Connected Vehicle Technology Scan

Vehicle Electrification and the Smart Grid

Assessment of the Supporting Role of Safety and Mobility Services

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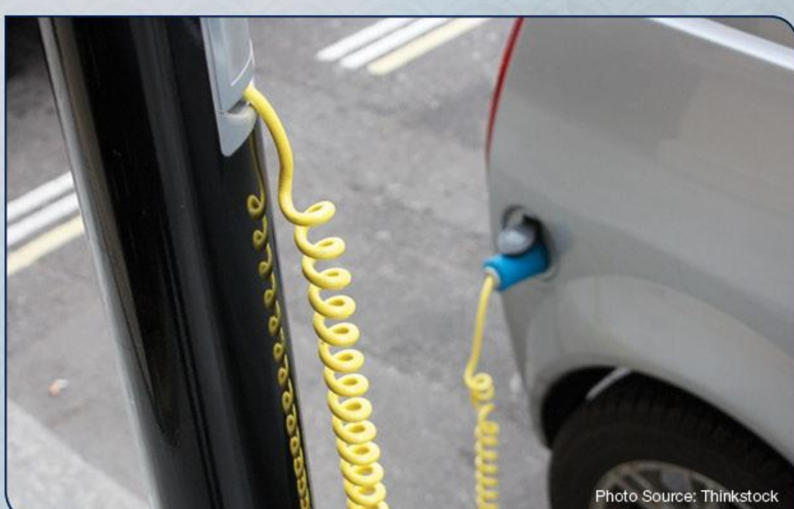

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16. Abstract

Electric Vehicles are the only type of cars that get "cleaner" over time, as electrical power generation begins to convert slowly over time to lower-polluting energy sources. Hybrids, plug-in hybrids, and battery electrics are conservatively estimated to reach a five percent national car park by 2030. Drastic increases in the price of gasoline resulting from oil shocks or major shifts in national energy and environmental policy, however, may push Electric Vehicles (EV) quickly beyond this small share. Should such critical changes occur, EVs will be poised to move beyond their current niche to gain wider scale acceptance and integration into transportation and energy infrastructure.

- Currently a number of automobile manufacturers are considering use of higher cost composite materials and other strategies to reduce the weight and improve the mobility range and performance of EVs.
- At the behest of consumers and freight and transit fleet operators, automobile manufacturers have to date designed, manufactured, and marketed EVs primarily as an urban mobility solution.
- Crash avoidance applications, designed to reduce vehicle-vehicle crashes such as forward collision warning and blind spot detection, would likely greatly benefit unconventional vehicle categories.

Vehicle-to-Vehicle cooperative crash avoidance systems, such as one that utilizes vehicle Dedicated Short Range Communications (DSRC) technology, is a potential future solution to reduce the safety impact of differences in vehicle size and structural compatibility. The benefits of widespread deployment of DSRC for Vehicle-to-Vehicle cooperative safety may spillover into the development of Vehicle-to-Infrastructure (V2I) applications.

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Table of Contents

Executive Summary

Hybrids, plug-in hybrids, and battery electrics are conservatively estimated to reach a five percent national car park by 2030. Drastic increases in the price of gasoline resulting from oil shocks or major shifts in national energy and environmental policy, however, may push Electric Vehicles (EV) quickly beyond this small share. Should such critical changes occur, EVs will be poised to move beyond their current niche to gain wider scale acceptance and integration into transportation and energy infrastructure.

EV battery technology has not improved to the degree needed to achieve the same range mobility as conventionally fueled vehicles. Electric powertrain hybridization and incorporation of regenerative systems such as braking and flywheels are steadily, but only incrementally, improving EV fuel efficiency and range performance. New Corporate Average Fuel Economy (CAFE) regulations in the next decade may drive the “light-weighting” or downsizing of some vehicle categories to achieve more aggressive fuel economy requirements, especially absent a breakthrough in vehicle battery technology. Light-weighting for battery electrics may be critical. Studies indicate that if primary vehicle mass is reduced between 40-59 percent, battery size and cost may be cut by nearly half without reductions in performance.

Currently a number of automobile manufacturers are considering use of higher cost composite materials and other strategies to reduce the weight and improve the mobility range and performance of EVs. Light-weight vehicles may be more fuel efficient, but it remains to be seen whether they will be able to afford as much protection for occupants in the event of a crash. To prepare for larger scale production of electric vehicles, and to allay concerns or perceptions that smaller, lighter vehicles may prove less safe in the event of a crash, collision warning and crash prevention technology will likely need to advance simultaneously with light-weighting.

At the behest of consumers and freight and transit fleet operators, automobile manufacturers have to date designed, manufactured, and marketed EVs primarily as an urban mobility solution. In urban areas, EV range is less of a factor. Short commuting or leisure trips are the norm, and for freight and transit carriers, smaller weight payloads are common. Where range is an absolute limitation, accessibility to charging infrastructure in both quantity (e.g. available charging/parking spaces per EV) and quality (e.g. fast charging/battery swapping or wireless charging) in urban areas may also be less of a challenge for drivers. The introduction of unconventional vehicle categories such as battery-only electric subcompact vehicles, micro-cars and e-bikes, which are easier to maneuver and park in the high density urban areas, is a noteworthy trend that supports vehicle electrification. There are nearly 70 urban car and bike-sharing schemes in the United States, and a number of these have raised the profile of these smaller electrified vehicles in higher density centers, mostly among the youngest generations of drivers.

Crash avoidance applications, designed to reduce vehicle-vehicle crashes such as forward collision warning and blind spot detection, would likely greatly benefit unconventional vehicle categories. In a crash between two differently sized and weighted vehicles, the greater impact of the crash on occupants in the smaller vehicle can be mitigated with advanced occupant protection measures such as airbags. Because the smaller vehicle lacks a larger, heavier energy absorbing frame, the greater risk of injury or fatality to the occupants of the smaller vehicle, however, can never be smaller than for larger vehicles. Motorized cycles in particular, whether conventionally fueled or electrified motorcycles or mopeds, typically lack any occupant protection features whatsoever. Furthermore, motor or pedi-cyclists are typically more likely to be involved in twice as many vehicle collisions than conventional vehicles because they are less likely to be noticed by other drivers in traffic.

Vehicle-to-Vehicle cooperative crash avoidance systems, such as one that utilizes vehicle Dedicated Short Range Communications (DSRC) technology, is a potential future solution to reduce the safety impact of differences in vehicle size and structural compatibility. Vehicle DSRC is an Wi-Fi based wireless technology that allows low-latency, reliable communications at highway speeds among vehicles and between vehicles and roadside elements, such as tolling gantries, traffic signals or parking facilities. Vehicle DSRC supports a number of mobility and safety-critical crash avoidance applications, and the US Department of Transportation is currently working with the auto industry to set the stage for deployment to begin in the next several years. Operational testing is now being conducted to evaluate Vehicle-to-Vehicle crash avoidance applications for several vehicle types beyond passenger vehicles, to include transit and heavy vehicles. To date, smaller lightweight EVs, motorcycles and bicycles, and other unconventional vehicle categories are not included in the testing effort for now. However, the US Department of Transportation has worked with industry to develop small aftermarket "vehicle awareness devices" that could provide existing non-equipped light vehicles, and potentially motorcyclists, pedi-cyclicsts and even pedestrians, capabilities to pre-empt potentially life-threatening collisions with other vehicles.

The benefits of widespread deployment of DSRC for Vehicle-to-Vehicle cooperative safety may spillover into the development of Vehicle-to-Infrastructure (V2I) applications. DSRC has not currently been deployed in a large scale by road or other transportation facility operators. In the future, however, V2I DSRC-based applications at traffic signals or parking facilities with EV charging stations may provide ancillary connectivity to upload safety diagnostics data, or download credentials. Credentials, for example, could include certificates that certify particular vehicle safety functions, such as operation of Vehicle-to-Vehicle cooperative safety applications. EV charging stations could be potential vehicle DSRC nodes that could not only provide connections to EVs, but also neighboring conventionally fueled vehicles that are similarly equipped with cooperative safety features.

The build out of "connected" electric vehicle charging infrastructure will improve the mobility range, fuel efficiency and environmental performance of electric vehicles. Distributed public charging infrastructure includes chargers in workplaces and parking facilities that allow drivers to "top-off" their batteries, which increases the range of battery electrics, but also the number the miles that plug-in hybrid vehicles can travel in more fuel-efficient and environmentally friendly all-electric-mode. EV telematics, vehicle DSRC and other communications technologies will play a role in dynamically matching and reserving the limited number of charging stations with a larger and rapidly growing number of EVs.

EVs are the only type of cars that get "cleaner" over time, as electrical power generation begins to convert slowly over time to lower-polluting energy sources. Vehicle electrification and connected charging infrastructure applications may establish a significant foundation for the "smart grid" in the long term. EV batteries may act critical energy storage devices in industrial and residential infrastructure to provide backup power, improving the resiliency of the energy distribution system. EV batteries in the long term may capture and store renewable sources of energy, such as wind and solar power generation, which cannot be tapped in response to demand and require considerable energy storage. Ultiimatley as battery technology improves, Vehicle-to-Grid (V2G) applications may calculate on pre-trip basis prospective vehicle miles traveled (VMT), selling back whatever charge that is not needed to complete given day's journey. EVs could then collectively act as spinning or frequency-response reserves for utilities that could counteract disruptions in generating capacity or spikes in electricity demand.

Introduction

By 2050, the number of vehicles in the world will double to two billion, placing enormous demands on our energy and transportation infrastructure, as well as the global environment.[1] In developing countries such as India and China, where most of the new automobiles will be driven, congestion, air pollution, and traffic fatalities are emerging as challenges that may impact economic development. In the United States and other industrialized countries, the focus is on reducing oil consumption—72 percent of which fuels the transportation sector—and dependence on potentially volatile oil imports.[2] The environmental impact of burning fossil fuels and the resulting global warming is also severe, with transportation accounting for 31 percent of carbon dioxide emitted by the United States in 2008.[3]

Running primarily on electricity rather than gasoline, electric vehicles consume little or no fossil fuels and, when running in electric mode-only, do not directly emit pollution. Electric vehicles and the "smart grid" are emerging as one of the main solutions to lower dependence on foreign oil and to reduce emissions of harmful pollutants and greenhouse gases. Electric vehicles are gaining popularity among environmentally conscious consumers, but are limited by their driving and range performance (vis-à-vis conventionally-fueled light passenger vehicles) and their higher than average relative sticker price.

The auto industry is reacting to consumers' growing environmental consciousness and price sensitivity, as well as to stricter federal fuel efficiency standards, which will rise from 2011's fleet average of 27.3 mpg to 54.5 mpg by 2025. The industry has responded to new government standards by enhancing the fuel efficiency of conventionally fueled light passenger vehicles, as well as improving electric vehicle technology. Electric vehicles could, however, considerably broaden their appeal with consumers should fuel prices begin to rise significantly. A significant rise in fuel prices will likely tilt the balance from conventionally light passenger fueled vehicles to electrics. Furthermore, improvements in collision avoidance technology may also inspire consumers in the future to choose smaller more fuel efficient vehicles. Smaller and lighter vehicles are candidates ideal for electrification, as reduction in vehicle weight generally improves the range performance of the battery.

The key technological constraint for electric vehicles is battery cost and capacity, which translates into limitations in vehicle performance as measured by driving range, horsepower, and weight payload capacity. A current pure plug-in electric vehicle can require up to eight hours to acquire a full charge, which provides only 100 miles of driving, and chargers will initially only be available in homes and a very limited number of parking spaces. This has given rise to the oft cited concept of "range anxiety," or the fearful prospect on the part of electric vehicle drivers of being stranded with a near emptied battery and no unoccupied recharging station within easy reach. Although range is a critical factor for light passenger vehicles that are driven both short distances within cities and longer distances between them, fleet electrics such as transit and short haul freight, which do not require significant range, may expand vehicle electrification. In urban areas in particular, new innovative "sharing" schemes and vehicle categories such as electric car sharing, EV battery exchanges, subcompact, micro-cars and electric bikes will also thrive as larger cities look for sustainable solutions for urban mobility.

The key and complementary technologies for reducing the current constraints on EV range and serviceability are new battery chemistries, innovative powertrain architectures, lightweight composite materials, and smart infrastructure models for providing parking reservation and charging services. There are a number of techniques for on-board charging (through hybridization or wireless charging) or off-board charging (through battery swapping or infrastructure based charging) that are quickly evolving. Lastly, home-based, publicly availably "fast charging," and future wireless charging techniques, along with telematics and navigation, should improve the appeal and performance of electric vehicles, as drivers can be alerted to their remaining battery range and directed to the closest available charging facilities to “fuel” their vehicles relatively quickly.

If these technologies are widely incorporated there will be major impact on transportation and energy sectors. First, as electric vehicle technology advances, and cost and performance improve in comparison to conventionally-fueled light passenger and fleet vehicles, market penetration of electric vehicles may hit a tipping point beyond which new strategies to manage energy and transportation infrastructure must come into play. First, a decrease in gas tax revenue may force the federal and state governments to reform transportation infrastructure finance, which relies primarily on gasoline taxes to pay for road maintenance and new construction.

Second, a mass of electric vehicles may represent both a challenge and an opportunity for utilities and the electrical grid. Electric vehicles may stress segments of the electrical grid during peak charging times and eventually may place undue demand on power generation capacity. With “smart grid” technology as part of the electric distribution infrastructure, drivers can be informed about the most opportune time for charging based on grid capacity and energy prices. In the long term, electric vehicles may further benefit from “smart grid.” Specifically, electric vehicles can communicate with utilities, opening opportunities to load balance electrical power generation, allowing homes and businesses to use excess charge from vehicles to meet other energy needs. This concept is known as Vehicle-to-Grid (V2G).

The work of implementing vehicle-to-grid networks suggests a parallel challenge to that of deploying vehicle Dedicated Short Range Communications (DSRC) for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications. DSRC is an IEEE 802.11a Wi-Fi variant wireless technology that allows low latency, reliable communications at highway speeds among vehicles and between vehicles and infrastructure elements, such as tolling gantries, traffic signals or parking garages. DSRC supports a number of mobility and safety-critical crash avoidance applications. Under the U.S. Department of Transportation’s Connected Vehicle program, the federal government hopes to begin the deployment of DSRC in light-duty vehicles sometime after 2013. The challenge for both V2G and V2I is coordinating infrastructure installation with the rollout of equipped vehicles on the roads and value-added applications. For electric vehicles, the risk for the success of V2G is that too few charging points may hinder demand as consumers see charging options as too limited to make the switch from gasoline-powered vehicles. Early deployment of V2G charging infrastructure, on the other hand, will leave most charging stations underutilized.

Ultimately, understanding the success of vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-grid communications and applications will require a proper accounting of the incentives to industry for adopting new technology in vehicles, and the value proposition for consumers and the public at large. This paper attempts to enumerate a number of new technologies and market conditions that may incentivize the adoption of electric vehicles and vehicle-to-X (V2X) communications.

Core Electric Vehicle and Infrastructure Technology

Electrics such as the Toyota Prius became popular in the early 2000's, and currently many auto manufacturers offer hybrids alongside their gasoline counterparts. The term *electric vehicle* refers to any vehicle that derives some or all of its power from electricity, but the category encompasses a number of models that differ greatly in terms of driving range and cost.[4] There are three broad categories of battery-based (as opposed to fuel-cell based) electric vehicles centered on powertrain: Hybrid Electric (HEV), Plug-in Hybrid Electric (PHEV), and pure Battery Electric Vehicle (BEV).

HEVs use both an electric motor and an internal combustion engine (ICE) in different configurations. Some hybrids use the electric motor to give a power boost to the vehicle without consuming more gasoline; some can operate in electric-only mode at slow speeds or for a certain driving range, using an internal combustion engine when more power or higher speeds are needed. Hybrid powertrains sub-categories include Mild Hybrid, Series Hybrid, Parallel Hybrid, and Series-Parallel (or Complex) Hybrid, which include single or multiple paths to power the wheels of a vehicle. Mild Hybrid is a conventional fueled and ICE powered transmission with a motor/generator that can be used to enable engine start/stop when idling. Series Hybrid uses an ICE to charge the battery, but the transmission is driven by an electric motor. Parallel Hybrids have parallel paths to power the transmission, one ICE, the other an electric motor that allows ICE traction or electric traction or both simultaneously. Complex Hybrids are like Parallel Hybrids, with multiple power sources for traction and for recharging the battery.[5]

Plug-in hybrid electric vehicles (PHEVs), on the other hand, allow for battery recharging through an external outlet. PHEVs can be of any hybrid configuration: Mild, Series, Parallel, or Complex. They typically have larger batteries and can travel farther in pure electric mode. PHEVs on the market today include the GM Chevrolet Volt, the Ford Escape Plug-In Hybrid, and the Toyota Prius Plug-In Hybrid, with others from Volvo, BMW, and Volkswagen expected in 2012.[6]

A battery electric vehicle (BEV) relies completely on an electric battery to power its electric motor, without having a conventional internal combustion engine as backup. Electric drive replaces the mechanical components of a conventional drive train: clutch, transmission, differential, and main drive shaft. The Nissan LEAF is the first battery electric vehicle to be sold in the US market, and has a range of approximately 100 miles on a fully charged battery. The Ford Focus Electric, due out in spring 2012, is also a pure electric vehicle. GM, Audi, Fiat, BMW, Volkswagen, Honda, Toyota, Mitsubishi and others intend to follow Nissan in development of BEVs by 2014.

Electric Vehicles are still a niche light passenger vehicle platform, but may grow. In 2011, HEVs, PHEVs, and BEVs together accounted for less than three percent of the market share in the U.S., with pure battery electrics making up less than 0.1 percent of total auto sales in the country.[7] To move beyond a niche and capture a major market share, EVs must improve in performance, primarily range and horsepower, and fall in cost by several orders of magnitude. A contributing factor in the success of EVs may be the availability of charging stations, though an improvement in cost and performance of battery "range" is likely more important to promoting further acceptance of electric vehicles by consumers.

Vehicle Battery Performance

The battery is the main component of an electric vehicle, representing most of the cost of the vehicle and also most of the technical challenges. Current and future battery technologies need to have excellent energy and power density, and be inexpensive, durable, and safe. The overarching performance requirement for electric vehicle batteries must provide energy to the vehicle powertrain continuously for long periods of time and be able to last for the lifetime of the car, all while being cycled, or charged and discharged constantly.

The performance of different batteries is judged by a number of properties such as cell voltage, energy and power density, maximum discharge, useful capacity (depth of discharge), charge efficiency, self-discharge rate, temperature range, maximum number of charging cycles and other characteristics. Batteries must not be too large or too heavy, and must operate efficiently in many different environmental conditions, including extremely hot and cold weather. Additionally, batteries must not pose safety risks under normal operating conditions or in the rare case of a crash where the structural integrity of the vehicle is compromised. Finally, batteries must meet lifecycle, performance scope, size and weight requirements, all while remaining within an acceptable cost range for automobile manufacturers.

An electric vehicle's battery technology mostly determines the vehicle's performance in terms of driving range and horsepower, as well as the internal and external design of the automobile. The evolution of complementary systems and technologies, including battery management systems, energy conservation systems, regenerative brakes and flywheels, is rapidly evolving. These features are designed to convert and conserve energy for use by the electric powertrain, and also may determine in some part how the performance electric vehicles fare in comparison to conventionally fueled vehicles.

Rechargeable batteries used in electric vehicles include lead-acid, nickel cadmium, nickel metal hydride, lithium-ion, lithium-ion polymer, and other chemistries. As mature as battery technology may be, its application in electric vehicles is in its infancy due to various technical and operational issues, such as how much energy they can store, what temperatures they can operate in, and how they can be replaced in the vehicle when they reach the end of their life. Some of these challenges have been overcome in recent years: batteries now last around ten years under normal driving conditions, and they can operate comfortably in temperatures as low as -30 degrees Celsius. Lithium-ion chemistries have proven most adept at meeting the technical and operational requirements of electric vehicles, and will likely prevail as the best solution for electric vehicle batteries in the next five to ten years.

Battery Size, Weight and Safety

Energy density and specific energy are two of the key performance measures for batteries. Energy density is the amount of energy stored in a given space per unit volume (Watt-hour/Liter). Since the battery volume is limited in an electric vehicle, energy density is what ultimately determines the vehicle's driving range. Specific energy, or energy per unit mass (Watt-hour/Kilogram), is also important, since an electric motor will have to work harder to pull a heavy vehicle or a large payload. Current energy densities for EV batteries are approximately 100-200 Watt-hour/Kilogram.[8] Lithium-ion batteries have about two to three times the energy density of lead-based or nickel-based batteries used in vehicles in the last couple of decades. In addition, a variety of materials can be used with lithium-ion batteries to vary specific energy, allowing battery manufacturers to tailor their product's performance to specific applications.[9]

Although it is possible to build batteries large enough for conventional vehicle driving ranges up to 300 miles, such batteries are prohibitively heavy and expensive. Cost effective energy densities result in a battery that provides 100 miles of driving on a full charge, in contrast to a gasoline-fueled vehicle that can go on average 300-400 miles on a single tank. A new manufacturer, Tesla Motors, is scheduled to release the Model S sedan with three battery pack options of 160, 230 and 300 miles per charge in 2012, but each range option costs $10,000 more than the previous model, mostly attributable to the battery cost.[10]

Because of their high energy density and high chemical reactivity, electric vehicle batteries often raise safety concerns. Lithium is inherently unstable and highly reactive as electrolytes are volatile and flammable with heat and pressure. With the adoption of lithium-ion batteries on cell phones and laptops, there have been several reports of batteries combusting.[11] Although there have been no reports of fires after crashes on the roadway, in 2011, the National Highway Traffic Safety Administration (NHTSA) identified fire hazards in Chevy Volt batteries after a side-impact collision test. The impacts caused coolant to leak, which eventually led to short circuits and fires that occurred hours to weeks after the crashes.

However, NHTSA closed its investigation after GM proposed to reinforce the battery pack to prevent leaks, and reiterated that it believes that, "electric vehicles show great promise as a safe and fuel-efficient option for American drivers." [12] With regards to safety, one approach to mitigate these potential risks would be to refrain from fully charging the battery, since a fully charged battery contains the most energy.[13] This approach may also improve the battery's ability to store energy captured through regenerative braking, or other future techniques such as through-the-road "wireless" inductive charging. However, keeping battery at a low state of charge reduces the driving range. To compensate for the loss driving range resulting from the safer reduced state of charge, battery packs must be enlarged resulting in a safer, albeit, heavier and more costly battery.

The battery must also be managed carefully to avoid overheating and combustion while the vehicle is parked and charging. If for any reason there is a risk of over-charging the battery, either from errors in determining the charging cut-off point, from intentional overcharging, or other contributing conditions such as ambient temperature, it may put the batteries and drivers in harm's way. It is critical that faster charging techniques that can charge batteries under a couple of hours must be carefully monitored by battery management systems. Fast charged batteries may even need to be actively cooled in order to maintain safety, which may add additional cost, weight and complexity to onboard battery and powertrain systems.[14]

New Battery Chemistries and Cost/Performance Factors

It takes at least five years for a new chemistry to be turned into a new battery. Therefore, no other new chemistries are on the horizon to replace lithium-ion in vehicles in the next five to ten years.[15] Current battery electric vehicles rely on lithium-ion batteries, while hybrid vehicles have traditionally relied on nickel-metal hydride technology, but appear to be shifting to lithium-ion as well. While the cost of lithium-ion batteries is gradually declining, cost still represents a significant hurdle as it accounts for a large portion of the total EV cost.[16]

Lithium-ion batteries will likely continue dominating the market for electric vehicle batteries in the next decade. First, lithium-ion batteries still strike a better balance of energy density, safety and cycle life than any other battery technology on the horizon. Other types of batteries with an energy density equivalent to lithium-ion batteries usually have noticeably inferior performance across these several performance criteria. Second, lithium-ion batteries are expected to significantly expand in capacity and improve in safety. The U.S. Department of Energy has set a goal of doubling the power and energy density of batteries by 2020,[17] and the latest research has already shown the possibility of up to an eight to ten times increase in capacity.[18,19] Lithium-ion battery safety concerns are also being addressed by experimenting with advanced electrolytes and additives.

Of the chemistries being considered for the long term, no technology has emerged yet as an optimal solution given the requirements for use in vehicles. However, potential chemistry of interest is lithium-iron phosphate in medium term due to performance and safety characteristics.[20] For the very long term, Lithium-Air Cells may hold some promise. In the research and development stage only, lithium-air cells potentially offer five to ten times the energy density of today's lithium-ion cells. However, this is a fledgling technology that has demonstrated only limited capacity retention on cycling. Lithium Air Cells may be further developed by 2016, but research effort is still needed to produce a commercially-viable cell that lasts the hundreds of cycles that are required for automotive applications. Non-lithium based chemistries for energy storage systems are being researched but are only expected beyond 2020.

Cost is the most critical factor in judging current and future battery technology. As stated, it is possible to build a battery with sufficient capacity to drive 300-400 miles, but the cost is prohibitive at the moment. Optimistic industry experts expect the cost of these batteries to come down 50 percent in the next three to four years, due to both economies of scale as electric vehicle sales ramp-up, and to further innovations in lithium-ion technology. It is believed by some that energy density for the same size battery will likely double, while staying at or below the price of today's batteries, and will result in 200 mile range batteries available in cars by 2020.[21] The U.S. Department of Energy's goal is to reduce the cost of batteries to $250/kWh by the year 2015, from its current range of $1000 kWh to $1300 kWh. Despite recent increases in production volumes over the last decade, costs have remained constant.[22] However, there is some doubt that an increase in scales of production will reduce costs significantly.[23] Plug-in HEVs would become more reasonably priced in comparison to conventional fueled vehicles if battery prices would decrease to about 500 $/kWh, assuming no significant changes in the price of gasoline occur. Cost reductions may need to rely on other innovations such as new chemistries or other improvements in complementary technologies.

Battery standardization and modularity may also reduce costs over time. Activities to standardize batteries are underway, as standardization will help bring costs down and convert electric vehicle batteries to a commodity in the same way as SLI (starting, lighting, ignition) 12 Volt lead-acid batteries are for conventional vehicles. Right now, electric vehicle batteries are designed by each auto-maker individually to fit into their cars; the vehicle's horsepower, acceleration, deceleration and range, as well as interior and platform design, are increasingly dependent on the form and functional requirements of the EV battery.

Standardization and modularity are stunted because EV platforms are designed around the battery pack, instead of vice-versa. Setting global automotive standards has proven difficult in the past, and currently batteries are seen, rather in a short-sighted way, as a point of competitive advantage and pride among auto makers.[24] Battery standardization may not be in the best interest of some battery manufacturers who may rely on proprietary technologies and interfaces, but standardization may reduce costs and push competition and innovation to other parts of the EV supply chain. Furthermore, standardization would drive down manufacturing costs, and improve the value of the vehicle. Modularity does this by making battery swapping possible or complete replacement easier near the battery's end-of-life.

The value of batteries when they reach the end of their lifecycle is a major cost and technology consideration. As the cost of the battery is the key driver of the price of an electric vehicle, another factor to consider may be the resale value of EVs at the end of the battery's life. Many conventional cars are driven much longer than ten years, which is the current estimate of the lifecycle of an EV battery. Given that the battery price makes up most of the cost of a new electric vehicle, and batteries are not standardized or modular, it is unlikely that battery replacement will be a viable option. It follows that the market for used electric vehicles, or used EV batteries might be quite small, and recycling EV batteries cost-effectively and safely will be a challenge that is yet to be completely addressed.[25]

However, the possibility exists that although used batteries may not be suitable for driving vehicles, they might be recycled into a source of cheap energy storage for either other mobile or stationary applications. This recycling, known as EV battery secondary use, may potentially increase the resale value of EVs, at least over the long term, assuming a number of critical developments take place over the next decade. According to P3 North America, the global EV/HEV original battery market will likely rise from 6.4 mill kWh in 2012 to 19.5 Million KWh in 2015, representing nearly $15 billion.[26] Recycling of these components may be critical reclaiming the residual of this considerable manufacturing investment.

The secondary battery application is the use of a high grade battery from an electric or hybrid vehicle in an application that is different from its use in the original parent vehicle. There are several critical factors that will determine whether a large market will develop in secondary use batteries. The first factor is a market enabler such as automotive original equipment manufacturers (OEM) battery buy-back programs. Batteries will also need to be robust enough retain sufficient capacity for a number of different applications, and a secondary market will still need modularity and standardization to thrive.

Most importantly, success of a market for secondary use EV batteries will depend on development and demand of large numbers of stationary and mobile applications, and may be stunted by competition from newer, less engineered batteries. Potential mobile applications include off-highway construction vehicles, marine shipboard power supply, and rail. (In particular, for trains and trams, stop and go activities like shunting and rail yard operations are likely candidate applications). Stationary applications include uninterruptable power supply for hospitals, data processing centers, cell phone towers, or other critical service infrastructure. Home applications include backup power and home solar renewables integration. Utility applications could be for large scale solar/wind energy generation and community energy storage. Given that EV batteries can last between seven and ten years, the full emergence of a market for secondary use batteries will likely take a decade to emerge.

Complementary Technologies and Innovations

In order for electric vehicles to approach the range and horsepower performance of gasoline-powered vehicles, a number of complementary technologies that directly or indirectly support the battery have been developed. Electric powertrains will get more efficient, alternative energy recapture or storage systems will likely emerge, new materials will make cars lighter, and innovations such as lightweight carbon fibre bodies and frictionless tires will contribute to improving electric vehicle energy efficiency. All of these efforts will enhance EV performance and reduce exclusive dependence on improvements in battery technology to improve the driving range.

Some complementary technologies attempt to capture energy from the vehicle's motion or external environment. Hybrid vehicles use the engine to recharge the battery and also capture energy from vehicle control systems through *regenerative braking*, a process whereby the car's kinetic energy is converted into electricity and stored in the battery when the car decelerates. Certain cars like the Toyota Prius or the Fisker Karma have the option of embedding *solar panels* into the car roof. On the Prius, the solar cells power the air conditioner so that it can function without having to take power from the engine.[27]

The high-end Fisker Karma, starting at $103,000, can use some of the energy captured by the solar cells to assist the battery. However, the limited area available to rooftop solar cells means that they are not able to propel a vehicle without a battery; in fact, Fisker claims that the cells help extend electric driving range only by 200 miles annually.[28]

In the future, new technologies such as *carbon fiber vehicle bodies*, or even new energy storage systems such as *flywheels* may improve the performance of Electric Vehicles. Carbon fiber vehicle bodies will also contribute to improving overall energy efficiency. Carbon fiber is both ten times stronger than regular-grade steel and about the quarter of the weight. Furthermore, carbon fiber bodies are also safer and reduce the number of parts needed to assemble a vehicle. Several automakers appear to be making carbon fiber composites an integral part of a new generation of electric vehicles, mostly “micro-cars” such as the EV SmartCar, intended mostly for intra-city driving.

Carbon fiber is being more widely used in aerospace to create ultra-strong and light components to improve aircraft fuel efficiency, and is recently being seen in automotive. New carbon-fiber vehicles, however, will go beyond current implementation of composite body panels seen in some cars today, to create structural composite components.[29] Some cars, like the BMW i8 micro car, are making extensive use of carbon fiber in the body to build incredibly light but safe vehicles.[30] In 2013, BMW plans to launch two mass-produced vehicles with carbon fiber composite passenger cages: the battery-powered i3, formerly known as the Megacity, as well as the hybrid i8. Carbon fiber enables vehicles to carry heavier batteries, which can enable longer range.

Unlike its application in aerospace, carbon fiber is still cost prohibitive for wide scale use in automotive. Carbon fiber is generally made by polymerizing the petrochemical acrylonitrile into polyacrylonitrile (PAN). PAN is then extruded into fibers and carbonized in a sophisticated oven. The problem is that carbon-fiber composites cost at least 20 times as much as steel, and the automobile industry is not interested in using them, however, until the price of carbon fiber drops from $8 to $5 (and preferably $3) a pound.[31] Current processing technology and feedstocks are not enough to support high volume demand for low-cost carbon fiber in the automotive sector, so organizations such as Oak Ridge National Laboratory have established a consortium to push the cost and complexity down. For example, Oak Ridge National Lab has worked on the development of precursors that contain more carbon by weight than traditional PAN and are easier to process. The resulting fibers, which have about half the performance of PAN-based fiber, would be good for auto body panels but not structural components. Oak Ridge National Lab’s target, however, is to develop low-cost, higher-performing fibers for use in structural components. [32]

The advantages of lightweight vehicles are greatly enhanced in vehicles with electric powertrains. Vehicle light-weighting requires a redesign of the entire automotive supply chain with regards to materials, product design, and process design. There are several technologies such as High Stencil Steel, Glass Fiber, Aluminum Space Frame and Uni-body, Magnesium that are currently lower cost than composites.[33] However, reduced costs composite materials may significantly advance alternative powertrain vehicles such as EVs. Studies indicate battery size and cost by may be cut by nearly half, if primary mass is reduced by 40%-59%.[34] Unfortunately, established auto manufacturers already have considerable sunk investment in heavy, mostly conventional-steel vehicles, and that significant new investment would need to be made to mass produce lightweight vehicles. The growing popularity of EVs and the need to improve their range performance, along with long term trends in federal fuel efficiency standards, may slowly incentivize the auto industry to introduce composites and other light-weighting technologies.

Carbon fibers are also being introduced in *flywheels*, which may be a key complementary technology in improving electric vehicle performance in the future. Flywheels work in a similar fashion to regenerative braking, in that both convert kinetic energy into electrical energy. Flywheels are more efficient than regenerative brakes because they do not convert energy to a charge on the battery. This is less wasteful in that it converts kinetic energy from the car's wheels into another form of kinetic energy within the spinning flywheel, rather than into a chemical potential in the battery. For example, from regenerative brakes, only 35 percent of the kinetic energy lost in braking is retrievable, but with flywheels, it is estimated that nearly 70percent can be recovered. Flywheels not only recapture energy, but store it for long enough periods to be useful, much like a battery. Flywheels, furthermore, have longer lifetimes than batteries, which are only functional up to 2000 charging cycles, or about ten years' worth of driving. Volvo is currently designing future cars to incorporate flywheels.[35]

In the meantime, the auto industry has introduced *new powertrain architectures*, *battery management systems*, and *electric vehicle telematics* to compensate for the limited range of EVs in comparison with conventionally fueled vehicles. The auto industry has also responded to consumer "range anxiety" by introducing gasoline power "range extenders." Extended-range electric vehicles, such as the Chevy Volt, have a gasoline generator that powers the electric motor once the battery is depleted, an architectural form of Series Hybridization. The Volt drives approximately 50 miles on the battery, and the gasoline generator kicks-in to drive the powertrain, extending the range by 344 miles on a full tank of gas.[36] The Volt is then plugged-in to recharge the battery. Some future range-extenders contemplated by technologists for light passenger or smaller vehicles also include small, flexible hydrogen fuel cells. Fuel cells create electricity to power an electric motor using hydrogen and oxygen from the air. This approach consists of using a relatively low power fuel cell in conjunction with a reformer, which removes the carbon, from a conventional fuel such as gasoline.[37]

Another powertrain architectural innovation is "through-the-road" hybridization. The BMW i8 is implementing a form of complex hybridization in which the gasoline engine recharges the battery as the car is moving, instead of waiting to plug-in at a charging station.[38] A "through-the-road" hybrid starts with a conventional two-wheel drive train, and adds electric drive to provide traction to the other two wheels. The separate systems pull together when extra power or four-wheel drive traction is needed. When power demand is low, at low speeds or low acceleration settings, the electric drive operates alone. The drive from the IC engine is disengaged through an automatic clutch or automatic shift to neutral, and the IC engine is stopped. The system is based on the premise that 10-15 horsepower is required to propel a medium size automobile along a flat road at a steady 60 to 70 mph and that a relatively small amount of electric power applied to the rear wheels would be able to cope with up to 85 percent of normal driving.

A "through-the-road" hybrid is aided by the combustion engine during only start up and when extra energy is required for acceleration and hill climbing using the front wheels. The batteries for the electric drive system in this configuration are regenerative charged when the vehicle brakes. If normal braking does not supply enough energy to keep them charged, the batteries can be recharged by light braking on the electrically driven wheels, while the IC engine drives the other pair of wheels. The "through the road" power transmission gives the configuration its name. Through-the-road hybridization, "range extension" and other powertrain architectural innovations are evolving quickly in automakers attempts to establish relative performance parity of electrics with conventional fueled vehicles.

The Battery Management System (BMS) is also an essential complementary component of an Electric Vehicle. BMS monitors the state of a battery, measuring and controlling key operational parameters, and thus ensuring safety while letting the driver know the charge state of the battery. BMS communicates with the electric *vehicle telematics* systems which includes pre-trip planning, particularly navigation.

Electric Vehicle navigation calculates battery range as total mileage distance, but also must subtract range due to anticipated traffic, weather, road grade and terrain, and even driver behavior to compute a realistic EV range. While the vehicle is in-transit, the BMS and the vehicle telematics systems must also evaluate current charge levels and, when low, will alert drivers to the nearest unoccupied electric vehicle charging station, providing turn-by-turn directions. Future vehicle telematics applications may also include parking reservations for a location with a charging station for the particular period of time needed to recharge the vehicle.

Electric Vehicle Charging Infrastructure

One of the key advantages of Plug-in Electrics (Plug-in Hybrids and Battery) over non-pluggable straight Hybrids and conventional fueled vehicles is that they can be 'refueled" directly from nearly anyplace with access to the electrical grid. This means vehicles can be fueled from home. Ironically the disadvantage is that there are a dearth of places beyond the home, upon which EVs can charge away from home, potentially limiting the effective range of these vehicles. However, there is some uncertainty as to how much publically available charging infrastructure is needed, understanding current limitations in battery technology and vehicle range.

There are approximately 30,000 gas service stations to support approximately 200 million vehicles in the United States, or about 6,000 vehicles per station. For light passenger plug-in electric vehicles, it is a safe assumption that there is at least one charging station at home, per vehicle. There are a number of key questions for understanding needs for charging infrastructure. First, how many chargers are needed to accommodate the number of EVs on the road beyond the home garage? Second, where do chargers need to be frequently placed to coincide with a typical passenger or fleet vehicle's duty cycle or trip activity? And third, given placement and limits on battery technology, charging speed, and average range of vehicles, how densely (or sparsely) distributed do charging stations need to be?

The state of battery technology dictates the amount of charging infrastructure that is necessary. A European study suggests that approximately 40 miles (65 km) of charge depleting range is necessary for a plug-in hybrid battery if no charging infrastructure is available beyond the owners' home residence. The range could be lowered to approximately 12 miles (20 km) if public charging infrastructure is available. This implies a tradeoff – improved battery technology requires less public charging infrastructure.[39]

There are four major locations for charging stations: home, work, depots (for fleet vehicles) and public spaces such as off-street and on-street parking facilities, highway rest stops and even gas service stations. Most frequent charging locations would likely be the first three (home, work, depots). The questions for municipalities and other large institutions that provide parking are how many charging stations are needed, understanding how many electric vehicles there are in a given area, and how long on average EV drivers will dwell at a charging space. Public and work –based charging stations, where many EVs may need to share a small number of spaces, would likely need parking reservation systems to accommodate customers.

Home location charging is the entry point for all light vehicle plug-in and hybrid battery electrics. In suburban areas, where most people have single-family homes with attached garages and their own utility meters, an owner of an electric car can simply install a charger. In denser urban areas, where a majority of urban residents live in multi-unit housing, such as apartment complexes or areas with only public on-street parking, lack of chargers co-located with parking facilities may be an additional infrastructure constraint. Ironically, it is in these denser urban areas where the most desired trip activity is well within a limited range of battery electrics.

The duty cycle of light passenger vehicles is reasonably well understood – parked at night at home, driven to work or errands, parked for long periods during the day, and returned home in the evening. Fleet vehicles, such as transit and short haul freight have a similar charging cycle but are typically driven all day and parked at night. In particular, drivers may be concerned about whether they can find a charging station at their destination, and if so, how long the vehicle will be unavailable to drive while it waits to be fully recharged. Lack of widespread convenient charging infrastructure may be a contributing factor limiting overall demand for battery electrics, and may tilt the market in favor of hybrids which are not exclusively dependent on recharging from the grid.

Charger location, vehicle duty cycle and trip activity are important factors, but another critical element is charging speed. Some charging speed metrics may be *charging range per minute* and for occupancy time for chargers that are shared among many vehicles, *average time per charging session*. Conventional fueled vehicles can be fueled in no less in 20 minutes for 300 mile range cycle, whereas charging stations may take up to 8 hours for approximately 100 mile range cycle. Electric vehicle chargers come in three major modes for charging, depending on the speed of charging required: *Level 1*, *Level 2*, and *DC Fast* charging. Level 1 charging, the slowest, uses a 120 volt circuit, meaning that the car can be plugged into a standard electrical outlet. Level 2 chargers use a 240 volt circuit, and require special wiring, although this is generally no more than what is needed for a heavy-duty appliance such as an electric clothes dryer. Level 2 chargers are more likely to be found in public spaces, such as garages or in parking lots, especially at work locations where cars sit for long periods of time during the day. Using a Level 2 charger, a Nissan LEAF would be able to fully recharge in 8 hours, and a Chevy Volt, because of its smaller battery, in half that time.[40]

The quickest way to charge an electric vehicle battery is through what is known as DC fast charging. DC fast chargers use up to 400 volts of direct current (DC, as opposed to level 1 and 2 chargers which use alternating current, or AC). These provide around 3-5 miles of range per minute of charging, and can charge an average electric vehicle battery in under 30 minutes.[41,42] Fast chargers are most appropriate to be installed in public spaces where drivers intend to return to driving their vehicles after only short periods of being parked, or near major highways where battery electrics can recharge to continue long distance trips.

Implementation of DC Fast Charging is likely important in continued adoption of battery electrics. However, DC fast charging is expensive with price tags between $10,000 and $50,000 per installation. Most homes are not equipped to handle DC charging. [43] Furthermore, only certain battery chemistries support fast charging. The cost of DC Fast Chargers suggest that they will likely only be deployed in limited numbers to support fleet vehicles (transit, freight and rental fleet) and light passenger battery electrics in select locations, at least in the near term.

Charger Availability and Impact to EV Range and Efficiency

In the long term, however, the market will likely grow, with ABB estimating that the market for charging infrastructure solutions will be worth $1 billion by 2017.[44] While it is important to begin building some public charging infrastructure to increase the range Battery Electrics have beyond the home, there is also the concern that the number of charging stations and their distribution will not fit the number of electric vehicle drivers or their travel patterns. Chelsea Sexton, an electric vehicle advocate, argues the widely held perception that there needs to be a charger on every street corner is a misconception. Similarly, attempts to deploy infrastructure along highways, such as the I-5 corridor in California, are premature as people are not buying battery electric cars in order to drive between cities or cross-country. If deployment happens too fast, it will result in more chargers than cars, and these will be idle assets and perceived as a waste of taxpayer money.[45]

Electric charging points are difficult to find, with only approximately 2,000-3,000 available currently nationwide. In 2009, the Department of Energy awarded a $99.8 million grant to a company called ECOtality, followed by another $15 million in 2010, to run the EV Project, which is deploying 14,000 electric vehicle chargers in major metropolitan areas in California, Oregon, Washington, Arizona, Texas, Tennessee and the District of Columbia. The Project is also providing charging stations and paying installation costs for 8,300 qualified Nissan LEAF and Chevy Volt drivers in exchange for allowing the Project to collect and analyze data on their charging habits.[46] The EV Project is installing ECOtality's Blink brand Level 2 and DC Fast Chargers.

The availability of chargers not only impacts the range performance of battery electrics, but also influences plug-in hybrids fuel efficiency and environmental performance. Hybrids are designed so that they are not exclusively dependent on access to the grid for recharging. The distribution and availability of chargers, however, does have an impact on how "clean" Plug-in Hybrids can drive, or how many miles a plug-in can drive in all electric mode. Studies have shown charging during a vehicle's "dwell time," or when it is parked during the day, can have a significant environmental impact by increasing the miles that plug-in hybrid vehicles can travel in pure electric mode. A study by Oak Ridge National Laboratory found that 30 percent of vehicles are parked for more than seven hours at a time, or enough to fully charge a PHEV with a 20 mile electric range using a slower Level 1 charger. Also, 20 percent of stops were for more than two hours, long enough to fully charge a PHEV-20 using a faster Level 2 charger. If public charging infrastructure were to be fully built out, the study found more than a 30 percent reduction in gasoline consumption and energy cost savings of around 0.7 cents/mile.[47]

Ultimately, expansion of charging infrastructure will likely reduce the emissions footprint of Plug-in Hybrids over time. To take advantage of Plug-in Hybrids topping off their battery to increase their all-electric mode mileage, drivers still must be coached into driving their vehicles to maximize use of the battery for propulsion (known as battery Charge-Depleting Mode). Eco-driving applications, systems in vehicles that coach drivers into better driving habits to improve fuel economy and environmental performance, are being implemented for both new conventional fuel vehicles and hybrid. Ford EcoMode, for example, is a software application available on the new Ford Fusion Hybrid that rates driver behavior. EcoMode offers up hints to improve eco-driving skills, based on smoothing out accelerations and decelerations, maintaining constant speeds in the correct gear and other criteria. EcoMode then provides feedback to the driver while in motion through an intuitive, un-intrusive rating system.

New Innovations: Wireless Charging Interfaces and Battery Swapping

There are two future innovations that would improve upon widespread deployment of level 1 or 2 charging stations at homes, workplaces, and depots, as well as the addition of DC fast charging in critical locations such as public parking spaces. The first is *wireless inductive charging* that essentially allows the vehicle to be charged in transit. The second is battery swapping, which enables batteries to be charged at service stations and swapped into cars, removing depleted packs. Both of these technologies make charging speed equivalent to, if not faster than, conventional gasoline re-fueling. Both, however, are constrained in the short term either by lack of standards or scale of deployment, or both.

A much less mature technology is inductive or wireless charging, which is currently being used in some electric vehicle chargers like the Qualcomm Halo. Researchers in universities and the private sector are examining how wireless charging could be embedded into road infrastructure, allowing cars to be charged while they are moving. Stanford University researchers have developed a high efficiency charging system based on magnetic resonance coupling, which transmits large electric currents between metal coils using magnetic fields, and researchers at Utah State University have achieved 90 percent efficiency in getting electricity to transmit through air.[48,49]

Deployment testing of wireless charging has been focused on transit systems. The Utah State University technology is to be tested on their campus with an electric bus that will be charged inductively as it waits for passengers at a station. The university estimates that charging this way can reduce the battery size by 85 percent.[50] In Augsburg, Germany, a test track is demonstrating using contactless inductive power transfer for electric tramways, which can charge both moving and stationary vehicles. New Bus Rapid Transit (BRT) systems with new dedicated right-of-way may also be a logical starting point for experimenting with wireless charging interfaces embedded in the road.

The starting point for widespread adoption of wireless charging may be transit and other fleet vehicles. Transit and short haul freight fleets such as postal delivery vehicles follow predictable routes and could kick start investment in wireless charging guideway. These investments in guideway may benefit other road users that share access to the network. Light passenger EVs might run on the same guideway at times and use the wireless interface to obtain supplemental charging to top-off their batteries. These EVs might be routed by their telematics and navigation systems that detect need or opportunity to top-off their battery, and suggest drivers change their route onto roads where such wireless charging exists for a portion of their trip.

Another charging concept is *battery swapping*, or off-board charging, which is a variation on the theme of fast charging. Conventional battery charging puts vehicles out of commission for long periods of time. Battery swapping, however, takes the vehicle battery charging process off-line, enabling vehicles to “fuel” in a similar way to gasoline powered vehicles at the pump. Battery swapping envisions standard electric vehicle batteries that can be physically exchanged with freshly charged batteries on demand at service stations. In this scenario, a car can pull up to a service station, swap the empty battery for a full one in about a minute, and continue on its way. The biggest proponent of this model is a firm based in Palo Alto, California, called Better Place. In Better Place’s model, the consumer owns the car, but rents access to spare batteries, akin to buying a cell phone and paying every month for service. The model is being tested in Denmark and Israel, and so far, only Renault has signed up to design cars to meet Better Place’s battery specifications.

The scale, cost and convenience of battery swapping must compete with infrastructure based charging to be successful. In battery swapping, EV’s are fractional owners of spare batteries. While this adds to the cost of owning and operating an EV for a consumer, it provides benefit – the ability to charge quickly. However, the cost of maintaining a battery distribution network – i.e. battery service stations – must be compared to the cost and convenience of other similar value-added charging options, such as infrastructure-based DC Fast Charging. These costs are likely to be passed through to consumers. Furthermore, battery swapping is constrained by lack of scale. Swapping is only likely to become a popular model if more automakers might dedicate themselves to a common battery swapping configuration.[51] Standardization and modularity of battery packs will likely be key to both the success of battery swapping, but also the predictability of the ease and cost of long term maintenance of vehicles.

Market Drivers and Barriers for Electric Vehicles

Both government and industry are responding to public sentiment on environmental issues and the risks of oil dependency. Consumers' growing awareness of climate change and the role of transportation emissions in global warming have been the driving force behind the increasing attractiveness of electric vehicles. Drivers are increasingly desirous of going "green," and electric vehicles are the latest prominent symbol of environmental consciousness, as witnessed by the novelty and popularity of the Toyota Prius' second generation when it was first released in 2002. Overall, most likely the biggest driver of the demand for electric vehicles is rising gas prices, and an accompanying grassroots motivation to reduce dependence on foreign oil.

Electric vehicles are being pushed both from the supply and demand ends. Consumer environmental consciousness and sensitivity to high fuel prices are driving demand, while automobile manufacturers are competing to gain market share in this small but growing segment. Federal and state governments have provided incentives to both consumers and manufacturers in the form of favorable tax treatment; are subsidizing charging infrastructure to encourage demand for EVs; and are implementing fuel efficiency standards that require automobile manufacturers to seriously consider electric powertrains as a major component of their product strategies.

The major factors inhibiting the uptake of electric vehicles in the light passenger category are their high cost and driving performance in comparison to conventional fuel vehicles. Both factors are a result of limitations in battery technology. The cost and performance vis-a-vis conventional fuel light vehicles, and even some alternatives fueled vehicles, such as natural gas in niche categories such as fleets, may be impediments to broad, rapid market adoption of electric vehicles.

Today's push for electric vehicle technology is driven by energy and environmental needs, not exclusively by transportation demands, such as the need to improve safety and mobility. Speaking at the Electric Drive Transportation Association's annual conference in April 2011, the Secretary of Transportation suggested the United States was at a tipping point for vehicle electrification, due in part to a broad concerted effort by the Federal Government to improve the vehicle fuel efficiency and to encourage the use of clean renewable power generation. The White House aims to have one million electric vehicles on the road by 2015, a goal supported by the Department of Energy, which is leading the way in providing grants for research and development, as well as outreach to consumers and electric utilities. This wave of electric vehicle deployment has also benefitted from the American Recovery and Reinvestment Act of 2009, which included provisions to spur research on battery technology and deploy electric vehicle charging infrastructure across the country.

Fuel Efficiency Standards and Emissions Reductions

Despite the claims of many manufacturers that EVs are *zero emission vehicles*, many electric vehicles recharge using electricity generated at power plants that emit global-warming and smog-forming pollutants. Therefore, the concept of *well-to-wheel* emissions is a more accurate measure of the environmental credentials of EVs, rather than just tailpipe emissions. Electric vehicles produce little or no tailpipe emissions, depending on the powertrain (Battery electrics no fossil fuels). For hybrid electric vehicles, fossil fuel emissions depend on the vehicle powertrain, battery size and the ability of the vehicle to drive the furthest number of miles in all-electric (battery charge-depleting) mode.

It is often said that Electric Vehicles are the only type of cars, as opposed to gasoline, diesel or other fossil fuel based vehicles, that get “cleaner” over time, as the electrical power generation begins to convert slowly over time to lower-polluting energy sources. When battery electric vehicles (BEVs) are recharged using renewable energy sources like wind, solar, or hydropower, they in theory are not responsible for any greenhouse gas emissions or air pollution at all. Notably however, even if BEVs are recharged with electricity from power plants that use fossil fuels, they are up to 99 percent cleaner than conventional vehicles and can cut global warming emissions by as much as 70 percent.[52]

Fuel efficiency standards are spurring auto manufacturers to build electric vehicles. Corporate Average Fuel Economy (CAFE) is the sales-weighted average fuel economy of a manufacturer’s passenger vehicle fleet when measured in miles per gallon (mpg).[53] In April 2010, a rulemaking by the Environmental Protection Agency (EPA) and the Department of Transportation (DOT) limited carbon dioxide emissions to an average of 250 grams per mile by model year 2016, which is the equivalent of raising fuel economy standards to 35.5 miles per gallon (mpg).[54] Building on this, in July 2011, the White House announced an agreement which will result in a 54.5 mpg standard for passenger vehicles and light-duty trucks by model year 2025.[55]

Electric vehicles have immense potential to help manufacturers meet these new standards. The 2010 rulemaking allows automakers to count the first 200,000 to 300,000 electric vehicles sold by model year 2012 as emitting zero grams per mile of carbon dioxide; beyond that point, the EPA will count the carbon dioxide emitted by power plants to produce the electricity consumed by the car. Plug-in hybrids will be judged based on the percentage of miles driven on gasoline, with those driven on electricity counted again as zero emissions.[56]

However, automobile companies do not need to manufacture electric vehicles exclusively to meet CAFE standards. Other alternatives, such as compressed natural gas, hydrogen fuel cell, electric, ethanol, and diesel all are potential fuel system and powertrain options. Also, gasoline and diesel vehicle fuel efficiency still has room to improve. According to JD Powers, conventional fueled powertrains can gain by gasoline direct injection, turbocharging, “Ecoboost,” variable value timing, cylinder deactivation, and start-stop (or mild hybridization). Transmissions are also improving efficiency as well. Total gains from each of these innovations range from 1 percent to 15 percent.[57]

Government Incentives and Consumer Sentiment

Governments at all levels have provided, and drivers have taken advantage of, tax and other public incentives to lower the cost or increase the advantages of owning alternative fuel vehicles. Many states provide rebates of up to $7,500 for the purchase of an electric vehicle or to cover charger installation, and some also include preferential access to transportation facilities such as access to carpool lanes (High Occupancy Vehicle or High Occupancy Toll lanes) or parking spots. Federal incentives include tax credits ranging from $2,500 to $7,500 as part of the stimulus package, and a charger tax credit of up to $1,000 for individuals and $30,000 for businesses that expired at the end of 2011.[58]

On the supply side, the economic stimulus package of 2009 (the American Recovery and Reinvestment Act) provided $2.4 billion in grants for battery technology and electric vehicle infrastructure, aimed at accelerating domestic manufacture of electric vehicles parts. The money is meant to create nine new battery plants, and provide funding to 21 other plants that build electric vehicle components.[59]

Market Penetration of Light Passenger Electric Vehicles

The Department of Energy hopes to have one million plug-in electric vehicles on the road by 2015. Most auto industry analysts, however, think this goal is unlikely to be reached. James Sweeney of the Precourt Energy Efficiency Center at Stanford University describes the goal as "very aggressive," considering that hybrids, which were not hindered by the need to create extensive charging infrastructure, still took over a decade to reach 3 percent of the U.S. passenger car and light truck market.[60]

Estimates of the market penetration of electric vehicles vary widely. To put the Department of Energy's goal of one million electric vehicles on the road by 2015 in perspective, a Deloitte study from 2011 predicts a gradual adoption of plug-in and battery electric vehicles in the U.S., with sales reaching 465,000 units by 2020, representing three percent market share, with only 60,000 of those sold by 2015.[61] According to the head of manufacturing at Deloitte UK, Dave Raistrick, while electric vehicles represent the future of the automobile industry, the cars on the market today do not meet consumer expectations for driving range, charging time, and purchase price.[62]

Estimates from other analysts point to mild growth in EVs. JD Power and Associates, a global marketing information services firm, predicts that *global* sales of battery electric vehicles will only reach one million around 2017, from a global production base of 60 million vehicles per year.[63] The company predicts that cumulative hybrid plug-in and battery electric vehicle sales in the U.S. will only reach 750,000 by 2015, again short of the government's goal. They also expect that hybrids and plug-in hybrids will reach a 9.3 percent market share by 2020, but that battery electric vehicles will remain a minor player, capturing only 1 percent of the market.[64]

Manufacturing of key EV components currently do not have large enough economies of scale of production to see reduced costs reflected in sticker prices. In particular, there are very little economies of scale on the largest cost component, the battery. Generally, the less than expected growth may be the consequence of two main factors. One is concern among consumers about the range of these vehicles and charging infrastructure availability both at home and away; the second is the higher than average sticker price.

Battery Electrics, "Range Anxiety" and Other Consumer Compromises

There are a number of factors inhibiting consumers and fleet operators from buying battery electric vehicles, the most important of which may be range anxiety. Current battery technology is at the point where a battery that provides around 100 miles on a single charge is the most feasible from a cost and weight point of view; 100 miles is the stated range of the Nissan LEAF, for example.

Potential car buyers will likely view range as an important factor in purchasing an Electric Vehicle. The Department of Transportation's highway data shows that less than 1 percent of all vehicle trips are more than 100 miles,[65] meaning that current battery range is more than enough for day-to-day vehicle use. However, consumers are still wary of being stranded on longer trips, given long charging times and the fact that public electric vehicle chargers are not abundantly available. This is a major factor in reducing the attractiveness of electric vehicles for many consumers, who fully expect to have a vehicle that is both fuel efficient, and has the flexibility to be driven for both short trips and long distances.

Confusion surrounding the installation of electric vehicle chargers at home is also potentially a major factor inhibiting the sale of electric vehicles. Installing home chargers is a complex process that involves a large number of entities ranging from permit issuers to contractors to utilities, and takes an average of 40-50 workdays.[66] [67] Streamlining this process is one of the keys to increasing the attractiveness of EVs for consumers. To this end, Ford has teamed up with the consumer electronics store Best Buy to create a hassle-free process for buyers of the Ford Focus Electric, due out in spring 2012. The dealer will contact the store when an electric vehicle is purchased, and Best Buy will step in to install the charger in the customer's house, getting the required permits and working with contractors to complete the installation.[68]

The compromises that Battery Electrics impose on drivers, such as limited range and lack of simple convenient recharge modes at home and away, may have an impact on consumer demand. The 2011 US Green Automotive Survey conducted by JD Power and Associates showed that only 26 percent of consumers are likely to consider buying a Battery Electric when thinking of alternate powertrains. Hybrids (51 percent) are the most likely option, since they do not require extra infrastructure, while Plug-in Hybrids (37 percent) are in the middle.[69] Hybrids will likely continue to be a more preferred choice for consumers over battery electrics or Plug-in Hybrids for the foreseeable future, at least until range of battery electrics improve and charging convenience and infrastructure options expand.

EV Pricing, Operating Costs, and Residual Value

These problems are compounded by the fact that despite the federal tax incentives, electric vehicles are more expensive than their conventional counterparts. The 2011 Nissan LEAF starts at $32,500, and the Chevy Volt at $39,145 before tax savings. In an interview with the Wall Street Journal, Ford's global director of electrification, Nancy Gioia, said they believe the initial adopters of the Ford Focus Electric will be "higher-income drivers who are willing to overlook the technology's limitations in an effort to curb greenhouse gas emissions."[70] As a niche in their portfolio, the auto manufacturers see EVs as a marquee product, one that showcases their technological prowess and commitment to environmental sustainability to consumers and the public at large.

Much has been made of the fact that the higher initial purchase price of electric vehicles will be made up by lower operating costs over the lifetime of the vehicle. Electricity as fuel is much cheaper than gasoline with the gasoline fuel equivalent cost to recharge and drive an EV cited as around a $1 per gallon. However, an analysis of fuel costs by JD Power and Associates shows that the high upfront cost of the battery ($10,000-$15,000) erases most of the operating cost savings. JD Powers calculates that electric vehicle total cost of ownership (upfront purchase price and ongoing fuel purchases) is only lower than a conventionally fueled vehicle with a modest 25 MPG rating, when the cost of gas rises to $6/gallon. Some lower price conventionally fueled vehicles, such as the Chevy Cruze Eco, can achieve 42 MPG at a sticker price of $20,000. In contrast, a Chevy Volt is nearly double the cost within roughly the same size and feature segment.

Even customers moving down to lower featured vehicle segments may not choose EVs if looking for total cost savings and fuel efficiency. At $3.50/gallon, someone switching from a larger Sport Utility Vehicle to a smaller battery electric Nissan LEAF would experience considerable savings in fuel costs (but at the expense of size, power, and driving range). However, at the $32,000 price tag of the LEAF, buying a more fuel efficient compact car like a Ford Focus would be far more cost-effective when considering total cost of ownership.[71] This consumer calculus may be trickling down and starting to impact the demand for EVs. GM announced in March 2012 that it was suspending production of the Chevy Volt for five weeks because of slow sales.[72]

Lastly, the fuel savings achieved from EVs are also not likely reflected in the residual value of the car after it has been purchased. Generally there are no yardsticks for appraisers to evaluate residual value of electric vehicles because of the uncertainty of the value of the battery, the most costly EV component, at its useful end-of-life.[73] Kelley Blue Book and other evaluators are apprehensive about predicting the retail value of a car with a partly used battery pack. Without better evaluations, car buyers may be more reluctant to purchase EVs, given the risk of discovering their major investment may be worth much less in the future than they initially considered at the time of purchase. Over the long term, recycling, standardization and replacement of battery packs in older vehicles, as well as better understanding of the lifecycle of EVs might make appraisers and purchasers less pessimistic in their estimations of value of electric vehicle.

Fleet Electric Vehicles and other Personal Mobility and Freight Systems

Most public attention has been paid to the prospect of millions of light passenger electric vehicles over the next decade. However, commercial vehicles that travel short distances—such as transit bus fleets, taxis, or short haul delivery vehicles—represent in many respects a better opportunity for expanding electrification. Freight and passenger carriers may deploy electric fleets over time to improve fuel efficiency and environmental performance of their operations. New modes of urban mobility, such as car-sharing, electric-bikes, microcars and other unconventional vehicle types will also lift the technology's profile on city streets.

Transit and freight vehicle fleets have been among the earliest adopters of electric vehicles. Milk trucks in Britain in the 1960s were the first to use battery electric vehicles, designed to make deliveries without disturbing sleeping customers with the roar of engines in the early hours of the morning. Hybrid electric bus fleets are popular transit vehicles in cities such as New York and San Francisco, and electric buses are being used as school buses. The Federal Transit Administration estimates that approximately 10 percent of transit fleets in the U.S. are electrified. Although long-haul freight carriers are unlikely to switch to electricity in the near future, given the slow advances in battery technology that would be required to produce the required range and horsepower needed to pull heavy cargo, EVs may find a niche in last mile freight delivery services. As part of its goal to improve fuel economy in its global fleet by 20 percent by 2020, for example, UPS has invested in 2000 alternative energy delivery vans, with 300 of those being hybrid electric or plug-in electric vehicles.[74]

Moreover, other modes such as motorcycles and bicycles may move to electric, especially in those built for use in urban settings. E-Bikes (also known as Electric-Assist bicycles or Pedelecs) are generally a bicycle-type frame with a battery and motor mounted on the rack and rear wheel assembly to provide traction. E-Bike batteries are typically removable for charging while the bicycle is not in use. Electric bicycles are gaining currency abroad and in the US.[75] While bicycling is mostly a recreational activity in the U.S., a shift towards using bikes for personal mobility is taking place in major cities with the advent of bike sharing and bike lanes. As biking grows more popular, we may begin to see a rise in the popularity of electric bikes in the US. Finally, motorcycles or electric bicycles may even begin to serve as commercial fleets to courier packages the last mile. FedEx uses electric-powered tricycles to deliver packages in Paris, France, averaging 15 packages per hour. FedEx touts them as improving efficiency by allowing delivery to occur in pedestrian-only areas, as well as for being operationally viable and cost effective alternatives to bigger delivery trucks.[76]

Bicycles, bike sharing and even car-sharing may be a large growth area for electrification because current battery technology meets the range requirements for short trips, a pattern that predominates in most dense urban areas. For consumers, there are low barriers for entry for electric bikes, as these vehicles or their drivers generally are not required to be licensed, taxed or insured as motorized road vehicles, depending on the jurisdiction, although certain conditions of maximum power and/or speed are met. E-Bikes also do not require separate extensive charging infrastructure, given that batteries can be quickly charged by any 120 volt wall outlet. Furthermore, through bike sharing schemes, electric bicycles can be easily paired with public transit to improve urban mobility. Bike shares at transit nodes can provide last mile connectivity to destinations that are not within walking distance of a metro or bus stop, for example.

Electric Vehicle Micro Car-sharing or car rental is another niche for electric vehicles. There are between 40 urban bike-sharing schemes, and 70 car-sharing schemes in the US, raising the profile of these smaller vehicles, especially among younger drivers who are a major consumer segment for vehicle-sharing arrangements. Auto manufacturers have embraced branded or co-branded car-sharing, such Daimler with Car2Go in the US and Peugeot in Europe, to raise the marketing profile of their brand. A number of mainstream car rental and car-sharing services deploy electric vehicles. Car2Go, a subsidiary of Daimler AG, established the world's first all-electric car-sharing network in San Diego, California, with a fleet of 300 Smart Fortwo Electric Drive (Smart ED), or a "microcar." Car2Go fleets are located throughout cities' greater downtown areas, can be accessed on-demand and rented by the minute, or booked up to 24 hours in advance online via smartphone. Car2Go differs from conventional car-sharing in that members may use the vehicle for as long as they like, without committing to a specific return time or return location. The driver can finish the rental in any available public parking space within the specific area or at one of the specially marked Car2Go spaces. Other rental companies, such as Hertz with *Connect by Hertz*, or Enterprise with *WeCar* also feature hybrids that can be rented by the hour. CityShare in the San Francisco Bay Area, like Car2Go, features electrics and a diverse fleet subcompact and micro-cars designed fit in city parking spaces too small for many vehicles.

Urban electric car sharing is ideal because it requires neither the range of conventional vehicles, nor exclusive access to charging infrastructure throughout an urban area. The electric Smart Fortwo can travel up to 84 miles on a full charge and recharging a battery from zero charge takes up to eight hours. Range is not a challenge to adoption because charging is seldom necessary during the day, as the daily stretch covered by Car2Go drivers in urban areas rarely exceeds six miles. Furthermore, members are told the range of the vehicle ahead of time so that if they plan on taking larger trips, they can choose vehicles that are fully charged in the vicinity. [77] Like electric transit fleets, charging is typically completed in the evenings at a centralized depot, or decentralized depots' such as designated parking spots, reducing the need to build out a distributed charging infrastructure to support the car-sharing fleet. If members discover that their electric vehicle has a low charge, they will be asked to drop it off at a charge station. Car2Go will also have a third-party maintenance fleet to move the vehicles to charge points at the end of the day so that they can be charged overnight.[78]

Widely dispersing rental or car-sharing depots, and for EVs their charging and maintenance activities, may be one factor that could expand participation in car sharing. According to Scott Griffith, CEO of ZipCar, there are currently ten million people within walking distance of one of their shared vehicles, with only one million actually registered for their service. There may be potential growth in expanding services in the car-sharing and rental fields for households that do not own cars beyond the current depot footprint, especially if numbers expand and convenience and availability spreads in the same coverage area. The field is potentially expanding with the creation of peer-to-peer car sharing services that let households that do own cars rent them out to others who are vetted by the car sharing service center, enabling those sharing their cars to pocket considerable earnings, while expanding choice for renters.

Ultimately, proliferation of unconventional vehicles, be they transit, short haul freight, car-sharing or bicycle fleets are ideal starting points for electrification. Electric vehicles may make the biggest impact in meeting niche mobility and freight needs in places where drivers can live and work with the limited range that current battery technology offers. Furthermore, smaller downsized vehicles such as microcars may be more attractive from a safety perspective as collision warning and prevention systems begin to find their way into light duty passenger vehicles.

Smart Grid, Vehicle Electrification and Connected Mobility Services

If electric vehicle numbers grow quickly, this phenomenon will present both a challenge and an opportunity for utilities and the electrical grid. Over time, electric vehicles may stress segments of the electrical grid during peak charging times and eventually may place undue demand on power generation capacity. The solution to these problems is in the establishment of a few critical “smart grid” components. Specifically electric distribution infrastructure that can update electric vehicle owners or operators regarding the most opportune time for charging based on grid capacity and energy prices.

The electric power grid has remained largely the same for the past century, but efforts are underway slowly to modernize it. Smart Grid is defined as an electrical distribution system, integrated with power generation and end users relying upon communications technologies and sensors to “improve reliability, resiliency, flexibility, and efficiency (both economic and energy) of the electric delivery system.”[79] The smart grid has three main advantages for both energy consumers and producers. First, it will allow consumers to monitor their electricity usage and reduce their energy bills. Second, it will help utilities more efficiently tailor their supply to match energy demand, reducing the amount of energy wasted and greenhouse gases emitted. Third, the smart grid will give electricity transmission and distribution networks the ability to diagnose, monitor and fix problems.

Smart grid will aid in the integration of new renewable energy and “micro-generation” facilities into the power system. In a smart grid world, customers will be able to program when their dishwasher runs to take advantage of lower electricity prices at off-peak hours when renewable power is generated, adjust the temperature of their house to save energy while they are at work, and will instruct their electric car to return energy to the grid during peak working hours, while preserving enough charge to get them home in the evening. Vehicle-to-grid (V2G) power balance loads by "valley filling" (charging at night when demand is low) and "peak shaving" (sending power back to the grid, or reducing when demand is high).

Distributed Generation (DG) and refers to the small-scale generation and storage of heat and electric power, usually incorporating renewables, by individuals, small businesses and communities to meet their own needs, as alternatives or supplements to traditional centralized grid-connected power. Distributed generation refers to relatively small-scale generators that produce several kilowatts (kW) to tens of megawatts (MW) of power and are generally connected to the grid at the distribution or substation levels. In 2009, about 13,000 commercial and industrial DG units with a combined capacity of about 16 gigawatts (GW) were connected to utility systems in the U.S. Of these units, 10,800 (83%) were smaller than 1 MW, averaging 100 kW each.

Utilities are interested in monetizing the growing electricity demand from electric vehicles to enhance their revenue.[80] They are, however, concerned that excess demand may push them over the supply limit or even cripple the grid. Yet utilities also see an opportunity to leverage electric vehicles for energy storage and to help balance load on the grid. Steps that the utilities must take to make the smart grid work with electric vehicles include 1) Turn-key home installation of chargers, 2) time-of-use charging and fast-charging, 3) renewable energy inclusion scalable demand side management and 4) finally bi-directional V2G powerflow and home energy storage and backup. Utilities are currently at the very early stages of development of the first two, with renewables and bidirectional power flow possible in the medium to long term.

SmartGrid and Frequency Regulation: Balancing Power Supply and Demand

In order for the electrical grid to function reliably, electricity demand and supply must be perfectly matched at all times. Traditionally, utilities have done this by bringing certain types of power plants and/or generators on-line and off-line as needed, a process known as frequency regulation.[81] However, additional power sources used to meet peak demand tend to be more expensive and more polluting than baseline generation and can therefore contribute more to greenhouse gases and other emissions. Not only is ramping up generation to meet peak electrical demand expensive and environmentally damaging, one of the challenges in using renewable energy resources, such as wind or solar, is that they cannot be tapped on-demand and require considerable energy storage in order to be integrated into the grid.

Two major potential solutions are electric vehicles and other home-based appliances that store energy, such as hot water heaters. Lithium-ion, the battery technology deployed in EVs, are increasingly being used as frequency regulators, as they have the ability to absorb and discharge energy quickly. As a result, as vehicle-to-grid communications advance, electric vehicles have the potential to help utilities better balance supply and demand and can aid in integrating renewable power resources into the system. The maximum benefit to the overall electricity system will come if electric vehicles are given special rates to encourage charging at off-peak hours, mainly at night. Night charging will make better use of off-peak capacity and help balance the load on the system. Nighttime also happens to be when renewable power resources, such as wind, tend to be more plentiful. Luckily, charging at night implies home charging, which is the most common state of affair for electric vehicle owners. Rates for EVs need to be distinguished from the rates for other traditional household consumption. Being able to meter and charge different rates to different devices to enable this type of charging control is an impetus for developing the smart grid.

In the long term, electric vehicles will not only be able to use excess grid capacity at night, they will also be able to sell electricity back to the grid to shave peaks in demand. This is one conceivable way for electric vehicle owners to begin to regain some of their considerable investment in their vehicles. Many vehicles will sit in a parking lot during the day, when electricity demand is highest. EVs could communicate to the grid on how much charge they need to get home, and could then transmit the remaining electricity to the grid for a set price. For light-duty vehicles, this scenario will probably not be operational in the near term, but this vehicle-to-grid activity is plausible using heavy-duty fleets like school buses, which are idle during the day and parked together at a depot, meaning that there is large energy storage capacity in one consolidated location, where bidirectional power transmission can be cost-effectively established.[82]

Light-duty passenger vehicles, however, are not typically parked at depots and therefore the cost and complexity managing them as a mobile energy storage resource remains a major challenge.[83] The grid is not equipped to deal with small distributed micro generators or energy storage facilities, so in order to make use of individual cars as grid electrical storage resources, power aggregators need to be established. In September 2011, NRG Energy Inc., bought the U.S. license for an aggregator technology developed at the University of Delaware, paving the way for vehicle-to-grid transmission to take root in the country.[84] However, there are still worries about the quality of the power that will be transmitted to the grid, and the effect this will have on battery life.

Even without the establishment of highly distributed bi-directional vehicle-to-grid transmission facilities, electric vehicles could still help reduce demand at peak times. A short-term compromise solution short of smart grid is home/EV micro-generation and storage. Nissan has developed a commercial off-grid solution that allows energy stored in its Nissan LEAF electric vehicle to supply power to an individual home through a connection with the house's electricity panel. This vehicle-to-home system would permit a car to discharge stored electricity when people are home in the evenings, and demand is high, and charge the car in the early morning hours, when demand is low, thereby reducing the burden on generation utilities.[85] Home owners or businesses can add distributed-generation capacity, such as wind and solar facilities to their property that could supplement the grid, and improve energy efficiency by cutting out resistive losses as electricity is transmitted through the grid.

Diversity in power generation and storage not only benefits industrial and residential infrastructure energy efficiency and resiliency, but also positively impacts transportation mobility and sustainability. Electric vehicle charging stations are different than their conventional fuel counterparts in that they can be placed almost anywhere with access to the electrical grid. Electric charging stations can even fit in very constrained spaces, whereas gas stations may only be placed where there is sufficient space and requisite environmental permits for underground tanks. This means far more potential charging nodes per square mile are possible than for conventional fuel stations, most at trip origins and destinations, rather than intermediate stops such as gas stations.

The charging stations, in contrast to conventional fueling stations, can also be nomadic and sited in response to events or changes in traffic patterns. Portable charging stations, for example, allow demand for charging facilities to be matched dynamically according to geography, adding nodes to the grid wherever they are required.[86] For example, automotive service organizations such as the American Automobile Association (AAA) currently provide emergency roadside recharging for stranded electric vehicles.[87] AAA roadside charging uses a generator driven by a truck's power-takeoff influence; or from a spare lithium-ion battery pack; or a generator fueled by either compressed natural gas or biodiesel. Besides roadside assistance, these nomadic charging nodes can be more flexibly dispersed, placed temporarily according to demands of traffic or as incentives for EV use in particular areas. Setting up portable charging stations within a city to establish charging oases in areas devoid of public charging infrastructure, or even at sporting event venues or other special events, may act as an incentive to encourage the use of electric vehicles, much like unfettered use of High Occupancy Vehicle (HOV) lanes by EVs and other low-emissions vehicles.

Smart Grid connectivity the last mile to the vehicle -- from the transformer to the home, depot, or workplace charging station – is the challenge for the energy sector in the short run. Given low growth of plug-in electrics, utilities are not yet concerned about the power generation resources needed to charge a large numbers of electric vehicles simultaneously. Instead, they are worried about the last mile transmission capacity from the transformer to the house, in the scenario where a number of electric vehicle owners plug in at the same time on the same block to overload a transformer.[88] Many utilities are therefore closely tracking where vehicles are purchased and where they will be charged – utilities and auto manufacturers are now sharing customers, necessitating a new model of sharing information and coordinating purchase and installation of equipment. Utilities will also now need to have better relationships with their customers in order to learn more about plans for electric vehicle purchases and to offer the best rate plans. However, most utilities are in a "wait and see" mode, expecting no changes needed to their grid unless EV penetration increases significantly in the next five years.

The long term challenge for the smart-grid is to make energy production and distribution more efficient and flexible, and electric vehicles will play a major role. The vision of a smart energy is to balance of volatile, largely distributed, low-volume energy production, storage and consumption.[89] Plug-in EVs may in the future act as temporary home or depot generators (hybrids providing electricity to the home or grid via their powertrain alternators), storage (through battery packs), or consumers (through charging stations).

As the energy and transportation sectors account for most of the country's greenhouse gas emissions, vehicle electrification and smart grid integration will be a powerful way to reduce environmental impacts without compromising mobility or comfort. [90] The current smart-grid transportation effort will be focused on communicating energy supply and demand information from well-to-wheels – across the entire energy production and distribution lifecycle, and even extending it to the production and operational lifecycle of vehicles (well-to-auto plant-to-wheels). Measuring the de-carbonization of the energy supply chain used to both manufacture electric vehicles and to operate them as well as analyzing driving and charging behavior over time, will be critical to understanding fully the overall reduced environmental impact of all types of electrics.[91]

The Smart Grid and Implications for the Connected Vehicle

In order for thousands and eventually millions of EV's to become key energy elements of a new smart grid system-of-systems, the critical task before the automotive and utility industries will be integration of these vehicles and other electrical devices in a way that is interoperable, scalable, distributed, recoverable (in the event of disruption) and robust.

To understand the scale of the connectivity challenge, the National Research Council suggests that by 2030, 13 million PHEVs and BEVs, nearly 4.5% of the expected national fleet, could be sharing both the road and the grid. Furthermore, there are likely currently approximately 130,000 gas stations in the United States, and there will likely be 23,000 public EV charging stations by 2015. V2G not only includes the energy interface, but also a communication link, either wired or wireless, that is able to provide feedback between the vehicle battery management system, the charger and even the premise's electrical meter.

V2G interoperability's scalability and robustness challenge can be addressed by both the Grid (V2G power) and the telecommunications infrastructure (V2G Communications). V2G power interoperability is key, especially if publicly available charging infrastructure needs to expand to meet the demands of EV drivers. Public charging infrastructure (e.g. on- and off-street parking facilities) will only work if all plug-in electric vehicles and chargers, no matter their make or manufacturer, standardize their interfaces, in particular their charging connectors. The charger is the centerpiece of the vehicle-to-grid (V2G) power interface and includes the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premise's wiring to the electric vehicle.

In 2001, the California Air Resources Board adopted the Society of Automotive Engineers (SAE)'s "Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler" standard, known as J1772, for vehicles sold in California starting with model year 2006. Following that, the SAE Motor Vehicle Council endorsed an updated version of J1772 in January 2010, which has put it on the track to be widely adopted as electric vehicle manufacturing moves forward. J1772 specifies "general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America."[92] It also includes safety features. J1772-compatible vehicles include the Nissan LEAF, the Chevy Volt, the Toyota Prius Plug-in Hybrid, the Ford Focus Electric, the Tesla Roadster, and the Mitsubishi MiEV, among others; charging stations that meet the standard include those produced by AeroVironment, Coulomb Technologies, General Electric, and ECOtality.

The SAE J1772 power standard covers Level 1 and Level 2 charging, but the most used standard for DC Fast Charging is known as the CHAdeMO standard, after the association of the same name. CHAdeMO was founded in Japan by Nissan, Mitsubishi, Fuji Heavy Industries, the Tokyo Electric Power Company, and later Toyota. Many current EVSEs and cars are being built with both J1772 connectors and CHAdeMo connectors, but it is expected that the standards will merge or a dual-connector standard will be developed soon.

In contrast to Vehicle-to-Grid power, Vehicle-to-Grid communication technologies have been taking center stage in the push towards vehicle electrification. Electric vehicles are built with a number of communications terminal devices, typically designed to communicate with vehicle chargers, utility meters or telematics “cloud-based” services. Functions include applications to find the location of the nearest charging station over wide geographic areas that a vehicle may roam, or when arrived to establish power management session over a short distance with a charger to monitor energy loads, energy usage and optimize consumption, or to interact with the meter and the smart grid.

There are two types of communications technologies for electric vehicles and the smart grid, wired and wireless. Power Line Carrier (PLC) is the most prominent wired technology. Power Line Carrier, which uses the electric power cord to transmit data between the grid and vehicle, has gained traction among energy providers as the main communications technology. PLC has an advantage in that the shared wired medium between energy and information exchange greatly minimizes communication security vulnerabilities that might be more pronounced for a wireless system. Wired vehicle-to-grid communication is expected to initiate two-way secure message exchanges. These messages may, for example, differentiate electric vehicles from other appliances for smart grid applications, and support time- or price-based charging preferences.

A potential substitute to wired V2G communications is wireless. One current wireless technology contemplated for vehicle-to-grid is an inexpensive short-range peer-to-peer technology called ZigBee. ZiBee is based upon an IEEE 802.15 family of standards related to Wireless Personal Area Networks. ZigBee is a suite of communication protocols using small, low-power digital radios for personal area networks. ZigBee has a limited transmission range of 10-75 meters, a data rate of less than 250 kbps, and supports only simple devices, but it is perfectly suited for industrial control and monitoring, sensor networks, and building automation because of its low cost, high security and the variety of supported network types. In particular, ZigBee is known for its fairly low power consumption, which is a huge advantage over other wireless solutions, especially for battery-operated distributed devices used for smart metering.

Furthermore, Zigbee is bundled with some based application management features. The ZigBee application management suite, or profile, is another key differentiator between ZibBee and other communications technologies and standards. ZigBee Smart Energy public profile is a collection of device descriptions and functionality that enables utilities to intelligently manage energy loads, monitor energy usage and optimize consumption in a secure environment. ZigBee Smart Energy Profile ZigBee is seeking to become the de facto standard in wirelessly managing home-area networks to enable smart metering. Although vehicles are typically are not power starved in the same way as small portable appliances might be, use of ZigBee for vehicles may make sense if home automation networks become ubiquitous. If there is a ZigBee network already available in the home dedicated to linking multiple consumer devices in the home to the electrical meter, then linking the vehicle to the same network would make implementation of Vehicle-to-Grid less complex for the consumer to configure.

Although not yet universally embraced, many utilities and equipment manufacturers have adopted the ZigBee Smart Energy Profile in 2007 to enable communication between smart meters and devices. However, other short range wireless technologies, such as Wi-Fi or even vehicle Dedicated Short Range Communications could also provide V2G connectivity if a home-area network has been established from the smart meter. Wi-Fi Direct is a standard that allows Wi-Fi devices to connect to each other with no need for a wireless access point, in a fashion similar to ZigBee. Vehicle Dedicated Short Range supports Communications (DSRC) for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. DSRC is an IEEE 802.11a Wi-Fi variant that has protocols that also enable peer-to-peer connections, but are able to accommodate safety critical applications at high speeds. If Wi-Fi Direct, or vehicle Dedicated Short Range Communications gains traction in the marketplace, and if efforts are made to create application management profiles the same or similar to that being contemplated by the ZigBee Alliance, then both of these technologies may also play a role in V2G in the long term.

Ultimately, the only advantage of one wired or wireless solution over another is likely how simple it would be for consumers to set up the connection to and from charging station and the smart meter, and the level of effort needed to ensure that the connection is maintained and working properly. To enable DSRC, Wi-Fi or other local area networking technology to be equipped in EV infrastructure, government and industry might work together by establishing (or incorporating existing) data sets and standards, and encourage companies to develop a core set of EV related applications such as charging mobile payment, parking guidance and reservation applications that might utilize local area wireless systems.

Vehicle-to-Grid and Vehicle-to-Infrastructure Mobility Services

There are some overlaps between V2G and some safety and mobility functions envisioned by automakers and transportation researchers. Some V2G applications can also include a number of existing and future vehicle mobility and safety services, and these could be broadly categorized by three phases: pre-trip, in-transit or post-trip.

Conventional pre-trip planning for EVs, for example, includes priming of climate control (so that a vehicle can be warmed or cooled while still charging, prior to the departure, to reduce drain on the battery), or upload of updated list of charging stations into a navigation database, with route generation/guidance and potentially parking/charger reservation. In-transit applications might include a few conventional vehicle mobility applications, such as mobile payment (e.g. tolling, services drive-in etc.) or parking guidance. Finally, there may be other post-trip applications that may overlap with electric vehicle charging and frequency regulation, such as parking electronic payment. These post-trip applications may overlap with some vehicle safety applications. For example, vehicle maintenance and safety management applications may take advantage of connectivity at charging station access points to exchange diagnostics data with telematics service providers for off-board analysis.

Interaction between EVs and these application services would likely shift rapidly between different telecommunications media, where the appropriate media is chosen for the application in its pre-trip, in-transit or post-trip phase. The choice of a system, such as Wireless Personal Area Networks (WPAN, e.g. Bluetooth and Zigbee), Wireless Local Area Network (WLAN, e.g. DSRC, or WiFi) and Wide Area Networks (WAN, e.g. cellular) communications will depend on availability access nodes, or coverage, in different trip phases. For example, an EV telematics system connected to the cloud through a cellular modem could run an off-board query of all available chargers within the vehicle driving range while in-transit, calculated from current charge levels, taking into account real-time traffic information. A reservation could then be placed on a parking spot with a charger near the final, or alternatively an attractive intermediate destination (e.g. rest stop, restaurant), reserving it for the exact time required to fast-recharge the battery. In post-trip phase, a local area/personal area wireless technology, such as ZigBee, Wifi, DSRC, could handle grid management telemetry and even perhaps manage the financial transactions related to parking and charging.[93]

There could conceivably be models where short range technologies could be utilized in the in-transit phase, rather than wide area. Such local area mobility applications could also operate in "publish and subscribe" application mode, where data or alerts that are relevant in a predefined area, such as is within the range of Wi-Fi or DSRC, are exchanged between vehicles (V2V) and infrastructure (V2I).[94] "Publish and subscribe" may be a model for all DSRC-based mobility applications in the "in-transit" phase, and in particular some specific electric vehicle applications such as parking/charging. For the example above, alerts could highlight availability and location of chargers and empty spaces to drivers subscribed to receive them within a locally defined area such as a city block with on-street parking or a parking garage. These messages then would be published, or passed along, from a charger to vehicle then chained vehicle-to-vehicle, with "subscribed" vehicles provided last yard guidance, pulling the vehicle into an empty charging station.

This local "publish and subscribe" mobility application model differs slightly from most online centralized charger occupancy/or reservation service models in which the status spaces are aggregated and transmitted to all Electric Vehicle drivers via a cloud based service. In contrast to a centralized reservation system, a local "publish and subscribe" system would be peer-to-peer, and would benefit from lower telecommunications cost, and built in relevance (to local users) and fairness by allowing first come/first serve access, but still providing the driver convenience through last-yard guidance to the available parking slot.

Vehicle Crash Avoidance Technology and Electrification

The goal of vehicle electrification is first to improve fuel efficiency and environmental performance. However, there is a trade-off between fuel efficiency and safety. In the past, vehicle weight gains have defeated improvements in fuel economy. An MIT study determined that if drivers today were driving cars of the same size and power that were typical in the 1980s, average mpg would be almost 40 miles per gallon, rather than the current average of just under 30 miles per gallon of the last decade. Most of that new technology in improving fuel economy has gone into compensating for additional weight and horsepower.[95] Energy savings in many areas, including vehicle and home heating/cooling, often are stunted by direct rebound effects, as consumers respond to improvements in energy efficiency by increasing energy consumption. This "take-back" of efficiency improvements in vehicles, where fuel efficiency gains are taken back by consumers in the form of larger vehicles--rather than more fuel efficient ones--may be driven by preferences for roomier, and what also might be perceived to be safer, automobiles.

It is uncertain how government fuel efficiency standards, however, may stunt the take back effect. Significant reductions in vehicle horsepower and weight may be associated with aggressive increases in CAFE standards in the future, and significant increases in gas prices might also reinforce these trends. Moreover, reductions in horsepower, size and weight may, over an extended period of time, slowly tip the balance slightly toward more electrics and other alternative fuel vehicles in automotive manufacturers' portfolio of models.

Vehicle-to-Vehicle crash avoidance systems will overall benefit both larger and smaller vehicles, but incremental benefits to smaller vehicles will much greater. In many vehicle-vehicle crash scenarios, larger and heavier cars are generally safer than smaller ones. In relation to their numbers on the road, small cars account for more than twice as many deaths as large cars. A 2011 Department of Energy analysis showed that decrease in vehicle weight with the same platform footprint increased fatality risk per vehicle mile traveled by 1.43 percent for average cars.[96] Part of this may be accounted by vehicle size and structural compatibility between two vehicles that have collided. For example, in frontal crashes involving two vehicles, the solid, energy-absorbing elements of each vehicle often do not meet. This is the result of either lateral mismatch of structural elements, when the structures bypass each other instead of meeting head-on, or vertical mismatch, when the structures override and underride each other. The vertical mismatch scenario often occurs in crashes between light trucks and smaller passenger cars. When the vertical mismatch occurs, the "crumple zone" structures in the front of the vehicles are underutilized and the crash forces are not ideally managed, resulting in excessive intrusion into the occupant compartment in severe crashes. Statistical analysis to untangle the effects of size and mass on occupant protection measures is complex and not yet conclusive. Some studies show that size may be a larger factor than weight, and that reducing wheelbase and track width may increase fatality risk as well.[97] NHTSA has in the past conducted vehicle crash compatibility research looking at how larger vehicle categories, such as Sport Utility Vehicles, may increase the fatality or injury risk to occupants in smaller vehicles in the event of a crash.

Vehicle Safety applications, in particular Vehicle-to-Vehicle collision warning applications, may play a major role in the long term electrification of vehicles. New Corporate Average Fuel Economy (CAFE) regulations may significantly improve the prospects of electric vehicles, and drive the "light-weighting" or downsizing of some vehicle categories to achieve fuel economy requirements. Light-weight vehicles may be more fuel efficient, but it remains to be seen whether they will be able to afford as much protection for occupants in the event of a crash. To prepare for larger scale production of electric vehicles, and to allay concerns or perceptions that smaller, lighter vehicles may prove less safe in the event of a crash, robust collision warning and crash prevention technology will likely need to advance simultaneously with light-weighting.

An effect on occupant protection of a combination of different weights, sizes and even shapes between two vehicles in a crash is known as crash compatibility. Lighter electric vehicles and motorcycles will benefit from Vehicle-to-Vehicle collision avoidance. GM and Nissan have taken pains to ensure that Chevrolet Volt and Nissan LEAF are as safe as larger cars, and both achieved Institute for Highway Safety recommendations for safety. Even lighter weight subcompact or microcar hybrids and battery electrics would likely have larger mobility range and ultimately reduced well-to-wheels emissions, but would likely need to address the issue of crash compatibility and occupant protection to achieve acceptable crash ratings and consumer acceptance. Vehicle-to-Vehicle crash avoidance systems may be important in addressing the weight, size and shape differences between vehicles in a number of crash scenarios. If Vehicle-to-Vehicle crash avoidance features are equipped on all cars, as is envisioned by US Department of Transportation and the auto industry over the course of the next ten years, the risk of fatalities that result from vehicle crash incompatibility may be diminished by reducing the number of incidents of vehicle-vehicle collision overall.

Smaller lighter vehicles must be well designed to provide the near the same level of occupant protection as larger vehicles. For motor- or pedicycles, however, occupant protection is orders of magnitude more difficult and the need and for crash avoidance is more urgent. Helmets and special garments are typically the best protection that riders can rely upon and afford. According to the NHTSA, in 2006, 13.10 cars out of 100,000 ended up in fatal crashes. The rate for motorcycles is 72.34 per 100,000 registered motorcycles.[98] Motorcycles also have a higher fatality rate per unit of distance travelled when compared with cars. In the multiple vehicle accidents involving motorcycles, the driver of the other vehicle violated the motorcycle right-of-way and caused the accident in two-thirds of those accidents. Multiple-vehicle crashes (head-on, side-swipe, failing to give-way) and loss of control crashes on both straight and curved sections of road are dominant types of fatal and serious injury motorcycle crashes.

Under the U.S. Department of Transportation's Connected Vehicle program, the federal government hopes to begin the deployment of DSRC for vehicle-to-vehicle crash avoidance applications in light-duty vehicles sometime after 2013, and in heavy vehicles after 2014. Vehicle-to-Vehicle Dedicated Short Range Communicates based crash avoidance applications are currently being targeted at a number of different crash scenarios, such as *opposite direction collision* (e.g. head-on), *rear-end collision*, *control-loss maneuver*, *drifting same lane*, *left at intersection across path*, *intersection straight crossing path* and up to twenty other crash scenarios. Current V2V collision warning applications addressing these crash scenarios under development include *Emergency Brake Light Warning*, *Forward Collision Warning*, *Intersection Movement Assist*, *Blind Spot and Lane Change Warning*, *Do not pass Warning*, and *Control Loss Warning*. Other future applications may be introduced as well. However, current and future V2V applications may potentially address, according to NHTSA, about 4,409,000 police-reported or 79 percent of all vehicle target crashes.[99]

It should be noted, however, that an effective V2V crash avoidance systems would require a large proportion of the vehicles on the roads to have adopted this DSRC technology in order for it to have notable impact on most classes of vehicle--vehicle crashes. Given the slow turnover of the car park, as new V2V equipped vehicles replace older vehicles without the technology, the challenge is to kick start deployment and gain momentum in equipage, taking advantage of network effects in technology acceptance. (e.g. the increasing number of V2V equipped vehicles, the more likely you as an equipped user will encounter another V2V equipped vehicle, the greater the overall crash avoidance utility and the more attractive the system is to new entrants considering purchasing a V2V option). To trigger this virtual circle of deployment, the US Department of Transportation has conducted research on the development and deployment of potential Vehicle Awareness Devices (VAD) and more sophisticated Aftermarket Safety Devices (ASD) for existing vehicles, which outnumber new vehicles by over ten to one.

Currently there is no operational testing of motorcycle-to-vehicle crash avoidance, though the Connected Vehicle program may still address the needs of motorcycles, cyclists and even pedestrians at some stage in the future. V2V applications may prove very important for preventing the larger proportion of motorcycle-related multiple vehicle crashes, especially in denser urban areas. V2V applications may address crashes occurring at intersections, such as *right turn, or straight or left crossing path* scenarios, where the low visual conspicuity of motorcycle riders and driver inattention to approaching motorcycles are often factors in collisions.[100] Fitment of active safety technology, in particular DSRC, might reduce the safety impact both vehicle downsizing and light-weighting, and as better position micro-cars and motorcycling as a safe and attractive mobility option for consumers.[101] Motorcycles, in particular electric-powered motorcycles, would benefit considerably from V2V safety applications.

Both Vehicle Awareness Devices and Aftermarket Safety Devices are designed to provide some V2V collision avoidance functionality, with the VAD providing one-way functional warnings to other drivers. Both VAD and ASD use GPS and Vehicle DSRC to be powered via an automotive cigarette lighter or a standard 110 volt connection, and are mounted to the dashboard of a vehicle, in a fashion similar to a personal navigation device. VAD and ASDs are currently being designed to work with late model light passenger vehicles.. These low cost, lower functionality devices are designed to provide vehicles that would not normally be equipped with V2V with some one-way or two-way collision warning features at reduced cost and complexity of integration into vehicle. Ultimately it is hoped that adoption of some very basic Vehicle-to-Vehicle collision avoidance applications that are part of a VAD or ASD module in a personal navigation devices might provide improved safety for later model light vehicles, and may ultimately be customized for use in motor- or pedi-cycles.

There is a transportation infrastructure element that supports the maintenance and secure operation of vehicle-to-vehicle crash avoidance applications, and electric vehicle charging infrastructure and the smart grid may play a supporting role for all vehicles, not just electrics. Vehicle-to-Vehicle using DSRC applications may be able to take advantage of the unique characteristics of charging stations, and for that matter, conventional fuel stations: convenient locations and dispersed geographical distribution, and frequent interaction with vehicles in the pre-trip and post-trip phases. The US Department of Transportation, along with consortia of automakers is designing a specific credentialing process for Vehicle-to-Vehicle safety applications, where maintenance of privacy and security of safety data are incorporated into the system by design. One of the main requirements of a vehicle DSRC network is to guarantee that every car will communicate with a certificate management authority periodically in order to ensure that the collision avoidance application featured, DSRC-equipped vehicle can be verified as functioning properly. After a DSRC vehicle passes through diagnostics and self-checks, it is deemed to be properly functioning and then issued a security certificate verifying that it is trusted system. A security certificate is then transmitted to the vehicle from a certificate management authority, where it is thereafter attached to the Basic Safety Message (BSM). The BSM is a dynamic message transmitted every 100 milliseconds to all surrounding vehicles via DSRC, providing a set of critical data elements needed to support collision avoidance applications, such as vehicle localization (e.g. where in lane), direction, speed and the status of key automotive elements such as the braking system. The certificate is attached to the BSM to verify its authenticity, specifically the integrity and freshness of the safety data being transmitted to other vehicles. This is done to ensure that other V2V equipped vehicles trust that the car sending the BSM is trustworthy and not sending erroneous safety data, and also that the safety data is not compromising to the privacy of the driver.

Electric Vehicle charging stations are like gas stations, in that vehicles must visit them on a regular basis to recharge or refuel. Vehicle safety applications, in some cases, may upload diagnostics data, or download credentials from the V2V certificate authority at charging stations. USDOT has contemplated deployment of DSRC roadside units at gas stations as a way to ensure that all DSRC vehicles, in particular those vehicles that may not have another channel through a telematics service provider or some other communication systems, have at least one distribution channel available to them to accept new or updated credentials.[102] A similar concept could be extended to electric vehicle charging stations. EV charging stations could be potential vehicle DSRC nodes that could not only provide connections to EVs, but also neighboring conventionally fueled vehicles that are similarly equipped with cooperative safety features.

Ultimately, as crash prevention systems such as vehicle-to-vehicle DSRC are deployed to such a scale and effectiveness in the next two or three decades, consumers may find themselves more willing to trade larger, heavier, less fuel efficient, but more crash-worthy vehicles (i.e., vehicles with structure and weight to absorb the energy of a crash to protect the occupants) for smaller, lighter, more energy-efficient ones. With improvements in safety resulting from deployment of crash avoidance systems, automotive engineers will be able to revisit confidently the grudgingly accepted trade-off between size, weight, safety and energy efficiency. There is no indication that this reversal would happen in the near or medium term, but ultimately the goal of simultaneously improving both safety and fuel efficiency as well as environmental performance is one that is worth pursuing.

Conclusion

A number of high profile information technology companies have entered the automotive space in recent years with a focus on driving innovation in support of the fundamental values of transportation safety and environmental sustainability. Google chose the hybrid electric Toyota Prius for their self-driving vehicle, which is a testament to the future potential of crash avoidance and automation. Tesla comes out of Silicon Valley with a singular focus on producing high performance battery electrics. Even for traditional automakers such as GM, Ford, Toyota, Nissan and others, electric vehicles are showcases for a number of advanced technologies and services such as alternative powertrains, advance batteries, and telematics.

Despite the failure of battery electric vehicles such as GM's EV-1 to take off in the 1990s, electric vehicles look set to finally establish a niche presence in light global auto production. According to P3 North America, there are nearly 29 new electrified vehicle models with a narrow production base of nearly 1.6 million vehicles. The key technologies that may ensure electric vehicles' further success in the marketplace are battery attribute improvements – improved energy densities, recharging times, and durability – that lower the cost and improve the range, efficiency and powertrain performance of the vehicle.

Absent improvements in the battery, the approach the auto industry is likely to take is a transitional one, eschewing large-scale production of battery electric vehicles for hybrid-electric ones that can bridge the gap in range and performance between EVs and gasoline vehicles. Over the long term, new battery chemistries may improve range and performance of battery EVs to equal that of gasoline-powered light vehicles and even medium-duty freight vehicles. Another force for EVs will be powertrain system modularity, such as standardized batteries and interfaces, which can drive scale and volume of components to reduce costs and improve vehicle resale value. Lastly, rollout of fast charging stations or battery swapping, both expensive now, could improve prospects for battery electric vehicles.

As progress in the development of lightweight composites and other advanced materials takes hold in the auto industry, EV production lines may see the first re-tooling and preparation for mass production of lighter weight vehicles. New Corporate Average Fuel Economy (CAFE) regulations may significantly improve the prospects of electric vehicles, and drive the "light-weighting" or downsizing of some vehicle categories to achieve fuel economy requirements over the long run. The light-weighting of vehicles may push automakers to incorporate more active safety, or collision avoidance features. Crash avoidance, particular communications-based Vehicle-to-Vehicle systems, may be important in building the consumer confidence in smaller, lighter weight electrified vehicles and motorcycles.

Electric Vehicles are the only type of cars that get "cleaner" over time, as electrical power generation begins to convert slowly over time to lower-polluting energy sources. Two ways to improve the environmental and fuel efficiency performance in the interim is implementation of eco-driving, electronically coaching drivers to improve their driving habits, and providing distributed public charging infrastructure that allows drivers to top-off charge more frequently–increasing the miles that plug-in hybrid vehicles can travel in pure electric mode. Charging infrastructure build out is likely critical, but must be balanced. There is a risk that too few charging points may hinder demand as consumers see charging options as too limited to make the switch from gasoline-powered vehicles. One risk for public agencies and private sector facility operators is that too early deployment of V2G charging infrastructure may leave most charging stations underutilized.

In the long run, the market for Smart Grid services may sort out these demand and supply considerations for utilities. Smart Grid will likely emerge over time, allowing drivers to find the most opportune time, price, and location to charge their EV batteries (or in the long term, sell back their power to the grid). Ultimately, Vehicle-to-Grid communications will allow drivers to be more conscious of their energy consumption patterns, while at the same time enable them to overcome gaps in serviceability, such as range and charging point accessibility limitations with the current battery technology and scant footprint of charging point infrastructure.

Electric Vehicle telematics may ultimately provide the connectivity needed to provide seamless and carefree matching of electric vehicles with available parking and charging points. As the electric smart grid matures, vehicle-to-grid communications may be able to provide easy connections to ensure that while the vehicle is parked, managing the battery and transactions, such as charging and billing, can be done simply and remotely. Future wireless smart grid technologies and systems will likely be able to collect and measure energy usage and accurately summarize vehicle miles traveled (VMT) and other measures of energy and transportation efficiency. Future vehicle Dedicated Short Range Communications (DSRC) in particular, may not only provide reliable Vehicle-to-Vehicle safety applications, but can be leveraged to provide “smart grid” support for Vehicle-to-Grid.

In the quest to make transportation more environmentally sustainable and to diversify energy sources, electric vehicles have a big role to play. A portfolio approach, where appropriate vehicles and fuels are chosen based on intended usage and application requirements may hold the answer. Battery electric systems are ideal for short-range urban mobility in light passenger vehicles, motorcycles, and transit fleets, leaving longer-range passenger travel and freight to the hybrid electric vehicles or ultra-efficient gasoline- or diesel-powered vehicles. For those sectors where electrification is impractical, such as heavy-duty freight and other industrial modes, sustainable biofuels such as cellulosic ethanol or other new fuel technologies can help reduce oil consumption and greenhouse gas emissions.[103]

However, at the moment, electric vehicles cost more and are more limited in performance than gasoline- or diesel-powered vehicles. Automakers are constantly improving the efficiency of the internal combustion engine. Many of the technologies that have been described to improve the performance of electric vehicles, such as fast-chargers, lighter car body materials, frictionless tires, and flywheels, are also serving to increase the fuel efficiency of standard vehicles. At high gas prices, EVs will become more attractive to consumers than conventionally fuelled vehicles. Drastic increases in the prices of gas, however, are unlikely without an oil crisis or some other major shift in energy and environmental policy, such as commitment to a comprehensive greenhouse gas reduction regime. Should such critical changes occur, however, electric vehicles will be poised to move beyond its current niche to gain wide scale acceptance and integration into transportation and energy infrastructure.

Over decades, widespread use of electric vehicles in our surface transportation system is likely to further erode the basis upon which transportation infrastructure is currently financed. The Highway Trust Fund, which is funded in greatest part by an 18 cent tax per gallon of gasoline, is the major source of funding for road maintenance and construction in the U.S, and has eroded in purchasing power. Since electric vehicles use little or no gasoline, EV drivers will not be contributing to the Fund. On the other hand, however, as EVs become more common and total mileage driven by the EV fleet rises above that driven by conventional gasoline vehicles, there will be consequences for the financial sustainability of the Highway Trust Fund, as well as the erosion of the principle of “user pays” (i.e. the compact between the highway users and highway agencies that users fees are equitable and that they are directed to maintain or construct roads). For this reason, the some states have conducted research on how highway taxes or user fees for electric and other non-gasoline powered vehicles may be collected based on other proxies of use, such as vehicle miles traveled, or kilowatt hour of electricity used.

About the Connected Vehicle Technology Scan and Assessment Series

Under sponsorship from the US Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS-JPO), the *Intelligent Transportation Society of America* (ITS America) is conducting the *Connected Vehicle Technology Scan and Assessment* project.

This multi-year scanning series of *Connected Vehicle Insight* reports will assess emerging, converging, and enabling technologies outside the domain of mainstream transportation research. ITS America seeks technologies that will potentially impact state-of-the-art or state-of-the-practice in ITS deployment over the next decade, with an emphasis on the "connected vehicle."

The *Technology Scan Series* notes trends, technologies, and innovations that could influence, or be leveraged as part of, next-generation intelligent transportation systems within the next five to seven years. The series' focus is on developments in applied science and engineering and innovation in data acquisition, dissemination, processing, and management technologies and techniques that can potentially support transportation.

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This publication was developed by ITS America on behalf of the U.S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office in the interest of information exchange. The opinions, findings and conclusions expressed in this publication are those of the author(s) and not necessarily those of the Research and Innovative Technology Administration. If trade or manufacturers' names or products are mentioned, it is because they are considered essential to the object of the publication and should not be construed as an endorsement by either ITS America or the Research and Innovative Technology Administration.

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References

[1] Brad Plumer, "One billion vehicles hit the road. Are we ready for two billion?" Washington Post. Available at http://www.washingtonpost.com/blogs/ezra-klein/post/one-billion-vehicles-hit-the-road-are-we-ready-for-two-billion/2011/08/22/gIQA1am4WJ_blog.html (accessed October 31, 2011).
[2] U.S. Energy Information Administration, "Oil: Crude and Petroleum Products Explained," July 2011. Available at http://www.eia.gov/energyexplained/index.cfm?page=oil_home#tab2 (accessed March 4, 2012).
[3] U.S. Energy Information Administration, "Emissions of Greenhouse Gases Report," December 2009. Available at http://www.eia.doe.gov/oiaf/1605/ggrpt/ (accessed October 1, 2011)
[4] U.S. Department of Energy, "Alternative Fuels & Advanced Vehicles Data Center," October 2011. Available at http://www.afdc.energy.gov/afdc/ (accessed September 29, 2011).
[5] Presentation: Electric Powertrains, MIT Electric Vehicle Team, April 2008 http://web.mit.edu/evt/summary_powertrains.pdf
[6] MIT Electric Vehicle Team, "Electric Powertrains," April 2008. Available at http://web.mit.edu/evt/summary_powertrains.pdf (accessed September 29, 2011).
[7] Mike Omotoso, Presentation at the Smart EV 2011 Executive Leadership Forum, Washington, DC, November 7, 2011.
[8] The Axeon guild to Batteries, 2012 http://www.axeon.com/getdoc/abb2a51a-ea57-416f-bdc4-79cbe7104d4f/Our-Guide-To-Batteries.aspx
[9] University of California at Berkeley, Center for Entrepreneurship & Technology, "The Electric Vehicle Battery Landscape: Opportunities and Challenges," December 2009.
[10] Dana Hull, "Electric Cars Race Toward a Better Battery," Chicago Tribune, July 23, 2011. Available at http://articles.chicagotribune.com/2011-07-23/site/sc-cons-0721-autocover-20110723_1_electric-cars-lithium-ion-battery-nissan-leaf (accessed February 22, 2012).
[11] Matthew Shaer, "iPhone Explodes Midflight, Emits 'Dense Smoke'," The Christian Science Monitor, November 29, 2011. Available at http://www.csmonitor.com/Innovation/Horizons/2011/1129/iPhone-explodes-midflight-emits-dense-smoke (accessed February 22, 2012).
[12] Jerry Hirsch, "NHTSA ends Chevrolet Volt fire probe, endorses GM remedy," Los Angeles Times, January 20, 2012. Available at http://www.latimes.com/business/money/la-fi-mo-volt-fire-20120120,0,5038267.story (accessed March 5, 2012).
[13] A123 Systems, Inc., "Usable Energy: Key to Determining the True Cost of Advanced Lithium Ion Battery Systems for Electric Vehicles." Available at http://www.a123systems.com/resources-overview.htm (accessed February 22, 2012).
[14] Axeon Guide to Batteries, 2012 http://www.axeon.com
[15] Jason Forcier, A123 Systems, 2011 Consumer Electronics Show (CES) Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[16] Pike Research, Electric Vehicle Batteries, Lithium Ion Batteries for Hybrid, Plug-in Hybrid, and Battery Electric Vehicles: Market Analysis and Forecasts – report abstract, 2011.
[17] U.S. Department of Energy, "Vehicle Battery R&D: Current Scope and Future Directions," October 2011. Available at http://www.orau.gov/battery2011/presentations/01howell.pdf (accessed February 22, 2012).
[18] U.S. Department of Energy, Lawrence Berkeley National Laboratory, "News Release: Better lithium batteries are on the way from Berkeley lab," September 23, 2011. Available at http://newscenter.lbl.gov/news-releases/2011/09/23/better-li-ion-batteries/ (accessed February 22, 2012).
[19] Northwestern University, "News Center: Better Batteries," November 14, 2011. Available at http://www.northwestern.edu/newscenter/stories/2011/11/batteries-energy-kung.html (accessed February 22, 2012).
[20] Pike Research, Electric Vehicle Batteries, Lithium Ion Batteries for Hybrid, Plug-in Hybrid, and Battery Electric Vehicles: Market Analysis and Forecasts – report abstract, 2011
[21] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[22] Kammen, M.D, Arons M.S, Lemoine, D., Hummel, H., Cost-efectiveness of Greenhouse Gas Emission Reductions from Plug-in Hybrid ElectricVehicles, Goldman School of Public Policy Working Paper No. GSPP08-014, 2008.
[23] Plug-in Hybrid and Battery-Electric Vehicles: State of the research and development and comparative analysis of energy and cost efficiency Françoise Nemry, Guillaume Leduc, Almudena Muñoz, Joint Research Centre Notes – 2009 European Commission
[24] Ibid.
[25] James Kanter, "Fancy Batteries in Electric Cars Pose Recycling Challenges," New York Times, August 30, 2011. Available at http://www.nytimes.com/2011/08/31/business/energy-environment/fancy-batteries-in-electric-cars-pose-recycling-challenges.html (accessed September 29, 2011).
[26] P3 North America Presentation – Secondary Use of Electrified Vehicle Batteries, May 30, 3012
[27] Toyota USA, "News Release: 2012 Toyota Prius, America's Best-Selling Hybrid, Adds Revised Styling and Advanced Infotainment Features," September 2011. Available at http://pressroom.toyota.com/releases/2012+toyota+prius+hybrid+styling+advanced+infotainment+features.htm (accessed March 4, 2012).

[28] Fisker Automotive, "2012 Karma." Available at http://www.fiskerautomotive.com/en-us/karma/features/technology (accessed March 4, 2012).
[29] "Getting The Steel Out, Automakers push ahead on energy-saving carbon fiber composites despite questions of economic viability," Marc S. Reisch, Chemical and Engineering News, Vol 89, number 39, September 26, 2011
[30] Bill Howard, "BMW's dazzling iCars: More carbon fiber Chevy Volt than Nissan LEAF," Extreme Tech, August 1, 2011. Available at http://www.extremetech.com/extreme/91600-bmw%E2%80%99s-dazzling-i-brand-why-they-opted-for-a-carbon-fiber-chevy-volt-not-a-nissan-leaf (accessed March 4, 2012).
[31] "Carbon-Fiber Composites for Cars," Oak Ridge National Laboratory Review, Volume 33, No. 3March 2000
[32] IBID
[33] Lightweight Materials for Transport: Developing a Vehicle Technology Roadmap for the Use of Lightweight Materials MIT Roundtable: "The Future of Manufacturing Innovation – Advanced Technologies March 29, 2010 Charles Fine Professor, Sloan School and ESD Richard Roth Director, MIT Materials Systems Laboratory - http://www.alum.mit.edu/sites/default/files/IC_assets/news/images/alumninews/Fine_Roth.pdf
[34] IBID
[35] "Technology Quarterly Q4 2011: Flywheels - Reinventing the Wheel," The Economist, December 2011.
[36] General Motors, "Chevy Volt FAQs." Available at http://gm-volt.com/chevy-volt-faqs/ (accessed March 4, 2012).
[37] Can Fuel Cells Help the Battery EV Market? May 11, 2011 Lisa Jeram, Pike Research http://www.pikeresearch.com/blog/articles/can-fuel-cells-help-the-battery-ev-market
[38] Bill Howard, "BMW's dazzling iCars: More carbon fiber Chevy Volt than Nissan LEAF," Extreme Tech, August 1, 2011. Available at http://www.extremetech.com/extreme/91600-bmw%E2%80%99s-dazzling-i-brand-why-they-opted-for-a-carbon-fiber-chevy-volt-not-a-nissan-leaf (accessed March 4, 2012).
[39] Plug-in Hybrid and Battery-Electric Vehicles: State of the research and development and comparative analysis of energy and cost efficiency Françoise Nemry, Guillaume Leduc, Almudena Muñoz, European Union Joint Research Centre: Institute for Prospective Technological Studies, Technical Notes, 2005.
[40] Csaba Csere, "Quest of Electric-Car Makers: One Plug to Charge Them All," New York Times, August 28, 2011.
[41] U.S. Department of Energy, "Battery Chargers for Electric Vehicles," http://www1.eere.energy.gov/vehiclesandfuels/avta/light_duty/fsev/fsev_battery_chargers.html (accessed September 29, 2011).
[42] U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity, "Plug-In Hybrid Electric Vehicle Charging Infrastructure Review," November 2008. Available at http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf (accessed September 29, 2011).
[43] "Nissan to Market D.C. Fast Charger for Under $10,000," New York Times, November 11, 2011, Jim Motavalli
[44] ABB introducing new DC fast-charger in Europe for €9,988, 28 March 2012, http://www.greencarcongress.com/2012/03/abb-20120328.html
[45] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[46] The EV Project, "Overview." Available at http://www.theevproject.com/overview.php (accessed September 29, 2011).
[47] Dr. Jing Dong and Dr. Zhenhong Lin, "Within-Day Recharge of Plug-In Hybrid Electric Vehicles: Energy Impact of Public Charging Infrastructure," Oak Ridge National Laboratory. Presentation at the Transportation Research Board's 91st Annual Meeting, Washington, DC, January 24, 2012.
[48] Mark Shwartz, "Wireless power could revolutionize highway transportation, Stanford researchers say," Stanford Report, February 1, 2012. Available at http://news.stanford.edu/news/2012/february/wireless-vehicle-charge-020112.html (accessed February 8, 2012).
[49] Laura Cowan, "In-Road Wireless Electric Vehicle Charging Breakthrough Yields 90% Efficiency," Inhabit, August 2, 2011. Available at http://inhabitat.com/researchers-make-breakthrough-in-wireless-in-road-ev-charging/ (accessed March 5, 2012).
[50] John Hollenhorst, "Electric bus charges wirelessly at U of U," November 16, 2011. Available at http://www.ksl.com/?nid=148&sid=18116082 (accessed March 7, 2012).
[51] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[52] Union of Concerned Scientists, "Battery Electric Vehicles (BEV)." Available at http://www.ucsusa.org/clean_vehicles/technologies_and_fuels/hybrid_fuelcell_and_electric_vehicles/battery-electric-vehicles.html (accessed September 29, 2011).
[53] U.S. National Highway Traffic Safety Administration, "CAFE Overview – Frequently Asked Questions." Available at http://www.nhtsa.gov/cars/rules/cafe/overview.htm (accessed November 1, 2011)
[54] U.S. Environmental Protection Agency, "EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks," April 2012. Available at http://www.epa.gov/oms/climate/regulations/420f10014.htm (accessed September 29, 2011).
[55] The White House, "President Obama Announces Historic 54.5 mpg Fuel Efficiency Standard," July 29, 2011. Available at http://www.whitehouse.gov/the-press-office/2011/07/29/president-obama-announces-historic-545-mpg-fuel-efficiency-standard (accessed September 29, 2011).
[56] Dexter Ford, "Deciphering M.P.G.: The Meaning of 35.5," New York Times, February 27, 2011.
[57] Presentation JD Powers and Associates, EV Forum, November 2011

[58] Plug In America, "State and Federal Incentives." Available at http://www.pluginamerica.org/why-plug-vehicles/state-federal-incentives (accessed March 3, 2012).
[59] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "DOE Report: Recovery Act Boosts Advanced Vehicle Investments," July 21, 2010. Available at http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=16173 (accessed March 4, 2012).
[60] "Raising the Volt-Age: Is Obama's Goal of 1 Million Electric Vehicles by 2015 Realistic?" Scientific American, February 18, 2011. Available at http://www.scientificamerican.com/article.cfm?id=one-million-electric-vehicles-by-2015 (accessed September 29, 2011).
[61] Deloitte Consulting LLP, "Gaining traction: a customer view of electric vehicle mass adoption in the U.S. automotive market", 2010. Available at http://www.deloitte.com.br/publicacoes/2007/MFG.Gaining_Traction_customer_view_of_electric_vehicle_mass_adoption.pdf (accessed September 29, 2011).
[62] "Deloitte study concludes mass adoption of electric vehicles in Europe is some distance away", Green Car Congress, March 10, 2011. Available at http://www.greencarcongress.com/2011/03/deloitte-20110310.html (accessed September 29, 2011).
[63] International Organization of Motor Vehicle Manufacturers, "2010 Production Statistics." Available at http://www.oica.net/category/production-statistics/ (accessed October 1, 2011).
[64] Mike Omotoso, Presentation at the Smart EV 2011 Executive Leadership Forum, Washington, DC, November 7, 2011.
[65] U.S. Department of Transportation, Federal Highway Administration, "Our Nation's Highways 2010, Fig 4-5: Trip Length as a Percentage of Daily Vehicle Trips and Daily Vehicle Miles." Available at http://www.fhwa.dot.gov/policyinformation/pubs/hf/pl10023/fig4_5.cfm (accessed September 29, 2011).
[66] Chelsea Sexton, 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[67] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[68] Naureen Malik, "Best Buy to Sell Ford's Electric Charging Stations," Wall Street Journal, January 7, 2011. Available at http://blogs.wsj.com/digits/2011/01/07/best-buy-to-sell-fords-electric-charging-stations/ (accessed September 29, 2011).
[69] Mike VanNieuwkuyk, Presentation at the Smart EV 2011 Executive Leadership Forum, Washington, DC, November 7, 2011.
[70] Ibid.
[71] Mike Omotoso, Presentation at the Smart EV 2011 Executive Leadership Forum, Washington, DC, November 7, 2011.
[72] Jerry Edgerton, "Chevy Volt a bad sign for electric car sales?" CBS News, March 5, 2012. Available online at http://www.cbsnews.com/8301-500395_162-57390448/chevy-volt-a-bad-sign-for-electric-car-sales/ (accessed March 5, 2012).
[73] Green Car Reports, Nikki Gordon-Bloomfield, May 18,2011 http://www.greencarreports.com/news/1060221_buying-or-leasing-an-electric-car-why-residual-value-matters
[74] Industry Executive Panel Discussion, 2011 Electric Drive Transportation Association Conference, Washington, DC, April 20, 2011.
[75] J. David Goodman, "An Electric Boost for Bicycles," New York Times, February 1, 2010.
[76] Jonna McKone, "FedEx Makes More Efficient Deliveries with Zero Emissions Electric Bikes," TheCityFix.com, August 30, 2010. Available at http://thecityfix.com/blog/fedex-makes-more-efficient-deliveries-with-zero-emissions-electric-bikes/ (accessed September 29, 2011).
[77] "Car2go, Daimler-Backed Sharing Program, to Go Electric in San Diego," New York Times, Josie Garthwaite Wheels Blog. http://wheels.blogs.nytimes.com/2011/07/13/car2go-daimler-backed-sharing-program-to-go-electric-in-san-diego/
[78] "Car2go Brings First All-Electric Car-Sharing Service To The U.S," Fast Company (Co.Exist), Ariel Schwartz, 2012 http://www.fastcoexist.com/1678254/car2go-brings-first-all-electric-car-sharing-service-to-the-us
[79] U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, "Smart Grid." Available at http://energy.gov/oe/technology-development/smart-grid (accessed September 29, 2011).
[80] John Gartner, 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[81] Matthew L. Wald, "Hold That Megawatt!" New York Times, January 7, 2011. Available at http://green.blogs.nytimes.com/2011/01/07/hold-that-megawatt/ (accessed March 4, 2012).
[82] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[83] Panel discussion at the 2011 CES Technology and the Environment Session, "A Computer on Wheels: Meet the Electric Car." Las Vegas, NV, January 2011.
[84] Erica Gies, "The Cash-Back Car: NRG Wants to Buy Electricity from EV Owners," Forbes, September 28, 2011. Available at http://www.forbes.com/sites/ericagies/2011/09/28/nrg-buys-u-s-license-to-enable-the-cash-back-car/ (accessed September 28, 2011).
[85] "Nissan developing new vehicle-to-home power system for LEAF in Japan, aiming for commercialization this fiscal year," Green Car Congress, August 2, 2011. Available at http://www.greencarcongress.com/2011/08/nissan-20110802.html (accessed November 2, 2011).
[86] Scenario presented at the U.S. Department of Transportation's Applications for the Environment: Real-Time Information Synthesis (AERIS) Transformative Concept Workshop, Washington, DC, July 13, 2011.

[87] PluginCars, "AAA Introduces Roadside Emergency Charging for Electric Cars," August 24, 2011. Available at http://www.plugincars.com/aaa-introduces-roadside-emergency-charging-electric-cars-107663.html (accessed March 4, 2012).

[88] Panel discussion at the 2011 Electric Drive Transportation Association Conference session, "Utility/Electric Drive Implementation Plan," Washington, DC, April 21, 2011.

[89] "Establishing a Smart Grid Node Architecture and Demonstrator in an Office Environment Using the SOA Approach," Dagmar Koß, Denis Bytschkow, Pragya Kirti Gupta, Bernhard Schatz fortiss GmbH, Florian Sellmayr, Steffen Bauereiß, Technical University of Munich, 2012

[90] U.S. Environmental Protection Agency, "U.S. Greenhouse Gas Inventory," August 5, 2011. Available at http://www.epa.gov/climatechange/emissions/usgginventory.html (accessed September 29, 2011).

[91] LowCVP study demonstrates the increasing importance of measuring whole life carbon emissions to compare vehicle performance http://www.lowcvp.org.uk/assets/pressreleases/LowCVP_Lifecycle_Study_June2011.pdf

[92] SAE International, "SAE Electric Vehicle and Plug In Hybrid Electric Vehicle Conductive Charge Coupler." Available at http://standards.sae.org/j1772_201001/ (accessed September 29, 2011).

[93] Conversations with Walton Fehr, ITS Joint Program Office, Research and Technology Administration, U.S. Department of Transportation.

[94] VANET, Vehicle Applications and Inter-Networking Technologies, Editors Hannes Hartenstein and Kenneth P. Laberteaux, 2010, p.56

[95] American Economic Review 2012, 101(December 2011): 3368–3399, http://www.aeaweb.org/articles.php?doi=10.1257/aer.101.7.3368

[96] Assessment of NHTSA's Report, "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs" Draft Final report prepared for the Office of Energy Efficiency and Renewable Energy, US Department of Energy, Tom Wenzel, Lawrence Berkeley National Laboratory, November 2011

[97] Physics Today, January 2006, "Vehicle Design and the Physics of Traffic Safety," p.52

[98] NHTSA's National Center for Statistics and Analysis (2007) ,NHTSA: Motorcycles Traffic Safety Fact Sheet (DOT-HS-810-990), 1200 New Jersey Avenue SE., Washington, DC 20590: National Highway Traffic Safety Administration, retrieved 2011-04-18

[99] "Frequency of Target Crashes for IntelliDrive Safety Systems," National Highway Traffic Safety Administration, DOT HS 811 381 October 2010, p5.

[100] "Intelligent Transport Systems And Motorcycle Safety" Megan Bayly, Simon Hosking, Michael Regan, Monash University Accident Research Centre, Australia, Paper number 07-0301, National Highway Traffic Safety Administration, p. 3

[101] Presentation, Automotive Safety Council – Active Safety, the Time is Now, January 2012

[102] U.S. Department of Transportation, "Footprint Analysis for IntelliDrive V2V Applications, Intersection Safety Applications, and Tolled Facilities: Pre-Decisional Discussion Document," March 2009. Available at http://www.its.dot.gov/research_docs/pdf/12Footprint.pdf (accessed September 29, 2011).

[103] Dale Gardner, Presentation at the 18th World Congress on Intelligent Transport Systems session, "Global Energy Trends," October 17th, 2011, Orlando, FL.

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