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A Comprehensive Approach to Transforming Transportation

Chairman Shimkus, Ranking Member Tonko, members of the Subcommittee, thank you for this opportunity to address this hearing on the future of transportation. My name is John Farrell, and I'm the Laboratory Program Manager for Vehicle Technologies at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) in Golden, Colorado. For the last five years I've managed NREL's research and development (R&D) efforts that fall within DOE's Office of Energy Efficiency and Renewable Energy (EERE) Vehicle Technologies Office portfolio. This work includes innovation in fuels, engines, electric vehicle technologies, fueling and charging infrastructure, and systems to support integration of vehicles, the grid, and the built environment. In addition, I act as Project Technical Lead for DOE's multi-lab, multi-office Co-Optimization of Fuels & Engines (Co-Optima) initiative.

Prior to joining NREL, I worked for 15 years in ExxonMobil's Corporate Research Laboratory. There, I applied my expertise to R&D programs, including collaborations between ExxonMobil and Ford, Caterpillar, Toyota, and other manufacturers. I have served on the advisory board for the Princeton Combustion Energy Frontier Research Center and have advised the U.S. Department of Defense on research initiatives. I hold a bachelor's degree in chemistry from Purdue University and a PhD in physical chemistry from the University of Colorado, and I completed my post-doctoral studies at Sandia National Laboratories.

Our nation's transportation system today is a marvel of utility and complexity. It might be tempting to assume that advances in vehicle technologies, especially engines, have run their course. Nothing could be further from the truth. In fact, we see before us a wave of innovation that will dramatically reshape the concept of transportation as we know it today—innovation that is being spurred on by DOE, NREL, other national laboratories, universities, and a wide range of industry partners.

The work led by DOE, NREL, and the other national labs holds the promise to revolutionize American energy productivity. This translates into mobility that is more convenient, affordable, and energy efficient, which will deliver major benefits including enhanced domestic economic prosperity and a stronger position in relation to global competitors.

Last year alone, vehicles moved people more than 3 trillion vehicle-miles and transported some 11 billion tons of freight—goods worth more than $32 billion each day to the American economy. Those vehicles used 70% of the record 19.69 million barrels of petroleum consumed per day. For the typical American, transportation is the second greatest expense after housing, and the average city commuter wastes approximately 42 unproductive hours per year stuck in traffic.

A full spectrum of transportation R&D is underway to improve the efficiency, performance, and affordability of transportation options for consumers and businesses. Electric-drive vehicles (EDVs), including fully electric, hybrid, plug-in hybrid, and fuel cell vehicles, are a substantial focus for NREL, as are autonomous and connected vehicle innovations. At the same time, we're making huge strides in improving the more conventional fuel and propulsion technologies that will continue to play an important role in transportation solutions for decades to come. Biofuel and natural gas-fueled vehicles provide opportunities for greater energy security and economic growth through the use of domestic resources.

In each instance, the world-class expertise and scientific capabilities of the national laboratories are being leveraged for the early-stage research that's pushing innovation forward. As valuable breakthroughs emerge, they provide government and industry decision makers with the scientific foundation needed to objectively weigh options, so consumers and businesses can reap the benefits.

Optimizing Efficiency of Vehicles with Internal Combustion Engines

Given the time it can take to develop and bring new automotive technologies to the marketplace, the high-energy density offered by liquid fuels, and the extensive network of gasoline distribution and fueling infrastructure, vehicles with internal combustion engines will continue to comprise a significant portion of the nation's vehicle fleet for at least the next few decades. DOE and NREL are spearheading the Co-Optima initiative to simultaneously improve fuel and engine performance with enhancements that build on the vehicle technologies and infrastructure already in use across the nation.

More efficient and sophisticated engines are already being introduced to the market, but their performance is limited by current fuels. Co-Optima researchers are thinking about fuels in a new way, as design variables to optimize these engines, with an eye toward revolutionizing the entire on-road fleet, from light-duty passenger cars to heavy-duty freight trucks.

DOE, NREL, and partners from eight other national labs and 13 universities are providing industry with the scientific underpinnings needed to accelerate introduction of high-performance fuels and engines. Much of the Co-Optima research is focused on components known as blendstocks that can be added to fuel and used in smaller but more powerful and efficient spark-ignition engines. Blendstocks can be produced from a wide spectrum of domestic resources, including non-food, domestic biomass such as forestry and agricultural residues, energy crops, algae, and other renewable and surplus waste resources. Leveraging domestic biomass resources can support rural economies, create much-needed new jobs in farm country, and enhance energy security while keeping energy dollars in America.

Recent Co-Optima findings pinpoint five options of chemical families that show the greatest promise for creating blendstocks capable of meeting these goals with advanced versions of the engines most of us use today. In addition to researchers' work in the lab, Co-Optima analysts are developing a comprehensive understanding of the cost, infrastructure and vehicle compatibility, and air quality implications of producing these blendstocks.

While the research team has made considerable progress towards its goals, significant work is still needed to maximize passenger vehicle fuel economy and performance. Current Co-Optima scientific experimentation is focused on identifying how engine parameters and fuel properties will work in tandem to improve light-duty gasoline-fueled spark ignition engine efficiency and emissions in the near term. Research is also examining strategies to deliver similar benefits through optimization of fuels and engines for heavy- and medium-duty trucks. In addition, the team is exploring development of revolutionary engine technologies for a longer-term, higher-impact series of solutions.

Ultimately, this early-stage R&D and analysis will provide fuel producers and engine makers with greater flexibility in delivering fuels and components needed to put the most efficient and high-performance cars and trucks on the road. Combined with other R&D already underway, Co-Optima strategies present the opportunity to save American consumers and commercial truck operators as much as $35 billion dollars per year at the pump, while maximizing vehicle performance and efficiency, leveraging domestic fuel resources, boosting jobs, and enhancing energy security.

Taking a Full-Systems Approach with Sustainable Mobility

Today’s transportation system is poised for dramatic transformation at the nexus of connectivity and automation. Rapid proliferation of automated vehicle technologies and connected, on-demand mobility services, coupled with lightning-speed advances in communications and sensor technologies, are revolutionizing the way people think about moving individuals and goods from Point A to Point B.

Optimized systems solutions can reduce congestion, smooth traffic flows, maximize occupancy for fewer “empty” miles, recommend quicker routes, and allow vehicle rightsizing. Identifying novel mobility solutions requires that we view mobility as a network of services, travelers, and environments—rather than simply vehicles and roads.

NREL's Sustainable Mobility research supports DOE’s Systems and Modeling for Accelerated Research in Transportation (or SMART) Mobility initiative in integrating research focused on fully-electric vehicles (EVs), the electric grid, renewable energy sources, buildings, and transportation infrastructure to move energy savings and connectivity to the next level.

Communication between vehicles and infrastructure gives drivers the ability to make better driving decisions, and automated controls can eliminate stop-and-start patterns by accelerating and slowing vehicles in concert with traffic light timing. Communication between cars not only improves safety, but also traffic flow by allowing automated control of speeds and distances between vehicles.

One important area of research is assessing the potential impacts of connected and automated vehicle technologies on fuel use and efficiency, vehicle miles traveled, and consumer costs. NREL analyses point to a wide range of possible energy scenarios, ranging from a tripling of light-duty vehicle consumption (due primarily to convenience encouraging a higher volume of travel), to a 40% decrease from today's levels of energy consumption (thanks in large part to technology improvements).

An element critical to the success of these transformational transportation solutions is EVs’ potential to help balance loads and improve the resiliency of our nation's electricity infrastructure. Renewable energy sources are naturally variable, requiring energy storage or a hybrid system to accommodate daily and seasonal changes. Vehicle-to-grid technology makes it possible to store surplus electricity generated from intermittent renewable solar and wind sources in EV batteries during non-peak periods and feed power back to the grid when needed, enhancing grid stability and reducing electricity costs at peak hours. Another solution is to produce hydrogen through electrolysis and use it to power a stationary or vehicle fuel cell to produce electricity during times of low power production or peak demand.

DOE and the national labs play a critical role in leading the early-stage scientific research and analysis needed to ensure that future mobility solutions maximize benefits for society and the economy while fostering a diverse domestic energy supply. NREL is working collaboratively with organizations including federal, state, and regional transportation agencies, and the lab is exploring opportunities to construct a dedicated facility to further enhance the nation’s capabilities in this burgeoning arena.

Accelerating Introduction of the Next Generation of EDVs

EVs use only one-third as much energy per mile driven as conventional vehicles. Since hybrid electric vehicles’ (HEVs') commercial introduction in 1999, more than 3 million

HEVs and more than 490,000 EVs have been sold, and automakers are rolling out new models at a record pace. Even with this encouraging growth in adoption rates, there are still barriers to overcome before we can expect EDVs—EVs, HEVs, plug-in HEVs, and fuel cell electric vehicles (FCEVs)—to dramatically decrease our nation's overall energy consumption.

NREL and the national labs have played a pivotal role in providing fundamental science and engineering expertise to spur the development and commercialization of EDVs. In 1993 NREL and DOE recruited the Big Three automakers—General Motors, Chrysler, and Ford—as partners to identify the most promising component technologies and system configurations, leading to some of the world's first production-feasible HEV prototypes. Principles established in the course of NREL's original research continue to guide EDV designs, and modeling and simulation software tools created by the lab are still being used by engineers across the country.

The lab has also played a critical role in the advancement of FCEV vehicle and infrastructure technologies. FCEVs offer the benefits of zero vehicle emissions, along with a driving range of more than 300 miles and a lightning fast refueling time of three minutes. However, even with FCEV models becoming commercially available in recent years, development of hydrogen fueling infrastructure is still in its infancy, and additional research is needed to address key remaining cost and performance barriers.

Charging infrastructure, battery technology, and affordability are three major, interrelated challenges to greater EDV adoption that NREL and DOE research is working to resolve. Most EVs cannot travel as far on a single charge as conventional vehicles do on a tank of gas, and charging stations are often fewer and farther between.

NREL and DOE are working in partnership with national labs across the country to identify the technical, infrastructure, and economic requirements for establishing a national extreme fast charging (XFC) network for EVs. In addition, we are exploring managed and wireless charging options that can eliminate some of the time and logistics constraints imposed by traditional plug-in charging and integrate with the electrical grid to balance loads. The labs are also working to validate infrastructure components and fueling protocols that can support a larger network of hydrogen fueling stations for FCEVs.

Connected to the charging issue are the performance and cost of batteries, which are the most expensive EV components. Research to drive down battery cost and size, while improving range, safety, lifetime, and performance is key to making EVs accessible to larger numbers of consumers. NREL research and award-winning innovations such as the Battery Internal Short-Circuit Device and Isothermal Battery Calorimeters are making it possible to accurately pinpoint and fix battery overheating problems that can lead to safety issues.

Finally, while EDV prices continue to drop and new models provide a wide range of style and performance options, the additional upfront cost continues to pose impediments to broader adoption. That is why a major focus of our early-stage research is technology that will help EVs attain cost parity with conventional vehicles.

The lab continues to innovate in partnership with automakers and component suppliers to refine technology, boost performance, lower cost, and enhance appeal of EDVs. The NREL-led Computer-Aided Engineering for Electric-Drive Vehicle Batteries (CAEBAT) project involves collaboration with other national labs and industry leaders such as Ford, GM, and Johnson Controls in accelerating the development and lowering the cost of EV batteries with new computational and simulation tools. Work with partners such as John Deere, Wolfspeed, and Toyota USA as part of the DOE-sponsored Manufacturing Innovation Institute is pointing the way toward wide-bandgap semiconductor materials for EV power electronic devices that are smaller and more efficient.

In the last five years, NREL's early-stage scientific breakthroughs in EV battery and power electronics technologies have been recognized with three R&D 100 Awards, known as the "Oscars of Innovation." Eventually, these more recent innovations will make their way into vehicles in the marketplace, delivering efficiency, performance, and cost improvements for consumers.

Building Momentum for Maximum Efficiency in Freight Operations

More than $13 trillion in goods, equivalent to two-thirds of our entire gross domestic product (GDP), are shipped across U.S. roads each year. With fuel costs amounting to 40% of truck freighting expenses, greater fuel efficiency could save commercial fleet operators hundreds of millions of dollars, create hundreds of thousands of new jobs, and spur an overall $10 billion increase in America's annual GDP.

Independently, commercial truck electrification, automation, and connectivity promise to be major game changers. Collectively, these innovations can revolutionize freight mobility. DOE and NREL are taking a total-systems approach that combines vehicle battery advances with exploration of how a highly efficient in-road charging network might deliver productivity, performance, and operational benefits.

Connected and automated trucks could significantly decrease the cost of moving goods. Optimization of EV technology for heavy- and medium-duty vehicles, along with development of fast wireless charging will be key factors in meeting cost and operational targets by diminishing battery expenses and reducing the downtime required to charge freight vehicles. Integrating data on freight movement with vehicle connectivity and automation holds great potential to make the transfer of freight from heavy-duty trucks to other modes of transportation—including delivery vans, trains, ships, or even possibly drones—more efficient.

Platooning systems for freight trucks reduce aerodynamic drag and safely decrease the distance between vehicles, allowing multiple vehicles to accelerate or brake simultaneously. These systems incorporate vehicle-to-vehicle communications, radar-based forward object detection, and active braking systems. NREL researchers, in partnership with organizations such as Peleton, have discovered that this relatively low-cost technology can be used on existing vehicles to deliver fuel savings of close to 10%.

Even though manufacturers such as Cummins and Tesla have announced plans for electric trucks, these early models will only serve niche applications. Significant R&D is still needed to adapt EV technology for trucks across the wide range of vocations that comprise the commercial trucking fleet as a whole.

DOE and NREL are exploring fuel cell and battery strategies for truck electrification that could substantially reduce fuel expenses, lower maintenance costs, and reduce emissions. Although technology and infrastructure for medium- and heavy-duty EVs, HEVs, and FCEVs still have a long way to go, battery and operating cost reductions are moving freight operations closer to the 3–4 times efficiency improvements typically delivered by electric drivetrains.

NREL has long been considered a leader in medium- and heavy-duty vehicle research, with evaluations of vehicles, infrastructure, operational practices, fuel-saving alternatives, and implementation considerations, combined with analyses using validated data from field-based measurements that factor in the multitude of variables needed to ensure meaningful benefits for large-scale freight operations. In addition to work focusing on EV, HEV, and FCEV technologies, researchers are also working to maximize efficiency and performance of hydraulic hybrids, as well as biodiesel and natural gas-powered medium- and heavy-duty vehicles.

The lab has forged strong partnerships with industry leaders including Bosch, Cummins, Volvo, Parker Hannifin, Smith Electric, Navistar, and Odyne, along with fleet operators, to make sure that scientific research is addressing key national-scale challenges. DOE and the lab hope to establish additional forums and facilities to leverage the collaborative expertise of these government, research, and industry partners.

The Need for Big Data, Analytics, and High-Performance Computing

Optimizing technology solutions for a complex interconnected transportation system requires utilizing and coordinating massive amounts of information with new high-speed computational modeling and simulation tools. While this data explosion is already transforming transportation, maximizing mobility and energy productivity calls for new robust and efficient techniques to capture, store, analyze, and execute in real time.

Additionally, accurate and faster-than-real-time models of integrated transportation networks for large metropolitan regions are needed to direct, coordinate, and schedule the movement of people and goods. NREL and DOE are exploring new approaches to pave the way for these groundbreaking changes through fundamental advances in big data, analytics, machine learning, high-performance computing (HPC), and optimization/control theory.

NREL already offers the nation's most credible and complete transportation energy efficiency clearinghouses for validated and up-to-date statistics, data analysis, and tools, pairing information from government and private sector partners with expertise in analysis and applications. The data-driven insight and decision-making capabilities facilitated by NREL's robust arsenal of integrated tools help industry partners overcome technical barriers and accelerate the development of advanced transportation technologies and systems that maximize energy savings and on-road performance while reducing operating costs.

NREL's portfolio of databases—Fleet DNA, Transportation Secure Data Center (TSDC), National Fuel Cell Technology Evaluation Center (NFCTEC), and Alternative Fuels Data Center (AFDC), to name a few—feature real-world, on-road transportation and energy systems data and contribute to numerous R&D activities. Coupled with these world-class data resources and capabilities is NREL's wide assortment of models and tools that enable users to perform a wide array of tasks—evaluate real-world vehicle efficiency, compare powertrains, assess component improvements, use real-world data, or simulate representative drive cycles evaluating systems and components, compare battery-use strategies, and much more.

Conclusion

Yes, significant improvements to vehicle efficiency are underway, and concurrent advances in connected and automated technologies are rapidly transforming America's transportation ecosystem. Passenger vehicle fuel economy has improved significantly in recent years. Today's drivers can choose from EV, HEV, and optimized gasoline-fueled models with a range of automated features. Ride-sharing services make it possible to hail a car, track its arrival, and pay the fare with just a tap on a smartphone app. The Internet of Things is enabling connectivity and communications among drivers, vehicles, roadways, charging systems, transit networks, buildings, the utility grid, and more.

Research breakthroughs have helped make this possible, and marketplace competition continues to drive industry to embrace innovation. That said, we still have a long way to go, and DOE, NREL, and the national labs are working hard to push efficiency even further. Expanded automated vehicle capabilities could deliver even more convenient and affordable mobility options. More extensive vehicle electrification and charging infrastructure could drive down costs and boost efficiency. Introduction of more commercial FCEVs and hydrogen stations could result in a truly zero-emission fleet.

At the same time, we need to bridge from existing transportation resources. Americans will keep driving vehicles powered by internal combustion engines for years to come, so let’s work to make them as efficient and clean as possible. Our nation also has an abundance of domestic natural gas and biomass reserves that should be more effectively leveraged to provide additional transportation options.

We will continue to build on our existing relationships to advance this vision, including DOE public-private partnerships such as U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy) and the 21st Century Truck Partnership.

DOE, NREL, and the other national labs will remain dedicated to pursuit of innovations that promise substantial benefits to consumers and businesses, with new fundamental science and sophisticated systems-level technology integration to ensure that widespread adoption provides maximum affordability, reliability, and security benefits.