Testimony of Dr. Chris Gearhart
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I would like to thank Chairman Murkowski, Ranking Member Cantwell, and the members of the Committee for the opportunity to speak about the status of innovation in the automotive industry. I am Chris Gearhart, the Director of Transportation Research at the National Renewable Energy Laboratory (NREL), the Department of Energy's primary laboratory for research and development of renewable energy and energy efficiency technologies. Prior to coming to NREL, I worked at Ford Motor Company in their Scientific Research Laboratory for 16 years. During my last six years at Ford, I led their Hydrogen Fuel Cell Vehicle research teams.

Innovation has always been an important part of the automotive industry, but today the rate of change is faster than ever. There are technologies on the horizon that promise a future with cars that don't crash, that don't damage the environment, and that create new and exciting business opportunities we couldn't have imagined just a few years ago.

The Department of Energy (DOE) and its national laboratories are helping bring about this future. In particular, we are putting the unique expertise and capabilities of our national labs to work on new technologies that will reduce emissions, and promote energy diversity and security. Today the transportation sector in the United States accounts for 72% of the country's petroleum use and about one third of the United States' greenhouse gas (GHG) emissions.[1] Of these emissions, cars and light-duty trucks contributed 57%, roughly 1.5 billion metric tons per year (1,514 MMT in 2005)[2]. Recent studies have shown that a portfolio of technologies could reduce domestic petroleum consumption in the light-duty transportation sector by 80% by 2050.[2,3]

My testimony today will focus on the role of technology supporting this vision in four areas:

- Connected and autonomous vehicles
- Vehicle electrification and integration with the electrical grid
- Hydrogen fuel cell vehicles and hydrogen infrastructure
- Efficient internal combustion vehicles operating on biofuels

1 Annual Energy Outlook 2013, EIA, 2013

2 Transportation Energy Futures, EERE, 2013

3 Transitions to Alternative Vehicles and Fuels, National Research Council, 2013

Connected Vehicles
In the very near future, cars and travelers will transmit and receive information from each other and from the rest of the infrastructure that makes up the cities and highways they move through. This connectivity creates the potential to optimize mobility, energy consumption, and dramatically reduces the risk of car crashes. This future is coming very quickly. Although not common yet, many new cars are Wi-Fi enabled. Two thirds of American's have smart phones. These smart phones are turning travelers into sensors that provide real time data about traffic conditions on our highways. Its clear that Big-data and cyber-security are going to be increasingly important as connected vehicles become more prevalent. The national labs have significant expertise and capabilities in these areas.

Initial studies by researchers at NREL and Oak Ridge National Laboratory attempt to assess the range of possible energy effects of connected and autonomous vehicles.[4,5] These studies find that there are potentially large energy effects, but that the magnitude of these effects are uncertain. Technology that enables autonomous vehicles is advancing quickly. This time of year—with the Consumer Electronics Show just over, the North American and International Auto Show in Detroit in full swing, and the Washington Auto Show starting tomorrow— the number of press releases related to autonomous demonstration and partnerships is astonishing.

Cars are becoming the next consumer electronics, and consumer electronics companies are getting into the car business. One interesting example of this is that NVIDIA, a company that traditionally makes graphics cards for gaming platforms, is casting itself as a supplier of computer chips for autonomous vehicles. Their argument is that autonomous vehicles will require rapid onboard computing power and that the computing tasks required to fuse data from multiple sensor platforms into a coherent representation of what surrounds a vehicle are very similar to the tasks required to render a realistic 3-D image based on a mathematical model generated by a computer game.

At the highest level there are three ways that connectivity and automation can impact energy and emissions. First, they can improve the efficiency of vehicle movement so that each mile driven requires less energy. Second, they could enable wider adoption of vehicles that use alternative energy and help to shift transportation energy to more renewable energy sources. Finally, these technologies, particularly self-driving cars, will remove barriers to driving—potentially increasing the number of miles driven dramatically.

Connected vehicles that have information about various routes, traffic conditions, signal timing, and other factors impacting energy use can select the route that

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[4] A. Brown, J. Gonder and B. Repac, "An Analysis of Possible Energy Impacts of Automated Vehicles" , in Lecture Notes in Mobility, edited by G. Meyer and S. Beiker (Springer, City, 2014), pp. 137

[5] D. MacKenzie, Z. Wadud and P. Leiby: A First Order Estimate of Energy Impacts of Automated Vehicles in The United States, in 2014 TRB Annual Meeting, City, 2014

minimizes energy required at the wheels. If the vehicle is also a hybrid or plug-in hybrid electric vehicle, it may also be able to adapt the hybridization strategy to maximize the efficiency of the powertrain over that route. Vehicles that are both connected and autonomous can move in concert with each other, creating smoother traffic flow and reducing the amount of acceleration and deceleration when driving. Similarly, interactions among vehicles, traffic signals, and other infrastructure will optimize traffic flow in urban areas and reduce the amount of energy required for the same distance traveled. In long-haul trucks, connectivity and automation will allow trucks to form platoons and reduce energy consumption. An NREL study showed that at highway speeds, class-8 trucks could reduce fuel consumption by 6.4%. [6]

Connectivity may enable the use of alternative energy for transportation. Connected vehicles will know the location of the nearest compatible charging or fueling station. This potentially reduces some of the barriers to market penetration of these vehicles. Connected battery electric vehicles and plug-in hybrid vehicles can interact more directly with the electric grid. This may enable a deeper penetration of renewable electricity on the grid. Autonomous vehicles could self-drive to charging and fueling stations, returning fully charged when the driver needs them. This could increase the effectiveness of charging and fueling infrastructure, delivering the same benefits with fewer stations.

The greatest uncertainty associated with connected and autonomous vehicles is the impact these technologies will have on vehicle miles traveled. These technologies may make mobility more effective so that the same societal benefit can be achieved with fewer miles traveled. For example, connectivity enables ride- and car-sharing business models, such as Uber and Lyft, to have the potential to increase vehicle occupancy and mobility efficiency. It is also possible that these technologies will remove barriers to transportation access, which may increase the total number of miles driven. Presumably this would increase the mobility benefit to society, but it would also increase transportation energy use and emissions. Finally, with a fully autonomous vehicle, one can envision scenarios in which self-driving cars significantly reduce the cost of time lost while driving. This could promote greater urban sprawl and significant increases in miles traveled.

From an energy and emissions perspective, many of these effects are working in opposite directions. It remains to be seen which effect will be dominant. The Office of Transportation within the DOE's Office of Energy Efficiency and Renewable Energy is bringing together a consortium of national lab researchers to investigate the energy and greenhouse gas impact of these technologies. This consortium, known as the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility consortium, will examine the nexus of energy and mobility for

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6 Lammert, M.; Duran, A.; Diez, J.; Burton, K.; Nicholson A. (2015). "Effect of Platooning on Fuel Consumption of Class 8 Vehicles Over a Range of Speeds, Following Distances, and Mass." NREL/CP-5400-62348 http://www.nrel.gov/docs/fy15osti/62348.pdf

future transportation systems. Initial research will focus on connected and automated vehicles, urban science, decision science, multi-modal transport, and integrated vehicle-fueling infrastructure systems.

DOE's SMART Mobility consortium will support robust analytical and foundational efforts to define and frame opportunities in this space. In addition to models, tools, and applied analysis, the consortium will also support focused technology demonstrations in conjunction with cities or states to spur commercialization and inform future activities across DOE's transportation technology portfolio.

One example of research in this area that we are doing at NREL is an ARPA-e funded project called The Connected Traveler: A Framework to Reduce Energy Use in Transportation. For this project, NREL and our partners will create a network architecture that approaches sustainable transportation as a dynamic system of travelers and decision points, rather than one of vehicles and roads, in order to create personalized energy-saving opportunities. The project will use currently available transportation data from an urban U.S. city, as well as simulated data based on real-time and demographic information. The goal of the project is to develop algorithms to understand a traveler's preferences, tailor recommendations to the user, and identify personal incentives that will enable transportation system energy benefits.

Vehicle Electrification

Battery electric vehicles (BEVs) have the greatest potential to reduce vehicle energy consumption. BEVs convert about 60% of the energy from the electric grid to power at the wheels. For internal combustion vehicles this is closer to 20%.[7] This means that BEVs use only about one third as much energy per mile driven as conventional vehicles. Yet significant challenges to widespread deployment of battery electric vehicles remain. Chief among these are cost, energy density, recharge time, and charging infrastructure.

Because of the low energy-density of batteries, the distance a BEV drives on a single battery charge is considerably less than that possible on a typical tank of gasoline. Even with a large penetration of mass-market 200-mile range electric vehicles, such as the Chevy Bolt and the Tesla Model-3, it will be difficult to electrify all of the vehicle miles traveled. Most vehicle trips are short enough that electric vehicles have sufficient range to make these trips, even with current battery energy densities. Although short trips account for most of the trips taken, long trips account for a disproportionate fraction of the miles traveled, and the range of BEVs is not sufficient for these trips. Presumably, these additional trips will still be taken, just not in an electric vehicle. This sets up a dilemma for electric vehicle drivers. If batteries are small, they are inexpensive, but will electrify fewer of the driver's trip needs. As batteries get bigger, they will electrify more of the driver's trips, but at a

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7 https://www.fueleconomy.gov/feg/evtech.shtml

higher marginal cost. These two competing effects will likely limit the number of miles electrified. This effect is mitigated somewhat with plug-in hybrid electric vehicles. With these vehicles, the range limitations will not be a problem, but there will still be a limit to the number of miles that are electrified.[8]

The national labs are using their expertise in Li-Ion battery chemistry, high performance computing and simulation to help the automotive industry to shorten design time and improve the performance of automotive batteries. One example is the Computer-Aided Engineering for Electric-Drive Vehicle Batteries (CAEBAT) project. CAEBAT is accelerating the development of and lowering the cost of lithium-ion (Li-ion) batteries for next-generation electric-drive vehicles by developing new computer aided engineering tools for battery development.

Wide-band gap semiconductor materials allow power electronic devices to be smaller, more efficient and operate at higher temperatures than silicon based power electronics. This has the potential to further increase the efficiency of BEVs. The fact that these devices can operate at higher temperatures may also reduce the size of the cooling system required. The Next Generation Power Electronic Institute is a DOE-sponsored Manufacturing Innovation Institute that is bringing together 18 companies, five universities and two national labs to form a center of excellence in the development of wide-band gap semi-conductor devices.

Wireless charging is likely for next generation electric vehicles. In addition to convenience for consumers, wireless charging provides a mechanism for connected and autonomous vehicles to connect to the energy grid more directly. This is one of the ways that connected vehicles could access more sustainable energy.

Hydrogen Vehicles

Fuel Cell Electric Vehicles (FCEVs) fall between BEVs and internal combustion vehicles on the efficiency spectrum. They are about twice as efficient as conventional gasoline ICE vehicles.

Perhaps the most exciting development in FCEVs is the commercial introduction of the Hyundai Tucson and Toyota Mirai and the launch of the new Honda Clarity later this year. The commercial introduction of fuel cell vehicles has been made possible by more than a decade of innovation, supported by the DOE's Fuel Cell Technologies Office (FCTO), resulting in a more than 50% decrease in the cost of fuel cell systems. Projected fuel cell system costs have dropped from $124/kWh in 2006 to $53/kWh in 2015.[9]

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[8] M.A. Tamor, C. Gearhart and C. Soto: A statistical approach to estimating acceptance of electric vehicles and electrification of personal transportation Transportation Research Part C: Emerging Technologies. 26, 125 (2013).

[9] DOE Hydrogen Program Record 15015

Of course there are still significant challenges to be met, including cost-effective generation of renewable hydrogen and development of a robust hydrogen-fueling infrastructure. NREL is actively involved in all aspects of the DOE's hydrogen and fuel cell research portfolio.

Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) is a project launched by the FCTO within the Office of Energy Efficiency and Renewable Energy. This project leverages capabilities at the national laboratories to address the technology challenges related to hydrogen refueling stations. Led by Sandia National Laboratories and NREL and supported by a broad array of public and private partners, the H2FIRST project is a strong example of DOE's efforts to bring national lab capabilities and facilities to bear on both immediate and mid-term challenges faced by industry. H2FIRST was established by DOE's FCTO directly in support of H2USA, a public-private partnership co-launched by DOE and industry in 2013.

The Hydrogen Infrastructure Testing and Research Facility (HITRF) at the DOE's Energy Systems Integration Facility is an important part of the H2FIRST project. It consists of hydrogen storage, compression, and dispensing capabilities for fuel cell vehicle fueling and component testing.

The HITRF is the first facility of its kind in Colorado and will be available to industry for use in research and development activities. In addition to fueling fuel cell electric vehicles, the HITRF will serve as a proving ground for component, system, and control testing. The facility is representative of current commercially available hydrogen fueling stations, enabling NREL to validate current industry standards and methods for hydrogen fueling as well as perform testing for next-generation technology and controls.

Other examples of fuel cell innovations coming out of NREL are in renewable hydrogen production and hydrogen energy storage. Hydrogen can also enable intermittent renewables. NREL has demonstrated hydrogen production from water using solar and wind power. The hydrogen is then stored and used in fuel cells to provide power during off-peak hours when there is no wind or sun. NREL is also a world leader in the direct conversion of sunlight to hydrogen without the need for the intermediate step of power production and will continue to focus on much-needed advances.

Biofuel vehicles

Finally, I would be remiss if I didn't talk at least briefly about innovations related to the internal combustion engine. Although electrified vehicles will become increasingly important in the future, internal combustion engines will remain an essential part of the transportation system, particular for heavy-duty transportation. The DOE and the national labs are working on multiple research areas to improve the efficiency of internal combustion engine vehicles and the development of advanced biofuels to reduce the emissions impact of these vehicles. One area that is particularly exciting is ongoing research lead by the DOE to investigate the potential to co-optimize engines and biofuels to make the most efficient biofuel-engine system.

More energy-efficient and environmentally friendly vehicles call for simultaneous increases in powertrain efficiency and reductions in emissions, requiring substantial advances in internal combustion engines. In turn, advances in engine combustion rely on a thorough understanding of fuel properties, especially ignition kinetics behavior. By focusing on the intersection of fuel's physical and chemical properties, ignition kinetics, combustion, and emissions, NREL is supporting coordinated development of biofuels, advanced petroleum-based fuels, and advanced combustion engines.

NREL's combustion R&D bridges fundamental chemical kinetics and applied engine research to investigate how new engine technologies can be co-developed with fuels and lubricants to maximize energy-efficient vehicle performance. Researchers examine what happens to fuel inside the engine, how fuel interacts with equipment, and what emissions are produced. The results from and tools developed by the lab guide engine manufacturers in developing equipment and controls.

The DOE has launched an initiative, jointly funded by the Vehicle Technologies Office and the Bioenergy Technologies office, coordinating the efforts of more than 100 expert researchers across the national lab system to advance the goal of co-optimizing fuels and engines. This team will build on decades of remarkable advances in both fuels and engines. Groundbreaking research over the past 10 years has identified new combustion engine strategies that, especially if optimized to run on new fuels, would offer significantly higher efficiency and produce lower levels of engine-out pollutants than current engines. At the same time, research is advancing low carbon fuel options that can blend with petroleum-based feedstocks to significantly reduce GHG emissions and enable engine performance gains.

The confluence of these developments provides a rare opportunity to introduce co-optimized new fuels and engines that can achieve dramatic performance improvements at the enterprise level. Specifically this initiative targets a 30% reduction in per-vehicle petroleum consumption beyond the levels to be provided by the expected evolutionary, policy-driven improvements to today's fuels and engines. This 30% improvement reflects two contributions – efficiency and displacement. The efficiency improvement reflects fuel consumption reductions possible through introduction of new fuels that allow engines to operate at their maximum efficiency, freed from the constraints imposed by current fuels. While the engine of 2030 is expected to be more efficient that today's, we expect that new fuels could allow an additional 7-15% reduction in fuel consumption. The second contribution reflects displacement of petroleum through the introduction of 16 billion gallons of advanced biofuels by 2030.

Another important topic that doesn't fit into any of my four categories, but will have significant impact on fuel-economy is innovation in the area of light-weight materials. By replacing heavy steel components with components made of less dense metals, plastics, or composites, it is estimated that vehicle masses can be reduced by up to 20%, resulting in a 12%–16% reduction in fuel consumption and a similar reduction in GHG emissions. Larger mass reductions may be possible, but will require the wide spread adoption of active crash-avoidance technologies.[10]

The Institute for Advanced Composites Manufacturing and Innovation (IACMI), supported by the DOE's Advance Manufacturing Office and lead the University of Tennessee, will work to develop new low-cost, high-speed, and efficient manufacturing and recycling process technologies that will promote widespread use of advanced fiber-reinforced polymer composites. IACMI will focus on lowering the overall manufacturing costs of advanced composites by 50 percent, reducing the energy used to make composites by 75 percent, and increasing the ability to recycle composites by more than 95 percent within the next decade.

In conclusion, these are very exciting times for the automotive industry. The OEMs are coming out with new technology at an unprecedented rate. The DOE's national laboratories have unique world-class research capabilities that can help the automotive industry meet critical fuel-economy and emissions objectives. It is clear that the range of research now underway for these rapidly evolving technologies will achieve many benefits for the nation's transportation system — while improving energy efficiency, lessening environmental impacts, driving U.S. competitiveness, and providing all of us with more and better options for the mobility on which we all depend. These are exciting times.

Thank you. I would be happy to address any questions.

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[10] N. Lutsey, "Review of techical literature and trends related to automobile mass-reduction technology)