Green and Connected

White paper prepared for the Michigan Department of Transportation

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I. Introduction

Two of the most important developments in automotive technology 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 IntelliDrive℠ technology, has investigated the links 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.

IntelliDrive℠ and Vehicle 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 IntelliDrive℠ (succeeding the USDOT's VII, for Vehicle-Infrastructure Integration, program), targets safety, mobility, and environmental improvements through a combination of vehicle-to-vehicle and vehicle-to-infrastructure 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 IntelliDrive℠ effort.

IntelliDrive℠ 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, IntelliDrive℠ 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, IntelliDrive℠ 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, 40,000 Americans lose their lives in motor vehicle crashes (United States Census Bureau 2010). Each year, we lose millions of hours stuck in traffic. And every year, 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 IntelliDrive^{SM}, a system that allows vehicles to communicate with each other and the roadway. Vehicle-to-infrastructure (V2I) connectivity involves communication of the vehicle with the roadway, traffic signals, and other pieces of infrastructure, such as bridges. Vehicle-to-vehicle (V2V) connectivity entails vehicles equipped with communication devices that can speak to each other. Each has different benefits which are described below.

When fully deployed, IntelliDrive^{SM} will help drivers bypass congestion, and it will reduce crashes by providing advanced safety warnings. It will even be able to take over the vehicle when there is not enough time for the driver to react. IntelliDrive^{SM} will also help us manage traffic, alerting drivers to upcoming congestion, advising them of alternative routes(US Department of Transportation 2010), and altering the timing of traffic signals to improve traffic flow (Park and Joyoung 2009). It can even help owners with vehicle maintenance by reporting pending problems, keeping small repairs from becoming larger and more expensive.

Powertrain Electrification

Currently, there is an enormous amount of excitement surrounding the electrification of the automobile. During his election campaign, Barack Obama set a goal for the United States of one million plug-in electric vehicles (PEVs) on the road by 2010. Today, the U.S. is home to numerous federal, state, and local incentive programs intended to overcome the initial cost of PEVs. A review of the general press might lead to the belief that PEV technology is going to be the dominant powertrain in the next five years. However, there are significant hurdles to the wide scale penetration of PEVs, with cost being the most apparent. Concomitantly, the incumbent powertrain technology, the spark-ignited internal combustion engine, continues to evolve and improve. While it is likely that the trend toward vehicle electrification will continue, advanced powertrain technology options are many and somewhat uncertain.

The shift toward electrification can be separated into four distinct types of technology: hybrid electric vehicles (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. 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 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 mainstream.

The plug-in electric vehicle can, in its most simple form, be described as an HEV with the ability to plug into an electrical outlet. An example of PHEV is Bright Automotive's Idea delivery van. PHEVs still rely upon the internal combustion engine for a majority of the drive cycle—especially after the battery has been depleted. The key differentiator between HEV and 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 either by connecting to the electrical grid, or by the gasoline engine.

Similar to the PHEV, the extended range electric vehicle 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. 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.

The battery electric vehicle contains an all electric drivetrain. The battery is charged by connecting to the grid. Examples of BEVs are the Think City, the Ford Transit Connect, 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.

II. Linkages and Synergies

For this paper, we consider two measures for the electrification of the vehicle: First, is a more inclusive measure—the continuum from alternative fuels and propulsion systems, to hybrid electric vehicles (HEVs), to battery electric vehicles. Second, is a more limited measure—those vehicles that are grid enabled. The latter definition includes plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs), and battery electric vehicles (BEVs). Clearly, hybrid electric (non-grid enabled) vehicles present a much more viable solution to fuel economy challenge in the *mid-term* than do grid-enabled vehicles (GEV). Even so, however, 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.

As described in this paper, the addition of communication between the vehicle and the infrastructure offers potential for all forms of alternative and advanced powertrains to become more efficient. The communication of traffic updates, refueling stations, and other information presents opportunity for the vehicle to operate more efficiently—and effectively. Of the many technologies and strategies considered (hybrid electric vehicle, bio fuels, etc.), however, 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, possibly creating a smarter and more efficient system.

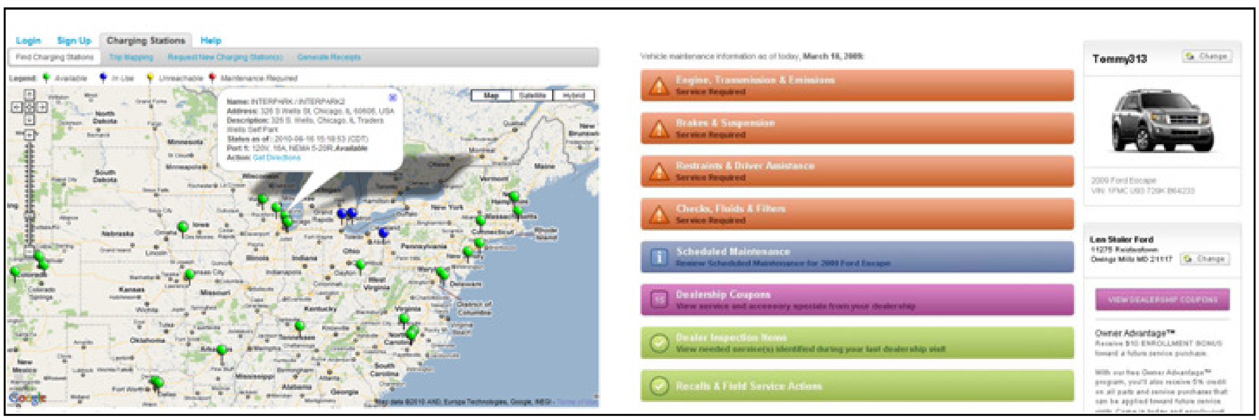
In essence, we can define at least three levels of connectedness with regard to vehicle and energy usage. From least to most connected, these levels increasingly enable the vehicle to interact with both the upstream energy generation, and transportation communications systems. These three levels of connectedness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

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.

Figure 1: Examples of simple transportation energy planning and mapping tools in use today. Left: Available ChargePoint charges in the United States.[1] Right: Typical Ford Sync diagnostic report.[2]



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).

Initial Grid-enabled Model 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 first steps toward a more efficient energy solution (Brown, Pyke and Steenhof 2010).

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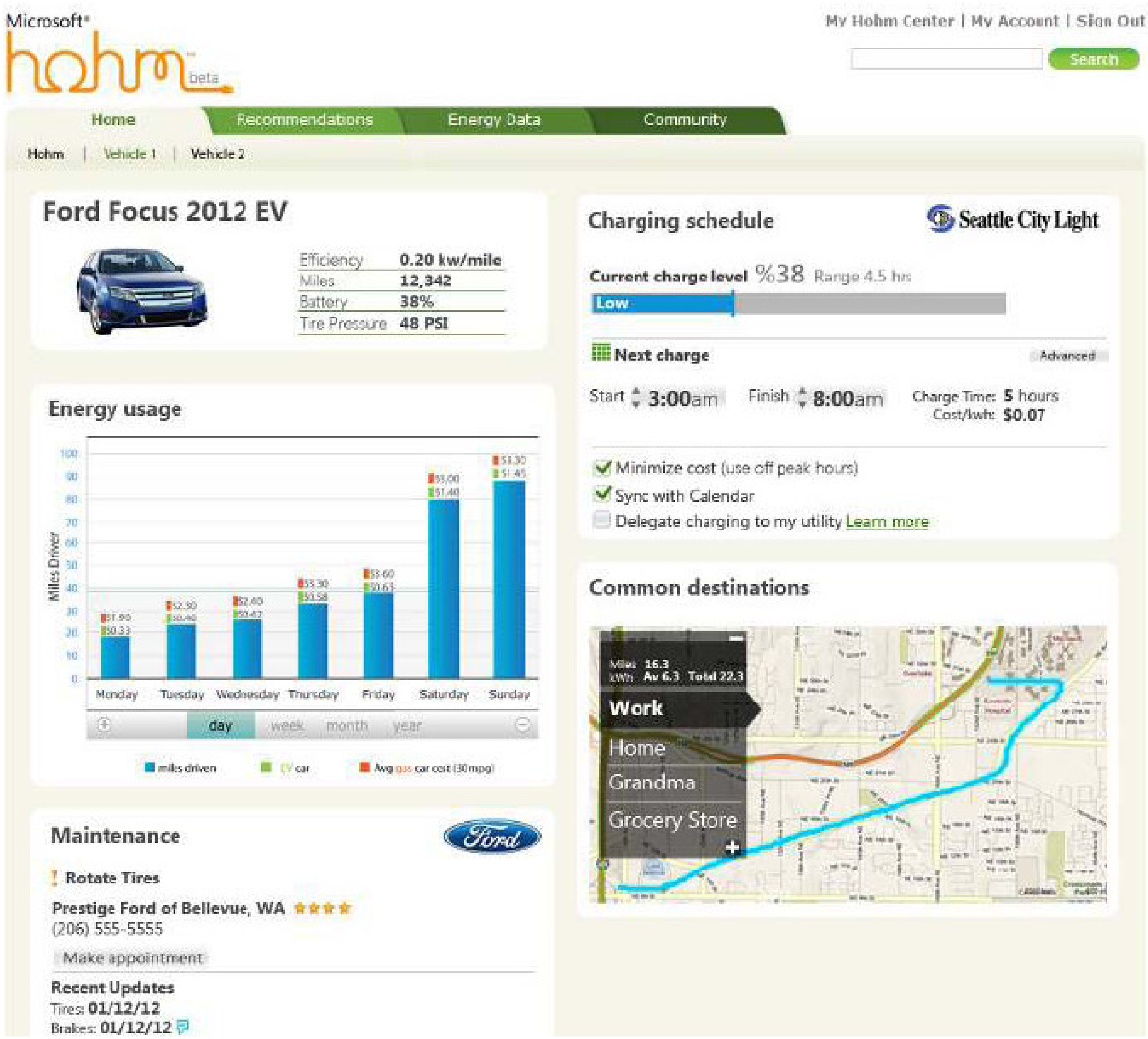
[1] https://www.chargepointportal.net/index.php/device/devicelocation.html
[2] http://www.syncmyride.com/Own/Modules/VHR/vhr_pdf_sample.pdf

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, 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 2: Example of grid-enabled communication. Future vision of Microsoft Home integrated electric vehicle monitoring (Batterberry 2010).

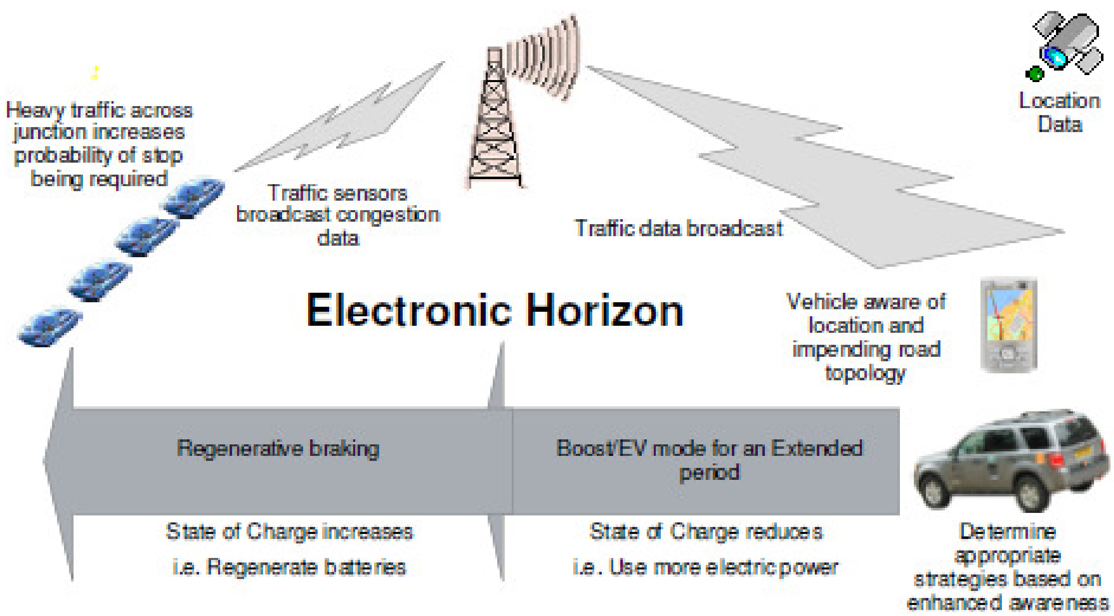


Integrated Energy-Transportation Efficiency Model

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 vehicle and IntelliDrive[SM] 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 3: 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 are moving closer to reality. However, many elements must come together for the benefits of alternative powertrains and connected vehicles to be realized. What are the enablers and barriers to a full-scale implementation and deployment of these vehicles? Overcoming logistical, technical, political, and workforce related barriers are all required to make these advanced technologies viable in the marketplace.

Full-scale deployment of disruptive, new green technologies (those that require a fundamental change in propulsion and/or fueling) requires a business model designed to cover costs, generate a reasonable profit margin, and also provide the product at an affordable and competitive cost to consumers. For a new vehicle to come to market in the traditional path from an established automaker, a number of factors must be considered long before development and engineering are to begin. These include, chiefly, an analysis of potential return on investment (ROI), along with market trend surveys, market size forecasts, potential number of sales, future fuel costs, future consumer preferences, and technology availability and its cost. In an open marketplace, these factors are difficult to estimate without a little uncertainty, leaving final decisions to rely more or less on intuition. Given a situation where the public sector is encouraging the mass adoption of a product or technology for a perceived public benefit, analyses of future trends and intuition provide even less comfort. The reason for this is that public sector involvement—usually in the form of subsidies and incentives—tends to be a short term remedy to address a skewed market which isn't providing, or driving consumers to, a preferred outcome.

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), 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 existing 3G and emerging 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).

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, the Japanese have adopted a charging port called CHAdeMO, while 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 IntelliDrive^{SM} 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

From a technical level much of what is required for both vehicle electrification and connected vehicles exists within the market. Powertrain controls engineers have been modifying vehicle systems for performance and fuel economy ever since and even before microcontrollers were introduced into vehicles. Engineers responsible for radio based systems and electrical interference are a large part of the automotive culture. On the vehicle, 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 systems evolve.

The most likely change to occur in the workforce due to these vehicles will be on the infrastructure side. 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. 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

The role of the public sector to promote the use of connected vehicle and electric vehicle technology differs in great detail.

With electric vehicles, where fuel economy is of primary concern, the public sector has recently taken a very aggressive approach through the use of subsidies, incentives, and mandates. It is clear that the powertrain technology of choice within the public sector, at least for the moment, is in vehicle electrification. Much of the public sector support has been in the realm of technological advances in battery technology and some focus on infrastructure challenges. At this point there has been little effort to encourage long-term behavioral change by consumers through public policy.

Public sector involvement in connected vehicle technology has been sparse up to this point. Where electric vehicles have support of subsidies, incentives, and to a certain extent mandates, connected vehicle technology is supported through the Intelligent Transportation Systems (ITS) Joint Program Office (JPO). Instead, the public sector has opted to rely on the private sector for much of the testing, development, and roll-out of connected vehicle technology.

The roll of the public sector in each of the technological areas is provided in the following section.

Electrification of the Powertrain is a Three-legged Stool

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 ordered the EPA and the DOT to develop tougher emissions standards for cars and light trucks, as well as to develop rules for increasing fuel efficiency for medium and heavy-duty trucks (Automotive News n.d.). 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

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 $100M(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 IntelliDrive^{SM} 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, IntelliDrive^{SM} 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.

After Subsidies and Incentives, Where Is the Business Case?

Necessary Components for a Business Case for New Green Technologies

According to a CAR survey on the tipping points necessary for IntelliDrive^{SM} (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 IntelliDrive^{SM} 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 is 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. How we get there from here has 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, any mass adoption of a new disruptive technology is still but a dream.

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 has received more than $2 billion in combined public and private investments in advanced battery development and manufacturing since 2008, making the state also the center of electric vehicle technology in North America. 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.

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