Green and Connected

White paper prepared for the Michigan Department of Transportation

Prepared by the Center for Automotive Research

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I. Introduction

Two of the most important developments in automotive technology currently underway are the introduction of vehicle communications and the electrification of the powertrain. While these two technologies largely have evolved separately, their future evolution will not be in isolation. Furthermore, these two technologies reinforce one another, each making the other more effective. Recognizing this potential, the Center for Automotive Research (CAR), with the support of the Michigan Department of Transportation (MDOT), a recognized leader in connected vehicle technology, has investigated the linkages and synergies between these two technologies and their coincidental development. This document presents CAR's thoughts on the potential of these two technologies to make each other stronger in the market. Ultimately, the goals of this paper are to raise awareness of the potential added benefits of being "green and connected" and to begin a dialogue on how best to achieve these benefits.

CAR and MDOT have several objectives in developing and releasing this white paper. First, they want to document the interactions between communication and electrification technologies, showing how their simultaneous development enhances both. Second, they seek to describe the technical, regulatory, and other factors that are needed to allow these technologies to achieve wide deployment and for the traveling public to realize their full benefits. Third, they want to explore opportunities for the State of Michigan to establish leadership and benefit the State's economy and industry.

Connected Vehicle Technology and Communications

The United States Department of Transportation (USDOT) has launched a national program to enhance vehicle transportation through the applications of communication technologies. This program, known as Connected Vehicle Technology (succeeding the USDOT's VII, for Vehicle-Infrastructure Integration, program), targets safety, mobility, and environmental improvements through a combination of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-device communications. Already, these technologies have been demonstrated in the State of Michigan and elsewhere. Led by MDOT, Michigan has committed itself to a leadership role within the national connected vehicle effort.

Connected vehicle technology allows vehicles to communicate with each other and the roadway to enhance situational awareness and ultimately enable cooperative, active safety systems. Rather than defining a specific technological solution, connected vehicle program consists of multiple in-vehicle and roadside communication technologies, along with data processing and applications that enable vehicles to obtain and share information with each other and the world, including transportation infrastructure operators. Thus, connected vehicle technology leverages existing 3G, 4G, and other communication networks where and when they make sense (such as for mobility applications).

The negative externalities of vehicle travel are stark. Every year, more than 32,000 people are killed and more than 2.4 million people are injured in traffic crashes in the U.S. (United States Census Bureau 2010). Each year, we lose millions of hours stuck in traffic. And every year, as a nation, we waste billions of dollars in fuel caught in traffic congestion (Schrank and Lomax 2009). Technology can change this. Today, the U.S. DOT, state DOTs, the American Association of State Highway and Transportation Officials (AASHTO), and private industry are working together to implement connected vehicle technology, a system that allows vehicles to communicate with each other and the roadway. V2I connectivity involves communication between vehicles and the roadway, traffic signals, and other infrastructure elements, such as bridges. V2V connectivity consists of vehicles communicating with one another.

V2V and V2I both offer numerous benefits to drivers and the transportation system as a whole. When widely deployed, connected vehicle technology will help drivers avoid crashes by providing advanced safety warnings and, when necessary, taking over control of the vehicle when there is not enough time for the driver to act to avoid a crash. It will help drivers avoid congestion through real-time and predictive route guidance (US Department of Transportation 2010). It will help transportation agencies manage traffic better, allowing them to alert drivers of upcoming congestion, recommend alternative routes and modes, and alter the timing of traffic signals to improve traffic flow (Park and Joyoung 2009). In addition, it can help agencies with asset management by using vehicle-based data to detect problems in the road surface or geometry. It also can help owners with vehicle maintenance by reporting pending problems, keeping small repairs from becoming larger and more expensive.

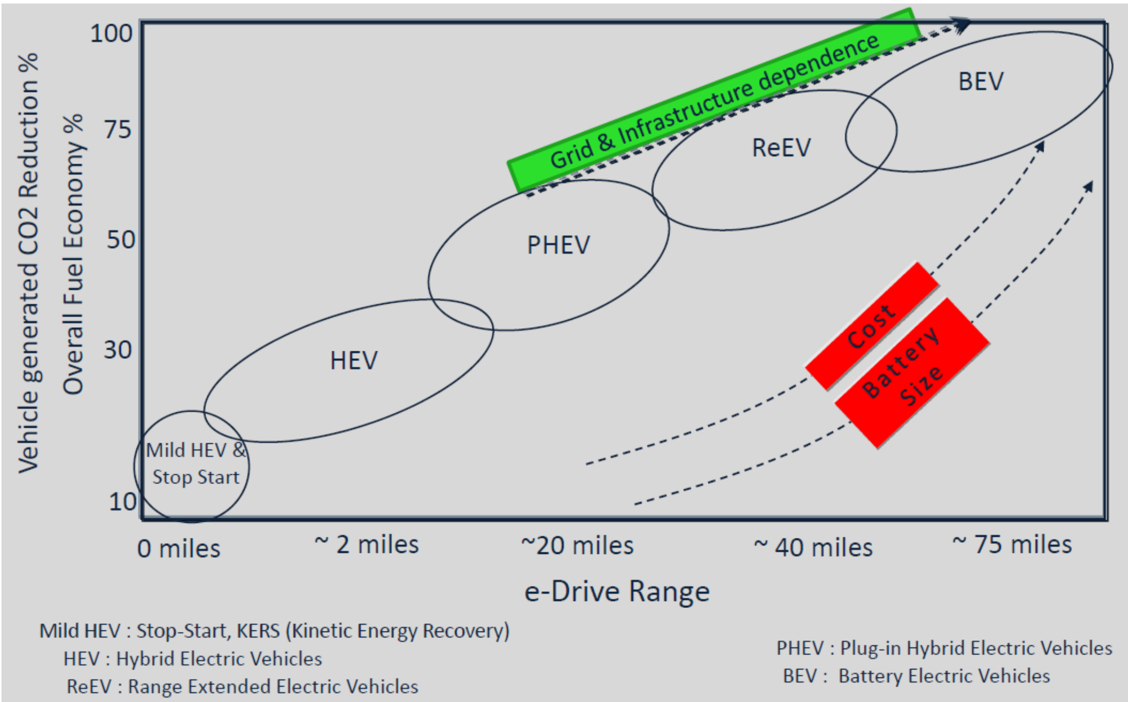
Powertrain Electrification

U.S. transportation energy use accounts for 28.1 percent of total U.S. energy use.[1] Concerns regarding air pollution, energy dependence, and increasingly, climate change continue to motivate the search for new transportation solutions. Much of the focus is on light-duty vehicle, as they account for 60% of U.S. transportation energy use and greenhouse gas (GHG) emissions. Generally speaking, the shift toward electrification can be separated into four distinct types of technology: hybrid electric vehicles (HEV, including mild HEV), plug in hybrid electric vehicles (PHEV), extended range electric vehicles (EREV) and battery electric vehicles (BEV). These technologies present (in order) an increasing reliance on electricity, longer e-drive range, and less vehicle generated CO_2 emissions (see Figure 1). The last three can be classified as plug-in electric vehicles (PEVs). These vehicles differ from internal combustion engines in that they require the management of high voltage, a skill critical to all PEV development is the power electronics or power conditioning. The automotive industry has not historically needed this skill set, but it will for electrification to succeed.

The hybrid electric vehicle (HEV) combines an internal combustion engine and an electric motor. There are three basic variations, belt alternator starter (or mild hybrid), integrated generator assist, and series-parallel. The three are presented from least expensive to most, and least efficiency gain to most. The Toyota Prius was the first high-volume series-parallel hybrid vehicle and has been on sale in the United States since 2000. Currently, most major manufacturers offer at least one, if not several, hybrid models, and it is fair to say that this technology has become somewhat commonplace. The sale of hybrid electric vehicles in the U.S. increased from 9,350 vehicles in 2000 to 274,210 vehicles in 2010 (see Figure 2). Today, more than two million hybrid electric vehicles are in operation.

[1] U.S. Department of Energy. Transportation Energy Data Book. 2011

Figure 1: Technology Choices: Degrees of Electrification
Source: Michael Moore. [PowerPoint Slides]. Presented to Michigan Plug-in Electric Vehicle Preparedness Taskforce. June 14, 2011.

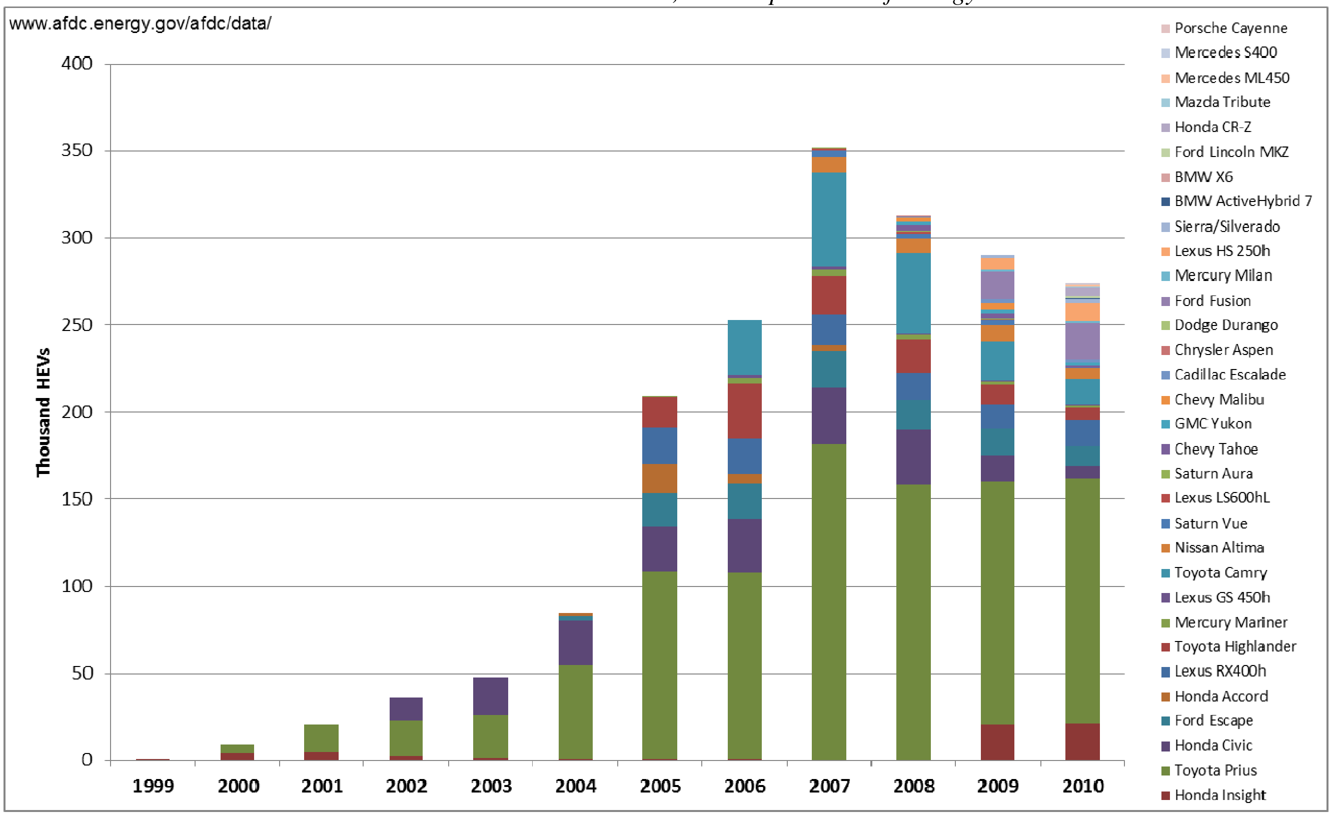


A plug-in hybrid electric vehicle (PHEV) uses rechargeable batteries, or another energy storage device, that can be restored to full charge by connecting a plug to an external electric power source (usually a normal electric outlet). A PHEV shares the characteristics of both a conventional hybrid electric vehicle, having an electric motor and an internal combustion engine (ICE); and of an all-electric vehicle, having a plug to connect to the electrical grid.

The key differentiator between an HEV and a PHEV is the battery. While HEVs typically use a Nickel-Metal-Hydride (NiMH) battery, PHEVs require the ability to access higher amounts of energy, and thus use lithium ion (Li-Ion) batteries. When depleted, the battery can be charged by the gasoline engine or by being connected to the electrical grid. The Toyota Prius can now be commercially converted (using aftermarket kits and tax incentives) to a plug-in hybrid by CalCars and a number of third-party companies. Another good example is the Bright Automotive's IDEA delivery van.

Similar to the PHEV, the extended range electric vehicle (EREV) uses a gasoline engine, an electric motor, and a Li-Ion battery. The PHEV blends the gasoline engine and electric motor to power the wheels. Conversely, the EREV drives its wheels entirely via the electric drivetrain. The gasoline engine powers a generator to create electricity, which is stored in Li-Ion battery. When depleted, the battery can be charged either by connecting to the electrical grid or by the gasoline engine. An example of this technology is the Chevrolet Volt, which is the first mass production EREV[2] available in the United States and its deliveries began in December 2010.[3] Because the technology does not require the blending of two powertrains to drive the wheels, the EREVs may require less complex control strategies than do HEVs and PHEVs.

Figure 2: U.S. Hybrid-Electric Vehicle Sales (1999 – 2010)
Source: Alternative Fuels and Advanced Vehicles Data Center, U.S. Department of Energy



The battery electric vehicle (BEV) contains an all electric drivetrain. The battery is charged by connecting to the grid, with regenerative braking adding some additional charging. Examples of BEVs are the Think City, the Ford Transit Connect Electric, and the Nissan Leaf. BEVs are currently limited by the range and cost of the battery. When the battery runs out of power, the vehicle can go no further until the batteries are recharged via the electrical grid. This characteristic of BEVs has given rise to the term "range anxiety" to describe why some consumers are reluctant to purchase a BEV—the fear that the vehicle will not be able to reach its destination before its batteries are fully depleted.

Plug-in hybrid electric vehicles (PHEVs) have been recognized for their potential to reduce transportation-related petroleum consumption and on-road greenhouse gas emissions, improve the nation's energy independence, and promote economic growth and security. Thus, the U.S. is home to numerous federal, state, and local incentive programs intended to overcome the initial

[2] Complicating matter, depending on how and when the battery pack drops to zero charge, the Volt operates akin to an HEV. That is, under some circumstances, the gasoline engine directly powers the vehicle, without passing power through the electric motor.
[3] Chevrolet Volt is also classified as "plug-in hybrid electric vehicle (PHEV)" in some cases since it operates entirely as an electric car for its first 40 miles after a full charge. See http://www.hybridcars.com/vehicle/chevy-volt.html

cost of PHEVs. For example, as part of the American Recovery and Reinvestment Act, the US Department of Energy announced the release of two competitive solicitations in March 2009 for up to $2 billion in federal funding for competitively awarded cost-shared agreements for manufacturing of advanced batteries and related drive components, as well as up to $400 million for transportation electrification demonstration and deployment projects. This Act also will help meet President Barack Obama's goal of putting one million plug-in hybrid vehicles on the road by 2015. Approximately 1.8 million additional PHEVs are projected to enter the market between 2015 and 2020.[4]

A review of the general press might lead to the belief that PHEV technology is going to be the dominant powertrain in the next five years; however, the wide-scale penetration of PHEVs faces significant hurdles, with cost being the most apparent. Concomitantly, automotive engineers continue to develop improvements to the incumbent powertrain technology, the spark-ignited internal combustion engine. While it is likely that the trend toward vehicle electrification will continue, advanced powertrain technology options are many and the mix of powertrain options likely to be offered in ten to twenty years remains somewhat uncertain.

II. Linkages and Synergies

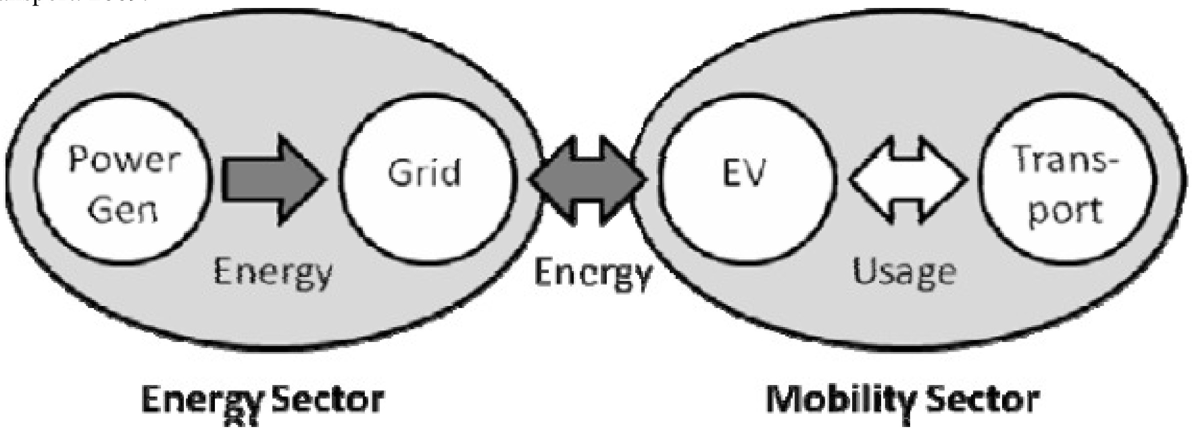
When looking at how electrification of the vehicle and connectivity interact, two definitions of electrification are useful. The first considers the wide continuum from alternative fuels and propulsion systems, to hybrid electric vehicles (HEVs), to battery electric vehicles. The second is more limited and simply divides vehicles into those that are grid enabled and those that are not. The latter definition includes plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs), and battery electric vehicles (BEVs). While hybrid electric (non-grid enabled) vehicles present a much more viable solution to the fuel economy challenge in the *mid-term* than do grid-enabled vehicles (GEVs), the higher costs of HEVs present a difficult challenge vis-à-vis the advanced internal combustion engine. Grid-enabled vehicles, in turn, may present the ability to achieve higher levels of integration between energy production and distribution and the vehicle and transportation infrastructure (see Figure 3).

As described in this paper, the addition of communication between the vehicle and the infrastructure offers the potential for all forms of alternative and advanced powertrains to become more efficient and more attractive to consumers. The communication of many types of information—e.g., traffic updates, status of smart charging infrastructure, details about energy storage technology and devices, telematics and smartphone applications for automotive platforms, and more—presents opportunities for a new transportation system in the digital age, as well.

Of the many technologies and strategies considered (hybrid electric vehicle, bio fuels, etc.), the grid-enabled vehicle potentially offers the greatest opportunity to capitalize on connectivity. In many ways, through the grid, the vehicle could become the communication focal point for a fully integrated energy system. The connected vehicle offers the opportunity to tie together the electric power generation and grid, and homes, to the transportation infrastructure, potentially creating a smarter and more efficient system.

[4] SENTECH, Inc. PHEV Market Introduction Study: Final Report. January 2010.

Figure 3: Plug-in Hybrid Electric Vehicle (PHEV) Links Energy and Mobility Sectors
Source: European Road Transport Research Advisory Council: The Electrification Approach to Urban Mobility and Transport. 2009.



In essence, we can define at least three levels of connectedness with regard to vehicle and energy usage. From least to most connected, these levels increasingly enable the vehicle to interact with both the upstream energy generation, and transportation communications systems. These three levels of connectedness can be described as: simple transportation energy planning and mapping, initial grid enabled communication, and the integrated energy transportation efficiency model.

Simple Transportation Energy Planning and Mapping

The first level of opportunity is the ability to efficiently plan (e.g., route planning, range estimation, smart parking, and identification of refueling locations) trips. Increasingly, it is possible to offer the driver guidance regarding the most efficient route and other pertinent information. For alternative fueled vehicles, connectivity will offer the ability to locate fueling (or charging) station locations, and calculate the most effective route considering refueling needs. Such transformative concepts are included in the Applications for the Environment: Real-time Information Synthesis (AERIS) Program currently under development at USDOT. [5]

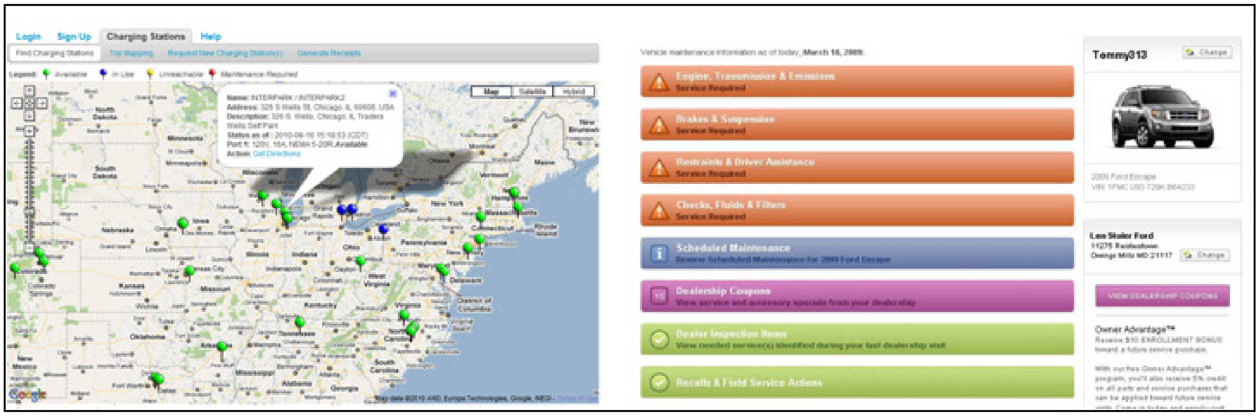
Several mobile applications offer the ability to monitor real-time engine diagnostics. Increasingly such monitoring may be applied to efficiency gains. Current service and support, and driver information will be complimented via integration of cloud computing strategies. For example, the user will have remote access (either computer or smart phone access to fuel consumption data, charging status, trip planning and other activities. For the BEV, the ability to have real time access to information on the location and availability of charging stations can be a critical piece of information—one that may provide consumers with confidence in a vehicle with a limited range.

OnStar is leveraging the power of Google technology to develop a number of new mobile app features that will provide with the most connected vehicle experience possible. A new "navigation" tab has been added to the home screen of the existing Chevrolet Volt mobile app on

[5] http://www.its.dot.gov/aeris/index.htm

the Android smartphone.[6] When a Volt owner presses this tab, they will be able to see the current location of their Volt pinpointed on Google Maps™, as well as their location relative to it. From this map screen, owners can use Google search by voice to vocally search for a destination with their Android handset, and see where that destination is related to the Volt's current location. They can then elect to send the destination from their Android phone to their Volt and have OnStar turn-by-turn directions to their destination waiting for them when they start the vehicle.

Figure 4: Examples of Simple Transportation Energy Planning and Mapping Tools in Use Today (Left: Available ChargePoint Charges in the United States.[7] Right: Typical Ford Sync Diagnostic Report.[8])



This model, in essence, adds the vehicle powertrain to the current connected vehicle portfolio. It is focused on analysis of traffic and location information, combined with the additional inputs of fuel economy and refueling locations. This level of connectivity is applicable to all forms advanced and alternative powertrains (e.g., connectivity also could be used to alert the driver of the locations of compressed natural gas refueling stations), and to a larger extent, to all types of vehicle trips.

Initial Grid-enabled Communication

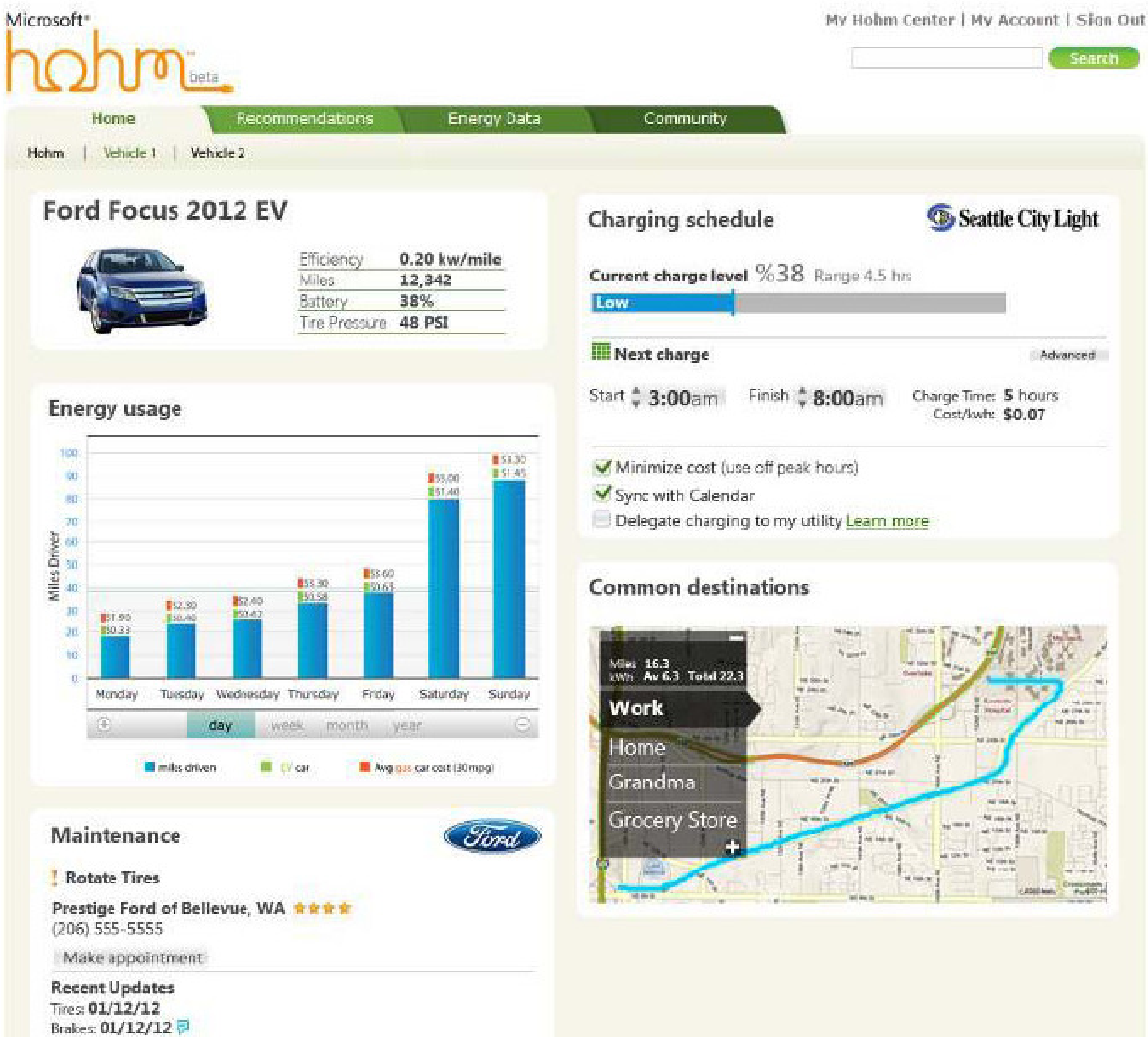
The second step in the hierarchy – specific to GEVs – is connecting the vehicle to the energy producing and transmission portion of the equation - the electrical grid. Minimally, this requires the implementation of smart metering (but not necessarily 'smart grid') either at the charging point or on vehicle. Grid-balancing strategies can be implemented via messages sent from the grid to encourage off-peak and interruptible charging. Furthermore, on-board technology service-area charging and tracking can be included. Connecting the vehicle to the energy delivery system—even in this basic level—enables the first steps toward a more efficient energy solution (Brown, Pyke and Steenhof 2010).

It also enables the increased ability to monitor, and control charging strategies thus empowering the vehicle owner to better manage energy usage. Several companies (GridPoint, Microsoft,

[6] http://www.prnewswire.com/news-releases/onstar-leverages-google-technology-to-connect-customers-to-the-chevrolet-volt-94028244.html
[7] https://www.chargepointportal.net/index.php/device/devicelocation.html
[8] http://www.syncmyride.com/Own/Modules/VHR/vhr_pdf_sample.pdf

Coulomb, etc.) currently are offering products that allow the vehicle owner to monitor energy usage and alter driving and charging patterns to increase efficiency.

Figure 5: Example of Grid-Enabled Communication. Future Vision of Microsoft Home Integrated Electric Vehicle Monitoring (Batterberry 2010).



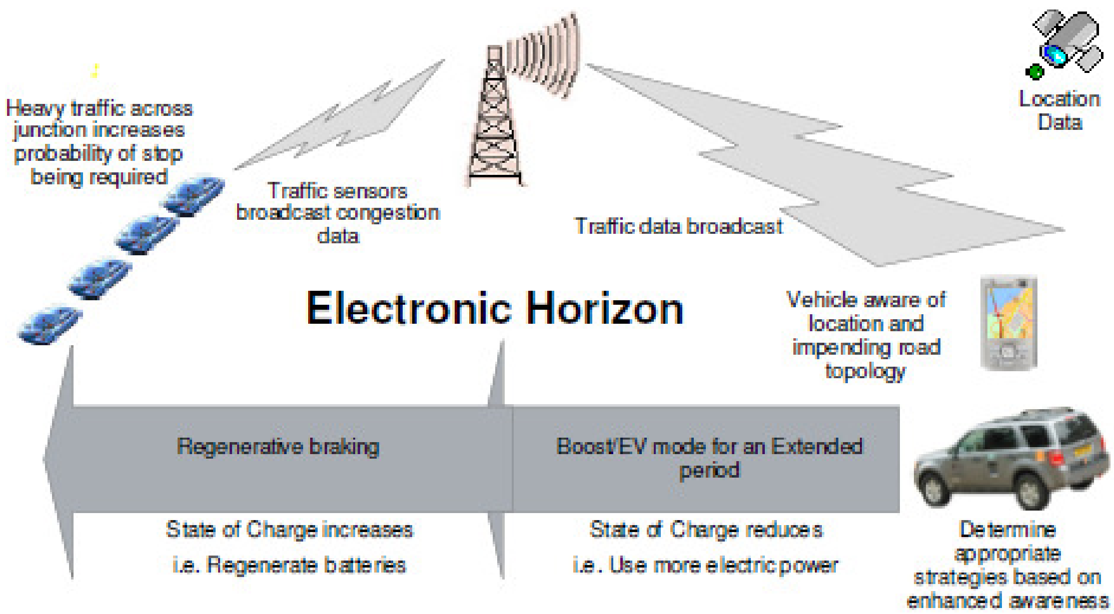
Integrated Energy-Transportation Efficiency Model

The third level of connectivity brings to bear the many synergistic strategies and technologies under development—both on the grid and the vehicle. Key to this is the inclusion of smart grid management, and including vehicle to grid storage strategies. Conceptually, a large fleet of GEVs presents an enormous amount of electrical storage capacity. This capacity could be leveraged for emergency back-up power, as a buffer for peak power needs, and maybe most intriguing, as a storage buffer for intermittent renewable power generation.

Through full communication between the connected vehicle technology systems, vehicles may also be able to tap the full potential of efficient driving. Much as hypermilers are able to modify their driving behavior to achieve the most efficient driving conditions in a given environment

(Zumbrun 2006), linkages between alternative powertrains and connected vehicle can open the door for a whole new level of efficient driving. For example, Ricardo developed a system called Sentience that is capable of analyzing road topography, traffic signs and signals, and other environmental hazards to determine the most efficient vehicle control schemes (GreenCarCongress 2009).

Figure 6: Schematic of Ricardo Sentience Program (Ricardo PLC 2009)



Each of the three levels is further enhanced by a more robust intelligent transportation system, yet such a system may not differentiate between propulsion types.

III. Enablers and Barriers to Deployment

The vision of advanced powertrains, electrification of the automobile, and a communication connection between automobiles and their surroundings, including the electric power system, is moving closer to reality. However, many elements must come together for the benefits of alternative powertrains and connected vehicles to be realized. In other words, the level of market penetration for vehicles using electrification as the primary "fuel" will depend on meeting the many challenges facing the automotive industry, including its suppliers, the utility industry and governments in general. Overcoming logistical, technical, political, and workforce related barriers are all required to make these advanced technologies viable in the marketplace.

Logistical and Technological Challenges and Opportunities

While there is a strong belief that disruptive technology such as connected and electric vehicles can provide a great deal of social benefits, there are several technical barriers that must be overcome to achieve acceptance in the consumer market. Barriers to entry include infrastructure, incumbent technology, and performance related expectation. At the same time there are technological enablers that could provide a gateway to consumer and corporate acceptance. Technological enablers can come in many forms including leveraging existing infrastructure, developing new use cases that benefit consumers and corporations that provide services to these vehicles, and various other technologies that improve the performance of these vehicles.

Infrastructure

Without a doubt, infrastructure is a key barrier to the adoption of both connected vehicles and GEVs. Infrastructure, however, is a two way street. Without infrastructure there is little incentive to purchase vehicles that rely on it. Without vehicles that depend on the infrastructure there is little reason to build out infrastructure. There has been some progress on this infrastructure issue, such as Ford's arrangement with Coulomb to provide in home charging stations (Abuelsamid 2010), Nissan's partnership with Better Place for battery swapping (Jones 2010), and various in-vehicle infotainment systems in development that leverage mobile operating systems (Lovy 2010), Detroit Edison (DTE) currently offers incentives to customers to install 240-volt charging station and competitive rates for plug-in electric vehicles, including incentives for off-peak charging,[9] but there is much left to be done to make GEV and connected vehicle infrastructure viable.

On the connected vehicle side, infrastructure, again, presents a challenge: for V2I to offer significant value to consumers, then significant roadside communications infrastructure is needed. Recent focus on V2V safety technology, combined with use of 3G and 4G networks, for non hard safety applications may present one way out of the infrastructure challenge, but even then intersection crash avoidance applications would be enhanced by infrastructure-based communications (I2V).

The Electricity Grid

The electricity grid is a collection of power plants and transmission and distribution facilities that produces and delivers electricity to end users. The penetration of plug-in hybrid vehicles will impact the grid in both immediate and long term - and the level of such impacts will depend on the quantity and timing of vehicle electricity demand. It is estimated that the addition of a PHEV with 5-10 KWH of usable battery capacity charged once per day could add an additional 21-43% (2200-4600 KWH) per year to the household electricity load (Yang and McCarthy, 2009).

The relative impact of PHEV charging loads on the grid depends on two factors: the number of PHEVs plugging-in to the grad and the charging behavior (fast vs. slow changing). At a high level, several studies show that existing grid capacity (including generation, transmission, and distribution) can fuel as much as 73% of PHEVs in the U.S. light-duty vehicle fleet vehicle if charging takes place 24 hours a day (or 43% of PHEVs for nighttime charging only – between hours 18:00 pm – 6:00 am). For the Midwest region, the idle capacity of the grid could supply almost 100% of the energy needs of today's light-duty vehicles if charging takes place 24 hours a day (or 61% of PHEVs for nighttime charging only – between hours 18:00 pm – 6:00 am).[10]

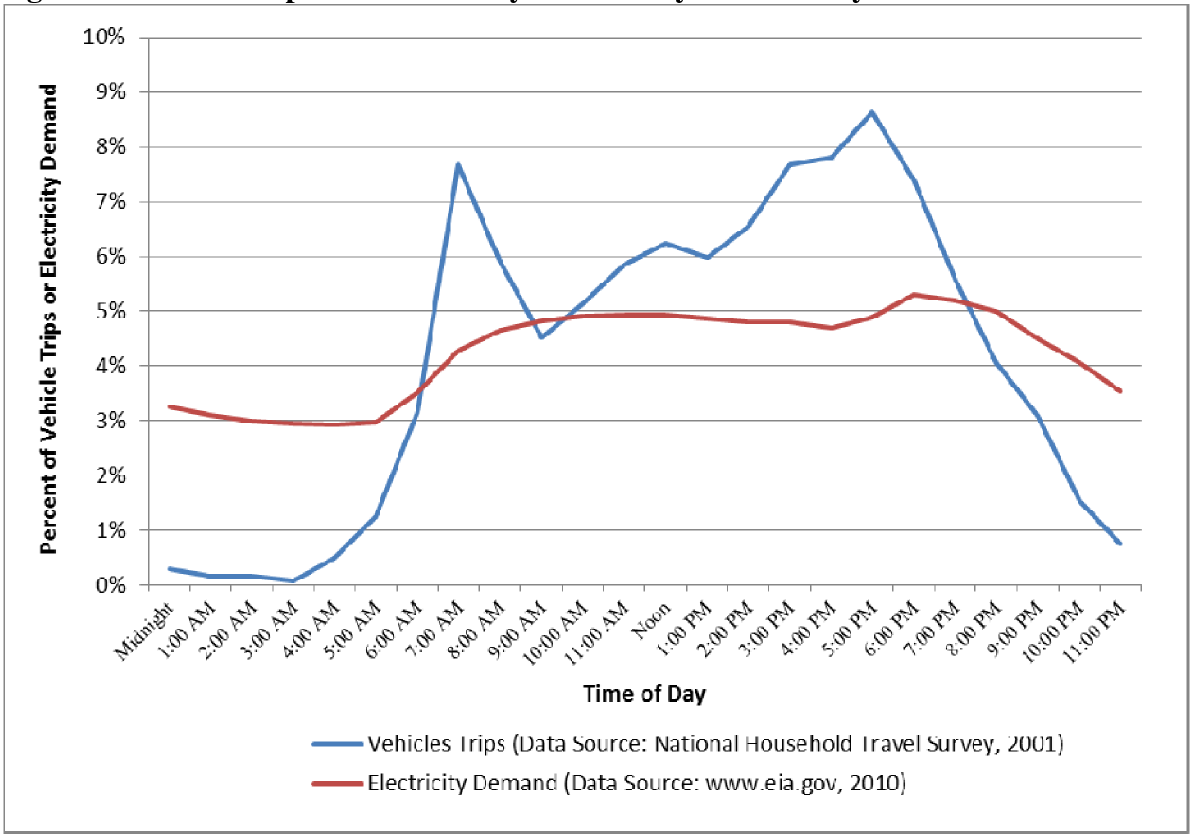
Because most vehicle trips take place during day time and the majority of cars in the existing fleet are parked over night, generally at home, residential areas are the most obvious candidate

[9] www.dteenergy.com/pev

[10] Rob Pratt. Potential Impacts of High Penetration of Plug-in Hybrid Vehicles on the U.S. Power Grid. June 2007. http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/phev/pratt_phev_workshop.pdf

locations for charging PHEVs, especially given that night time (e.g., between 11:00 pm and 6:00 am) is also the off-peak period for electricity demand (see Figure 7). Thus, connected vehicle technology can play a significant role in efficiently and effectively using the idle capacity of the grid.

Figure 7: Vehicle Trips and Electricity Demand by Time of Day



Standards

For the successful adoption of technology standards must live up to meeting the technological challenges of the industry. Both connected vehicles and GEVs have established some standardization. Connected vehicles have adopted Dedicated Short Range Communication (DSRC) as a standard for communication between vehicles and infrastructure. DSRC use a specific band of wavelengths and has adopted draft standards based on IEEE 802.11 MAC and Physical layers (similar to home Wi-Fi systems). Similarly, GEVs are working on standards as well. Currently SAE is developing a new standard for communication between the grid and vehicle (Ashe 2010).

However, there are many features of these technologies that are still yet to be standardized. For example, the wavelength used for DSRC in the United States is not the same as it is in Europe. As a result, manufactures must create tuned radios for each market, creating multiple configurations for a single component. Another example is the standardization of quick charging of GEVs: Japan has adopted a charging port called CHAdeMO, while the Society of Automobile Engineers (SAE) is pushing for a port following the standards that they are developing. Such disagreements on standards are driving undesirable vehicle design configurations, such as the Nissan Leaf requiring two charge ports to meet both standards (Herron 2010).

Battery Cost

Battery costs are an obvious barrier to the widespread use of GEVs. The exact price point at which GEVs become viable is unclear, but the United States Advanced Battery Consortium has set a target of $250 kWh. Achieving this price point would be substantial as it is assumed that today's batteries cost roughly $1000 per kWh. It is unclear when and if the price point can be met with some estimating anytime between 2015 and 2020 (US DEPARTMENT OF ENERGY 2010) and others believing it won't occur until after 2020 (BATTERIES AND ELECTRIC VEHICLES 2010).

However, the how of reducing cost is more critical than the when. Advances in cell chemistry and reductions in cost due to economies of scale are critical to driving down the cost. This indicates that there must be a compelling reason for consumers to purchase early GEVs to reduce cost.

Another method to reduce cost is to reduce the overall load of the vehicle. By using advanced weight reduction technology, streamlined aerodynamic design, and low rolling resistance tires, the size of the battery may be reduced and thus reduces the overall cost of the GEV. Such a strategy is being employed by BWM where the use of carbon fiber to reduce vehicle weight allows for a smaller battery (Reiter 2010). Using technologies that reduce vehicle load will be beneficial to all vehicles in terms of their efficiency but has special significance to electric vehicles since they are extremely sensitive to load.

Electric Vehicle Range

Due to the long charging time required for advanced automotive batteries, there are concerns that the millage of electric vehicles will not be great enough to cover an entire trip without charging (range anxiety). In addition, depending on environmental conditions and driver behavior, it is possible that the range can be quite variable from one day to the next (Loveday 2010). It is unclear as to how much weight range anxiety plays in to consumer decisions on purchasing BEVs. However, it is likely that limited range will play a role in the adoption of BEVs. Reducing charge times through new battery technology and charging strategies will help reduce range anxiety. While research into new battery chemistries and even reduced traffic congestion through connected vehicle technology can be used to increase range.

Distracted Driving

The issue of driver distraction is inseparably linked to many connected vehicle technologies. A case in point is texting-while-driving, it such a popular topic that a major daytime talk show was able to influence legislation to create a texting-while-driving ban in the State of Michigan (KAROUB 2010). Overcoming the perception that in-vehicle technology inherently increases driver distractions is not a simple issue. At the same time, new technologies offer the opportunity to increase safety if employed properly. Much work is needed in the research of Human Machine Interfaces (HMI) to ensure that interfacing with new connected vehicle technology is done in such a way that it limits distractions to the driver.

Workforce Needs

The evolution of vehicle technology driving electrification of the powertrain and development of connected vehicle technology has implications for the U.S. workforce, both in the automotive sector and beyond. At the most basic level, the traditional automotive region of the upper Midwest possesses workers with the needed skills to manage this evolution—powertrain controls engineers have been modifying vehicle systems for performance and fuel economy since before microcontrollers were introduced into vehicles, for example, and engineers and others responsible for onboard electrical systems are commonplace throughout the automotive sector—but the needed supply of these workers may be inadequate to support a sudden transition in technology. Furthermore, other regions of the nation, as well as regions outside the U.S., will be ready and willing to compete with the traditional automotive region as the vehicle continues to become less mechanical (Driving Change Consortium 2011). Most likely, the most significant change to the traditional model will be the integration of several disciplines. Fields such as mechatronics and electrochemistry will grow in importance as these new systems evolve.

Transportation agencies also may develop new workforce needs for more electrical and electronic engineers and technicians. Another option will be to contract out such work, as is often done now for tasks such as installing and maintaining traffic signals and dynamic message signs. Again, the supply of radio frequency engineers and technicians may need to grow to meet emerging needs. Installation of sophisticated controls and radio based systems into existing road infrastructure will require a greater knowledge of such systems where they otherwise did not exist before.

On the smart grid side, too, workforce needs will be evolving, but this will be a largely private sector endeavor, even though it involves infrastructure, much as the current electrical grid is in private hands. Introduction of an electrical grid infrastructure will require training for installation and maintenance of such systems. Such training programs are already under development (Underwriters Laboratory 2010) and will need to grow for the required level of skills needed at full deployment.

Role of the Public Sector

This section does not provide an answer for how a business case can be developed that will lead to mass adoption of an advanced technology motor vehicle. Rather, it will strive to determine what must occur in the way of manufacturers, consumers and infrastructure, before a true business case analysis can begin. In a general sense, this section will examine the role of the public sector in fostering implementation of green technologies through investments in start-up technology and support infrastructure and will raise the question of when government can step back and let the technology proliferate on its own.

The U.S. government has a substantial history of promoting advanced motor vehicle or fuel technologies and currently it is trying to encourage the growth of electric vehicles by subsidizing the manufacture and purchase. One of the chief questions surrounding public sector involvement in a market is how long that involvement will last. The history of governmental involvement in the automotive sector, including CAFE fuel efficiency standards, emissions requirements, and mandated safety technologies have led to improved products and also, higher purchase costs for consumers. However, despite the increased costs, consumers have embraced the broad policy objectives of lower fuel consumption, decreased emissions and safer vehicles. Acceptance has not been as universal when government involvement has attempted to promote a particular technology. For instance, programs in past decades which encouraged manufacture and adoption of natural gas, fuel-cell, electric, ethanol and other such vehicles, had good intentions, but the plug was pulled (literally) before consumers became comfortable enough with the technology that it became ubiquitous. Unless consumers are incentivized to purchase vehicles employing the new costlier technologies, the purchase price will remain higher than the alternative, older technology, thus impeding mass adoption of the technology. We now take a more detailed look at the current and previous government interventions in green technologies to determine if there are lessons that can be applied to bring these new technologies to the mass market.

Current Public Sector Intervention in Green Technology

Disruptive technologies, while offering many public benefits, are difficult to implement without support from the public sector, due to the overwhelming development and deployment costs. Currently, electrification of the automobile and connectivity of the motor vehicle are the latest in a long line of disruptive technologies that will be examined here and compared with previous attempts at bringing new green technologies to the auto sector. Public sector intervention in disruptive technologies is like a three-legged stool requiring subsidies, incentives and policies to keep it standing. First, subsidies are required for research and manufacturing facilities, then incentives are offered to consumers for the purchase, finally, policies are needed to encourage long-term behavioral change by consumers. To date, few such policies exist.

Subsidies to Build

The current administration has placed a heavy emphasis on the electrification of the powertrain. It has created more than 14 federal grant programs related to the advancement of the green automotive industry. These programs support activities including research and development (R&D), vehicle and parts manufacturing, fuel production, battery development, vehicle purchasing, and the development of infrastructure that supports the deployment of green automotive technology. One of the largest grants was the Advanced Battery and Electric Drive Component Manufacturing Grant, as given by the Department of Energy (DOE). It includes $2.4 billion in American Recovery and Reinvestment Act (ARRA) funding that provides grants for R&D, battery development, vehicle manufacturing, workforce development, and infrastructure development (US Department of Energy 2009). The federal government also provides loans and loan guarantees to businesses engaged in green automotive technology manufacturing, and alternative fuel production, mostly financed through the DOE.

Several states also offer subsidies to manufacture electric and other alternative powertrains in their states. For example, the Indiana Economic Development Corporation offers the Indiana 21st Century Research and Technology Fund, which provides $50,000 to $5 million in grants and loans to support proposals for economic development in high technology industry clusters. Incentives are available for qualified alternative fuel technologies and fuel-efficient vehicle production.

Michigan, while it does not offer grant or loan programs, does offer six tax credit programs relating to R&D, manufacturing, and battery development. Their Advanced Vehicle Battery Manufacturer tax credit offers up to 75 percent of qualified expenses for vehicle engineering support battery integration, prototyping, and launching, and other credits relating to capital investments depending on the number of jobs created from such a project.

Incentives to Buy
The federal government provides incentives for individuals, companies, and lower levels of government to purchase alternative fuel vehicles (AFV). The amount of the credit usually ranges from $2,500 to $7,500, depending on the vehicle. Most federal incentives to buy expire after a manufacturer sells a specified amount of a certain type of vehicle, most commonly after 60,000 units are sold. The following are some of the federal tax credits available to consumers.

- Qualified Hybrid Vehicles Credit
- Qualified Fuel Cell Vehicles Credit
- Qualified Alternative Fuel Motor Vehicles (QAFMV) and Heavy Hybrids Credit
- Advanced Lean-Burn Technology Vehicles Credit (US Internal Revenue Service n.d.)

State incentives to purchase AFVs range from providing tax credits and rebates for vehicle purchase to exempting alternative fuel vehicles from standards imposed on traditional combustion engine vehicles. Fourteen states and six Canadian provinces offer tax credits for individual consumers to purchase such vehicles. Rebates and credits range from $500 to $10,000. One example is the Illinois Alternate Fuels Rebate Program, which provides a rebate for 80 percent of the incremental cost of purchasing an AFV (up to $4,000), and 80 percent of the cost of federally certified AFV conversions (up to $4,000).

Other states and provinces offer tax credits or rebates from $5,000 to $20,000 toward the purchase of AFV fleets. This type of incentive is particularly beneficial to manufacturers, because since fleet purchases are in bulk, they help signal consumer demand for vehicles and technologies. Of note is the Indiana Office of Energy Development Alternative Fuel Vehicle Grant Program, which offers grants to counties, cities, towns, townships, or school corporations to purchase automaker AFVs and for AFV conversions. A recipient may be awarded $2,000 for each automaker AFV purchased, and up to $2,000 for each AFV conversion. Nebraska and Oklahoma do not offer rebates, but do offer low-cost loans for consumers to purchase AFVs. Arizona and California offer small tax credits for consumers to purchase electric vehicle charging stations.

New Jersey, Washington, Rhode Island, and Washington D.C. exempt AFVs from sales, excise, and use taxes. Michigan and Washington also exempt AFVs from emissions inspections, and nine states permit AFV drivers to use high occupancy vehicle lanes (HOV), regardless of passenger amount (Sullivan 2010). Many municipalities in California and Arizona offer parking benefits to AFV drivers, such as the ability to park at metered spots for free or use specially designated parking spaces.

Policies
To date, there have been no concerted policies regarding alternative fuel vehicles. Several have come and gone, but none have been implemented long enough to change purchasing and manufacturing behaviors. Recently, however, President Obama announced an aggressive new set of fuel economy regulations. The rules, known as the Corporate Average Fuel Economy (CAFE) standards, set a 2025 target of a 54.5 mpg fleetwide average. That includes a 5 percent mpg increase every year from 2017 to 2025. A single policy such as this will help direct

automaker R&D to build more fuel-efficient vehicles, but it will not change consumer demand, especially if gas prices remain affordable.

Mandates are another way the federal government can influence the market. Safety features such as seatbelts and airbags have been mandated by government, and mandates have also been used to improve fuel economy. Connected vehicles are in an early stage, however, and the only upcoming mandate relating to connected vehicles is a NHTSA decision on vehicle to vehicle communication technology, coming in 2013(US Department of Transportation n.d.). Therefore, there is room for more federal action in this market.

Current Federal Role in Connected Vehicles

The role of the public sector to promote the use of connected vehicle and electric vehicle technology differs in great detail. As part of the Research and Innovative Technologies Administration, the U.S. DOT runs the Intelligent Transportation Systems (ITS) Joint Program Office (JPO). This program receives $100 million (US Department of Transportation n.d.) in federal funding and has Department wide-authority in coordinating the ITS program and initiatives among Federal Highway, Federal Motor Carrier Safety, Federal Transit, Federal Railroad, National Highway Traffic Safety, and Maritime Administrations(US Department of Transportation n.d.). The ITS-JPO houses the connected vehicle technology program, which has been established to promote safer, smarter, and greener transportation (IntelliDrive USA n.d.). This program accounts for about 50 percent of the total federal funding for ITS. Therefore, unlike alternative powertrains and the electrification of engines, connected vehicle technology currently does not receive a significant amount of federal financial support.

History of Government Intervention in Green Technology

As mentioned, many governmental initiatives have been implemented overtime, but none have had the staying power necessary to impact consumer demand. Powertrain technologies that have been supported by the public sector in the past have included: electrics and hybrids, fuel cells, biofuels and compressed natural gas. While there have been many attempts to encourage the development and deployment of these alternative powertrain technologies, including the use of mandates and incentives, there has been little effort within the public sector to entice consumers to purchase these products over the long term. In addition, these technology choices have shifted over time creating confusion within the automotive industry on where to spend research dollars. For example, hydrogen fuel cell technology was encouraged as early as 1990 as a technology of choice through the Spark M. Matsunaga Hydrogen Research, Development, and Demonstration Program Act. Over time, other programs were developed to promote hydrogen fuel cells in vehicles. However, in 2009 U.S. Energy Secretary Steven Chu announced a suspension of federal funding for hydrogen car research, to focus on what the Department of Energy considers efforts that may pay off sooner. There are several other examples of such shifts in automotive powertrain research funding including the use of compressed natural gas, biofuels, and electric vehicles. To truly provide a direction on future automotive technology, the public sector might need to adopt a long-term policy focused on energy and transportation as a whole.

Components Needed to Create a Business Case for New Green Technologies

According to a CAR survey on the tipping points necessary for connected vehicle deployment, the two main obstacles to deployment are the lack of a comprehensive plan and a funding source for installation on roadways (Wallace and Sathe Brugeman 2009). Even though this survey was performed for a study on connected vehicles, the answers could apply to many of the previously mentioned green technologies. In the case of connected vehicles, if the U.S. DOT were able to help secure a funding source to install the necessary support infrastructure and a mandate that the connected technology interface with the governmental-installed infrastructure, then deployment could be achievable.

As with disruptive green technologies and connected vehicle deployment, agencies and companies need to advocate for support from Congress. To gain this support requires increased public awareness of the technology's benefits. The safety and mobility benefits of connected vehicle technology and those of new green technologies are clear to those most closely involved in their development, but bringing the consumer—and ultimate supporter—of the technology on board may prove to be much more difficult.

This section has discussed the development costs, the required political capital, and the investment in support infrastructure, without asking how a consumer commitment is achieved. Clearly, technologies can be developed, built, and deployed with no real assurance of mass adoption by the consumer. In the case of green powertrains, replacing an existing support fueling infrastructure is a monumental hurdle, both in cost and convenience. Determining how we get there from here raises many unresolved questions. What will be the will of the public and governments to stay involved and support these technologies? Will societal benefits remain clear, or will private sector issues dominate the long-term decision process? Until these questions are resolved, mass adoption of new, disruptive technology remains a significant challenge.

IV. Opportunities for Michigan

As the traditional home of the North American automotive industry and as a recognized leader in the development of connected vehicle technology (Wallace and Brugeman 2010), from the both the vehicle and infrastructure sides, Michigan has a tremendous opportunity to lead in the union of green, or plugged-in, and connected, as well. Furthermore, Michigan is home to 17 advanced battery companies in a variety of stages engaged several different stages of battery production, representing nearly $6 billion in capital investment and predicted to create roughly 20,000 new direct jobs over the next 10 years. The state is anticipated to produce nearly 20 percent of the world's lithium ion batteries, making Michigan the new worldwide center of advanced battery technology and production. [11] As a result, Michigan is ideally poised to become a world leader in the next generation of vehicles that are electrified and connected, as well as safer and less polluting. To take advantage of this enviable position, however, Michigan will need dedicated leadership from both the public and private sectors, as well as coordination between the two.

[11] http://www.snaletechnology.com/michigan-lithium-ion-batteries-for-electric-vehicles.html

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