem for, you know, the price that we can offer these vehicles to the consumer. We do watch that closely. In fact, the important work that's happening when we move from Generation One technology, the Volt that came out in 2010 and where we are today with Generation Two and the Volt 2E as well. In that period, what we're doing is trying to streamline our use of those materials, in many cases. It's trying to reduce the way, reduce the amount of lithium or the amount of cobalt in these systems so that they still operate. They're safe. They're durable, dependable, but that we can reduce the cost by peeling out and improving either the engineering process, the architecture of the system or also the manufacturing process itself in how we apply the material.

We get more and more effective, and that's part of the learning process of developing and innovating.

Senator MANCHIN. Let me thank all of you as a panel, because you have been extremely informative and very professional.

The CHAIRMAN. Well, thank you, Senator Manchin.

No pun intended, but that was a critical question.

[Laughter.]

No, it is so important to the discussion because we recognize that we have extraordinary opportunities for advances in these technologies, but if we can't safely, reliably and affordably gain access to those base elements that we need to manufacture them, and I appreciate what you have said, Ms. Gross, that this is not just in the automotive.

As we look to build out many of our renewable energy sources, whether it is wind turbines and the fact that you need to have the coating on the blades and the coating comes from so many of these minerals.

It is an issue that, I think, has finally registered an appropriate level of attention within the government. We have certainly been pushing it for years on the Energy Committee. Now we feel like we have a chorus of voices that are saying, hey, yeah, this is really important. Let's not forget it.

Let's go to Senator Stabenow.

Senator STABENOW. Thanks very much, Madam Chair. And thank you again to all of you.

There are so many different kinds of issues that come into play here from infrastructure to rare earth materials to all of the research that needs to be done.

I want to start with something a little bit different that goes to another need that we have in all of this. Ms. Bailo, you talked about that, and that is talent, stretching our talent right now in what is happening.

One of my big concerns is that when you look in the big picture, National Association of Manufacturers says the next seven years we will create three and a half million new manufacturing jobs—and at the moment we could fill one and a half million of them. As we look at this piece of it as well, not only engineers, not only scientists, but skilled trades. People that can do coding. People that are interested in a career in technical education.

So my question would be, and I will start with Ms. Bailo because you had mentioned this specifically and you are working with a variety of folks in this context. What are your thoughts on how we look at our educational system and can best prepare individuals for jobs, not only tomorrow, but that are right here, right now and redesigning? I am working on efforts to support more options in college, but also redesigning and expanding career and technical education in high school and lifting up the privately funded, skilled building trades training centers that we have in Michigan and other places.

I don't know how many times somebody has said to me in a manufacturing operation, just give me a skilled welder, give me an electrician that can do the pieces that need to be done. So what should we be doing in that space?

Ms. BAILO. Thank you.

I mentioned it's a passion of mine, so I'll try to not talk for a long, long time.

I think we have to look at the entire chain of education and think of ourselves as a lifelong learning industry and country starting with even very young children in their education to begin to enlighten them into new ways of thinking, innovative ways of thinking. A different mindset is needed in today's industry than existed before. So starting there and then working your way up through.

I think we need to eliminate the notion that every person needs to go to a four-year institution, because some people are honestly better skilled and will enjoy a quality of life and get rewards from what they love to do. You need to follow your passion, and we need to provide students that show that aptitude a place. It doesn't have to be four years. We also need to provide opportunities for apprenticeships, internships, even starting in high school to again, build that passion. We need the skilled trades, not only to manufacture the products, but to work on the infrastructure that we need for connected autonomous vehicles, to do the coding, et cetera.

The other piece of the puzzle, I believe, is in the four-year institutions today, we are teaching children to think vertically, mechanical engineering, industrial engineering. And in today's world, you need to be a systematic thinker. So how we can start thinking about new ways to manage education, supplanting the standards of education that we require today with certification programs. We have a great example of Udacity, which is entering the university space that basically says, we're going to guarantee you a job. It's a very low price you have to pay, around $2,000, 18 months. You have a certificate, and you get a job immediately. If that job becomes obsolete or changes, you go get another certificate. So there's a number of things that we can think about to enable that lifelong learning.

The other part is with technology eclipsing so rapidly, if we are not continually teaching and training our existing workforces, then they will also become obsolete. It has to be a lifelong learning way of doing business.

Senator STABENOW. Thank you.

I believe that strongly. I think this is a major issue for us and we will develop new technologies and not have the talent, the skilled people, that we need for that.

Anyone else want to comment on that briefly?

Yes, Mr. Wimmer.

Mr. WIMMER. The impact of technology on the workforce is clearly significant, as you mention. It's really an issue Toyota has been working on and, to some extent, struggling with for a while.

Universities have a role to play but so does industry. Technology is moving so quickly these days that there needs to be a lot of work. We must work together with universities to develop programs that ultimately help provide the skills and the training for both university graduates and engineering fields as well as the technicians to come right to work into the workplace.

We're currently partnering with over 50 community colleges and other institutions to train the technicians for our dealers, for our manufacturing facilities. They can come in and work on tools to prepare them for life in the industry.

We're also working to promote STEM at a variety of K through 12 schools, again, focusing on both the technical career path as well as a university engineering career path.

Finally, I'd like to mention our company's strong support for the reauthorization of the Perkins Career and Technical Education Act. I understand it's been reauthorized in the House, and we would hope that the Senate would continue or consider passing the bill as well.

Senator STABENOW. Absolutely.

Yes, Ms. Gross.

Ms. GROSS. Yeah, I just, you know, when we talk about this very quickly changing industry, it's almost mind boggling what's going on right now. And if I just, sort of, share a couple, just tidbits.

Applications from Silicon Valley into GM have increased 100 percent over just the last couple years, so there's incredible interest in the innovation that's being announced these days. And that innovation does spur the movement of folks around with the talents that we're going to need, because it's just a very different place than it was before.

The second one is that 35 percent of our salaried workforce at General Motors right now has been with the company less than four years. Stunning. But that's the kind of movement in our industry bringing in the talents that we're looking for.

And so, just as Bob said, we're also looking very carefully and investing in STEM programs. In particular, we've made some recent investments in Girls Who Code making sure and blacks, black girls who code as well, to make sure that we're looking at, not only diversity, but the talents and the STEM resources and the capabilities that we're looking for also to drive the innovation that we need.

Senator STABENOW. Terrific.

Yes, Mr. Dorobantu.

Dr. DOROBANTU. At Eaton we are concerned with the future of our workforce and the quality of that workforce. Our normal, traditional university programs do not produce enough engineers, especially in the fields that are now in place, software and controls, electronics and so forth.

So we work with universities, obviously, to try to lay track for our workforce through the more traditional channels like internships and so forth, but we have worked also with some leading universities to establish certificate programs around, for example, systems engineering and manufacturing technologies.

I will say that we do spend a lot of time and resources in retraining, continuously retraining, our workforce. That is important.

And last but not least, we do have policies in place trying to tap into the talent pool, the diversified talent pool. Right now, our industry looks very mechanical, engineering, very non-diverse oriented. We have to change that because there's just too much talent that we're not tapping into. And I can get back with details, if you need those.

Senator STABENOW. Great. Thank you.

[The information had not been received as of the date of printing.]

Senator STABENOW. I know I am about to get—I'm sorry, Doctor, did you——

Dr. KHALEEL. Sure, I actually wanted to give you an example.

Last week I was in Corktown, Michigan, and we had a meeting with Michigan State University——

Senator STABENOW. Yes.

Dr. KHALEEL. ——and Michigan Economic Development Council about really trying to come up with a new program of how we gear to train a workforce around manufacturing. And you know, the idea is to bring the capabilities of the university to Detroit, but then to co-locate with the Corktown facility so people learn how to deal with the new equipment and things like that.

In the State of Tennessee, as you know, the Governor, now, said we can, actually everybody in the state can go and do a two-year college free. Right?

So we're trying to actually, around Oak Ridge National Lab with the community colleges, to reinvent the program, 2+2. You could spend two years in the community college and come work or train in the national lab on some of the tools that we have. Then if you decide you want to go to the next level and go to the university, then the University of Tennessee may be able to do that. That's in the works. We're thinking about it, and I think it's really an important concept.

The other thing is, within the State of Tennessee, we have something called the Bredesen Center. It's for graduate students who actually do their research at Oak Ridge National Lab. Many of them are from the University of Tennessee, but there is a parallel program for other students from other universities. And that, actually, is quite enriching for the students and for the lab, not just from a research point of view, but they learn other things, in terms of innovation, entrepreneurship and things of that nature.

So that's really another role that the national labs can play in helping folks in the country moving forward.

Senator STABENOW. Thank you.

I am so glad you could come to Corktown. It was my pleasure to be there when that facility was opened.

Dr. KHALEEL. Yes.

Senator STABENOW. It was truly a great example of partnership with the Federal Government, the state and the private sector.

Dr. KHALEEL. Right.

Thank you, Senator.

Senator STABENOW. Thank you.

The CHAIRMAN. Thank you, Senator Stabenow.

As we are talking about how we get more, particularly young people, into these fields in manufacturing and all of the really high-tech skills that we need, I am reminded that in most Alaska villages that I visit, it's not the person with the Ph.D. that has great value. It's that young kid that can repair the snow machine, that can repair the four-wheeler.

Senator STABENOW. Yes.

The CHAIRMAN. They are the ones that we all look to.

So making sure that we are not only training them on the manufacturing end and, again, kind of, the fun stuff. It is those who will be repairing and working on these advanced vehicles. It is one thing to know how to fix your father's Oldsmobile and the engine that was underneath it and now today so much of it is computer-related and making sure that those who can be on the repair end of things have those same appropriate skill sets as well. So it is changing.

I just have a couple more questions that I will ask and then I will turn back to Senator Stabenow before we conclude.

I want to pick up on something that you raised, Ms. Gross, when I asked the question about infrastructure and what more we need to be doing. You pointed out what I think is the appropriate role of working with the utilities and a recognition that there needs to be some level of coordination, or certainly communication, so that there is a better understanding as to how, particularly with EVs, we can maximize the efficiencies. It goes to a statement that was made earlier and this might have been by you, Ms. Bailo, that we can't make folks buy things they don't want. It is how we are communicating with the public about what is happening with these advancements and how they might benefit you, and if they do, how you can be a better participant.

Senator Stabenow and I were speaking before the hearing here about driverless vehicles, and I will be the first one to publicly admit out loud they scare the living daylights out of me.

[Laughter.]

And she described, or you described as well, Ms. Gross, your experience last weekend of driving hundreds of miles without touching the wheel.

What is the effort out there within the industry to help better educate the consumer, make us feel more comfortable, but also allow us to recognize the benefits that can come when we are smartly using the advanced technologies that the industry is clearly poised to help deliver? It is, kind of, a broad question, but I am curious to know what your response might be.

Ms. GROSS. Yeah, it's a wonderful, wonderful question because it's, sort of, at the crux of the opportunity right now is how do all players play together and take on part of the role, because it is a very large challenge.

It's unifying utilities and their role in building and installing infrastructure. It's also rallying environmental groups and industry groups to cooperate on national awareness campaigns.

You know, there's a lot of, there's just a lot of cooperation that has to go on.

Maybe if I just touch on first the infrastructure side of it. Back in 2007 when we were just penciling out the Volt program and we were, sort of, reflecting on what we had learned from EV1 in the '90s, it was very clear that one of the major strategies that was either going to make or break electric vehicles was going to be the engagement of electric utilities because we had learned in EV1 that they have to be a partner right by your side. So back in 2007 we set up a very large and broad partnership with EPRI, the Electric Power Research Institute, and about 50 of its utility members who were very forward-leaning looking at electric vehicles. Then so, we back then said now we've been working on this a decade. Now we're up to 200 or so utilities that really work very cooperatively together on aligning policy priorities, aligning talking points, so that when they're talking to consumers and we're talking to consumers, we're using the same vocabulary. We're answering questions in the same way. We have the same understanding of how the grid operates and where the issues are and where the issues are not and where the opportunities are.

And so, these areas and then lastly, the role of national, you know, encouraging EV education and awareness and the role of utilities. Utilities are so uniquely positioned because not everybody buys a car from General Motors. We'd love that if that were the case, but we don't have access to every consumer, but a utility has access to every single consumer purchasing electricity in that service territory. And that path to speak to consumers about the importance of electric drive and what it means to the grid, our data also suggests and many of the studies out there too, suggest that consumers would rather hear utilities talk about electric vehicles and the role of electricity in transportation than talk to dealers or automakers because they're viewed as very trusted third-party experts on electricity. So, I think that that role of utilities cannot be emphasized enough when it comes to, sort of, the role of the, sort of, what else could happen.

When I look at some of the things that have happened on the federal level—Department of Energy had a program in place called "EV Everywhere." They were also coordinating and convening industry experts, academia, NGO's, everyone who is a stakeholder in the EV market. We were working together on EV awareness campaigns, and it just needs to be more. It needs to be—we need to invest in this, sort of, messaging. And we need to, sort of, show a vision nationally.

One thing I can point to that has been a really nice piece of glue is the effort by DOT in cooperation with the Department of Energy in establishing these alternative fuel highway corridors across the country. Now there's no money assigned to that. It would be great if it were also funded, but just simply the notion of creating a map of charging stations across the country from coast-to-coast has allowed local utilities and states to, sort of, recognize how, if they do their part, it glues into this larger strategy and vision for EV infrastructure.

So just simply creating a vision and communicating that federally and nationally is really, really helpful to help these, sort of, disconnected pieces, but important, important local stakeholders participate in the solution space for how we get these vehicles growing and adopted in the marketplace.

The CHAIRMAN. Let's go to Dr. Khaleel and then——

Dr. KHALEEL. So, I think, Senator, first of all we face multiple challenges. The consumers worry, as Carla mentioned, about range, so they're anxious about the range, the driving range. The other thing they're anxious about is time to charge their car, you know, today and with today's technologies it takes about 30 minutes to charge a battery to 80 percent capacity. So that's also a concern. Then there is another concern regarding uncertainty of the demand, so you don't know where these charging stations need to be.

So the utilities, when we speak to the utilities that we work with, clearly, they're willing to engage, but the issue is also cost. The cost needs to come down.

There are uncertainties that the consumer face, but also the utility folks face to where they place it, it is part of their business model and so on. So I think the critical thing for us to do is to overcome these challenges.

And one way to overcome these challenges is really for us to win the energy race in these areas. We need to innovate and we need to do, to perform, research, work together. The companies, the U.S. companies, along with the innovation capacity that we have in the country, that includes the national labs and universities, to really, you know, move ahead of these challenges.

Ms. BAILO. Just a couple quick examples about things that have worked to educate the public.

One is when Nissan first launched the Leaf in the early 2012 period. The thing that worked very well was cooperating with cities directly and dealerships directly and holding public forums with just "Meet your EV day" and "This is how you charge the vehicle," "This is how the vehicle performs."

A second example is the Columbus Smart City Initiative of which Vulcan donated $10 million for basically increasing the number of EVs by three times, charging stations, et cetera, within the whole city. Part of that initiative involves local businesses and working with the automakers, taking the products to a company for a day-long event, ride and drive, let people drive the vehicle, let them understand how to charge the vehicle, let them see how it can be integrated into their daily lives. Seeing is believing, and until we have the momentum of word of mouth, these kinds of events really, really seem to be working.

Dr. DOROBANTU. So I'd like to shift the discussion a little bit onto commercial vehicles, much more passenger car vehicles, of course, on the roads, but if you look at it from an energy consumption perspective, the commercial vehicles are right behind the light duty segment in terms of how much CO2 is emitted and how much fuel is being burned. Furthermore, that consumption is increasing in time as opposed to the passenger car market where, because of all the work that's being done and all the focus that's on it, the total emissions are actually going down.

So the commercial vehicle space is different. It has very different challenges. We do not have the consumer there, but we do have the fleets or the operators of these vehicles and they have different needs than the consumers in light duty. For them, the vehicles are a means of performing work. So, for them, things like down time is critical. Total cost of ownership is critical. So there are other means, there need to be other means who reach that community.

Things that have worked are demonstration programs, as well as investments. I will give one example. We're working actively with NREL to look at how the grid and fleets of commercial vehicles that have batteries on them could interact and could provide benefit and, in fact, improve the value proposition of electrifying commercial vehicles by offering grid services. That's a different process. The end result is the same. It's the education of stakeholders, but the stakeholders in the commercial vehicle space have a very different bag that they're trying to optimize.

Ms. GROSS. Might I also add one more point when I think about consumer awareness and really grabbing consumer's attention and that is, I talked about the share mobility programs that were operating around the country right now. We have 300 Bolt EVs in our Maven program which is a ride-sharing/ride-hailing program in six cities in the United States. In those 300 vehicles, we've been operating only about 18 months or so, we have had 400,000 riders in Bolt EVs. These are 400,000 people that didn't have the ability to experience what we always say is a "butts in seats" experience where you experience the drive in a car which changes your mind instantly about how fun these vehicles are to drive. So that's another form of how we're embedding electrification in the ability to get the vehicles out there, driven, so that people can experience and ask the driver, hey, what am I driving, this is really fun. That's another form of awareness growing in the country.

The CHAIRMAN. Senator Stabenow.

Senator STABENOW. Well, thank you again, Madam Chair.

I want to talk about public-private partnerships in my last questions, because we know we have basic research and then we have what companies are doing in terms of commercialization and so on.

The big debate, it seems to me, that we have, in terms of the Federal Government's role, of course, sometimes we are doing it, sometimes we are not, is this piece in the middle which is sometimes called "the Valley of Death." You get ready to commercialize or get ready to take that step and then there is not the support in the middle of that.

One of the things Department of Energy has done is the SuperTruck program. Dr. Dorobantu, I know that your company is a participant in this, so I wanted to get your thoughts.

As you know, 50/50 cost share, public-private partnership promoting research and development and demonstrating technologies to improve, as you were talking about, commercial vehicles, the Class A tractor trailer trucks, and the goal is to improve, by more than 100 percent by 2020. I should just remind all of us that trucks haul as much as 80 percent of the goods for the country. They make up only 4 percent of the vehicles, but they are 20 percent of the fuel. So a major way to save fuel economy is to focus on trucks. What is your assessment of the SuperTruck program at this point?

Dr. DOROBANTU. So, just——

The CHAIRMAN. Push that button.

Senator STABENOW. I'm sorry, yes.

Dr. DOROBANTU. There are actually two SuperTruck programs. One has been successfully concluded a couple of years back, and then there's another one that has recently been launched.

Senator STABENOW. Correct.

Dr. DOROBANTU. So I'll talk about the one that——

Senator STABENOW. We know the first phase had a number of impressive results.

Dr. DOROBANTU. Right.

Senator STABENOW. I am just wondering, as it goes forward what we need to do.

Dr. DOROBANTU. Right.

What this program allowed us to do, the industry as a whole, not, obviously, not just Eaton, is to provide laser sharp focus on fuel efficiency at the system level.

There's been many investments in very particular technologies which were needed and the technologies have evolved. In a complex vehicle, many technologies have evolved. But what SuperTruck allowed manufacturers and suppliers to do is to put these technologies together in packages and see what actually works and what doesn't when they're put together as a system. It helped the industry sort out many options and prune some of these technologies, but also, we now have the technologies from SuperTruck that were evolved under the first SuperTruck program already in production. They're saving fuel today.

So to give you some feel about this. When the SuperTruck program started, most of the Class A trucks were averaging about six miles per gallon. The SuperTruck program itself produced some mind-blowing results so we're looking at 10, 11, 12 miles per gallon trucks, but those were research trucks. What we are seeing with the trucks that are coming out today, that are incorporating the technologies that were demonstrated and that were straightened out under the SuperTruck II program, those trucks are in the 7.5 to 8.5 miles per gallon today. Moving from under 6 to 7.5, 8 miles per gallon, in a period of maybe, five, six years, that is a tremendous achievement. It has impact in the fuel consumption, it has impact in the cost of transportation and it has impact in our competitiveness worldwide.

When we started SuperTruck, we were way behind the European trucks. Now we are, with the combination of technologies that were developed under SuperTruck and very stringent CO2 regulations that were recently enacted, we're in a position to overtake the Europeans that pride themselves in being fuel efficient by bounds and leaps. So very excited with the outcome of the SuperTruck program and we're looking forward at this second addition.

Senator STABENOW. Well, thank you, Doctor.

We are going to need you to help tell this story. I indicated earlier that vehicle technology, the Innovation Act, with the Chair's support and the Committee, is in the Energy bill on the Floor which is very important. But I do need to say, that we are going to have a big debate on this, in general, of these partnerships because the Administration has proposed cutting nearly $1 billion from the Department of Energy's Office of Science and cutting the Vehicles Technologies Office budget by 73 percent. So we are going to be having a lot of discussion. We are going to need your help, all of your help, on why this is important.

And then just to that, broadening as we look at other countries because we know we are in a competition with other countries. You are in competitions between companies, obviously, as well. For all of us, this is about American leadership and remaining the leaders in this technology.

Mr. Dorobantu, your company, I know, does business in 175 different countries, including the U.S., and we are glad you are in Michigan. Can you talk about, a little bit more about, how the U.S. compares to other major world economies in terms of supporting technology innovation? And from your perspective, how does a company with a global footprint decide where to invest its research and development dollars?

Dr. DOROBANTU. Thank you. That is a complex question.

But I'll start, when we look around the world at what other people are doing, what other countries or regions are doing, we're seeing a significant competition in terms of advanced technologies, obviously, coming from Europe.

I will give one example of how other countries do this. So the United Kingdom, for example, has realized about five, ten years ago that it had lagged behind from being a leader in the automotive world, to becoming a lagger. They have made some crystal-clear decisions in terms of investment and strategy to redress that situation. They view it as an economic, competitive edge to invest in innovation. What they have done is they have set a massive public-private partnership called the UK Automotive Council. They funded it sufficiently for a period of ten years so that they have the stability in that. And then they have defined a number of key technologies that, if successful, would put the UK back into the saddle. They are funding anything from startups to major starts with this sharp strategy and with long-term funding associated with it. They do use the 50/50 cost share mechanism to make sure that, you know, it's not a bunch of scientists, perhaps, like myself, that make decisions and then turn out to be wrong. So, they, the cost share with the industry is a mechanism of ensuring that the research is guided toward actual commercialization.

I think in terms of how we operate globally, well, we obviously have to be where our customers are. So, we do that. But we have also global resources, and we have centers of excellence that have global reach. So our investment, in terms of technology, is done here in the U.S. and this is where we put our advanced technology monies. What we do have in other parts of the world, we have engineering centers that are, of course, trying to adapt these technologies and optimize them for the specifics of those markets.

Senator STABENOW. Thank you.

Thank you, Madam Chair. I would love more questions, but I know in the interest of time at this point, I will save those for another day.

Excellent panel, and we appreciate your input.

The CHAIRMAN. Thank you, Senator Stabenow.

I would certainly hope that the recent move that we made in the Congress to lower that corporate rate is going to be one of those forcing mechanisms, if you will, that would allow many others to look at the United States as the place to either return some of that business to allow for more of whether it is the R&D or the manufacturing. Hopefully, that helps with the competitive aspect of it.

I, too, want to thank everyone for the information that you have shared with us today. Nobody really thinks about Alaska as being innovators in the automotive sector, but we have been plugging in our cars for decades.

[Laughter.]

All of the cars that I have ever owned had a head bolt heater, the little plug is sticking out of the car, out of the front of the grill, and you just plug in your car because if you don't plug in your car, it doesn't start the next morning, at least this time of the year in Fairbanks where I learned to drive.

So, maybe not the precursor, but we certainly understand what it means to plug your car in, and I am just amazed and very inspired by the level of innovation that we have heard here today. Maybe I need to take advantage of some of the ride sharing that you have talked about, but still the driverless one, I am going to feel compelled to still reach for the wheel or be more hands on. I will get used to it.

Before we do close though, I want to thank Bob Yoffe and Joe Koch and all of the convention staff that made this hearing possible and allowed us to work our staff with yours. It was a good opportunity. I certainly have enjoyed it.

Senator Stabenow, I am just even more motivated to come to Detroit, come to Michigan——

Senator STABENOW. Great.

The CHAIRMAN. ——and see more of what you have going on. And you, in turn, are welcome to come to Alaska and you can see——

Senator STABENOW. Yes.

The CHAIRMAN. ——how in our little communities, the Mayor of Cordova, one guy, saying, you know what? We are going to be a demonstration case in our little fishing village and start them one little charging station at a time.

Senator STABENOW. That's right.

The CHAIRMAN. So we may have to bring you up to Cordova, and I will go to Detroit.

Senator STABENOW. That's a deal.

The CHAIRMAN. With that, we stand adjourned.

[Whereupon, at 11:51 a.m. the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

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January 25, 2018 Field Hearing
The Road to Tomorrow: Energy Innovation in Automotive Technologies
Questions for the Record Submitted to Dr. Mohammad Khaleel

Questions from Ranking Member Maria Cantwell

<u>Question 1</u>: We have seen composites in Washington state advance dramatically.

It has taken years of work in advanced materials to get where we are.

And there has been significant private sector investment, as well as public-private sector collaboration, including with our national labs. Now, we are beginning to the see that investment pay off through the increased use of composites not only in aviation, but the automotive sector as well. The BMW i-3 is just one example.

But it also means jobs in areas like Moses Lake, Washington and Port Angeles Washington, where composites are helping to bring economic development to areas where it is needed most.

(1a) Dr. Khaleel, can you tell us about some of the research going on at Oak Ridge as it relates to new materials for vehicles?

(1b) When it comes to composites and other advanced materials, can you talk about the importance of organizations like the Institute for Advanced Composite Manufacturing Innovation (IACMI) to further development of composites?

<u>Answer:</u>
1.a. The modern materials research tools at ORNL, coupled with dedicated, world-class expertise, allow our scientists to analyze and build new materials at the atomic scale. We discover and make new materials; we study their structure, dynamics, and functionality; and we use high-performance computing to understand and predict how they will behave in applications.

ORNL's low-cost carbon fiber and composites work is focused on reducing production cost of industrial-grade carbon fiber by approximately half to enable widespread deployment in high volume, cost-sensitive automotive applications.

ORNL is home to DOE's Carbon Fiber Technology Facility (CFTF)—a 42,000 sq. ft. innovative technology facility. The CFTF offers a highly flexible, highly instrumented carbon fiber line for demonstrating advanced technology scalability and producing market-development volumes of prototypical carbon fibers and serves as the last step before commercial production scale.

The CFTF has made available for licensing a new method of producing carbon fibers from multipurpose commercial fiber precursor—such as fibers used in carpeting or clothing. The technology has the potential to reduce carbon fiber production costs by more than 50%. In addition, the method reduces energy consumption by as much as 60% and has applications across the aerospace, transportation, energy, and infrastructure industries. LeMond Composites was the first company to license the acrylic fiber method, with plans to take the technology to market.

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ORNL is leveraging its expertise in advanced and composite materials and additive manufacturing in partnership with the University of Maine and its Advanced Structures and Composites Center to develop new methods and uses for forest-based biomaterials, including for automotive and other industrial applications—a partnership supported by EERE's Advanced Manufacturing Office.

ORNL is also home to DOE's Manufacturing Demonstration Facility (MDF), where we collaborate with automakers to create lightweight, complex components for the transportation industry. Some of our most high-impact research in this space revolves around advances in the tool and die industry—creating custom molds, for instance, for new vehicle designs quickly and at a much lower cost than in conventional manufacturing practice.

We are working with Ford and Volkswagen to produce low volume composite tooling out of high temperature thermoplastic materials via additive manufacturing. We are also collaborating with American automotive tooling companies to produce high-volume stamping dies via large-scale metal additive manufacturing.

ORNL collaborated with Local Motors to develop materials processes for 3D-printing the chassis of the world's first 3D-printed car—the Strati—using the big-area additive manufacturing (BAAM) machine developed by ORNL and Cincinnati Incorporated. Building on that success, the laboratory 3D-printed the Shelby Cobra electric sports car, used as a living laboratory for integrating advanced vehicle technologies, at the MDF using the BAAM system. Local Motors leveraged the same technology to additively manufacture the chassis for its Olli autonomous shuttle bus.

1.b ORNL is a founding partner of the Institute for Advanced Composites Manufacturing Innovation, one of the Manufacturing USA centers for innovation. IACMI, the Composites Institute, has assembled a consortium of almost 160 members, including more than 120 companies and the economic development offices from 6 core partner states, committed to moving carbon and other advanced fiber composites into mainstream use in strategic application areas for the United States, including vehicles and transportation. IACMI, working with ORNL and other innovation partners, is working with leading OEMs Ford, Fiat Chrysler Automobiles, and others as they team with partners in their supply chains such as Dow, Faurecia, DuPont, BASF, and PPG to develop and demonstrate new materials and processes on the path to large scale deployment.

IACMI and the LIFT (Lightweight Innovations for Tomorrow) organization have opened a manufacturing scale-up facility at Corktown in Detroit, Michigan, where industry and institute members can conduct research and development in lightweight metals and advanced composite materials. ORNL, for instance, is collaborating on a project at Corktown to develop new, lighter materials for electric vehicle battery shielding.

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The composites community is excited about the impact carbon fiber will make when deployed in mainstream automobiles. In addition to reduced energy use, this will create new jobs and grow the market for carbon fiber components beyond an already strong 12% compound annual growth rate.

IACMI is also partnering with leading trade organizations such as the American Chemistry Council and the American Composites Manufacturer's Association to identify workforce development needs and deliver targeted training and retraining programs to the composites industry as it grows.

In addition to the capacity building impact of the organization, the breakthrough technology work being led through the institute is fulfilling the enormous potential for energy savings and carbon reduction and creating a global composites recycling industry. This is being realized through more efficient utilization of some of the 50 million pounds of annual carbon fiber scrap that would otherwise go to the landfill and is instead being used to manufacture new automotive products such as the seatback created as a result of an IACMI and the Composite Recycling Technology Center (CRTC) project.[1]

Along with the technology advances, the collaboration with industry and trade organizations is strengthening visibility for the industry and expanding opportunities for to train the current and future workforce at all career entry points. Workforce development opportunities include hands-on training and to-date have benefited over 1,200 people from across the U.S.is at the technician level training provided by IACMI and partners.

IACMI was built to leverage core competencies and infrastructure at ORNL, and in its first three years, this public-private partnership has generated more than $70M in infrastructure and capacity building investment, including key facilities that are unique to the Americas and critical for US companies' global competitiveness.

As an example, Dow and Ford have been working with IACMI on new materials and manufacturing processes to reduce the cost and cycle time for automotive carbon fiber components. These are currently demonstrated in the Ford GT, with plans to develop further so they are suitable for high volume platforms. This success builds off ORNL investments in both the Manufacturing Demonstration Facility and the Carbon Fiber Technology Facility and is a model example of how the US leveraging strategic innovation assets to support global competitiveness in manufacturing.

Question 2: As more electric and alternative fueled vehicles enter into the marketplace and are on the road, this presents an opportunity for infrastructure development.

[1] http://iacmi.org/2017/09/14/composite-recycling-technology-center-produces-first-ever-automotive-seatback-using-recycled-carbon-fiber-from-elg-carbon-fibre-ltd/

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(2a) What are some of the obstacles in deployment of electric vehicle (EV) and alternative fuel charging infrastructure?

(2b) How can industry partner with the Department of Energy to bring about increased infrastructure?

Answer:
2.a. To boost consumer acceptance of electric and alternative-fuel vehicles, recharging/refueling stations must be convenient, accessible, reliable, and numerous. A vehicle range that limits long-distance travel has been a significant barrier to the adoption of EVs.

In a September 2017 DOE report, *National Plug-In Electric Vehicle Infrastructure Analysis*, researchers at the National Renewable Energy Laboratory (NREL) found that an extensive and convenient network of fast-charging stations spaced about 70 miles apart along the U.S interstate system could enable reliable inter-city travel and encourage wider EV adoption. The report suggested that 400 such stations would need to be built for this purpose.[2]

In October 2017, a DOE report issued by Idaho National Laboratory, NREL, and Argonne National Laboratory identified technical gaps to implementing an extreme fast charging network in the United States. The aim of this DOE/national lab consortium is to develop charging stations with 400-kilowatt capability—which would recharge a battery-powered EV in less than 10 minutes. The report addressed challenges in three key areas: better batteries with higher energy density, extended lifetimes, and lower cost; vehicle improvements to handle the higher voltage through advanced power electronics, including solving the tradeoff between driving range and recharge time; and infrastructure challenges such as standardization of vehicle systems and recharging stations, careful planning of station siting, and efforts to limit impacts to the larger power grid.[3]

2.b. ORNL and the other national laboratories actively seek out industrial partners for research collaborations that seek to solve complex challenges.

We think that the electrification of the US fleet will require three major breakthroughs that reduce the range anxiety and uncertainty that is slowing adoption of electrified vehicles.

First, we need to increase battery energy density and reduce cost. We need more energy, in less weight and volume, at a lower cost. The Department of Energy and the National Laboratories contain the nexus of scientific talent, world-class materials research instruments, and the high-performance computing facilities to reveal the next generation of batteries that reduce range anxiety.

[2] http://www.nrel.gov/docs/fy17osti/69031.pdf
[3] http://energy.gov/sites/prod/files/2017/10/f38/XFC%20Technology%20Gap%20Assessment%20Report_FINAL_10202017.pdf

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Second, we need to co-develop the vehicle batteries and power electronics to enable automated charging of vehicles in minutes instead of hours using extreme fast charging technology. Extreme Fast Charging delivers charge to vehicles 50 times faster than conventional charging technologies.

Finally, we need a viable vehicle charging station and standards, with DOE-led demonstrations that are co-developed with the electric grid to deliver several megawatts to vehicles at convenient locations. The DOE has the ability to significantly accelerate the electrification, and all of these breakthroughs must be done with industry partners that will drive the vehicle sales and infrastructure installations that will achieve massive electrification in the US.

For example, we partnered with Toyota, Cisco Systems, Evatran and Clemson University to install an ORNL-designed 34-kilowatt wireless vehicle charging system that can charge passenger vehicles five times faster than conventional plug-in systems at the same efficiency as a wired connection. We are targeting a 100-kilowatt system for next year on the way to an ultimate 350 to 400-kilowatt system. We are currently working with United Parcel Service to develop a bidirectional wireless charging system with higher ground clearance for the company's delivery trucks. Evatran has since developed a commercial wireless EV charging system based on this breakthrough, "Plugless," which it plans to roll out as automakers introduce vehicles with wireless charging technology.

In another project, we collaborated with Clemson University to develop a novel method to anticipate the demand for electric vehicle charging stations and to assist communities with infrastructure planning for inter-city travel. The data-driven method, developed with input from the California Department of Transportation, considers electric vehicle volume and random timing of vehicles arriving at charging stations to determine the optimal number of chargers needed in the near- and long-term.

Question from Senator Tammy Duckworth

Question: Advanced manufacturing is an important issue that plays a central role in multiple industries. Furthermore, progress in the field is critical to maintaining U.S. competitiveness in the global marketplace.

Dr. Khaleel, your testimony specifically discussed the important role advanced manufacturing plays in energy innovation in the transportation sector. You shared that these techniques can increase the energy savings over the lifecycle of a vehicle by improving manufacturing efficiency, as well as creating lightweight materials that increase fuel economy.

In your opinion, how can Congress help facilitate further progress in advanced manufacturing to boost innovation and improve energy savings in the automotive industry and across all sectors?

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Answer:
Advanced manufacturing research at the national laboratories involves working hand-in-hand with industry to lower the cost and energy intensity of manufacturing methods, in order to enhance the sector's global competitiveness and bring manufacturing jobs back to U.S. shores.

While the United States has world-class innovation capacity and a unique culture of entrepreneurship, there has historically been significant under-investment in many of clean energy's most promising and important technologies. As these technologies have advanced, market barriers have become a more significant and visible limitation to the speed of deployment. Our sense of urgency is further increased as we see the rest of the world investing billions of dollars in clean tech R&D and deployment while the impacts are becoming more apparent in our daily lives.

At ORNL, we are utilizing the MDF to encourage research collaborations to advance lightweight, complex components for the transportation industry. One highly impactful research area is lowering the cost of tools and dies by additively manufacturing molds to be used to make components for new vehicles. Our Battery Manufacturing R&D Facility at the MDF supports research into new battery materials from the nanoscale up to industrially relevant scales, including roll-to-roll manufacturing techniques to advance faster, more efficient production.

These remarkable breakthroughs would be difficult if not impossible for industry to solve alone. DOE's national laboratory system brings together world-class facilities and experts across a wide spectrum of disciplines to tackle scientific challenges from a vehicle's smallest component to solutions for energy-efficient, vast transportation networks, in collaboration with partners from industry, academic, and public institutions who help guide our research for the greatest impact.

The national laboratories are a remarkable asset for the United States, taking on large-scale, long-term research and development efforts that are outside the scope of industry or universities. Over the past 75 years, the labs have provided the science and technology breakthroughs needed to address compelling national problems. They offer an extraordinary set of resources for sustaining and advancing the nation's security, quality of life, and economic competitiveness.

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Questions from Ranking Member Maria Cantwell

Question 1: Significant developments in engine technology have led the way to greater fuel economy, however there is a limit to that which can be achieved through motor engineering alone.

If we are going to continue to drive down fuel consumption without dramatic increases in costs to consumers, it seems we need to do more in the way of "lightweighting," including furthering the use of composites.

Ms. Bailo, what are the trends the Center for Automotive Research is seeing on lightweighting?

The development of a passenger vehicle is a complex undertaking that requires many tradeoffs. Fuel economy improvement (or CO_2 reduction) is undoubtedly a critical goal during vehicle development. However, automakers must balance this objective with many others. CO_2 reduction opportunities for vehicles come from many different technologies and strategies (e.g., different powertrain technologies, engine downsizing, mass reduction, aerodynamics, and other means). How companies manage these tradeoffs is of critical importance.

During the vehicle planning process, each manufacturer must assess the costs and potential efficiency gains of each fuel efficiency option, and decide the most cost-effective pathway to meet program requirements and constraints. Design optimization is fundamental and is dependent on customer usage for the segment, vehicle attributes (including mass), manufacturing processes, and specific plant characteristics. Companies perform this optimization very early in the product planning cycle. Balancing these technological and strategic factors ensures the most effective technology packages are offered to meet the customer requirements.

For nearly one hundred and twenty years, the internal combustion gasoline engine (ICE) has been the standard for passenger vehicles. While battery electric vehicle (BEV) technology is advancing rapidly, there remains tremendous room to develop the ICE. The recent shift from port fuel injection to direct injection, increased use of turbochargers, and near-term technologies such as variable compression ratio cylinders and homogeneous charge compression ignition indicate the cost and performance of the ICE continue to be moving targets. ICEs, whether alone, or supplemented with electric motors and advanced batteries, are becoming more efficient every year, and will likely be an essential part of the automotive efficiency equation for years to come.

Mass reduction, through the use the alternative materials, is also a significant part of any manufacturers' CO_2 reduction strategy. New applications of composites, steel, and aluminum present viable mass reduction opportunities, and continued development and implementation of each of these material solutions is vital to meeting efficiency gains. CAR works closely with multiple industry stakeholders to track mass reduction and advanced material trends, and we have ongoing efforts via CAR's Coalition for Automotive Lightweighting Materials. The trend for body-in-white panels (the outer skin of the vehicle) that comprise most of the weight of the auto body is to move first from mild steel to higher-strength and lighter steels, then from these advanced high-strength steels (AHSS) to aluminum, and finally from aluminum to composites such as carbon fiber reinforced plastics (CFRP). Utilizing these alternative materials impacts cost significantly.

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Once an automaker launches a vehicle, material substitution for mass reduction becomes very difficult, so the vast majority of these changes must take place during the development phase. Changing materials for components such as trunk and hood lids may be possible, but beyond a select few, there are very few mass reduction opportunities available after the product launch.

What are some of the challenges and opportunities with increased use of advanced materials?

While substantial opportunity exists for implementation of advanced materials, such actions do present several challenges. In 2016, CAR published a report that identifies real-world barriers to vehicle mass reduction.[1] The report showed that the material supply chain is constrained for the many new advanced materials. In the development phase for advanced materials, vehicle manufacturers often have to engage with material providers to secure the necessary supply for their production components, something not necessary for the standard steel or aluminum production, where coils of base materials are readily available for purchase as commodities.

Components using advanced material represent a significant challenge for implementation. At least initially, manufacturing costs are higher with advanced materials, due to the higher base cost of materials, slower cycle times, and even duplicate tooling equipment required for higher volumes. For example, the highest strength metallic materials (e.g., specialty boron steel or 7000-grade aluminum) need to be heated to be formed into parts, and this heat treatment adds time and cost to the manufacturing process. The formation of composite materials into auto body outer skin panels can require even longer processing times using highly-specialized equipment and processes.

Stranded capital is also a concern for vehicle manufacturers and suppliers. The installed infrastructure of metal forming presses, welders, and paint systems represents hundreds of billions of dollars, and it would need to be replaced, or at least significantly upgraded and enhanced to apply to advanced materials such as CFRP. Capital availability for such investments is itself a constrained commodity for every automaker, and manufacturers' projections on future vehicle volumes are also critical from a return-on-investment standpoint.

CAR has produced several reports that address this question in greater detail than can be provided in this response.[2] These reports illustrate both the opportunities advanced materials offer for vehicle mass reduction, as well as the many substantial challenges ahead.

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[1] Baron, J. (2016). *Identifying Real-World Barriers to Implementing Lightweighting Technologies and Challenges in Estimating the Increase in Costs.* Ann Arbor, MI: Center for Automotive Research.

[2] Baron., J., & Modi, S. (2016). *Assessing the Fleet-wide material Technology and Costs to Lightweight Vehicles.* Ann Arbor, MI: Center for Automotive Research.
Stevens, M., Modi, S., & Chess, M. (2016). *Mixed Material Solutions: Alternative Materials for Door Assemblies.* Ann Arbor, MI: Center for Automotive Research.
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Questions for the Record Submitted to Ms. Carla Bailo

Question 2: Ms. Bailo, numerous studies, including from the Department of Energy, academic and environmental organizations have shown that, with the current grid mix, electric vehicles provide significant well to wheels emissions benefits compared to gasoline-powered vehicles. These benefits increase with additional renewable power to the grid.

Do you disagree with these studies? If so, can you provide the basis for this disagreement?

In virtually all instances, a BEV charged on the current U.S. grid, *on average,* outperforms the ICE in terms of CO_2 emissions—sometimes significantly. As natural gas and renewable energy sources increasingly replace coal generation in this country, the U.S. grid will continue to become cleaner. This shift will likely increase the CO_2 advantage of BEVs relative to gasoline powered vehicles.

However, due to variation in the grid, it may be misleading to assume an average CO_2 reduction applies to every case. Due to differences in power generation mix (i.e., more or less coal, renewables, and the like), some regions may perform much better or much worse than the national (or even regional) average.

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Questions for the Record Submitted to Ms. Britta Gross

Questions from Ranking Member Maria Cantwell

Question 1: As more electric and alternative fueled vehicles enter into the marketplace and are on the road, this presents an opportunity for infrastructure development.

What are some of the obstacles in deployment of electric vehicle and alternative fuel charging infrastructure?

How can industry partner with the Department of Energy to bring about increased infrastructure?

What role do utilities play in electric vehicle charging infrastructure development?

Answer:
EV charging infrastructure today has not attracted sufficient investment to establish a compelling foundation of EV charging stations across market sectors. This suggests that the EV charging infrastructure market remains a challenging business case and thus uncompetitive. This market will become more viable and competitive over time, for example, as hardware costs decrease, as installations become more streamlined through enabling building codes, and as station utilization increases. But this early market currently requires additional investment to close the infrastructure gap and establish a network of charging stations that is highly visible to consumers and drives consumer confidence in the ability to drive EVs anywhere at any time. EV infrastructure is also key to attracting innovative and advanced mobility solutions, such as car-sharing, ride-hailing and autonomous vehicles. The ability to introduce and grow these advanced mobility services relies on a robust foundation of EV charging infrastructure, especially DC fast charging.

From a practical perspective, station siting poses a large obstacle to the buildout of EV charging infrastructure. Finding sites that can support EV charging loads, finding locations that consumers will find attractive and convenient, and getting various permits approved across multiple levels of government all pose challenges to infrastructure development. Without proper siting, some stations could be over-utilized, resulting in long waiting lines, while others could be under-utilized, undermining the business case for development. On the residential side, where most charging takes place, it has proved challenging to install EV charging at multi-dwelling units such as apartments and condos. Unique circumstances and the many parties often involved--Home Owners' Associations, property managers, and garage managers, for example—make installation burdensome and time consuming.

Finally, the lack of general consumer awareness about where EV charging exists poses an additional obstacle to the development of a robust network. Increased use of and better signage to direct consumers to EV charging stations can help spread awareness amongst road users.

The Department of Energy (DOE) can continue to play a very positive role to help increase EV infrastructure development. Past initiatives, such as DOE's EV Everywhere and the Workplace

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Charging Challenge, provided a platform to engage stakeholders across industry in robust discussions on how to develop EV charging infrastructure. This lead in part to the 2016 announcement by the White House of the "Guiding Principles to Promote Electric Vehicles and Charging Infrastructure." These principles represented the culmination of several years of vigorous work by stakeholders in government, including DOE, and the private sector. Ultimately forty-six industry members agreed with the vision articulated by the principles. These initiatives should be continued. Furthermore, the important work done in partnership between DOE and the Department of Transportation (DOT) in developing EV charging corridors can help form the basis of a national plan to implement EV charging infrastructure.

Utilities also play a vital role in the development of EV charging infrastructure and they must be active participants in increasing consumer awareness. Since most EV charging takes place at home and since workplace charging is key to growing EV awareness, the ability of utilities and their regulators to influence grid needs (for example, making sure electricity is cheaper than gasoline) is a key factor in growing the market. In 2007, GM partnered with the Electric Power Research Institute and over 50 utilities to launch the largest existing auto-utility collaboration focused on messaging and policy priorities, customer outreach and infrastructure, and vehicle to grid technology. The more varied role of utilities in the development of early market EV charging infrastructure, the better.

Question 2: Carbon fiber's high manufacturing cost and high performance make it an attractive recycling target, which can help bring about further adoption in the automotive industry.

There is a whole new industry that is beginning to emerge around composite recycling in Washington state.

Recycling not only prevents the waste going to landfills, but the recycling process itself significantly reduces the amount of energy needed compared to making new composites.

To what extent, if any, have your companies explored composites and composite recycling as you incorporate more advanced materials into your manufacturing processes?

Answer:
Earlier this year, GM revealed the 2019 GMC Sierra, which for the first time includes an option for a new carbon fiber truck bed, the "CarbonPro" box. The "CarbonPro" box saves 62 pounds in the truck bed. This new feature was developed jointly through a collaboration with Teijin, a premier carbon fiber manufacturer. Over the last several years, we have worked with Teijin to develop advanced carbon fiber/thermoplastic composite structures for production automotive applications. Since the system is recyclable, we can recycle scrap from the truck bed and use it in other components of the truck's structure. Though our use of composites and composite recycling is in its early stages, recycling makes sense due to the cost of composites. We would welcome the opportunity to keep you and your staff informed as our use of composites and composite recycling develops and matures.

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The Road to Tomorrow: Energy Innovation in Automotive Technologies
Question for the Record Submitted to Mr. Robert Wimmer

Question from Ranking Member Maria Cantwell

Question: Carbon fiber's high manufacturing cost and high performance make it an attractive recycling target, which can help bring about further adoption in the automotive industry.

There is a whole new industry that is beginning to emerge around composite recycling in Washington state.

Recycling not only prevents the waste going to landfills, but the recycling process itself significantly reduces the amount of energy needed compared to making new composites.

To what extent, if any, have your companies explored composites and composite recycling as you incorporate more advanced materials into your manufacturing processes?

Answer: Thank you, Senator Cantwell, for your question on Carbon Fiber (CF). Toyota is committed to the efficient use materials in our automobiles and designs that enhances recyclability at the end of life. As you mentioned, CF is energy intensive to produce, so finding ways to recycle and reuse this material has both environmental and CO_2 reduction benefits. To that end, Toyota is developing CF recycling technology and assessing ways to utilize recycled CF in body and component materials for new vehicles. Our philosophy is to use "the right material in the right place".