Automated, Connected, and Electric Vehicles

An Assessment of Emerging Transportation Technologies and a Policy Roadmap for More Sustainable Transportation

A report for the

GRAHAM ENVIRONMENTAL SUSTAINABILITY INSTITUTE

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Preface and Acknowledgments

The authors thank the Graham Environmental Sustainability Institute for the grant that enabled this report and the associated transportation policy roadmap. In our grant application we identified four major problems with our current transportation system: Our near total dependence on oil for transportation; the high and unacceptable injury and death toll from road accidents; the high and increasing cost of traffic congestion, and the relatively low use of public transportation.

Just three years ago when we applied for the first phase of the grant it seemed that the transportation technology breakthroughs and associated policies that could meaningfully address these major problems were years if not decades away. One of our tasks was to better estimate the timing of those technology breakthroughs. That would in turn help establish a timetable for a set of policy recommendations to help enable the public sector to integrate these private sector breakthroughs within the broader public policy goals of creating livable, sustainable communities.

What we have found is that most of the emerging technologies were not as far in the future as we had thought, and the need for a public policy roadmap to integrate these technologies that this report was intended to address was more timely and urgent than it seemed just three years ago. We also found that these emerging technologies were likely to have a more powerful and positive effect when they were coordinated and deployed together. One goal in the policy roadmap section is to identify ways to accelerate and integrate these emerging technologies.

In the space of just three years, a mass market for electric vehicles has emerged with 16 models of EVs available and with more coming. Smarter, more connected and safer vehicles are also now being sold. Nissan, Volvo, Tesla, GM and others are predicting personal vehicles that will assist drivers in achieving what is basically an autopilot mode under some circumstances as early as 2017. Volvo promises in ads that its cars will not cause accidents by 2020.

Although, as this report will detail, the timeline for completely driverless vehicles will take longer, many of the benefits and challenges of increasingly autonomous vehicles are sufficiently certain now for public policy and planning purposes.

In addition to the grant, the authors thank the Graham Institute for its Integrated Assessment framework and its focus on Livable Communities, which helped guide us in preparing this report. To a significant degree our work has been inspired and informed by the writings and work of University of Michigan associated authors and researchers.

In addition to the University of Michigan's Connected Vehicle Proving Center, led by co-author Professor Steve Underwood, we owe a debt of thanks to Susan Zielinski and her colleagues at the University of Michigan's SMART program (Sustainable Mobility & Accessibility Research & Transformation). Special thanks are also due to David Berdish, recently retired from Ford, whose work with Susan Zielinski on transforming transportation provided context for linking the emerging personal transportation technologies with public mobility networks and forms a key part of our overall approach. Several of David's colleagues at Ford, including John Viera, Michael Tinski and Nancy Goia, provided early advice and information. Bill Ford's presentations, including at the World Mobile Congress on Ford's Blueprint for Mobility and Ford's other sustainable transportation work have also been influential.[1]

We were also encouraged and informed at the outset of our work by the book, *Reinventing the Automobile: Personal Urban Mobility for the 21st Century,* two of whose authors, Lawrence Burns and Christopher Borroni-Bird, have been part of the University of Michigan community. The work of NextEnergy based in Detroit and associated with SMART has also been influential in our thinking. We have also worked with and been influenced by the insights and predictions of former Vice Chairman of General Motors, Bob Lutz, who is credited with launching the Chevy Volt and who now serves as Chairman of Via Motors.

We also would like to acknowledge our longstanding and informative relationships with Thurston Regional Planning Council, INRIX, EDTA (the Electric Drive Transportation Association), CalStart, the Electrification Coalition, Microsoft, Google, Ford, Nissan, Cisco, General Motors, The Rocky Mountain Institute, Liberty Mutual Research Institute for Safety, Climate Solutions, The Bipartisan Policy Center, the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Department of Housing and Urban Development (HUD), the U.S. Department of Defense (DoD), Southern California Edison, Portland General Electric, Seattle City Light, AAA Washington Tacoma Power, the Electric Power Research Institute, the Washington State Department of Transportation, the University of Washington, Joint Base Lewis-McChord, the Pacific Northwest National Laboratory (PNNL), the Idaho National Laboratory (INL), the National Oceanic and Atmospheric Administration (NOAA), The Puget Sound Regional Council, The Puget Sound Clean Air Agency, The Port of Seattle, and others who have provided insights and advice as speakers and panel members in a series of conferences we have organized, including one commemorating the 50th anniversary of the Seattle World's Fair called "*Transforming Transportation in the 21st Century*." This was the first conference we organized with this report in mind, and without the financial support and inspiration from the Graham Institute it would not have occurred.[2]

We also thank the U.S. Transportation Research Board (TRB) and the Association of Unmanned Vehicles Systems International (AUVSI) for sponsoring a key conference earlier this year on vehicle automation in which the authors participated and which provided additional insights on the timing of the emerging technologies as well as identification and informed discussion of many of the key policy issues facing those technologies. The previous TRB conference in 2013 also lead to an influential book called *Road Vehicle Automation,* [3] published in June 2014. Thanks to the Graham Institute, the authors of this report were able to write two chapters for that book, which summarizes some of the research and ideas set out in more detail in this report.

We also want to acknowledge Mohammad Poorsartep who managed this project in the first year and went on to greater things as a project manager at Texas Transportation Institute. Finally we want to acknowledge the help provided by Jane Lappin, Steve Shladover, and Bob Denaro who helped with the initial presentation of the results to the Automated Vehicle Symposium in San Francisco and helped craft the questionnaire for this audience. Mary Doyle, Carolyn Taylor, and James Sherman helped organize the SAE Convergence 2014 survey and invited the attendees to participate.

Introduction

This report presents a policy roadmap to advance sustainable transportation based on an integrated assessment of innovations in connected, automated, and electric vehicle technologies. It is written for and intended to assist policy makers in accelerating and integrating these innovations to help create safer, more affordable and more sustainable personal mobility.

Each of these emerging technologies taken alone represents an important advance in surface transportation. Taken and deployed together these three technologies can help resolve four of the major problems with current vehicle technology and address the objections some have to individual components of each of the three main emerging transportation technologies.

We will first summarize four major problems with current vehicle technology and briefly outline the emerging technologies that will help address and ultimately solve those problems.

We then discuss the methods and results from our ongoing expert review of vehicle automation issues and timing. The full method, survey, and results are described in the Automated, Connected, and Electric Vehicles: Expert Forecast and Roadmap for Sustainable Transportation. [4]

We conclude with a public policy roadmap that incorporates the data and suggestions from the expert review and the results from our extensive discussions from speakers, panel members and experts from the conferences we have organized and attended.

Our roadmap includes suggestions for a large scale demonstration project at one of the biggest urban area military bases in the country, Joint Base Lewis-McChord (JBLM) for reasons outlined in our initial grant application and in our chapter in the book *Road Vehicle Automation*.

It is fitting for a large scale demonstration project to be located on a Department of Defense base. It was the DoD that initiated significant interest in autonomous vehicles with a series of DARPA (Defense Advanced Research Projects Agency[5]) challenges, starting ten years ago in 2004.

The results of the first challenge supported the then prevalent view that driving was too complicated a task for machines. The challenge was to build a driverless vehicle that could navigate a 150 mile route through the Mohave Desert. Only one vehicle made it just eight miles into the course, and it took several hours to go that far. As a result, many experts, even those on the participating DARPA teams, believed that driverless cars would never happen.

But, as Erik Brynjolfsson noted[6]: "Just six years later, however, real-world driving went from being an example of a task that couldn't be automated to an example of one that had." Autonomous driving "on populated roads *is* an enormously difficult task, and it is *not* easy to build a computer that can substitute for human perception and pattern matching in this domain." He added: "None of this is easy. But in a world of plentiful accurate data, powerful sensors, and massive storage capacity and processing power it is possible. This is the world we live in now. It's one where computers improve so quickly that their capabilities pass from the realm of science fiction into the everyday world not over the course of a human lifetime, or even within the span of a professional career, but instead in just a few years."

Exemplified in Moore's Law, the doubling of computing power every two years has meant that in ten years we have had five doublings of power, leading to a vast increase in data processing, storage, and analysis. In addition, new and less expensive sensors have emerged to acquire data in real time.

We have come far in ten years with connected and electric vehicles as well. The first smart phone was sold by Apple in June of 2007 just seven years ago and now smart phones and related connected services including Google maps and navigation apps are ubiquitous. Ten years ago there were no electric cars being made or discussed by any major automaker. The first Nissan Leaf was sold just three years ago and now virtually all of the major automakers sell all-electric or plug-in hybrid electric cars.

The key point is that 10 years ago no one would have predicted that we might soon have the tools necessary to address some of the most persistent and challenging problems with existing transportation systems. As a result, public policy is now lagging behind the technology. One of the first challenges is to increase awareness of the tools we now have though education and project demonstrations.

The early history of electric and unmanned elevators provides some perspective. At first there was resistance due to fear, uncertainty, and doubt about safety and other concerns. It took years before most of the public was comfortable with taking an elevator without a human operator. But now no one thinks twice about getting on one and instead we are now irritated when it takes more than 30 seconds for one to come. Elevators have remade cities once limited to five story buildings with stairways. Elevators are now so common that no one remarks about them or even pauses to think about the fundamental changes they produced.

As with elevators, connected, autonomous and electric cars will not displace other transportation systems. These emerging technologies will not displace the livable sustainable community progress in encouraging more pedestrian walkability, biking, and transit. In fact, these technologies will make walking and biking much safer.

Instead, we recognize that personal automobile mobility will remain a major part of daily life in all communities, which needs to be much safer, faster, greener and more affordable. The U.S. Census Bureau reports that 86 percent of trips to work in 2011 were by private vehicles. The U.S. Energy Information Administration forecasts that annual miles per driver will rise from 12,000 in 2014 to 13,000 in 2032.[7] Although miles of driving per capita have fallen with high gas prices and the recession, the last several months have seen a resurgence of auto buying and travel. Every old technology car sold today will be on the road another 16 years or so.

A goal of the Integrated Assessment (IA) is to investigate short, medium, and long-term technical and policy solutions that will support the design of automated, connected, and electric power automotive solutions that are injury free and accident free, healthy, relaxed, efficient, and productive, and do not discriminate with regard to age and health. Whenever the discussion addresses state and local considerations the states of Michigan and Washington will be used for case study. We have involved planners from the Seattle-Tacoma region of Washington State to provide input on the local planning considerations addressed in the study.

The end we have in mind is a new personal urban mobility system without air pollution, nonrenewable energy consumption, deaths, injuries, wasted time and congestion.

Our expert survey was designed to help us construct a roadmap on how the vision will be attained, identifying research and development priorities, as well as identifying milestones and forecasting dates along the way[8].

The survey addressed both technological and policy milestones related to our connected, automated, and electric vehicle vision. Components of this advanced vehicle system include:

- Sensor technology for on-board sensor systems, which are able to deliver accurate and reliable information about the vehicle's environment including moving objects and pedestrians in any light, weather, and road conditions.
- Perception algorithms that use information obtained from on-board sensor systems and enable the reliable detection and recognition of relevant traffic features, such as traffic signs, curbs, obstacles, pedestrians, and vehicles.
- Localization technology that is crucial for path planning and decision-making. On a limited network of streets, the use of localization methods based on global positioning systems (GPS) and differential GPS (DGPS) along with inertial navigation (INS) may be sufficient. However, when moving on an extensive road network, it will be helpful to adapt an on-vehicle approach independent of GPS that matches a map of the area to the sensed environment to determine the vehicles precise location in the context of the map.
- Communication technology that enables reliable exchanges of information between autonomous vehicles (vehicle-to-vehicle, V2V), but also between the infrastructure and vehicles (vehicle-to-infrastructure, V2I). Communication helps owners to track their vehicle and enables cooperation between vehicles, and is relevant for improving the efficiency and safety of autonomous vehicles.
- Low-level vehicle control includes the control of actuators for steering angle, accelerator, brakes, and transmission, all exemplified in the widely-implemented electronic stability control.
- High-level vehicle control such as real-time decision-making, and the execution of driving maneuvers.
- Electric motors, battery capacity, and support of charging or battery-swapping capability

The forecast addresses near-term early stage autonomous vehicles limited to specific geographic areas such as 1) use in last-or-first-mile applications that feature separated or controlled road access or 2) areas with limited access such as on a campus or military base. Some analogize this concept as horizontal elevators. Another area of use for such systems would be in self-parking autonomous garages.

Next to be addressed are intermediate automated driving such as on limited access highways where the vehicle is self-driving from entrance to exit. Commuters, for example, would have productivity or free time while on the highway. This has been compared to autopilot systems.

Finally the forecast addresses fully automated or self-driving vehicles that are designed to carry passengers from the beginning to the end of their trip whether the vehicle is owned by the passenger or whether it is shared like an automated taxi. This concept is compared to chauffeured mobility. In such an end state fully autonomous vehicle could provide single mode, door-to-door transportation, like a taxi. This would be a quality-of-life enhancement for the mobility impaired in the many suburban and rural geographies where existing solutions are not available.

In summary, we believe that the policy community remains largely unaware of the pace and extent of the innovative and disruptive technologies that form the core attributes of smart, connected, autonomous electric vehicles. We also believe that the combination of these disruptive technologies is more powerful than implementing each one separately. In order to optimize the combination of technologies and approaches, there needs to be an integrated assessment and close coordination between the public and private sectors in the design and testing of these concepts in comprehensive real-time community pilot demonstration projects. The purpose of this report is to identify the research and policy challenges associated with the vision of an automated connected and electric vehicle and share this with public officials to enable a more informed dialogue on the future of road transportation in the United States.

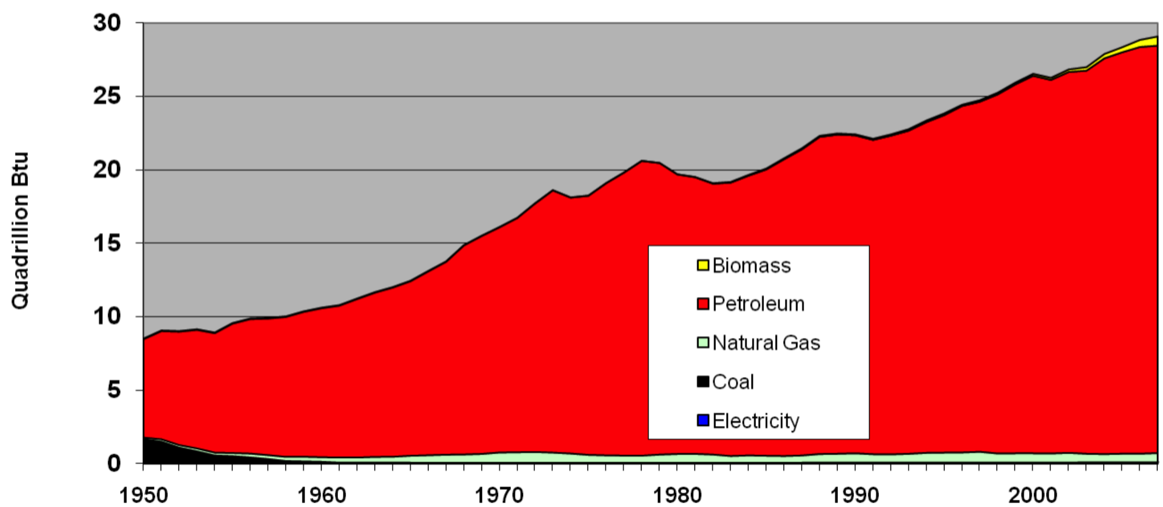
Four Major Problems with Current Transportation Technology

In a broad overview, there are four major problems with current surface transportation systems that can be significantly reduced with a combination of connected, autonomous and electric vehicles.

Problem 1: Oil Dependence in Transportation

Oil Has a Near Monopoly as a Transportation Fuel

Oil dependence in transportation harms human health, the economy, national security and the environment. Oil fuels 97 percent of U.S. transportation, as the chart below shows. The near total monopoly oil has on transportation is by itself a cause for concern. But, the negative consequences of oil dependence are serious and far-reaching.



Although the cost of oil dropped dramatically from over $100 a barrel in June 2014 to under $55 a barrel in December 2014, it is worth a reminder that oil was only $20 a barrel in the early 2000's both before and after 9/11. The steep rise in oil in 2007-2008 was one of the triggers for what became known as the Great Recession. As a fungible world commodity the price of oil depends on demand in other countries and supply decisions from OPEC as well as on stability in oil producing regions. Although we import less oil than we used to, America remains an importer of oil--with nearly half of our 20 million barrel a day use coming from oil supplied by other countries. The last time the U.S. was energy independent was in the 1950s.

In recent years, the U.S. has spent over a billion dollars a day to buy foreign oil. Henry Kissinger has called this the greatest transfer of wealth in human history. [9] The cost to the U.S. economy from oil dependence over the last two decades is in the trillions of dollars. [10] As President Obama has said, paying for foreign oil "stifles innovation and sets back our ability to compete." [11]

In the last few years, the U.S. has reduced its oil imports from nearly two-thirds to under half due to decreased demand and increased domestic production from new sources including hydraulic fracturing of tight rock formations and deeper and more remote off-shore oil drilling.

"Technology and high prices are opening up new oil resources, but this does not mean the world is on the verge of an era of oil abundance," according to the International Energy Agency.[12] Despite recent declines in the pace of demand, the world is using oil at a pace that is hard to visualize: "The world produces nearly 1,000 barrels of oil every second. If those barrels were physically stacked up, the pile would grow taller at the rate of 2,000 miles per hour."[13]

The recent drop in oil prices has been described by some as the equivalent of a tax cut. But when prices rise, it also acts like a tax increase. The stimulus measures enacted by Congress in 2009 were almost entirely offset by increased oil prices. Volatility in oil prices creates uncertainty and undue risk. Dependence on this world commodity continues to be dangerous.[14] This is especially true when much of the world's oil comes from unstable and undemocratic regions. The annual U.S. military cost to protect world oil supply lines exceeds $80 billion.[15]

Oil Use in Transportation Is a Major Producer of Carbon Dioxide

Even if oil were free, use of oil use in transportation is one of largest causes of anthropogenic greenhouse gas emissions.

Climate change may become the most important factor influencing transportation policy in the United States throughout the 21st Century. International, national and state climate policies will continue to focus t on reducing use of fossils fuels that emit carbon dioxide.

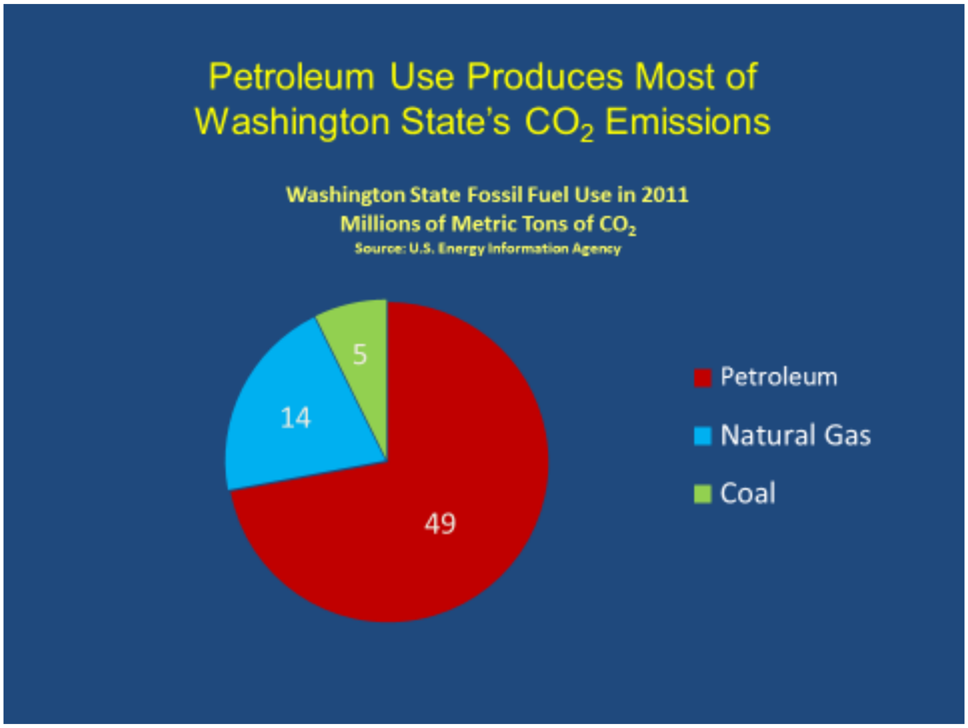
According to the United Nations:

> "[T]here is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and that these changes are in large part caused by human activities. While much remains to be learned, the core phenomenon, scientific questions, and hypotheses have been examined thoroughly and have stood firm in the face of serious scientific debate and careful evaluation of alternative explanations. Some scientific conclusions or theories have been so thoroughly examined and tested, and supported by so many independent observations and results, that their likelihood of subsequently being found to be wrong is vanishingly small. Such conclusions and theories are then regarded as settled facts. This is the case for the conclusions that the Earth system is warming and that much of this warming is very likely due to human activities."

Recent national efforts to reduce carbon emissions have focused on coal-fired electric generation, which the EPA has taken on in a series of regulatory actions. In several states, however, the electric grid is increasingly carbon-free.

In Washington State, the electric power grid is mostly hydroelectric, wind, solar or nuclear power, resulting in an increasingly carbon free power grid. Seattle City Light is the first utility in the U.S. that is carbon neutral. Tacoma Power, which supplies electric power to Joint Base Lewis-McChord, is 97% carbon free. The only coal-fired power plant in Washington State (it sells power to Puget Sound Energy) is legally required to be closed in 10 years.

In the U.S. Energy Information Agency 2014 report on state emissions, of the total Washington State CO_2 emissions of 69 million metric tons, 40 million was from transportation and only 7 came from electric power production. And as the chart below shows, burning petroleum (some oil is used for heating as well as in vehicles) produced 49 million tons of CO_2 compared to 5 million tons from burning coal.



A 2013 National Research Council study, *Transitions to Alternative Vehicles and Fuels*, found that electric vehicles and other alternative fuel vehicles could reduce petroleum use and GHG emissions in light duty vehicles 80 percent below 2005 levels by 2050.[16]

The *Transitions* report recommended[17] keeping the price of petroleum-based fuels from dropping below a floor level in order to assure "a profitable market for alternative fuels, and encourage consumers to reduce their use of petroleum-based fuels." It also called for low-carbon generation of electricity—less coal and more solar, wind and nuclear power.

The near total dependence on oil to fuel U.S. transportation is a major and daunting challenge to the economy, national security, human health and the environment. Moving from oil to electricity in transportation is one of the most immediate and viable solutions. As former Assistant Secretary for Policy and International Affairs at the Department of Energy, David Sandalow, has said: "To reduce oil dependence, nothing would do more good more quickly that making cars that could connect to the electric grid." [18]No technology has more promise to break the grip of oil on the U.S. transport sector than the plug-in electric vehicle."[19]

"Electrification of transportation is the best solution for dramatically reducing oil dependence. The electric power sector has substantial advantages over the current petroleum-based fuel system, and vehicles fueled by electricity are far more efficient than the conventional vehicles we drive today."[20] Electric motors "can turn 90 percent of the energy content of electricity into mechanical energy. In contrast, today's best internal combustion engines have efficiency of just 25 to 27 percent."[21]

A study by the Pacific Northwest National Laboratory found that over 70 percent of all the cars and light trucks in the United States could be powered by the existing power system by using off-peak power capacity accessible via smart charging computer applications that charged vehicles overnight.[22]

There are two power sources for electric vehicles: Batteries and hydrogen fuel cells. Batteries in gas-hybrid cars are charged by the gasoline engine, as in the original Toyota Prius. Plug-in electric vehicles (PHEVs), such as the Chevy Volt and the Ford C-Max Energi, have a plug for charging the battery from the electric grid and a back-up gasoline engine. In pure electric vehicles (EVs), such as the Nissan Leaf and the Tesla Model S, the batteries are charged only by a power cord connected to external electric power. Hydrogen fuel cells are seen by some as having a long-range potential to replace or augment batteries in electric vehicles.

A large scale demonstration project at Joint Base Lewis-McChord will be an appropriate place to help policy makers answer the question: What is next when the power grid is mostly carbon-free?

Oil Use in Transportation Is a Leading Cause of Premature Deaths

Tailpipe emissions of criteria pollutants, concentrated in urban areas, kill more people than car crashes. [23]

There are six criteria emissions—particulate matter, ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead—which are regulated under the Clean Air Act.[24] Although catalytic convertors and more efficient engines have reduced these emissions, research now shows that tailpipe emissions lead to more premature deaths than car crashes. Electric vehicles have no tailpipe emissions, and the electric power generating plants that provide EVs their electricity are increasingly clean and carbon free or are located far from urban areas.

Oil Use in Transportation Causes Water and Noise Pollution

An underappreciated benefit of moving from oil to electricity is the reduction of water and noise pollution. Oil dripping from vehicles on roads and parking lots carried by storm water runoff is a significant non-point pollution source in many areas of the U.S., such as the Puget Sound region in Washington State.[25] Copper shavings from brake linings, which are sharply reduced by regenerative brake technology in EVs, are also becoming a significant threat to aquatic life.[26] Urban noise pollution is also reduced as EVs run as quietly as bicycles—increasing the need for autonomous vehicles with their collision avoidance capabilities.

Problem 2: Fatalities and Injuries from Road Accidents

The ongoing carnage from U.S. road accidents — 33,561 fatalities in 2012, 2.4 million people injured, and billions of dollars in medical costs and property damage[27] — could be reduced by as much as 80 percent through road vehicle automation. Although the total is decreasing, there are still approximately 15 traffic deaths per hundred thousand population in the United States, or roughly 6 million crashes, 2.5 million injuries, and over 30 thousand deaths per year. Traffic accidents are the leading cause of death for citizens between the ages of four and 34 years of age.

New vehicles are now available with a growing array of automated driver assistance technologies, such as adaptive cruise control and lane keeping, to reduce driver errors leading to accidents. These technology applications are the precursors to truly autonomous vehicles in which the driver only needs to specify the destination and arrive safely. Fully autonomous vehicles may arrive in some applications as soon as 2020, with the ultimate potential for an 80% reduction in motor vehicle accidents. Autonomous vehicles will also decrease urban congestion and reduce pollution caused by stop and go driving by increasing road capacity without the need to build more lanes. Autonomous vehicles traveling safely at close intervals can triple the capacity of existing highways.

Problem 3: Congested Roadways

Traffic congestion wastes time and fuel, damaging the economy and the environment. Urban air pollution and greenhouse gas emissions increase dramatically in stop-and-go traffic. The estimated cost of traffic congestion is $121 billion annually, not counting the costs of the adverse health consequences of traffic related vehicle pollution.[28] The average American commuter spends approximately 250 hours on the road. Americans living in urban areas wasted about 5.5 billion hours sitting in traffic.[29] They also wasted 2.9 billion gallons of fuel.

The combined annual cost of traffic gridlock in Europe and the US will reach $293.1 billion by 2030, almost a 50 percent increase from 2013, driven mainly by urban population growth and higher living standards as a result of increased GDP per capita. "Over this period, the total cumulative cost of traffic congestion for these economies is estimated to be a staggering $4.4 trillion." "The scale of the problem is enormous, and we now know that gridlock will continue to have serious consequences for national and city economies, businesses and households into the future. Improving public transport infrastructure may provide more choice for travelers, but it won't solve the problem. Technology innovations like multi-modal routing and real-time traffic in connected cars and on mobile devices should be adopted more widely, helping to create smarter cities worldwide."[30]

Information processing and wireless communications capabilities, collectively called telematics, can make travel safer and more efficient by providing real-time, hands-free information to drivers. Telematics today can calculate the most efficient travel route, provide hints on how to avoid traffic, assure that an emergency response comes quickly, identify and reserve the nearest available parking space, and provide increasingly sophisticated and detailed information on desired destinations. The era of big data and wireless communication for drivers and their cars is creating what some call the "mobility internet."[31]

Autonomous vehicles will also decrease urban congestion and reduce pollution caused by stop-and-go driving in part by providing more real-time information but also by increasing road capacity without the need to build more roads. Autonomous vehicles traveling safely at close intervals and in more narrow lanes can triple the capacity of existing highways. Autonomous vehicles will enable dynamically and temporarily dedicated road lanes that will aid public transit, emergency vehicles and other priority usage

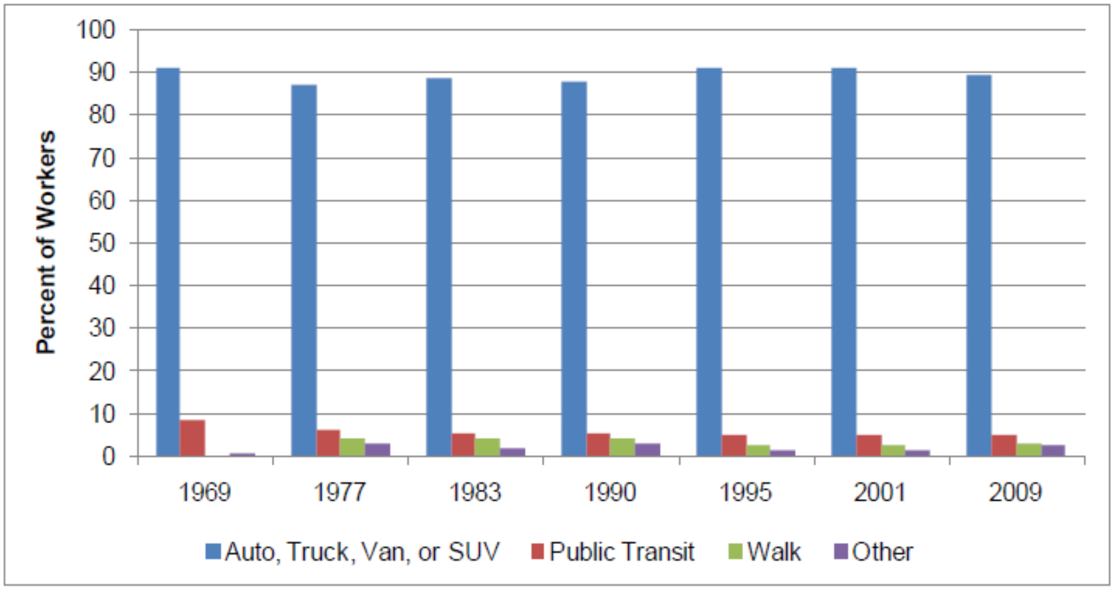
Finally, advanced telematics can enable future variable road pricing that will reduce peak congestion and provide a long-term sustainable and flexible method to pay for maintaining and operating urban road systems.

Problem 4: Underutilization of Public Transit

Due in part to changing work and family patterns—from one-wage earner households with set hourly schedules and one long-term employer, to two wage earners with variable hours at multiple employers—the percentage of daily work trips on public transit has declined from 6.4 percent in 1980 to 5.0 percent in 2011.[32]

In the Seattle area the Puget Sound Regional Council reports that transit ridership is now only 2.8% of the market share compared to 97.2% for non-transit vehicles share. Although the commute market share is 10%, the non-work percentage is only 1%. PRSC predicts that by 2014 total transit share will be 5%. Among other causes, commuters generally lack the flexible transit options and scheduling tools to meet their changing work patterns.

Trends in the Distribution of Workers by Usual Commute Mode
1969, 1977, 1983, 1990 and 1995 NPTS, and 2001 and 2009 NHTS.



Source: 2009 National Household Travel Survey (NHTS)

Transit applications of telematics can provide more flexible and accessible transit options into and around urban areas and help to intercept single occupant vehicles (SOVs) with easy-to-use park-and-ride transit options before SOVs enter core congested urban areas. This would increase urban transit use and reduce pollution. This is part of what Zielinski terms the "New Mobility Grid" in which advanced telematics help make public transportation more affordable, more user friendly, and more often used than today.[33] These new technologies are beginning to enter applications that enable commuters to reserve parking places at transportation hubs, and then reserve seats on buses, car pools, van pools and company transit options.

The Expert Review Method and Disruptive Innovation

The economic and social functioning of the U.S. relies heavily on personal vehicle ownership. However, in light of the problems noted above, many policy makers have promoted a "Smart Growth" model where the focus is shifted from single occupant personal automobile use toward walking, bicycles, transit, and various configurations of car sharing and ride sharing. Smart growth policies tend to reduce per capita impervious surface area (land covered by buildings or paved for roads and parking facilities), vehicle ownership and vehicle travel, and increase use of alternative modes compared with more dispersed, automobile-dependent, sprawled communities.[34]

However, forecasts of future consumer travel demand outside of the New York City metro area continue to have 90 percent and higher trip market shares forecast for cars overall in the coming decades even after considerable policy and budget focus to encourage denser patterns of land use and greater investment in and use of public transit. An example is the Seattle-Tacoma regions, where 95 percent of vehicle trips are forecast to be in cars even after spending billions on new rail transit and smart growth (Puget Sound Regional Council, 2012). Fortunately, the automobile, coupled with installed communication technology and new kinds of power plants, is transforming into a more sustainable means of movement where the mentioned problems could be mitigated considerably while still offering the same level of convenience and comfort of door-to-door transportation that has been desired by the public over the decades since World War II.

This project frames several conspicuous problems associated with today's automobiles, engages stakeholders in an investigation of the emerging technologies and the impact they could have on those problems, and explores a future roadmap where technology is applied to overcome problems. A global perspective has been maintained throughout the scenario building exercise regarding technological improvements changes with impacts on the U.S. The process has also evaluated the implications for sustainability and livability of the evolving automobile.

The word "disruptive" is used because current government planning activities have not yet come to grips with all the policy implications and sustainability implications of the battery-powered, non-polluting electric cars that are emerging from the automobile industry with high levels of computerization, wireless communications, and even automated controls. Such vehicles are on a development path to significantly reduce vehicle and pedestrian accidents while automatically triggering electronic user fee payments covering road maintenance and insurance based on daily usage metering. The three Es of sustainability—environment, economics, and equity—are all going be affected.

Expert Survey and Integrated Assessment

As a result of Phase 1 planning activities funded by the Graham Institute, the research team used the Integrated Assessment process and its results to produce a product addressing these disruptive technologies in sustainable mobility.

This Integrated Assessment applied a modified version of the Delphi methodology for the purpose of bringing together several communities of experts on future technological developments in sustainable automotive transportation. The Delphi technique, originated at the RAND Corporation in the late 1940s, is a systematic method for eliciting expert opinion for technology forecasting. It is a method for structuring communication among experts on a selected topic (in this case future innovations in automotive engineering related to sustainable transportation) and for facilitating structured group communication among the experts in order ultimately to reach a consensus on forecasts related to this topic.

The three essential features of the Delphi forecasting process are anonymity of the panelists, statistical summaries of the response, and iterative polling of the panelists with feedback. The Delphi technique generally has the following characteristics: email and web-based questionnaire, questions about both quantitative and qualitative scales, easy to understand instructions for the panelists, statistical feedback with each iteration measuring central tendency, some verbal feedback with each iteration, anonymity of the expert panel, written justification for outliers, iteration of the process until panel reaches a consensus, and the participants do not meet or discuss these issues face-to-face.

To achieve a structured dialog among people coming from different disciplines and policy perspectives, the team has employed an analysis of policy alternatives that features future scenarios for new personal mobility approaches based on critical uncertainties about the development of autonomous, electric vehicles. Scenarios of about one descriptive page each, with further data online for optional deeper exploration, were offered to stakeholders representing the public sector, the business sector, the non-profit sector, and academia for active discussion and improvement through a structured series of policy exercises.[35] [36] [37] combining face-to-face and online interaction via a modified Delphi method of eliciting stakeholder input with feedback provided from the other participants.

This method and the results of the survey are described in detail in the companion volume Automated, Connected, and Electric Vehicle Systems: Expert Forecast and Roadmap for Sustainable Transportation.[38]

Adopting a Vision: Disruptive Innovation

Transforming personal mobility has been called a "wicked problem:

> "It involves a system of highly interdependent systems, with the property that actions taken to improve one aspect of the system may produce unexpected reactions and unwelcome side effects. It is complex, ambiguous, and defies any straightforward progression from defining goals, through designing and engineering solutions, to manufacture of products and integration and deployment of systems. It is not like getting a man to the moon. It requires creative speculation about possibilities, ongoing critical discussion of principles and options, engagement of stakeholders with differing and perhaps conflicting interests, and responding flexibly to the unexpected twists and turns that emerge along the way to a solution."[39]

In other words, assessing the future of personal mobility is a perfect target for Integrated Assessment as described in this report.

One of the best presentations of an integrative idealized redesign of the automobile is presented in the book *Reinventing the Automobile: Personal Urban Mobility for the 21st Century* which provides a vision for a new automobile era with vehicles that are green, smart, connected, and fun to drive. The authors' idealized design for the automobile is a vehicle that is

- Safer because the "smart" automated vehicle systems enables the vehicle to drive itself and avoid crashes,
- Smaller because a safe crash-free vehicle also requires less fuel, produces fewer emissions, and is easier to park,

- Connected because wireless communications enable vehicles to communicate with other vehicles and the roadside to coordinate the flow of traffic and inform and entertain the passengers, and
- Greener because it takes advantage of alternative fuels, primarily electric power

The authors discuss the convergence of three major trends – growing urbanization, the electrification of energy and mobility systems, and the ongoing digital revolution in telecommunications and information processing. They bring them together in a comprehensive vision not only for vehicles, but also for personal mobility systems that support sustainable urban patterns.

First, as they summarize in the figure below, today's cars and trucks are primarily mechanically driven, powered by internal combustion engines, fueled by petroleum, controlled mechanically, and operated as stand-alone devices. Using an analogy to DNA, they explain that automobiles today essentially have the same "genetic makeup "as the automobiles pioneered by Henry Ford over a century ago.

The new automotive DNA is created through the combination of electric power, electronic controls and connected vehicle technologies. The new automotive DNA also supports vehicles that communicate wirelessly with each other and with the roadway infrastructure. When combined with GPS and digital maps the smart cars know precisely where they are relative to everything around them with a degree of accuracy sufficient for crash-free and self-driving vehicles. The safer vehicle can become lighter and more economical to be powered by electric motors for longer distances at a lower cost.

Second, a future Mobility Internet will do for automobiles what the Internet so far has done for computers. The evolution of the Internet has led now to where large-scale networks combined with powerful and inexpensive smartphones produce economies of scale and drive down the price of access to information. *Reinventing the Automobile* predicts that personal urban mobility in the future will create similar economies of scale. The authors explain that the smartphones and other devices provide access to appealing new services that motivate more widespread adoption. Similarly, the personal urban mobility networks will provide increased safety, enhanced mobility, and better air quality, all at a lower cost. .

Third, they combine electric drive vehicles with smart utility grids to create distributed, responsive energy systems.

Fourth, they envision an electronically managed, dynamically priced markets for electricity, roads, parking, and vehicles.

Their conclusions can be summarized in the following table:

Automobile DNA

Current DNA	**New DNA**
Mechanically driven	Electronically driven
Powered by internal combustion engine	Powered by electric motors
Energized by petroleum	Energized by electricity and hydrogen
Mechanically controlled	Electronically controlled
Stand-alone operation	Intelligent and interconnected

The authors conclude that it will take an idealized integrative design combined with sustained public and private investment to get beyond the inertia of scale and codependency on fuels, roads, and tax revenues inherent in the current automobile transportation system. By an "idealized design," they mean starting with the desired end in mind and then working backward to where you are today to develop a roadmap to your destination.[40] In this case the idealized design is self-driving, connected, and electric.

Burns[41] summarizes this vision of our transportation future: Driverless vehicles will emerge from the evolution of automation starting with driver assist (available now) and advancing to freeway and finally urban autonomy. All of this serves to optimize the movement of electric vehicles powered with electric motors and digital controls to reduce emissions.

The remainder of this report will detail other research issues for automated vehicle systems. At the level of large-scale cyber-physical systems we address integrative system design, wireless connectivity, and cybersecurity. At the level of vehicle systems we address sensing and perception, behavior planning, machine learning, and the interface with the human operator. We then address the design issues of adaptive graceful degradation, vehicle and capability prototyping, and testing, evaluation, validation, and verification.

First, moving from oil to electricity in vehicles addresses the concern that autonomous vehicle technology will result in more vehicle miles traveled and thus more greenhouse gas emissions and other pollution produced by conventional gasoline and diesel powered vehicles.

Second, the need to make EVs lighter to achieve longer range fits well with the capability of automated cars to avoid collisions. Automated cars over time may be able to substitute crash avoidance software for heavy structural elements and even airbags that mitigate collision damage when crashes occur.

Third, EVs will be able to avoid collisions with pedestrians and bike riders. Sustainable communities will be significantly enhanced when walkers and bike riders are safer. Car companies are already working on this.[42]

Fourth, wireless connectivity already exists that provides data to vehicles connected to the cloud. This enables EV drivers to know the shortest or most efficient path to a destination including developing traffic problems and information on the nearest charging stations. Strong mapping and routing capabilities will be critical for increasingly automated vehicles, as Google among others has been working to deploy.

Fifth, wireless connectivity is important for updating software and data in the car while in the owner's garage, and for the car reporting its status to maintenance providers. Tesla has included always on internet connectivity to enable constant trouble monitoring as well as downloading new capabilities overnight. Tesla has installed hardware in its newest production vehicles so that as it develops its autopilot software, the vehicles will be able to be increasingly more sophisticated and eventually self-driving.

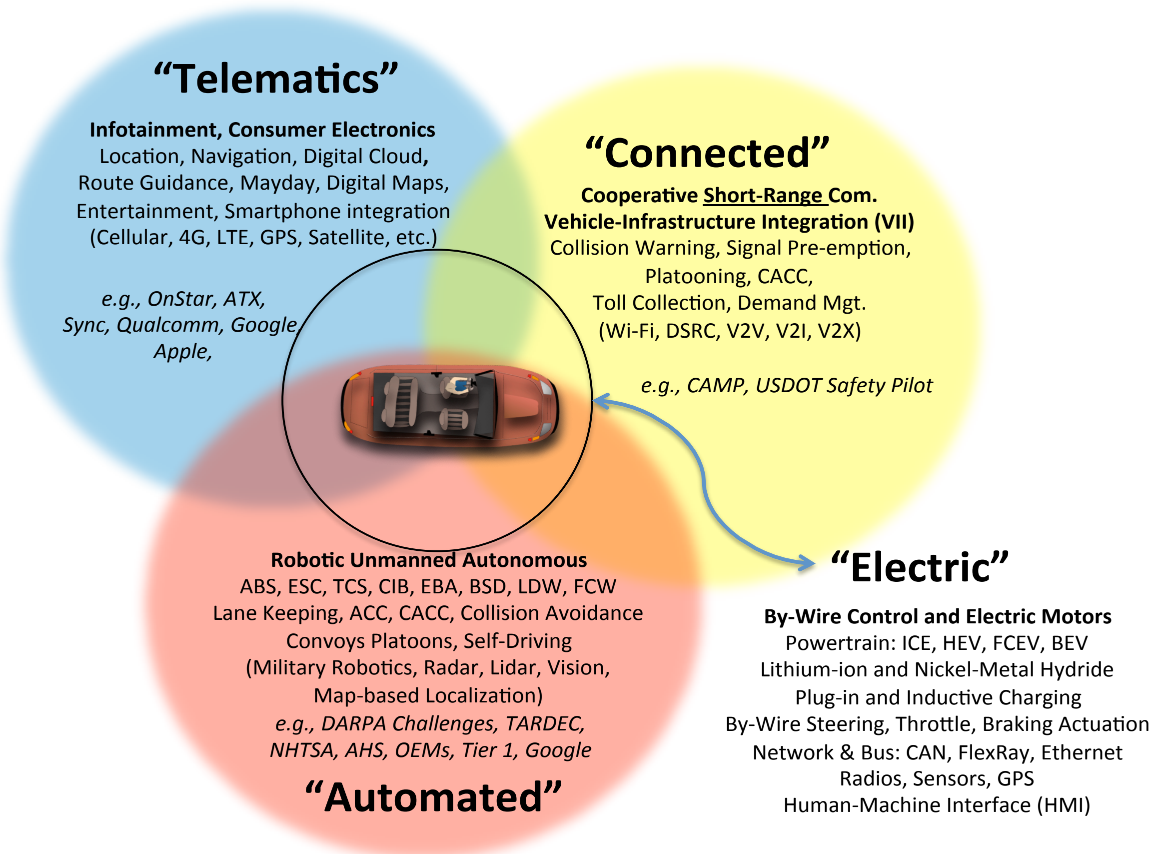
Finally, wireless connectivity supports vehicle-to-vehicle and vehicle-to-roadside communications that is important for safety and smooth traffic flow. The reduction of stop-and-go traffic congestion allows EVs to go longer between recharging the battery or otherwise refueling. Wireless communications to and from points beyond the range of in-vehicle sensors are likely to be important in automated driving to avoid collisions at blind intersections. Furthermore, the efficient interaction of EVs with the charging or refueling infrastructure – finding where it is and getting there efficiently – is already a part of dashboard displays installed in the EVs being sold as of this writing. In the long-run, EVs in a driverless mode may be able to go to a charging/refueling point on their own.

Survey Background: Automotive Technology Building Blocks

Redesign of the automobile is part of the mobility solution. In recent years the field of automotive electronics has given rise to several independent and related prospects including telematics, connected vehicles, and automated vehicles. However, these three communities have advanced relatively independently in terms of innovations, professional practice, organizational boundaries, and dialogue with others outside their communities. Public policy makers influence all three. One could argue, that "scientists and policy live in separate worlds with different and often conflicting values, different reward systems, and different languages." (Caplan, 1979) While scientists and engineers are more concerned with pure science and esoteric issues, government policymakers are action-oriented, and practical people concerned with obvious and immediate issues.

One value of Integrated Assessment (IA) in this study is in bringing together experts in the three automotive electronics engineering communities and the transportation policy community. This convergence of technologies and focus on integrated systems engineering is one of the critical paths on the roadmap to develop a fully automated or autonomous vehicle that address the sustainable mobility vision of this project. Envisioning an integrated technical and policy roadmap for the implementation of potentially disruptive innovation in the design of the automated and connected vehicle solution to sustainable mobility was enabled through bridging the three communities working on vehicle electronics, along with the power-train design community as well as the transportation policy and planning communities in the public sector. We conducted the IA in order to promote a unified vision of innovation of automotive electronics and communications technologies that will create new markets for automotive engineering solutions that will let the U.S establish and maintain a sustainable mobility system.

Transportation systems that move people, goods, and services in societies worldwide pose unprecedented environmental, economic, and social challenges, particularly with the growing urgency to conserve energy, cut back on carbon emissions and pollution, avoid crashes, and relieve congestions. Advances in electric vehicle (EV) technology, alternative energy, connected and automated vehicle systems, multi-modal transportation and intelligent transportation systems, offer great promise to address these challenges and have the potential to revolutionize the future transportation systems. However, each of the areas (connected, automated, and electric vehicles) has largely been under development separately, and while researchers around the world are making significant advances in each of areas, there is little work on how to integrate them to create a viable "system" that meets the dynamic needs of a changing society. Only by envisioning the "idealized" design of the connected and automated electric vehicles as a whole and working together to address long term sustainability will we be able to establish the scientific foundations and engineering principles needed to realize a cyber-physical approach to mobility and accessibility that is capable and dependable beyond what can be achieved today.



Four Automotive Electronics and Communications Technology Communities

Telematics: Information and Digital Maps

The first of the three communities is what has come to be known as "Telematics" with a focus on infotainment and consumer electronics designed to communicate with the driver and to help in locating, navigating, and guiding the vehicle and the road transportation network. This relatively mature area of automotive electronics engineering and product development emerged in the 1990s with recognizable services and name brands including GM OnStar and Ford Sync. Telematics products are discussed, featured, and demonstrated at professional conferences like Telematics Update, the Consumer Electronic Show, and meetings of the GENIVI Alliance, a non-profit industry association "committed to driving the broad adoption of an In-Vehicle Infotainment (IVI) open-source development platform."[43]

The adoption of telematics poses a dilemma for the consumer because while it provides a number of conveniences like route guidance and traffic information it also potentially distracts the driver and poses a serious safety risk. If an accident occurs, however, telematics also offers mayday services that save lives. Perhaps the most important telematics product is the digital map that updates continuously for localization and wayfinding in automated driving systems.

Connected Vehicle Systems: Safety and Security

An outgrowth of vehicle communication is a somewhat later development came in the area of what is now known as "Connected Vehicles" that feature communication between vehicles, that is, vehicle-to-vehicle (V2V), or between vehicles and the infrastructure, or V2I, and between vehicles and others including pedestrians or the cloud, or V2X. Examples of these short-range communication systems include collision warning, signal preemption, platooning, cooperative adaptive cruise control, toll collection, demand management systems like road pricing. The most advanced demonstration of connected safety systems is the US DOT Safety Pilot in Ann Arbor Michigan where 3000 vehicles were outfitted with Dedicated Short-Range Communication (DSRC) to demonstrate safety applications including warnings of potential collisions:

- Blind Spot Warning/Lane Change Warning, which warns drivers when they try to change lanes if there is a car in the blind spot or an overtaking vehicle.
- Forward Collision Warning, which alerts and then warns drivers if they fail to brake when a vehicle in their path is stopped or traveling slower.
- Electronic Emergency Brake Lights, which notifies drivers when a vehicle ahead that they can't see is braking hard for some reason.
- Intersection Movement Assist, which warns the driver when it is not safe to enter an intersection—for example, when something is blocking a driver's view of opposing traffic.
- Do Not Pass Warning, which warns drivers if they attempt to change lanes and pass when there is a vehicle in the opposing lane within the passing zone.
- Control Loss Warning, which warns the driver when another nearby vehicle has lost control.

One of the most recent issues concerning connected vehicles is the growing competition in the market of sensors for collision warning and collision avoidance. While the safety pilot in Ann Arbor demonstrated the real value of vehicle-to-vehicle communication with a large population of connected vehicles, it did not take into account the potential competition with radar and vision systems. That is, safety benefits of vehicle-to-vehicle communication are likely to be pinched by the growing demand for non-connected safety systems in new vehicles. While some make light of this market threat by pointing to the need for system redundancy, this risk comes to the forefront when taking into account the price and effectiveness of multiple sensor-based solutions, the need for other vehicles to have transceivers in order to communicate, and the years required for getting connected vehicles into the marketplace. It also doesn't help that the digital maps required for higher levels of automation are most likely to be updated by 4G cellular phone technology (i.e., telematics). If left only to the market, the short-range communication systems are not likely to have a large role in automotive safety applications or transportation in general. However, should the government decide to mandate, to regulate, or even to provide incentives for connected vehicle technology then the long-term value of V2V as a redundant safety feature with other high-value applications possibilities will be assured.

It is critical to be aware of the potential non-safety applications of connected vehicles. Vehicle-to-infrastructure (V2I) communication also supports the evolution toward the adoption of road pricing as a source of government finance for transportation. The connected vehicle systems that have been tested most recently for vehicle-to-vehicle safety applications will also support V2I automated toll collection applications that can assist with congestion pricing and the collection of user fees that have the potential to finance a sustainable transportation strategy. However, it should be noted that there are successfully implemented technical approaches to road pricing that do not require V2I radio transmitters in cars. Passive radio frequency identification (RFID) tags on the windshield can be read by toll gantries, with optical license plate reading as back up.

Finally, some of the most promising automated systems from both productivity and environmental perspectives involve cooperative or vehicle-to-vehicle automation including cooperative adaptive cruise control (CACC) and truck platooning. While CACC not only promises to make driving easier while reducing potential crashes, at higher levels of market penetration it promises to smooth out the flow of traffic and increase overall energy efficiency (Shladover, et al., 2012).

Specifically, V2V communication enables platoons to coordinate multiple vehicles simultaneously and avoid issues of latency sequence delays with a result of shorter headways and greater benefits in terms of reduced emissions and greater fuel efficiency. Furthermore, V2V communication support platoon entrance, exit, merging, and other vehicle behaviors that requires two-way signaling between vehicles. It also supports coordination of vehicles with traffic signal timing and crossing traffic at intersections.

Much of the progress in these areas has been made available through the conferences of the Intelligent Transportation Society of America, the Intelligent Transportation Systems World Congress, and the Transportation Research Board. Reports of engineering progress have also been made available through conferences and publications of the Institute of Electrical and Electronics Engineers (IEEE).

Automated Vehicle Systems: Crash-free to Driverless

The next generation of active safety systems will prevent crashes by taking over control of the vehicle under certain circumstances to actively avoid a collision. Braking systems are now enhanced to improve steerability, hasten deceleration, and prevent skids and loss of traction. Soon a bubble of sensors and actuators will enclose the vehicle and protect it from crashes. The vehicle of the future will assist with the driver with adaptive cruise control and lane keeping assist. The vehicle will warn the driver of potential crashes and intervene if for some reason the driver does not respond. Even when a crash is imminent the vehicle will take over to limit the impact. Many of these types of systems are options today on high-end or luxury vehicles. However, as with most automotive electronics the cost is going down and in the not-too-distant future low-end vehicles will be equipped and many of these features are likely to become mandated by governments to be a standard feature on all cars.

The key point is that a crash-free vehicle is not necessarily driverless. Systems are already and will continue to be designed to assist the driver and prevent crashes. The early active safety systems actually assist the driver and improve their control of the vehicle. On the other hand a self-driving vehicle must be designed with high assurance to not crash and these improvements in active safety and driver assist are steps in this direction. Over time as the population of crash-free vehicles increases on the roadway it is likely to open the door to more widespread customer acceptance and adoption of self-driving vehicles. Furthermore, since the driver is the primary cause of vehicle crashes as automation technology develops and takes the driver even further out of the control loop, there are additional benefits to be had. For example, if over 40 percent of fatal crashes involve alcohol, distraction, and drug involvement or fatigue, it that may help to find a source of control other than the driver. Looking far enough into the future, this trend toward crash-free cars may also reduce the need for passive safety and crashworthiness. In other words, the crash-free car can also be a lighter car with reduced vehicle mass and therefore more fuel-efficient.

Many recent developments in the automated vehicle community have emerged from projects sponsored by the Department of Defense (DOD) with an emphasis on robotic engineering associated with unmanned ground vehicles or what have become known as "autonomous" vehicles. While automation in the automobile can range from automatic door locks to the fully automated self-driving vehicle, more recently the Society of Automotive engineers (SAE), the National Highway Traffic Safety Administration (NHTSA), and the Germany Federal Highway Research Institute (BASt) have developed taxonomies of automated driving that define levels of vehicle automation ranging from no automation where the human driver performs all aspects the driving task, to full automation where the system executes steering, acceleration, and deceleration of the vehicle while monitoring the driving environment and providing failsafe control measures if needed. (SAE, 2013). For more complete definitions of the levels and other terms please refer to the glossary.

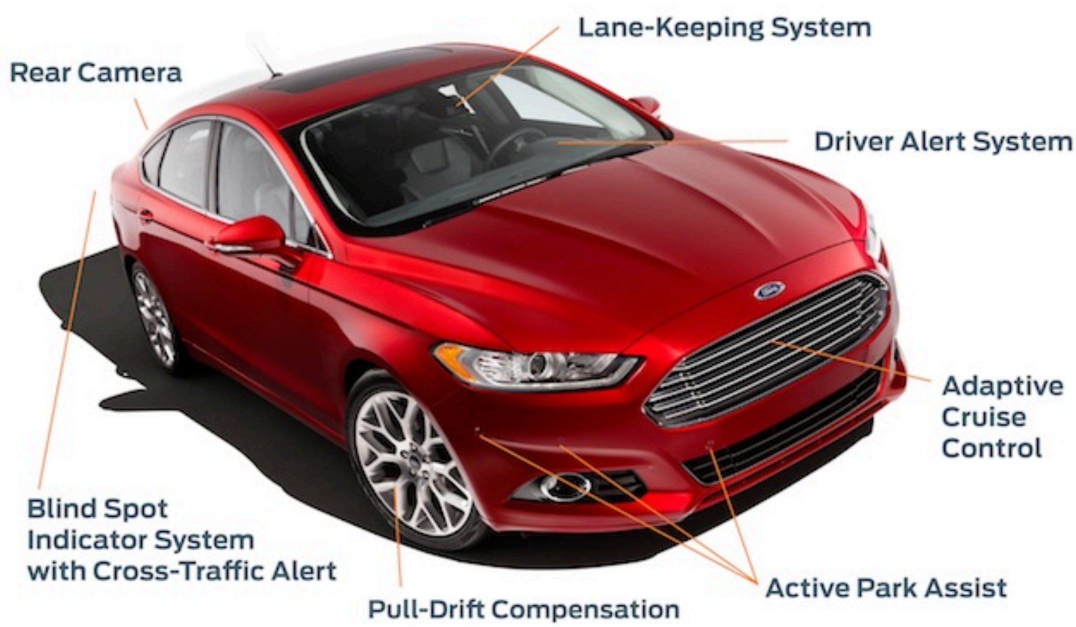
SAE Level	Name	Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	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*	System	System	System	**All driving modes**

SAE Definitions and Levels of Automation

For the purposes of this report an automated vehicle uses robotics to execute some or all of the driving tasks normally performed by the human driver. A fully automated, "autonomous," or "self-driving" vehicle does all the essential things that an ideal human driver does to guide the vehicle to its destination. The vehicle knows where it is and where it is going; senses the road, other vehicles, pedestrians, and other objects in its environment; navigates and selects a path toward its destination; and then moves according to the path while avoiding objects by actuating steering, throttle, and braking. While a fully automated vehicle can assume and perform all the driving task of the human driver there are also lower levels of conditional or partial automation where vehicle control may be limited to specified conditions, e.g., highway traffic at low speeds, or isolated locations, e.g., campus shuttle. In conditional automation the human driver must take over control of the vehicle in situations outside the scope of the automated driving feature.

Examples of automated features include adaptive cruise control, lane keeping, collision avoidance, convoy and platooning, and all the way up to the fully automated self-driving vehicle, also known as an autonomous vehicle in the Department of Defense. In our Integrated Assessment, we find it useful to categorize developments in the automated vehicle community in accordance with SAE's defined levels of automation including partial automation (level 2), conditional automation (Level 3), high automation (Level 4), and full automation (Level 5).

As mentioned above, the driver assist systems include features like antilock braking systems (ABS), electronic stability control (ESC), traction control system (TCS), crash imminent breaking (CIB), emergency braking assist (EBA), blind spot detection (BSD), lane departure warning (LDW), and forward collision warning (FCW). These function-specific systems are designed to assist the driver in controlling the vehicle and to improve overall safety. Other function specific driver assist systems include adaptive cruise control, lane keeping assist, and parking assist. However, these systems have already been introduced to the market and have widespread adoption and therefore are not a topic for this forecast. Likewise, more advanced combinations of these features like traffic jam assist and any simple coordination the adaptive cruise control and lane keeping features will not be addressed in this forecast.



2013 Ford Fusion, Introducing Automated Driver Assist Systems

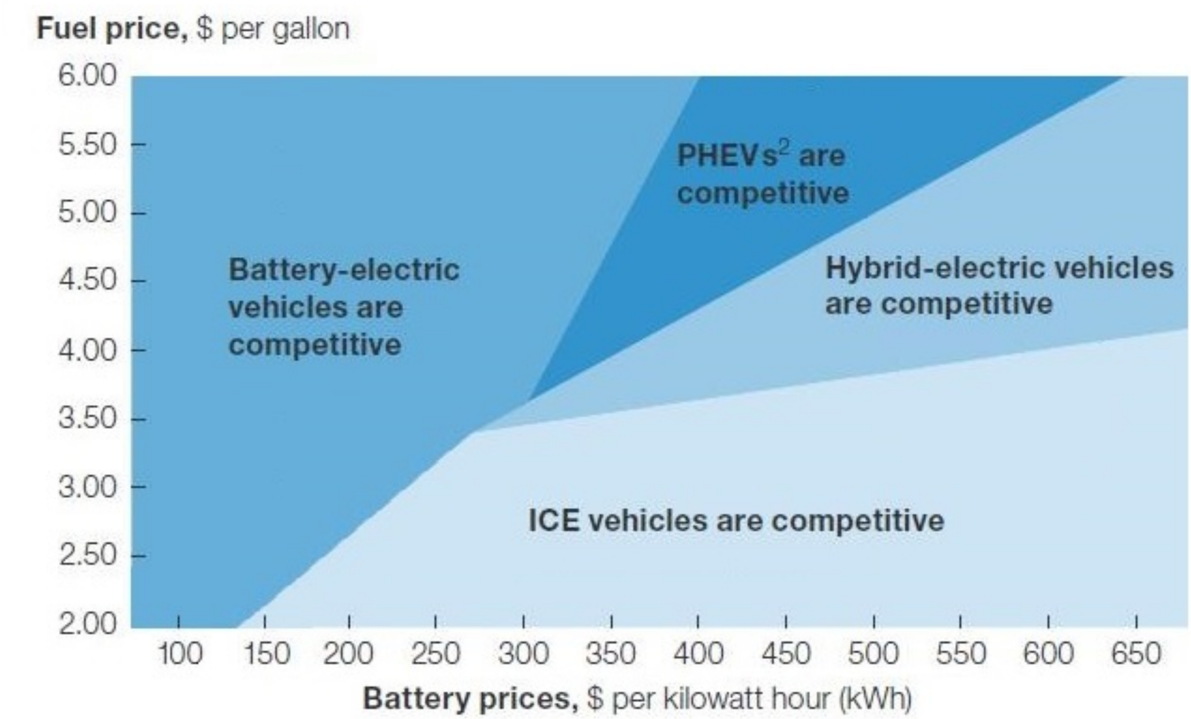
Electric Vehicle Systems: Powering Sustainability

As the section above detailed, our near total dependence on oil as a transportation fuel harms the economy, national security, health and the environment. As noted earlier: "To reduce oil dependence, nothing would do more good more quickly that making cars that could connect to the electric grid." Moving from oil to electricity in vehicle transportation is one of the key strategies for reducing greenhouse gases and further reducing our dependence on foreign oil imports, which still accounts for millions of barrels a day.

Sales of battery electric and plug-in hybrid vehicles started relatively recently with the Chevy Volt, the Nissan Leaf and the Tesla Roadster. The first Nissan Leaf was sold just three years ago and Nissan is now the largest selling EV. Today there are 16 models of EVs for sale, but total sales are still less than 1% of all car sales in the U.S. The sales curve for EVs is ahead of the curve for the original Toyota Prius, but is below optimistic expectations.

Part of the problem is fear, uncertainty and doubt about the new technologies in EVs. And even though the total life cycle costs are often demonstrably lower than a conventional gas powered car, there is a higher upfront cost as buyers are in effect pre-paying their fuel. Nissan has launched an aggressive educational program which seems to be having an effect. Showing the importance of education, Nissan has found that when fully briefed in educational settings, such as at an employer's offices after hours, buyers respond. One Nissan dealership that held the highest sales record last year helped pioneer that approach.

Sales of EVs will begin to take-off when the price of gas increases or the cost of batteries decreases to the point where it is more apparent that the advantage of electric cars becomes clear to the majority of buyers—much as digital cameras have replaced film cameras. The following chart shows one analysis of the cross over point:



[1]Assumes 240 watt hours per mile (as may be achieved with lightweight, efficient air conditioning) compared with today's 305–322 watt hours per mile.
[2]Plug-in hybrid-electric vehicles.

Source: US Energy Information Administration; McKinsey analysis

As of this writing, automotive industry experts speculate that Tesla and Nissan have a battery cost now that is between $250 and $300 a kilowatt hour. The Department of Energy is sponsoring research aimed at developing batteries that would cost $100-$150 a kilowatt hour. Tesla has started construction of a large-scale battery factory in Nevada in order to push the price of its batteries down to a price point that would enable it to succeed in a mass market for electric vehicles. Tesla's CEO Elon Musk predicts initial price parity with conventional gasoline cars in 10 years. "It's heading to a place of no contest with gasoline," said Musk." "The sooner this can be done, the sooner we can reduce carbon output and reduce the probability of a catastrophe," he added, referring to climate change." [44]

According to a recent Deutsche Bank analyst's report, "the internal combustion engine's dominance is actually almost over. Over the next decade, the cost of electric and combustion vehicles will more or less equal out; electrics could even be cheaper than combustion vehicles," which could "serve as a catalyst for significant expansion" of electric car sales.

The report notes two factors that could close the cost gap:

> "The first is that battery prices are expected to drop by more than half to $100 per kilowatt hour—not because of a scientific leap, but due to engineering improvements and economies of scale, particularly at Tesla's "gigafactory." The second factor is that combustion engines will get a lot more expensive. US gasoline efficiency standards, which require that light vehicle fleets average 54.5 miles a gallon by 2025, will incur added costs of $2,000 to $2,600 per vehicle. That will raise the total cost of a typical drive train—an engine, transmission, and fuel and exhaust system—to $7,000 to $7,600 per vehicle in the United States.
>
> "By comparison, using the $100 per kilowatt hour cost, a 47 kilowatt-hour battery pack capable of taking a car 200 miles on a charge only would cost about $5,400. When you add in the electric motor, the entire power train would rise to $6,100—a price advantage of almost $2,000 over a combustion car." [45]

Although pure battery electric vehicles have a limited range and relatively long recharge time (with the notable exception of Tesla), there are several models of plug-in hybrids that can avoid that problem including the new BMW i3, and the Chevy Volt both equipped with a small, range-extending, back-up generator engine.

Other models, such as Ford's C-Max Energi and Fusion Energi, as well as the plug-in Prius have a limited electric range that then shifts seamlessly to a back-up gas engine once the battery reaches a certain point of discharge. Range anxiety is not an issue for drivers of these models, who also enjoy above average miles per gallon from the gasoline they use.

Those who buy more limited range pure electric cars such as the Nissan Leaf, which gets around 80-85 miles on a charge use them within the confines of that range, some using them as a second commuting car for mostly urban driving. Some call this a "hybrid garage" where families with two cars (one an EV, the other a conventional gasoline car) have a choice depending on the travel objective. As with families who have both cell phones and landlines, the electric car is typically used far more often throughout the year which results in disproportionately higher number of miles traveled that are electric.

A key metric that is not currently being measured is the total number of electric miles driven in the U.S. It is likely to be much higher than the total percentage of EVs on the road, just as the cell phone use in some families is over 90% even though the number of land lines to cell phones maybe 50/50. [46]

The Chevy Volt, which has a range extender, is able to track the number of electric versus gas miles driven and could serve as one indication or estimate of the total electric versus gas miles driven by an average driver with a hybrid garage. As of October 2014 General Motors On Star data shows that collectively Volts have now been driven one billion miles, or more. About 629 million of those billion were driven using electricity. Over 32 million gallons of gas were saved by driving in that mode.[47]

When designing the Volt, General Motors found that 80% of all daily vehicle use was 40 miles or less. So GM designed the Volt to be all-electric for 40 miles and added a range extender in the form of a small engine that acted as a generator for the battery—which extended the Volts range for another 300 miles.[48] Bob Lutz, GM's Vice Chairman who pressed GM to make the Volt, is now chairman of Via Motors, a company making larger extended range pick-up trucks and vans. As one example of Volt's real world use, Jay Leno, who has a famous car collection and can drive any car he wants, drove his Volt the first 18,000 miles on 12 gallons of gasoline.[49]

General Motors 2014 Chevy Volt

Consumer Reports, which tracks customer satisfaction, reports that electric vehicles of all types rate among the highest in consumer satisfaction. Tesla received Consumer Reports highest consumer satisfaction rating again this year. It was also rated by Consumer Reports as the best car it has tested since 2007. [50] Tesla has also received the highest safety rating of any car tested by NHSTA.

Electric motors are 80% or more efficient compared to internal combustion engines, which are 30% efficient. This enables EVs to be more efficient and produce less CO_2 than conventional gasoline engines no matter what fuel is used for the production of electricity. In places like Seattle and Tacoma, where the electric power is carbon-free, a driver of an EV produces no CO_2.

On average for all states, the cost of charging an electric vehicle is about the equivalent of a dollar a gallon. In Seattle and Tacoma, the cost for electricity equivalent to a gallon of gasoline is about 50 cents. In other states, especially those with strong utility pricing programs the cost is 75 cents for a gallon equivalent:

"Electric utilities are a key part of the e-mobility revolution, and a growing number of them are getting on board. According to a new study by the Northeast Group, 25 utilities in 14 states currently offer rate structures tailored for EV owners – typically discounts for charging during off-peak hours.

The enlightened energy providers include 8 of the country's largest 15 utilities. In total, over 21 million U.S. utility customers have access to EV tariffs. In the 14 states with EV tariffs, the average equivalent "price per gallon" is $0.75." [51]

The federal government now requires labels on new cars to reflect the miles per gallon equivalent for electric cars and the cost savings for EVs compared to typical combustion engine cars.

Electric vehicles themselves do not produce local pollutants including noise pollution that is so common with internal combustion engines. More importantly, EVs in motion do not emit any of the six criteria pollutants such as fine particulates and ozone and nitrogen oxides that are responsible for more premature deaths in the U.S. than car accidents.

The power supply for electric vehicles is ubiquitous. EVs can charge from a standard 110 volt household plug or from a 220 volt circuit typical for household dryers. EVs can be charged in home garages and increasingly at work with relatively inexpensive charging stations. Dedicated public fast chargers are increasing with the number of EVs. The "I-5 electric highway" is a joint effort by California, Oregon and Washington to make it possible to travel from Canada to Mexico on Interstate 5 using fast charging stations along the way. Tesla (and soon Nissan and BMW) has a network of higher-voltage superchargers that enable drivers to travel on I-5 or from LA to New York with fast charging that is free to Tesla owners. Tesla is building out its supercharger networks in other parts of the U.S. and in other countries where it is selling its cars.

There is a need for curb stations to enable charging on city streets for those without garages and for users of pure electric vehicles and extended range EVs who would like to extend their all-electric mile capability during the day. Power for city street lights is typically 240 volts and can be used for curb side parking made even more practical with the move to LED street lights that use a fraction of the power compared to conventional street lights. A simple $8 NEMA 30 amp 50 volt plug (shown at left) can be installed at the base of electric light poles. It could be simple and inexpensive. Under a pilot project, users could pay cities a monthly fee for a permit similar to a handicap parking permit to provide access to the plug. Violators would receive a ticket just as for any other parking violation.

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A Public Policy Roadmap for Connected, Increasingly Autonomous, Electric Vehicles

This section provides a public policy approach on accelerating and integrating the new emerging technologies that will transform transportation. Sub sections start with electric vehicle, then move to connected, then increasingly autonomous vehicles and conclude with a sub section on enhancing public transit options with the new technologies. Most of the autonomous vehicles being tested are also based on electric drive platforms because robust drive-by-wire (use of electronic signals to communicate with actuators for steering, braking, and acceleration) are already present in EVs. Advanced constant 3G and 4G connectivity is also a feature of most EVs.

This section will be followed by an outline of a large-scale demonstration project at Joint Base Lewis-McChord, one of the largest Department of Defense bases, located in Washington State between Tacoma and Olympia in the Seattle region.

Leading by Example: Government EV Fleet Purchases and Education

Public knowledge about the new technologies is low and clouded by misperceptions on cost, performance, convenience and safety. Demand for electric vehicles is slowly building as drivers experience the cars for themselves. Among others, Plug-In America has identified the lack of public knowledge as one of the major obstacles to more rapid deployment of electric vehicles. It has focused on getting cars in front of the public by setting up driving and demonstrations and other educational efforts. [52]

Government can play a lead role in helping to dispel misinformation, doubt and uncertainty: Fleet purchases by federal, state and local governments can demonstrate, educate and publicize the cost-effective nature of EVs on a life cycle basis. Unfortunately, government fleet managers, with a few exceptions, have not been leaders on EV purchasing. For many fleet managers, it comes down to a checklist of assumptions on costs, maintenance and resale value that in many cases are incorrect.

For example, there are two Presidential executive orders issued in the Bush and Obama Administrations[53] that require EVs to be purchased by every federal agency with fleet over 20 vehicles once EVs are commercially available and are reasonably close in cost on a life cycle basis. There has been little oversight to ensure that those Executive Orders were implemented.

Although EVs are now commercially available and have total life cycle costs comparable to if not better than non-plug-in vehicles, GSA fleet managers have purchased few EVs. Region 10 of GSA, which is responsible for purchasing EVs for all federal agencies in the region including Joint Base Lewis-McChord, has bought only four EVs for JBLM–one Chevy Volt and three Nissan Leafs.

One reason Region 10 of the GSA has failed to buy more EVs turns out to be that they have required a separate charging station for each EV. GSA then said the price for each charger was $26,000 each—which nearly doubled the total cost of an EV compared to a standard car. But Level 2 plugs (240V, 50amps) for charging EVs can be installed for as little as $300.

Government fleet purchase of EVs is especially cost effective on a life cycle cost basis in Washington State, which has one of the lowest cost, carbon-free electric power grids in the U.S. Washington state also imports all of the oil it uses from other states or countries at a cost of $16 billion a year to Washington citizens. Thus, drivers as well as the state economy benefit from moving from oil to electricity in transportation. This would be a case of leading by example as backed up with a detailed set of calculations.

Washington State also has a legal mandate requiring state and local agencies to purchase EVs and other alternative fuel vehicles. Some state and local agencies, such as the City of Seattle and the City of Olympia have made progress in complying with the purchase of EVs. They are now in a position (as the federal government should be) to act as examples to individual consumers to dispel common misperceptions about EVs.

Nissan has helped several public fleet managers overcome their doubts regarding a purchase of EVs with an alternative lease arrangement. For example, Nissan now leases six Leafs to the City of Olympia. Because they are on a lease, they can be better compared to other standard leased vehicles.[54]

The Leaf fleet vehicles do not produce any local emissions, particulates, or ozone and eliminate oil discharges on streets and parking lots that is of concern for a city by Puget Sound where oil from internal combustion cars finds its way into the waters.[55]

King County Metro also now has a fleet of Nissan Leafs for their vanpool program called "Metropool." (See photo below). These vanpool cars get 500 miles per passenger per gallon equivalent compared to 42 miles per passenger per gallon on a typical Metro bus.[56] Metropool vehicles go in with a full charge, and can recharge during the day at low cost 110 or with higher cost 240 power plugs. The Ford C-Max plug-in Energi model and others could be used as EV vanpools with a longer roundtrip distance than the pure electric Leaf.

Larger vans can increase the miles per gallon per passenger. Via Motors, for example, has an extended range hybrid electric van on the market now that could reach 1,200 to 1,500 miles per gallon per passenger. And because it is range extended, it would eliminate any range anxiety concerns:

In summary, one of the most cost-effective public policy actions to accelerate EVs in the U.S. is a government fleet buying program followed by detailed reports on the savings and the reduction of emissions. Washington State, with its low-cost power and low-carbon power grid, could be a leader on educating the public and dispelling doubts and uncertainties regarding this technology, while saving money in the process.[57]

Utility Reform and Incentives

A second cost-effective set of measures to accelerate EV use is to encourage electric power utilities to become leaders in moving from oil to electricity in surface transportation. The following should be components of a comprehensive set of utility regulatory reforms that would save money, reduce emissions and provide an educational counterbalance to the oil and gas industry: In some respects, electric utilities can become the refineries and gas stations of the future.

- Define "energy conservation" more broadly to include not just conservation of electricity, but also of oil. Electric kilowatts and barrels of oil can both be measured in BTUs and compared for effectiveness and savings. (Energy can be measured and compared in several other alternative ways: oil energy can be measured by kilowatt hours, and electricity can be measured by barrel of oil equivalents (BOE).) The point is that energy conservation should include, measure and compare oil energy use. And since it is cost-effective to replace oil with electricity in transportation, while at the same time producing fewer carbon emissions, then that broader definition of energy conservation will lead to better public policy. But first the definition of "energy conservation" must change.
- Expressly permit utilities to meet energy conservation and carbon reduction mandates with actions that will encourage EVs such as by installing public charging stations, and converting utility fleets to electricity. In most states, utility laws and regulations limit the ability of utilities to increase electric use to replace oil use in transportation even when it would be significantly more cost-effective for consumers and fleet users.[58]
- Allow utilities to earn a rate of return on capital measures that will be used to replace oil BTUs with electric BTUs wherever it can produce demonstrable cost savings as well as a reduction in emissions.

- Require each utility to establish an electric transportation department to help create and administer programs to accelerate electric transportation.[59] Require detailed annual progress reports. Expressly allow expenses associated with these programs to be included in rates.
- Encourage utilities to develop pilot projects that reduce daily peak energy use with utility connections to EVs such as discount on off peak electric use and distributed storage of energy. The power grid is underutilized most hours of the day, including at night.[60] Shifting charging to nighttime will help make better use of expensive generation, transmission and distribution infrastructure.
- Encourage utilities to purchase and redeploy used EV batteries that are no longer optimal for cars, but can serve as a cost-effective back-up power source for emergency use and for storing intermittent solar or wind energy, among other uses.[61] As one example, solar power panel mounted on covered walkways in employee parking lots could be optimized with used EV batteries to store the solar power.[62] The Electrification Coalition has said creating a market for used EV batteries is one of the most effective ways to reduce the total cost of EV ownership.[63] Utilities are in the best position to jump start that market and to redeploy the batteries for a secondary use.
- Encourage utilities to provide public education on EVs. The public sees utilities as a trustworthy information source—which places utilities in a position to help counterbalance misinformation, doubt and concern created by others including the oil industry.

The national association of utilities that are investor-owned is the Edison Electric Institute. In reports and articles over the past two years, EEI has raised concern over what has been called a "utility death spiral," resulting from higher prices as mandated conservation and distributed generation reduce the number of kilowatt hours sold while still having high capital costs.[64] As kilowatt sales go down, the price of each remaining kilowatt hour must go up to meet the high and fixed capital costs of the power infrastructure—which in turn causes more customers to cut back or substitute their own generation. As one solution, EEI and others have suggested that utilities encourage electric vehicle use, which would not only reduce carbon emissions in most regions of the county, but would enable utilities to shift power use from peak to non-peak times.[65]

But to enable the shift to a more carbon-free and lower cost utility business model, state regulation will have to be overhauled and reformed. The California Public Utility Commission has taken a leading role in reviewing and reforming regulations, but in most states, including Washington State, public utility commissions must receive express legislative authority to be able to remove outdated and counterproductive regulatory restrictions. Last month a bipartisan group of Washington State legislators formed an EV Caucus intended to review and address roadblocks to accelerating the move from oil to electricity in transportation.[66]

Zero Emission Vehicle Legislation

A third cost-effective measure for most states would be to enact California's zero emissions (ZEV) mandates. Eight other states have adopted the California ZEV measure, which is permitted under the Clean Air Act.

In particular, Washington State, which of all states would benefit the most due to its low-carbon, low cost power grid, is the only West Coast State without a ZEV mandate. As a result, several models of EVs, which are only available in ZEV states, are not available in Washington State.

This measure would come at no cost to the state, auto dealers or the public. The cost to car companies is minimal because they must already comply with existing state ZEV laws, which now collectively account for 23% of the total car market.

In past Washington State legislative sessions, a ZEV requirement was blocked with car dealer and automaker pressure. But the technology has progressed to the point where dealers should now be in favor of providing more options to their customers—which are now denied by automakers.

Automakers also should no longer be as opposed to ZEV mandates. In ten years federal car and light truck mileage standards will require automakers to produce an overall fleet of car models that must average 54 miles per gallon. Today the best gasoline car on the road now, the Toyota Prius, gets only 45 miles per gallon. This means the mix of vehicles needed to comply with federal laws will have to include a substantial percentage of plug-in vehicles. Although ten years seems like a long time, automakers have product cycles that take 4-5 years. Having more states with ZEV mandates will result in a more robust and a less expensive supply chain by lowering costs with economies of scale-- much as Tesla intends to do with its large scale battery factory. As a side benefit, the ZEV mandate in California has helped Tesla in that automakers who do not meet their quotas may buy credits from those automakers who exceed their quotas. The resulting income has helped Tesla to raise the capital to build its new battery factory, which in turn will reduce battery costs for all vehicles. As an earlier chart illustrated, as gasoline prices go up or battery prices come down, EVs become more competitive with gasoline powered cars:

Gasoline prices have recently come down into the $2 a gallon range, although it is difficult to predict how long lower oil prices will last. Oil has had a 20 year recent history of sharp volatility.

On the other side, Tesla and Nissan battery prices per kilowatt hour have also come down and may soon reach $100 a kilowatt hour as discussed earlier in this report. Research into new battery technologies may also produce a breakthrough on lower costs and longer range, but Tesla and Nissan are making progress on lowering battery prices regardless of whether breakthroughs come as some predict.

Gasoline Taxes and Carbon Taxes

The sudden drop in oil prices from over $100 a barrel to under $55 a barrel in the last half of 2014 is a short-term set-back for more rapid EV deployment. But it is also an opportunity to increase the gasoline tax at the federal and state levels to make needed infrastructure repairs and improvements. A year ago the Washington State legislature considered but did not pass an 11.5 cent a gallon gasoline tax increase. But a year ago gas prices were high and rising, creating voter resistance. But in just one week in December 2014 national gas prices dropped 13 cent a gallon—more than the tax being considered by the legislature. Overall gas prices have dropped more than a dollar a gallon since their June highs in 2014 and are still falling. With billions of dollars in needed road and highway infrastructure, the public may be willing now to accept an 11 or 12 cent a gallon increase--especially compared to some of the alternatives to a gas tax.

Also, in the last decade, the gas tax has in effect been cut automatically year by year as new cars have become more efficient. It is not uncommon for drivers to trade in an older model car getting 20 miles a gallon for a new one getting 30 miles or more a gallon. But instead of concluding that the gas tax no longer works, the better view would be to index it to increases in fuel efficiency. By analogy to the Social Security System, just because payments did not keep up with inflation, the solution was to index it to inflation, not abandon it as unworkable.

EVs should be charged a fee representing what a gasoline hybrid such as the Prius would pay in state gasoline taxes for an average number of miles a year, which is 12,000 to 15,000 miles. In Washington State that works out to about $35-40 a year. Washington now requires EV drivers to pay $100 a year--more than double what a Prius driver pays.

An alternative to a gasoline tax increase would be a carbon tax, which is what Washington State Governor Inslee proposed in December 2014. That could increase the price per gallon of gasoline significantly more than a gasoline tax increase of 12 cents a gallon, which is why it may not pass.[67]

Charging at Work and at Public Locations

Tesla, BMW, and Nissan recognize that for EV sales to become mainstream, it is important to have places to charge other than at home. Tesla is building out a network of free superchargers that already enables a Tesla owner to travel from Los Angeles to New York or up and down Interstate 5 on the West Coast. Nissan and BMW are working on their networks.

But even those models of EVs that have gas engine range extenders that eliminate range anxiety, a public policy goal should be to maximize the number of oil-free electric miles driven by removing the obstacles to more workplace and public charging. Workplace charging can in effect double the number of electric miles for a Chevy Volt, Ford C-Max Energi or a plug-in Prius. But many employers are reluctant to install free charging over objections of employees without EVs.

One solution is to establish a permit system for workplace and long-term public charging (at park-and-ride lots and airports for example) using low voltage Level 1 charging. In an eight hour work day, charging from a 110 Volt plug can fully charge a Chevy Volt, C-Max Energi or Prius battery. Drivers would pay a small monthly fee of $10-$20 (based on estimates of the power costs) for a permit that would allow them to plug into an outlet. Driver would display a placard like the familiar handicapped placard. Cars without a permit that plugged into outlets would receive a ticket like for other parking violations.

One other related low-cost action is to install roadway signs indicating where there are charging outlets available and at what level (Level 1 at 110, Level 2 at 240 and direct current fast charging). Although most EV drivers can eventually locate charging stations without signs, the signs are useful to remind and assure prospective EV buyers that there are public places to charge. The effect is also one similar to peer pressure and will help remove an excuse some have to postponing an EV purchase.

Finally, Building codes need to be revised to ensure that new construction includes conduit to enable inexpensive post construction additions of charging plugs. Incentives for actually installing charging plugs in new construction could be done with credits, offsets and waivers of other requirement.

Public Education and Peer Pressure

The campaign against smoking applied public education, higher cigarette taxes and peer pressure to reduce a major public health problem. It has largely been successful as the number of smokers continues to decline and health improves.

A similar approach to oil dependence would be a low cost and effective way to reduce carbon emissions and tailpipe pollutants that now kill more people prematurely than car crashes.[68] Most people do not know much about the adverse effect on health from oil dependence and don't know much about the basics of EV ownership and use. Most people in Washington State don't know that because their electric power comes from mostly carbon-free sources, the most effective measure they can personally take to reduce greenhouse gas emissions is to make their next car an EV.

One effective way to communicate is to use high profile examples and peer pressure.

Governments, civic and environmental groups should take the lead as did government and the medical profession on tobacco. Some examples:

- Elected officials should lead by example and commit to driving EVs, just as most elected officials stopped smoking years ago to set an example.
- Environmental groups should sign up their members who own cars to a pledge ("My next car is electric"). Members of climate groups and heads of government agencies, who still drive gasoline cars should be pressured as much as doctors who still smoke.
- Educational campaigns and public service messages could identify and highlight well known and respected civic and business leaders who own EVs and use testimonials from them.
- Goals should be set, tracked and publicized such as the number of oil-free miles driven

Tax Credits and Other Temporary Incentives

The federal government took the lead on tax incentives for electric vehicles during the Bush Administration with a federal income tax credit up to $7,500 depending on the cars battery capacity. States have added other incentives such as the temporary use of HOV lanes in California and the exemption of battery powered EVs from sales tax in Washington State. Those states with incentives have much higher per capita sales of EVs, as would be expected. Countries with incentives do better than those without incentives.

The main justification for early incentives is to help get the new technology off the ground, to create economies of scale and to encourage buyers who might otherwise be reluctant to buy EVs at higher initial costs and with untested performance.

Compared to government incentives for wind and solar power, the incentives for EVs are relatively small. But as with all temporary incentives, they need to be revisited from time to time and improved or phased out.

When EV sales are 20% or more of total auto sales, a good argument could be made that most incentives should be phased out then, if not somewhat earlier. There is also an argument that incentives should be means tested and capped. One reason the federal government created a tax credit instead of a tax deduction was to give a bigger incentive to lower income earners, who might not benefit much from a deduction compared to a credit.

But as with any new technology from computers in the 1980s to digital cameras, flat screen TVs and smart phones, the early adopters who first help create a mass market are higher income people. As prices drop, the entire public benefits. Concern over a "digital divide" with computers owned mostly by high income earners has mostly disappeared from public policy discussions now that computers, tablets and smart phones have made digital access ubiquitous.

Sales of mass produced EVs basically started just four years ago with the Chevy Volt and Nissan Leaf. Now many of those initial models are coming onto the used car market, which may prove to be one of the best ways to introduce EVs to those unwilling to pay a new car price—as is the case for most people with existing gasoline models. Establishing a used battery market may also be another cost-effective way to reduce the total cost of ownership and assure buyers of one less thing to worry about with the new EV technology.

One concern is to avoid a general public backlash. Will allowing use of HOV lanes by EVs create more resentment than sales? California has limited the number of HOV permits and limited the time of the program. California initially started its HOV programs with gas-hybrid permits (such as the Prius), but those early models can no longer use the HOV lanes. Many early adopters bought their first Prius in order to gain access to the HOV lanes, but now find that they like them regardless of the permits. The Prius, once written off by critics as an expensive mistake, is now one of the best selling cars in the world.

One public policy conclusion seems clear: It is too early to eliminate the incentives that have started things rolling. Revisions would be in order if they improve the outcomes.

Connected Cars

Smart phones connected to the internet and cloud storage have transformed vehicles to the point where some call cars "mobility devices." It is difficult to believe that the first Apple smartphone was sold just seven years ago. Now there are well over a billion smartphones that keep getting smarter thanks to apps that number in the hundreds of thousands.

This connectivity now enables drivers to monitor traffic, road conditions, navigate to destinations along the best route, as well as being connected to all of the other increasing infotainment options. Tesla's Model S, for example, has a 17 inch computer screen that replaces most of the buttons and knobs used in a traditional car and provides always-on connectivity to the internet. As with an increasing number of vehicle makers, Tesla's system monitors the performance of the car and sends instant messages to the driver about problems. Tesla can download software updates to enhance performance, increase safety or change the look of the dashboard without having to drive to a service department.

Cars connected to smartphones have enabled Uber, Lyft and other ridesharing services; without connectivity they would not exist. Traditional taxi companies are having to adapt and adopt—after first trying to shut down these new competitors.

Always-on connectivity also brings challenges. Distracted driving is becoming more of a factor than it was when the main distractions were the radio, the front seat passenger and the back seat kids. Some states now ban used of hand held cell phones, but automakers now provide hands-free calls, which still create high levels of distraction, according to research from the AAA Foundation.

Connected vehicles also provide a pathway for cyber mischief, although that risk is now inherent in most transportation modes from planes to trucks to trains and needs to be addressed

Appendix ___ contains more background on the technical features and issues facing and created by connected vehicles.

The following is a suggested set of public policies related to connectivity:

- First, avoid measures that would ban the evolving technology. U.S. Department of Transportation Secretary Foxx has floated the idea of prohibiting navigation devices in cars, since people look at them to more easily find their destination and avoid getting lost and traffic. However, such devices are a significant time saver for consumers, and are capable of being used safely. Companies such as INRIX use data from connected cars to measure in real time traffic and road conditions and send that information to subscribers including FedEx, UPS and navigation services. Delivery trucks use the information to avoid delays and calculate the best delivery route.

- Rely on automakers and the existing legal system to balance features and safety. Automakers are concerned with their reputations and as a general rule will not irresponsibly put future sales at risk. Automakers can also foresee and realistically assume that some drivers will use cell phones and be distracted by other devices no matter what laws prohibit them. Concern for their reputation and avoiding legal liability imposed by the tort system will provide sufficient incentives to automakers to deal with the issues without banning useful technology including navigation systems.
- Allow emerging technology to make existing technology safer. As the next section on autonomous vehicles discusses, automakers are on their way to make distracted driving from all sources less dangerous than ever—cars that avoid distracted driving accidents such as rear end accident, inadvertent lane changes, collisions with pedestrians, bike riders and other cars.

Autonomous Vehicles

The vision of a driverless car future is captured in a short Google video that went viral in 2012. Steve Mahan, who is blind, gets behind the wheel of a car that takes him through the drive-up at a Taco Bell, then to the dry cleaners and back home. Along the way he says: "This is the best driving I've done in years."[69]

But, as shown in this section and Appendix __, that future is more than a decade away. Meanwhile, there are steps that can be taken that will accelerate the technologies that are the building blocks for increasingly autonomous cars. Other public policy steps need to be taken at the same time to integrate these technologies into a reformed legal, regulatory and insurance framework. .

Overall, a key along the way step is to educate the public and policy makers and demonstrate as well as test these increasingly autonomous vehicles in large-scale realistic demonstration projects. One such project is the University of Michigan Transportation Research Institute that broke ground in early 2014 on the U.S. DOT-funded Michigan Mobility Transformation Center at Anne Arbor, Michigan: "The $30 million simulated city, built like a movie set on 32 acres, will test connected vehicle and infrastructure technology to simulate crash scenarios in a realistic environment."[70]

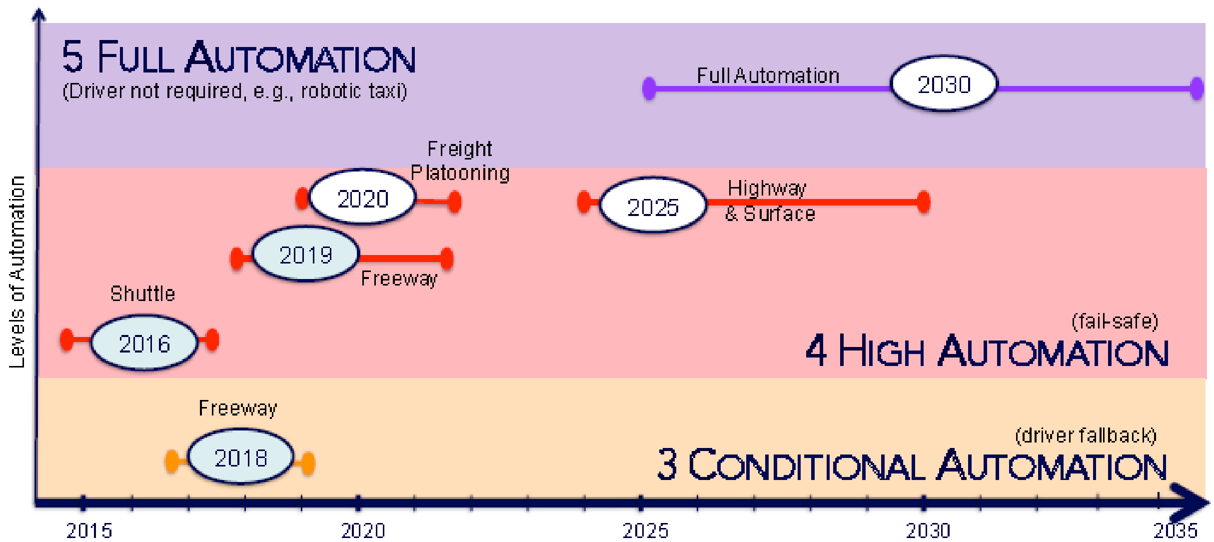
Another more advanced demonstration project, proposed in the following section, is to do further realistic testing with a variety of sensor and connected car technologies with several automakers and component makers on an existing small city environment at DoD's Joint Base Lewis-McChord--one of the largest military bases in the U.S. and a controlled, self-contained environment. Planning is underway for the first phase of testing a driverless shuttle system and other applications for driverless vehicles. Additional testing of intermediate autonomous features with a large, controlled population at JBLM could be done at the same time to more accurately determine insurance risk reduction (accident reduction) benefits.

Delphi Forecast of First Market Introduction of Vehicle Automation

As this section shows, the first market introduction of full autonomous vehicles is at least a decade away. But many of the features that comprise autonomous vehicles will be here soon. The full research report from

Connected Vehicle Proving Center presented in a companion report entitled Automated, Connected, and Electric Vehicles: Expert Forecast and Roadmap for Sustainable Transportation.

A panel of twenty experts in robotics, automotive, and transportation engineering were recruited by Connected Vehicle Proving Center in 2013 to engage in a year-long Delphi process of responding to a sequence of three questionnaires periodically delivered. This standard methodology of sequential iteration incorporated anonymous sharing of the survey results with other panelists before responding to the next questionnaire. The result was a set of forecasts for the future year of market introduction of specific systems including freeway automation, automated shuttles, freight platooning, high automation, and full automation.



The figure above plots the Graham Institute panel's median forecast year of market introduction for each of the three higher-level vehicle automation categories defined by SAE. These three levels break from today's available driver assistance automation – Level 1 and Level 2 – in that the automated driving system monitors the driving environment and takes appropriate action.

Level 3, Conditional Automation: In conditional automation the automated driving system executes steering, acceleration, and deceleration under specific conditions with the expectation that the human driver will respond appropriately to a request to intervene. It primarily works on freeways and other limited access highways. The Mercedes S Class available today is essentially a Level 3 vehicle on limited access highways.

Level 4, High Automation: This level of automation means the automated driving system not only monitors the driving environment and executes steering, acceleration, and deceleration control functions, but it also takes over the fallback performance of the driving task. That is, within the context of the mode of operation the automated driving system is responsible for managing issues and taking over the driving task even if the human driver does not respond appropriately to a request from the automated vehicle to take over control. In this case, the automation usually brings the vehicle to a safe stop on the shoulder of the road. Examples of environments suitable for high automation include freeway driving, campus shuttles, and valet parking.

Within Level 4, automated freight platooning enables trucks to travel together with other equipped vehicles in a tight, closely-controlled formation, creating a train of electronically connected trucks on limited-access highways. While there are many variations on the design and functionality of platooning systems with some relying more on the communication between two of more vehicles and others relying more on coordination through the infrastructure, the questionnaire did not specify the technology. Rather, the questionnaire specified the functionality of cooperative adaptive cruise control and automated steering to coordinate vehicles and shorten headways and reduce wind resistance. In this case there are drivers in all trucks, and the platooning does not require a dedicated freeway lane.

Also within Level 4, the shuttle is a fully automated application that travels at low speeds within a closed or gated campus that places some limits on the vehicle and pedestrian traffic in that environment. Shuttle vehicles generally operate at speeds below 20 miles per hour and in some cases may travel along separate paths dedicated exclusively to their use and in other cases travel on roadways or other surfaces with mixed vehicle and pedestrian traffic. For example Google recently began experimenting at NASA Ames Research Center with a two-seat prototype with no steering wheel or other controls other than a stop-and-start button. Similarly the United States Army Tank Automotive Research, Development and Engineering Center (TARDEC) is planning a shuttle system for Fort Bragg to help transport wounded warriors from their barracks to the Army Medical Center and back.

Level 5, Full Automation: This level of automation is similar to level 4 except that it is extended to all modes of driving in all traffic conditions and roadway environments. The automated driving system engages in full-time performance of the dynamic driving task. These types of systems may take on the role of an autonomous chauffeur in a robotic taxi that picks up riders and drops them off before moving autonomously to the next rider or parking/charging space. The vehicle is designed to fail safely and return the vehicle to a minimal risk condition if a problem occurs. Level 4 is the fully automated form of transportation that has captured the imagination of the general public as described by Google. It promises to offer a feasible alternative for the mobility disabled as well as autonomous package delivery and other solutions that are independent of a human driver.

The spread of years indicated on the bars behind the dates prior to and after the median represents the interquartile range of responses, meaning here the number of years between the average of the first (lowest) quartile of responses, and the average of the third quartile of responses, which is a date that is one or more years beyond the median. So, for example, the median forecast date for the automated shuttle systems is 2016 and the interquartile range is two years from 2015 to 2017. This shows a relatively high degree of consensus for the near term, i.e., 2016, market introduction of the automated shuttle.

By contrast, there is much less consensus on the market introduction of full automation with a median forecast of 2030 and an interquartile range of ten years between 2025 and 2035. One panelist forecasted as early as 2019 and another panelist forecasted it would never be introduced to the market. However, it is interesting to note that over the course of the three rounds of the survey the number of "never" forecasts for all the of the levels went from nine in the first round to only one in the third round. This and the generally lower interquartile ranges over the course of the three Delphi rounds indicated a growing expert confidence in the overall technical feasibility, consumer acceptance, and institutional support for all levels of vehicle automation.

Summary of Public Policy Recommendations on Vehicle Automation

Our first and highest public policy recommendation is to conduct a large-scale testing and demonstration project at Joint Base Lewis-McChord as outlined in the following section. Other recommendations include the following:

- Avoid enacting laws that restrict the ability of auto makers and component suppliers to test autonomous vehicles and systems. For example, provide an exemption for all testing on DoD military bases and for test protocols under the supervision of the DoD and other federal agencies. Regulations recently enacted in California as well as preliminary work by the Uniform Law Commission would likely restrict and add delays to the promising work by DARPA, which was the DoD agency that launched the autonomous vehicle technology revolution in 2004. Those tests and others under the auspices of the federal government should be exempt from new state regulations restricting autonomous vehicle testing and deployment.
- Existing auto liability law will provide sufficient incentives to automakers and others to safely test and produce autonomous cars. Those states with the fewest additional registration, insurance, certification and licensing restrictions will be in the best and most flexible position for pilot and demonstration projects. The Google self-driving test cars have traveled hundreds of thousands of miles-- without causing an accident before California adopted its new regulatory restrictions. Existing insurance, licensing and reporting requirements are sufficient for the testing stages.
- Remove cell phone restrictions on drivers of existing cars that have automatic braking, lane keeping and other safety features, collectively known as adaptive cruise controls. This is an incentive for drivers to add these safety features and will help accelerate a mass market by lowering the costs of the systems.
- Provide funding to the Washington State Traffic Safety Commission to work with insurance research institutes to test and publish a peer reviewed report on the efficacy of increasingly autonomous features. One location for the testing would be at Joint Base Lewis-McCord with its population of younger drivers and the ability of the military to help establish control groups for collecting accurate, publishable data.
- Provide flexibility and incentives for insurance companies that provide discounts for drivers of increasingly autonomous cars.
- Require adaptive cruise controls, lane keeping and automatic braking for new state and local vehicles as they are added to government fleets and collect data comparing accident rates of new technology to old technology vehicles.

Increasing and Improving Public Transit with Smart, Connected, Autonomous, Electric Vehicles

Smart, connected, increasingly autonomous vehicles can have a significant role in increasing and improving public transit. Most public transit trips are commuting trips for work, with relatively few non-work trips. A focus on improving work transit commuting with advanced technologies should be a priority.

Mass public transit works best with high density populations that lead to frequent and express transit service. In the 1950's large numbers of New York City commuters who lived outside of Manhattan and its boroughs drove to a train station (the origin of the word "station wagon,") and were dropped off by a spouse, who had use of the car for the rest of the day. But since the 1950's the work force has dramatically changed, with both spouses now working, often in separate locations and for several different employers over shorter periods of time. This demographic and work place change has been one reason for the relative decline of public transit in most areas of the U.S. outside of the New York City region.

By analogy to New York's train station commute system, an expanded system of high-tech park-and-ride centers for commuters can create rider collection points that would enable more express bus service to the most congested employment centers in an urban region. Technology applications could enable commuters to reserve and pay for a parking place and a seat on a bus, train, carpool or vanpool—and soon even have the car park itself in a reserved area, saving more time and allowing cars to be parked closer together, a form of automated valet parking. Eventually, driverless cars could drop off commuters and return home to cut the cost of parking spaces and to enable households to get by with one vehicle. A system of public transit vanpools or employer-provided vanpools that pick up commuters from park-and-ride centers also enable more commuters to travel to work in areas outside the urban core where high-volume express bus service is not cost-effective.

In late 2013 the American Public Transportation Association celebrated the highest number of transit rides since 1956.[71] But as the Atlantic Cities blog, the *Washington Post* and others asked: "Shouldn't it be upset that over a period when the country added roughly 150 million people, transit ridership went up zero percent?"[72] Atlantic Cities provided the following graph:

The authors in the *Washington Post* article said public transit "was a small and stagnant part of the transportation system":

> "We are strong supporters of public transportation, but misguided optimism about transit's resurgence helps neither transit users nor the larger traveling public. Transit trips did rise between 2008 and 2013. But so did the U.S. population, from 304 million to 316 million, as did the total number of trips made. Simple division suggests that, if anything, transit use fell between 2008 and 2013, from about 35 trips per person annually to 34. Many numbers look impressive without denominators, but anyone who examines transit use as a rate — whether as trips per person or share of total travel — will find that transit is a small and stagnant part of the transportation system.
>
> "Transit receives about 20 percent of U.S. surface transportation funding but accounts for 2 percent to 3 percent of all U.S. passenger trips and 2 percent to 3 percent of all U.S. passenger miles. In fact, use of mass transportation has remained remarkably steady, and low, since about 1970. There is nothing exceptional about last year's numbers; they represent a depressing norm."[73]

Most U.S. transit use occurs in a handful of dense cities. As transport scholars David King, Michael Manville, and Michael Smart said:

> "New York alone accounts for a third of all transit travel. A close look at the report shows that while U.S. transit trips increased by 115 million from 2012 to 2013, trips on New York's Metropolitan Transportation Authority rose by 123 million. In other words, transit use outside New York declined in absolute terms last year. This fact shows how crucial public transportation is to our largest city and how small a role it plays in most other Americans' lives."[74]

As noted in the introduction, in the Seattle area transit ridership is 2.8% of the market share compared to 97.2% for non-transit vehicles share. Although the commute market share is 10%, the non-work percentage is only 1%. The Puget Sound Regional Council (PSRC) predicts that by 2040 the total transit share in the Seattle region will be 5%--using optimistic assumptions.

What is needed is a new set of strategies—and technologies—for increasing and improving transit. As noted in the Washington Post: "Building transit systems is not the same as having people ride them, and people riding transit more is not the same as people driving less (plenty of transit riders are people who used to walk)…. Increased subsidies for public transportation have neither reduced driving nor increased transit use."[75]

The Seattle area now has the 9th worst traffic congestion in the U.S. Peak commute times are increasing as more than 30% of the working population in the counties north and south of Seattle commute into Seattle mostly along Interstates 5 and 405.[76] Increasingly stop-and-go traffic extends for 40 miles or more north and south in the morning and evening commutes. Planning to be at work on time means leaving even earlier in order to add a cushion of time—which ends up wasting even more time.

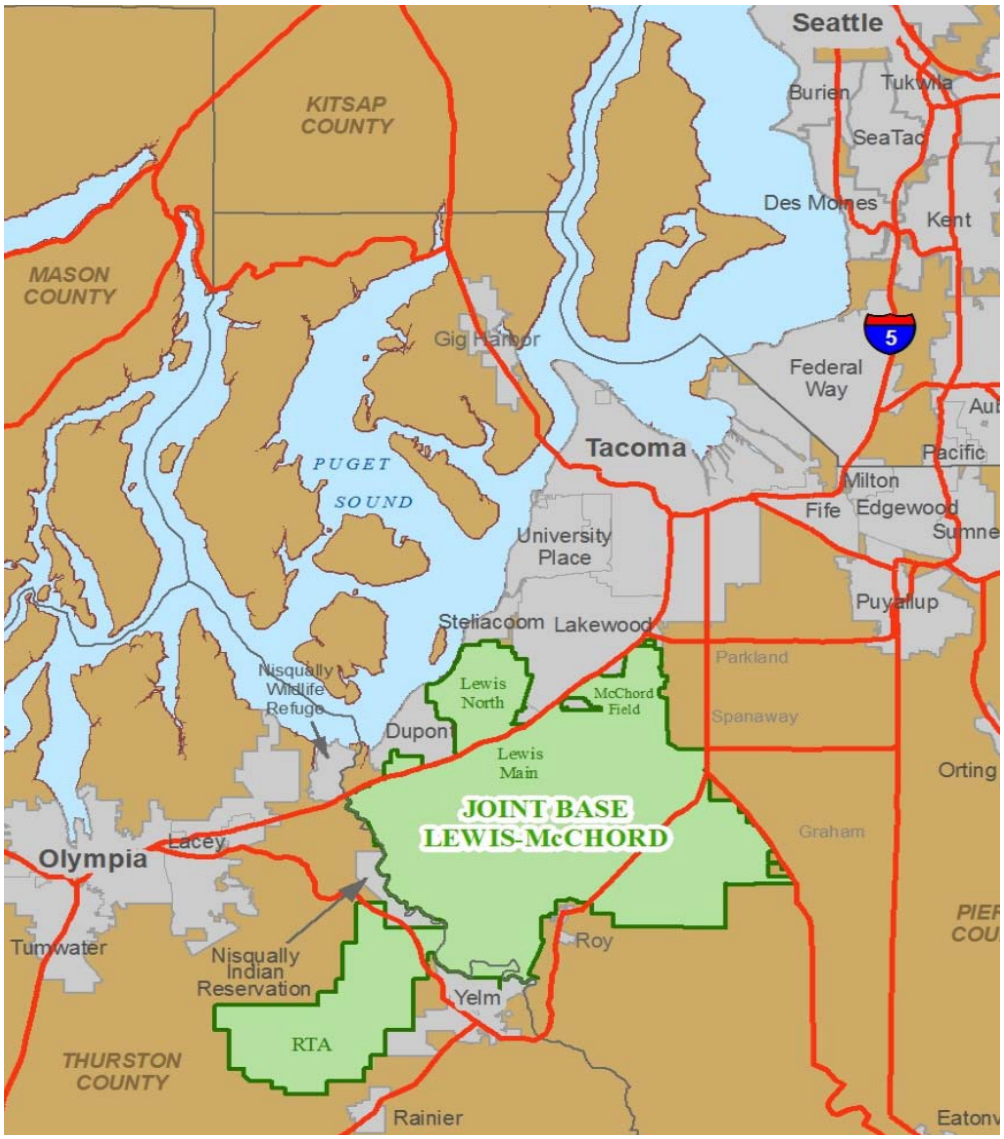
Smart, connected, increasingly autonomous, electric vehicles can be an essential part of an improved transit system. Using the Seattle region as an example, the following is a public policy roadmap for accelerating and integrating these new technologies to help expand and improve public transit:

- Create a system of high-tech park-and-ride centers, where commuters can use smartphone apps to reserve and pay a reasonable fee (less than urban center parking) to reserve parking places and seats on an express buses[77], light rail, flexible carpools or vanpools. Finance the high-tech centers with public-private partnerships and allow housing development rights to airspace above or along-side the centers as well as allowing for retail amenities, including coffee stands, and package delivery kiosks, where commuters can order items during the work day and pick them up on the way home. Allow as an added offset costs, paid advertising as at the airport and on the side of buses. Permit and encourage flexible carpools, vanpools, car-sharing and company transit systems, such as Microsoft's Connect[78], to use the parking and pick up locations at the new centers.
- Encourage use of electric vehicles by providing low-cost 110V plugs at park-and-ride centers, in order to maximize the number of electric miles traveled. A Chevy Volt plugged into an inexpensive standard 110 volt household plug during an eight hour work day will fill its 40 mile capacity electric battery at minimal cost. Cover open parking lots with canopies topped by solar panels for additional carbon-free charging. Create a simple permit system, outlined in the EV section above, for EV parking to further minimize the costs of the charging stations for commuters—or include it in the price of a reserved space.
- Increase the number of regional park-and-ride spaces in order to attract and intercept more occupant vehicles entering into congested core urban areas. Many park-and-ride lots in the greater Seattle region fill up by 7:00am and are one of the bright spots in the effort to reduce congestion into the urban core.[79] The master plan approved over a decade ago for Interstate 405 called for thousands of new park-and-ride spaces, but none have been built. I-405 is now one of the worst congested roadways in the U.S.
- Consolidate the fragmented ownership and operation of park-and-ride centers.[80] Provide real-time information over the Internet and on programmable freeway signs on what spaces are available and where along with the apps that allow a space to be reserved. Work with employers to create new areas for picking up and dropping off passengers using company transit systems.
- Reform the Washington State Commute Trip Reduction Act (and similar acts in other states) to provide incentives for employers to reduce congestion, emissions and accidents. Employees heading to and from work create roadway congestion and as well as the emissions and accidents that accompany that congestion. Employers should be required to include estimates of the carbon commute emissions when they report their carbon footprint. Create and test incentive programs for employers who encourage low-carbon commuting, such as targeted tax credits or regulatory exemptions. Create other methods to recognize and reward employers who reduce congestion, pollution and carbon emissions associated with getting their employees to and from work.

- Require King County Metro (and other transit agencies in the U.S.) to encourage employers to form more electric vanpools that are also flexible. Vanpools are one of the most cost-effective effective transit options in the Seattle region, and with EV vanpools can reduce urban pollution and CO_2,[81] but are limited by a requirement to always have the same five or more members in the vanpool. Amend the program to encourage flexible EV vanpool arrangements using employer data bases on their employees and smartphone apps to organize daily vanpools that may have a different passenger make up each day. Microsoft has created a pilot program for flexible carpools called micro-transit that matches riders.
- Use local permit standards to increase use of innovative private sector transit as Microsoft was required to do by the city of Kirkland in order to reduce intersection congestion before it could get building permits to expand their campus. As a result, Microsoft created its own high-tech transit system called The Microsoft Connector to bring employees to its campus and uses a company run on-call shuttle system within its campus. [82]
- As gasoline engine vanpool are retired, lease replacements electric vanpool vehicles (either all electric or with range extender back-up engines) and equip them with driver-assistance automation applications that will reduce rear end collisions and inadvertent lane departures. Leasing instead of purchasing is an increasingly a viable option for accelerating the move from oil to electricity and incorporating autonomous features in vehicles. [83] Purchase of gasoline-powered, low-automation vehicles today yields increasingly obsolete technology on the roads for a decade or more, making it more difficult to meet carbon, pollution and accident reduction goals.
- Establish vanpool routes from park-and-ride centers that could be eventually transformed into pilot programs for autonomous shuttles. One set of routes would be to take troops and workers from their homes in electric vanpool vehicles to Joint Base Lewis-McChord and then shuttle them with on-base driverless electric shuttles, as the next section discusses as part of a whole-system approach for a large-scale demonstration project of the emerging technologies.

A Large-Scale Integrated Demonstration Project at Joint Base Lewis-McChord

There is a need for large-scale, real-world testing to work out the integration of the emerging connected, autonomous and electric vehicle technologies and to build public understanding and confidence. Joint Base Lewis-McChord (JBLM), one of the largest military bases in the U.S., is an ideal location for this testing. JBLM is located along both sides of Interstate 5 near Seattle, between Tacoma and Olympia in Washington State.



This section will propose a whole systems approach, where testing of several technologies and approaches can be integrated to save costs and create a practical working model for broader application.

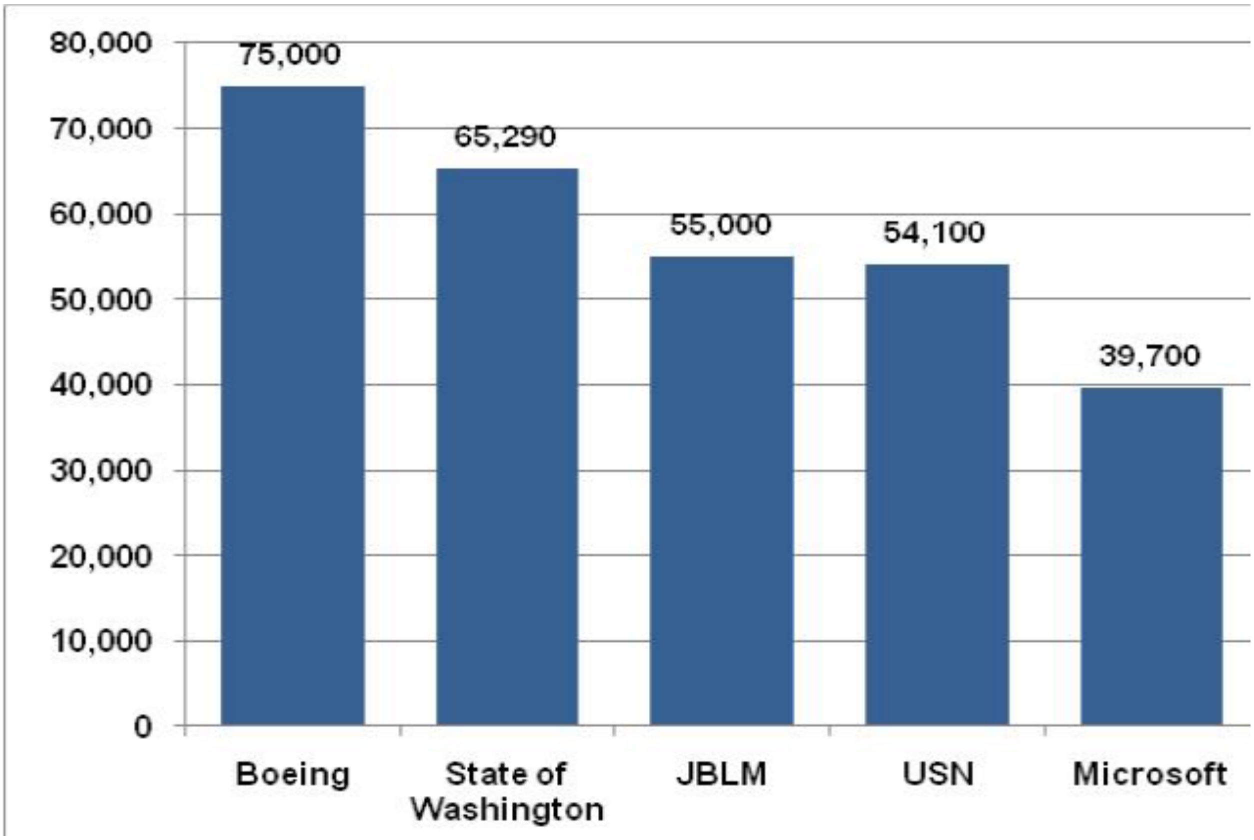
As part of a whole systems approach, testing at JBLM should include testing of cybersecurity for connected vehicles, secondary use of vehicle batteries to back-up mission critical circuits and to reduce costs, and control group data collection to establish cost-effective insurance approaches for connected and autonomous vehicles. Testing could also include integration of charging with utility providers to reduce peak demands and increase reliability. Transit innovations, discussed above, can be tested at both on base, which has an advanced livable communities model, and moving people on and off the bases on Interstate 5 which passes through JBLM and is one of the most congested sections of I-5 in the state.

With federal government budget and sequestration concerns, a primary goal of the testing at JBLM should be to demonstrate that the outcome of the integrated application of these new transportation technologies will be cost-effective and result in savings not only of dollars, but of mission time and lives.

Testing of the combination of connected, electric and autonomous technologies at a military base is an appropriate extension of the work started in 2004 by the U.S. Department of Defense (DoD) through its Defense Advanced Research Project Agency (DARPA), which carried out a series of autonomous vehicle competitions in order to develop driverless vehicles for military use. The DARPA competition produced successful prototypes which led to the more rapid development of autonomous vehicle technology for civilian use.[84]

There is also recognition that military bases can serve as an ideal place for controlled testing which can result in both military and civilian benefits. The DoD and the Department of Energy (DOE) have signed a Memorandum of Understanding to use the purchasing power of the DoD (and its capability to do large-scale controlled experiments) in order to test technologies that hold the promise to save energy and lives in both the military and civilian applications.[85]

JBLM, one of the largest Department of Defense bases in the U.S., is the size of a small city (it would rank 7th among Washington State cities) and ranks third in the number of employees in Washington State, with the largest number of employees on single campus in the state.[86]



JBLM has unique and favorable attributes for testing the emerging vehicle technologies and associated systems:

1) The power supplied to the base by Tacoma Power is over 95 percent carbon-free hydroelectric, wind, solar and nuclear power with one of the least expensive power costs per kilowatt hour anywhere in the U.S.;
2) JBLM is adjacent to two project areas receiving livable community grants coordinated by the U.S. Department of Housing and Urban Development, Environmental Protection Agency, and Department of Transportation;
3) The portion of the Interstate 5 highway running through the base is one of the most congested road segments on the West Coast and needs cost-effective solutions;
4) JBLM has an existing vanpool program that can be expanded and used for experiments in smart, connected, increasingly autonomous, electric vehicles;
5) JBLM is an award winning leader among U.S. military bases for its strong commitment to environmental sustainability as well as livable community design;
6) It has strong civilian support at the local and state level through the South Sound Military & Communities Partnership and through new state level initiatives;
7) Private sector companies located nearby are leaders in different aspects of the emerging technologies outlined in this chapter, including Google, Microsoft, Nissan, Ford, INRIX, Airbiquty, VoiceBox, Amazon, PACCAR, and Boeing;
8) State and local public officials frequently demonstrate leadership on technical and environmental issues;
9) Residents of Western Washington have historically been early adopters of technology that improves the environment and the sustainability of communities.

The integrated, large-scale testing at JBLM would include the following elements:

1) Incorporation of a new petroleum and CO_2 reduction goal into the existing Department of Defense program of Net Zero energy—a net zero carbon goal;
2) Implementation of smart, connected electric vanpools for troops as well as contractors for commuting to and from the base – perhaps flexible versions of what Microsoft calls micro-transit;
3) Implementation of an on-base EV shuttle system to move transit commuters inside the base;
4) Testing of driverless EV shuttles initially in limited numbers, then with expansion to all on-base shuttles;
5) Testing of driverless and platooned vehicles along I-5 and I-90 from JBLM to the Yakima Firing Range in central Washington State;
6) Testing of information protocols and standards in applications linking vehicles to infrastructure and data;
7) Creation of connected transportation hubs north and south of the base to allow for reserved parking, flexible car pools and vanpools;
8) Creation of incentives for military and civilian base employees to purchase EVs or to use transit;
9) Testing of used vehicle batteries as back-up power sources for mission critical circuits;
10) Testing of bi-directional power supplies for EVs that are capable of providing back up power and ancillary power services.

Planning effort is underway to detail the design of project components and muster resources for this large-scale demonstration of electric, automated mobility on and around Joint Base Lewis McChord.

Conclusion

In summary, we believe that the policy community remains largely unaware of the pace and extent of the innovative and disruptive technologies that form the core attributes of smart, connected, autonomous, electric vehicles. We also believe that the combination of these disruptive technologies is more powerful than implementing each one separately. In order to optimize the combination of technologies and approaches, there needs to be close coordination between the public and private sectors in the design and testing of these concepts in comprehensive, large-scale demonstration projects. This report has identified the research and policy challenges associated with the vision of automated, connected, and electric mobility, with a public policy roadmap on initial steps to achieve this vision.

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"Paul Hanna, fleet and facilities supervisor for the city of Olympia, says he loves the Nissan Leaf all-electric car he uses for work. The city will lease six for two years. The all-electric car produces zero greenhouse emissions and logs the equivalent of 115 miles per gallon of gasoline.

"Each vehicle will cost the city about $7,400 for the two-year lease….Governments usually prefer to purchase vehicles. However, Nissan is willing to tailor-fit these leases to meet a city's needs. This leads to fewer upfront costs and quicker savings on fuel, said Stephanie Meyn, program manager for Western Washington Clean Cities. "Olympia was the first to keep going at this and make it happen," Meyn told The Olympian. "Other people will see them as a relatable example."

"By 2018, Washington cities must purchase all-electric or biodiesel vehicles for any replacements to their fleet. "Danelle MacEwen, program specialist with the Public Works Department, said the city will soon launch a public communication effort about the vehicles."

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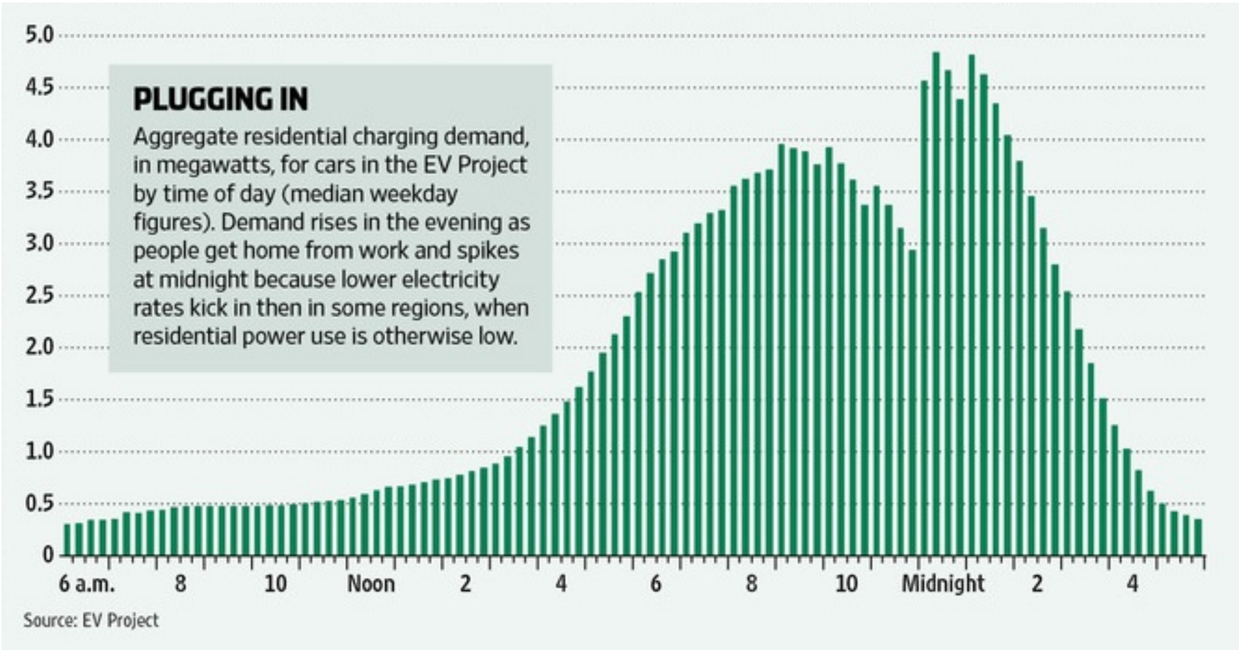

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Edison Electric Institution, *Transportation Electrification*, June 2013 http://www.eei.org/issuesandpolicy/electrictransportation/FleetVehicles/Documents/EEI_UtilityFleetsLeadingTheCharge.pdf

65 Kelly-Detwiler, P., "Electric Vehicles Could Save U.S. Utilities From A Death Spiral,," *Forbes*, August 7, 2014 http://www.forbes.com/sites/peterdetwiler/2014/08/07/electric-vehicles-could-save-u-s-utilities-from-a-death-spiral/

The Economist, "Electric cars could help save power utilities from a "death spiral," ," *The Economist*, October 4, 2014. http://www.economist.com/news/business/21621850-electric-cars-could-help-save-power-utilities-death-spiral-adapting-plug-ins. Excerpts:

"After '"rate hikes",,' the most common phrase in America's electricity industry these days is '"death spiral"..' The recession clobbered demand, and it has not recovered. Last year Americans used 2% less electricity than in 2007. The government's Energy Information Administration reckons demand will grow by less than 1% a year between now and 2040.

"What the industry needs is a new business model. The best prospect is plug-in electric vehicles. Today, Americans' daily spending on energy can be split into two large chunks: about $1 billion on electricity and $1.4 billion on fuel for their vehicles. In the past, electricity providers had no way to tap into the latter market. Plug-in cars should change that."

[66] "Sen. Mark Mullet launches state Electric Vehicle Caucus,," *Issaquah Press*, December 16, 2014 http://www.issaquahpress.com/2014/12/16/sen-mark-mullet-launches-state-electric-vehicle-caucus/

[67] British Columbia enacted a carbon tax that, among other things, has increased the price per gallon of gasoline by 27 cents a gallon.

[68] See section ___above Caiazzo, F., Ashok. A., Waitz I.A., Yim, S.H.L., Barrett, S.R.H., "Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005," Atmospheric Environment, Volume 79, November 2013, pp. 198-208 http://www.sciencedirect.com/science/article/pii/S1352231013004548

[69] https://www.youtube.com/watch?v=cdgQpa1pUUE&feature=player_embedded

[70]Knell, N., "Connected Cars,," December 17, 2014 http://www.govtech.com/transportation/March-2014-Connected-Cars.html

[71] http://www.apta.com/resources/statistics/Documents/2013-q4-ridership-APTA.pdf

[72] Jaffe, E. "Maybe Transit Isn't Surging After All," Atlantic Cities blog, May 24, 2014 http://www.theatlanticcities.com/commute/2014/03/maybe-transit-isnt-surging-after-all/8702/

[73] King, D., Manville M. and Smart, M., "Use of public transit isn't surging," *Washington Post*, March 3, 2014 http://www.washingtonpost.com/opinions/use-of-public-transit-isnt-surging/2014/03/20/0b44e522-b03b-11e3-95e8-39bef8e9a48b_story.html

[74] Id. David King is an assistant professor of urban planning at Columbia University. Michael Manville is an assistant professor of city and regional planning at Cornell University. Michael Smart is an assistant professor of city planning at Rutgers University.

[75] Id. INRIX, an international traffic data company based in the Seattle area, has documented the effect transit strategies has had on congestion using their vast data base on road use. For example, when a light rail line was built connecting downtown Seattle to the Seattle-Tacoma International airport, INRIX historical and current data comparisons show that there has been no reduction of congestion. Replacing buses to and from the airport with light rail has unfortunately increased the total trip time for those using public transit to the airport.

[76] Traffic congestion is not only increasing with population, but with the rebound from the recession and significantly lower gasoline prices compared to the last six years.

[77] "To attract even more riders, buses need to be more comfortable, safe and inviting. Follow the example of Microsoft's Connector and make riding an express bus an upscale experience with better seats, better lighting, laptop outlets and even cup holders." Marshall S., and Agnew B., "Fast-forward to a time when innovation moves the region," *Seattle Times,* November 16, 2007 http://seattletimes.com/html/opinion/2004016735_roads16.html

[78] Roe, A., "Climb on board the Microsoft bus," *Seattle Times* September 25, 2007, http://seattletimes.com/html/eastsidenews/2003900596_microsoftbus25e.html;

Romano, B., “Microsoft adds to list of perks,” *Seattle Times*, Sept. 7, 2007, http://seattletimes.com/html/microsoft/2003872782_microsoft07.html (The article quotes Microsoft General Counsel Brad Smith: "One of the great things about these buses is not only that it gets people to work faster than the commute they have today, but it makes them more productive or just makes the ride more enjoyable if they want to surf the Internet.” In planning the routes, Microsoft studied where its Puget Sound-area employees live and whether they are well-served by public-transportation options.) Although Microsoft’s Connector bus service has been in operation since September 24, 2007, it is still not allowed to pick up riders at regional park-and-ride facilities.

[79] Marshall S., and Agnew B., “Fast-forward to a time when innovation moves the region,” *Seattle Times* November 16, 2007 http://seattletimes.com/html/opinion/2004016735_roads16.html

[80] Park-and-ride structures in the Seattle region are owned by several agencies including the Washington Department of Transportation, Sound Transit, and King County Metro. This fragmented ownership has been one impediment to the adoption of innovative and cost-effective road congestion solutions.

[81] Marshall, S., “King County Metro is in a Bind,” *Seattle Times*, June 23, 2013, http://seattletimes.com/html/opinion/2021243420_stevemarshallopedxml.html. As discussed above, King County Metro has a vanpool fleet of all-electric Nissan that get 500 miles per passenger per gallon equivalent compared to 42 miles per passenger per gallon on a typical Metro bus.

[82] Unlike Kirkland, the City of Seattle has no similar requirement for the increasing congestion in South Lake Union caused by the Amazon expansion. Amazon, which is a leader in moving products from the time of Internet order to delivery, could use its logistical skills in moving employees to its South Lake Union campus. It knows where its employees live and what their schedules are, even those schedules that are not standard. Amazon also maintains one of the world’s largest cloud data storage services.

[83] Transit agencies should follow the lead of the Washington Department of Enterprise Services (DES), which has set up a leasing program for Nissan Leafs. The Western Washington Clean Cities Coalition report that the program “has helped the state departments of Corrections, Ecology, and others integrate Nissan Leafs into their fleets. Each fleet took advantage of a Nissan leasing agreement that allows the lessor to take advantage of the electric vehicle sales tax credit and doesn't lock them into a particular technology over the long term.” The Washington State Department of Transportation was the first state agency to use the Nissan Leaf lease option. http://wwcleancities.org/resources/publications/

[84] Wilson, J.R., “*A driving force: DARPA’s Research Efforts Lead to Advancements in Robotics and Autonomous Navigation*” http://www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2564

[85] “Energy and Defense Departments Announce Agreement to Enhance Cooperation on Clean Energy and Strengthen Energy Security,” July 27, 2010, http://web.archive.org/web/20101215142122/http://energy.gov/news/9278.htm

[86] Hodges, C, Personal interview with Joint Base Lewis McChord Garrison Commander, November 14, 2013