The Electric Car Is Back (with Help from New Batteries, a Smarter Grid, and Uncle Sam)

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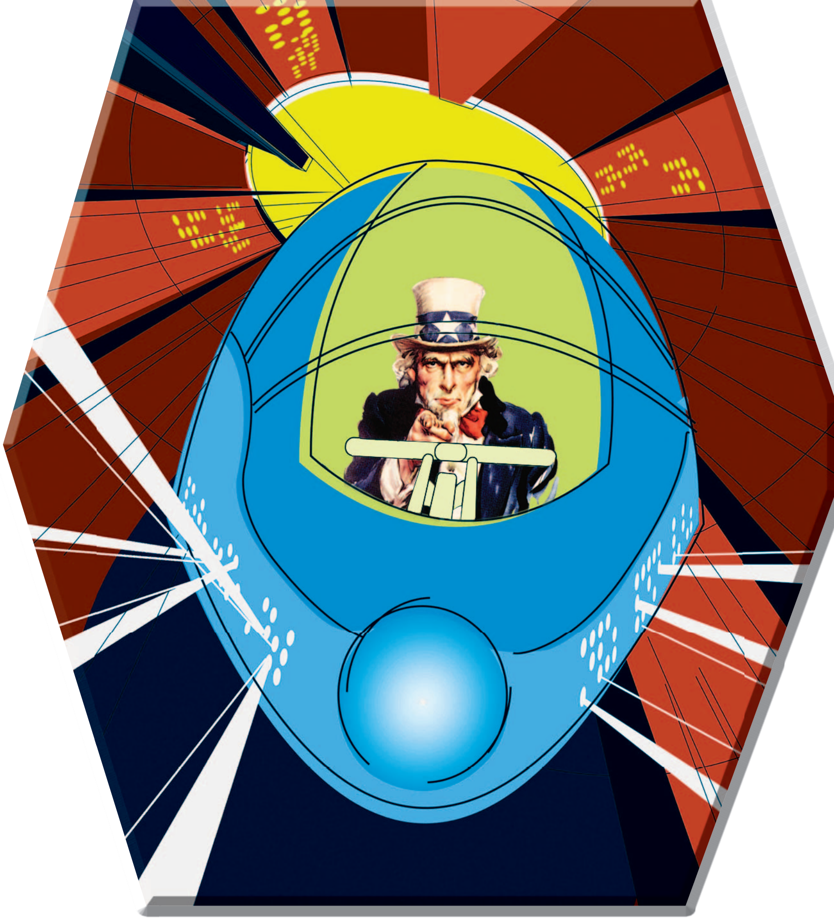

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A New Car, a New Grid

WHY ELECTRIFIED TRANSPORTATION? WHY NOW? FOR DECADES, inventors, manufacturers, and consumers have tinkered with the idea of electrifying transportation. To date, however, the global transportation fleet remains fossil fuel based. Other technologies such as hydrogen fuel cells and biofuels have also been "on the near horizon" for years. So what makes electrified transportation feasible now, and how likely is it that it will transform the transportation sector? Let's look at the facts.

- Investment in electric vehicles (EVs) has moved beyond the fringe, with organizations such as Google spending $10 million for plug-in EV research and testing and Warren Buffett investing in a Chinese electric car company.
- The U.S. government has committed to a goal of 1 million plug-in EVs in the next five years and will provide more than $2 billion in stimulus spending for advanced battery development in hybrid electric systems.

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- ✔ Most major domestic and international original-equipment manufacturers (OEMs) are planning to bring plug-in EVs to market within the next three years.

Rapid advancement in battery technologies, the warm reception given to hybrid EVs (HEVs) by consumers, and the advent of strong policy incentives have all paved the way for a transition to electrified transportation, with "how much" and "how quickly" yet to be determined. Potentially large and concentrated new loads, however, mean this development is worth worrying about. The good news is that the concurrent transition of the utility industry to a smart grid and the increased use of demand resources can help.

EV Technology Definitions

The term EV has actually come to include several different vehicle technologies. The main types available today are listed below.

- ✔ **HEVs:** Hybrid electric vehicles run on gasoline with a motor and use batteries to improve fuel efficiency. They do not use electricity from any external source.
- ✔ **Pure-EVs:** EVs run on an electric motor powered by batteries that are recharged by plugging in the vehicle.
- ✔ **Plug-in PHEVs:** PHEVs can be charged with electricity like EVs and run under engine power like hybrid electric vehicles. The combination offers increased driving range with potential large fuel and cost savings and emission reductions. There are two types: *parallel hybrids* are PHEVs in which both the electric motor and the combustion engine are mechanically coupled to the wheels through a transmission. *Series hybrids*, also known as *extended range electric vehicles* (EREVs), are PHEVs in which the electric motor is directly coupled to the wheels and the combustion engine is only used to charge the batteries when needed.

In all types of EVs, energy otherwise lost as heat in braking can be recaptured through the use of a generator connected to a battery. The EV has the advantage of mechanical simplicity but a limited range with present battery technology. The hybrid electric and the plug-in hybrid vehicle have the advantage of using the battery to optimize the efficiency of the onboard internal combustion engine. The efficiency improvement is accomplished by reducing the size of the internal combustion engine required to achieve expected performance, which allows tuning around a narrower RPM-torque range.

Commercial trucks offer some interesting opportunities to improve efficiency through the use of onboard batteries for powering auxiliary equipment. For example, bucket trucks used by the utility industry often idle at job sites to provide power for the hydraulic systems that lift and move the bucket. An onboard battery can power the hydraulic system and allow the internal combustion engine to be shut off. Figure 1 shows a hybrid electric bucket truck for utility use. In addition, other industrial applications of similar technology show great promise. For example, any time a load is lifted and let down with a crane or hoist, using regenerative braking and a battery will enable the system to recapture energy as the load is being let down rather than losing the energy as heat in braking.

figure 1. Hybrid electric bucket truck for utility use. (Photo courtesy of Dueco.)

table 1. Comparison of transportation technologies.

	Pros	Cons
Gasoline	✔ Known technology	✔ Limited availability in the longer term
Natural gas	✔ High energy density and quick refueling ✔ Domestically available fuel sources	✔ Safety concerns ✔ Volatile price ✔ Lack of roadside infrastructure
Diesel	✔ More efficient than gasoline technology ✔ Proven technology ✔ Infrastructure already exists	✔ Relies on foreign fuel sources ✔ Concerns about noise and smell
Fuel cell/hydrogen	✔ Very high potential efficiency ✔ No local emissions	✔ Lack of hydrogen infrastructure ✔ Storage is difficult ✔ High cost and short equipment lifetime
PHEV or EV	✔ No tailpipe emissions in all-electric mode, with a net reduction in CO_2 ✔ High efficiency and performance ✔ Electric "fuel" is widely available, relatively inexpensive, and highly flexible	✔ Battery cost is still significant ✔ Long charging times ✔ Some additional infrastructure required

Technology Competition

As electric vehicle technology has progressed in recent years, competing technologies have developed as well. A comparison of the competing technologies is shown in Table 1.

The various vehicle technologies available today may not only compete with each other but could actually have strong synergies. For example, a plug-in hybrid vehicle could have an internal combustion engine powered by a fuel cell or natural gas driving a generator to charge the batteries to extend the range.

State of Technology

All the necessary technologies to build electric vehicles and plug-in hybrid- electric vehicles exist today. Proof-of-concept vehicles and specialty vehicles such as the Tesla sports car are currently on the road. The battery and control technology is still being refined, however. Most potential manufacturers are looking at lithium-ion batteries as the best balance between cost, durability, and performance. But the price premium for lithium-ion batteries will be substantial until volume production brings the price down.

In spite of a higher initial price, electric vehicles and plug-in HEVs may still look economic to operate due to the cost of electricity relative to gasoline. For example, electricity at around US$0.10/kWh translates to an equivalent gasoline cost of about US$0.70 per gallon. With the current US$7,500 maximum incentive from the federal government for a passenger vehicle in the United States, a plug-in hybrid or EV could still pay back the initial purchase cost within the first 25% of its life. With the expected price drop of the batteries in the coming years, a huge market for EVs may be expected in the longer term, even without government incentives.

Apart from the economics of the vehicle purchase and operation, EVs and PHEVs have several advantages that may give the technology a strong chance of succeeding:

- ✔ The reduction in petroleum usage could significantly reduce dependence on foreign oil, resulting in increased energy security. An HEV with a 40-mi (65-km) range could eliminate the need for 2 out of every 3 gal (7.5 out of 11 L) of gasoline consumed by a traditional gasoline vehicle.
- ✔ Such vehicles offer lower net CO_2 emissions than cars with traditional gasoline engines (electric utility emissions versus vehicle emissions).
- ✔ They will have no tailpipe emissions (NO_x, dust, etc) when operated in the electric mode.
- ✔ EVs and PHEVs can use the existing electric infrastructure for charging.
- ✔ Such vehicles have the potential to aid the shift to renewable energy sources and make the transport sector more sustainable.
- ✔ Electric vehicle performance is likely to be on a par with or superior to that of similar conventional vehicles, with better acceleration and very fast response. Their lower center of gravity should enhance stability. Lithium-ion technology and other battery advancements can lead to extended ranges in the electric mode. Fast-charging technology or rapid battery change-out could be developed to overcome many of the issues with range. The vehicles are extremely quiet.

Table 2 shows a partial listing of announced vehicle production plans, with a brief vehicle description.

table 2. Sample of vehicle production plans as of November 2009.

Manufacturer	Model	EV Type	Consumer Availability	Electric Range (miles)	Total Range (miles)	Battery Size (kWh)
Buick		PHEV	2011	10	300	8
Chevrolet	Volt	EREV	Late 2010	40	300	16
Cooper (BMW)	Mini E	EV	Now	156		28
Fisker	Karma	PHEV	2010	50	300	22
Nissan	LEAF	EV	Late 2010	100		24
Tesla	Roadster	EV	Now	220		53


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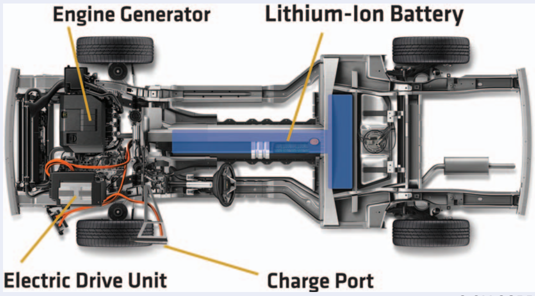

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Potential Electric Utility Impacts

EVs and PHEVs will increase energy usage on the electric utility grid. Given the relatively short duration of the existing peak load on the electric utility infrastructure, EVs and PHEVs up to very large market penetrations may not require major new investments in generation and transmission if customers can be given incentives to charge their vehicles during off-peak hours. Initially, however, the impacts on the distribution system are likely to be significant. In an individual home, owning an electric vehicle may mean needing to upgrade the utility's local transformer and service drop or perform electrical upgrades in the home. To the extent that multiple EVs or PHEVs show up in a subdivision, other distribution upgrades may be necessary.

Coupled with the smart grid and batteries on the distribution system, EV and PHEV charging could become part of an integrated electric system with the ability to adapt to varying conditions. For example, short-term (5 min or less) interruption of charging could help with electric utility distribution system regulation and renewable integration (such as residential solar). Interrupting charging for longer periods of time such as 30 min could also benefit the electric utility by reducing the amount of generation that needs to be kept in spinning reserve. With further development of the technology, the batteries in EVs and PHEVs could be used to temporarily provide power to a home in an outage or even to provide power back to the utility. This feature will not be available with first-generation EVs and PHEVs, however.

The batteries used in EVs and PHEVs are an excellent size and technology for small local-storage installations. A local-storage battery of this type at a home could be charged during off-peak hours, which in turn would allow the vehicle to be charged during peak hours via discharge of the local battery. The result would be reduced impact on the utility at peak hours as well as a local battery that can be used for backup in outages.

In general, one can distinguish three ways to control the electricity charging process for the electric vehicles:

- ✔ **Demand response:** influencing the moment of charging, e.g., in response to pricing signals
- ✔ **Demand-side management:** active management of the electricity demand, e.g., to prevent overloading of the grid
- ✔ **V2G:** the possibility of discharging the battery and supplying energy to the grid, e.g., at times when electricity prices are high.

These can be very interesting ways for utilities to prevent problems in the grid, but utilities can also use the storage capacity available in electric vehicles to incorporate larger amounts of renewables. With large numbers of vehicles an extended control system will be required, but with such a system a large amount of grid-connected storage capacity may become available. The user profiles are very suitable for this application, as it is not very important to the end user *when* the vehicle is charged; it is only important to know it is charged when needed. As most vehicles are used for only a limited number of hours each day, the benefits offered by demand response, demand-side management, and even V2G can be very compelling.

EV Charging

Battery charging will be one of the biggest challenges for automotive manufacturers, utilities, customers, and other parties to work through. The rate of charging will be a matter of trade-offs. For example, in the United States, a 40-mi-range PHEV might take six hours to charge at 120 V or three hours to charge at 240 V. At 120 V, the utility and the homeowner may not require any upgrades to the electrical service. At 240 V, however, it is almost certain that the homeowner and perhaps the utility will have to perform service upgrades. The range of the vehicle will also have a major effect. As vehicle range increases, the electrical demand for charging power will have to increase proportionally to keep charging times reasonable. Another issue will be the availability of charging stations at work, at shopping locations, or along streets and roads. There are questions about who should provide the charging services (possibilities include utilities, commercial establishments, parking garages, employers, and third parties). Then there are questions about how to handle the billing for charging away from home. Solutions could be as simple as swiping a credit card or as complex as having the charge added back to the customer's home utility bill. Tracking usage for road taxes will also be necessary at some point.

Perhaps the most important charging issue is the safety of the car owner and the general public. Cords running from vehicles to plugs in houses or on roadside charging stations could lead to electrical and tripping hazards.

The electric vehicle supply equipment (EVSE) consists of a supply device, a power cord, and a connector.

- ✔ **Supply device:** This device is the main component of the electric vehicle charging station. Typically it supplies electrical power and provides shock protection; it may also contain information systems for measuring the amount of energy delivered while an EV is charging. For Level 1 and 2 charging (see definitions below), the actual charger is located onboard the EV.
- ✔ **Power cord:** This is a cable that carries electrical current and communication signals from the supply device to the connector. For Level 1 and 2 charging, this cord conducts alternating current from the EVSE to the onboard charger.
- ✔ **Connector:** This is a plug on the power cord that connects the EVSE to charging sockets on the electric vehicle. In 2010 the Society of Automotive Engineers is expected to approve SAE J1772, the "SAE Electrical Vehicle Conductive Charge Coupler," as the national standard for EVSE connectors, to be used in virtually all electric vehicles in the United States.

Level 1 Vehicle Charging

Level 1 charging is done with a standard outlet and voltage level that is present in all homes and businesses. Using this level of charging may require an upgrade to existing electrical service. Level 1 charging can take 8–14 hours to fully charge an EV, however. For this reason, Level 1 may not be the customer's preferred charging method. Level 1 specifications are as follows:

- ✔ 120-V ac single-phase nominal electric supply
- ✔ 12–16-amp maximum continuous current with 15–20 amps of minimum branch circuit protection.

table 3. Typical set of charging options developed for an EV.

EVSE	Utility Service	Usage	Charge Power (kW)	Time to Charge
Level 1	110 V, 15 A	Opportunity	1.4	18 hours
Level 2	220 V, 15 A	Home	3.3	8 hours
Level 2	220 V, 30 A	Home/Public	6.6	4 hours
Level 3	480 V, 167 A	Public/Private	50–70	20–50 min

Level 2 Vehicle Charging

Level 2 charging is faster than Level 1 and is expected to be a popular option for home charging. Level 2 will often require an upgrade to existing electrical service and will require a permanently wired and fixed charging station location. Level 2 can fully recharge an electric vehicle in less than half the time required for Level 1. Level 2 specifications are as follows:

- ✔ 240-V ac single-phase nominal electric supply
- ✔ 32–70-amp maximum continuous current with 40 amps of minimum branch circuit protection
- ✔ ground fault protection, no-load make/break interlock, cable/connector safety breakaway.

Level 3 Vehicle Charging

Level 3 charging, also known as fast charging, is a high-powered technology that can fully charge a vehicle in 20–30 min. The amount of power required for Level 3 charging is beyond the capacity of most residential electric service, however. For this reason, Level 3 is not expected to be implemented for most residential use. In addition, standards for Level 3 have not yet been finalized.

Table 3 shows a fairly typical set of charging options developed by an EV manufacturer.

In-Home Charging

Table 3 demonstrates why the purchaser of an EV would want to pursue charging that would be faster than Level 1. Although a purchaser could buy the vehicle and simply plug it into a 110-V outlet in a garage, carport, or porch outlet, the charging time for a nearly discharged vehicle would be 18 hours. An EVSE with 220-V, 15-A Level 2 charging would cut the charging time down to eight hours, and an EVSE with 220-V, 30-A Level 2 charging would cut the charging time down to four hours.

Level 2 and Level 3 charging will require an approved EVSE permanently wired at the charging location with an appropriate home circuit to feed the device. The location of the EVSE will vary according to whether the home has a garage, a carport, or perhaps just street parking. In all cases, the owner of the vehicle and the general public must be protected from electrical and tripping hazards. A garage, carport, or outlet close to a dedicated driveway can likely be made safe by simply installing an EVSE in a wall location near where the vehicle will be parked. Street charging, however, will require checking to make sure the street right-of-way is not violated and is used with permission. A special charging pedestal will be required, along with appropriate locking capability, to assure safety. Multifamily homes and apartment complexes will present some of the same challenges as single-family homes with street parking.

Charging at Businesses, Commercial Sites, and Work

The concept behind many of the EVs will be to provide a range that makes the vehicle useful even if it is only charged at the place of residence. The availability of charging at the owner's place of work and at commercial charging sites will however extend the range and value of such vehicles. In some cases, stations may offer "opportunistic" charging at Level 1 that will be as simple as an available 110-V outlet. Much of this charging will probably be offered as a "perk" for employees or shoppers. In such cases, the charging may be free to the end user or accounted for by a flat fee that can be paid in a variety of ways. Place-of-work or commercial charging will have the same issues of location and safety as residential charging; the location could be at a secured garage or in a parking lot, using a pedestal.

Third-Party Charging Stations

At least initially, third-party charging stations will be treated like any other customer served by a utility. A supplier of the service will make application for service at a specific location. Any installed facilities will have to meet all electrical and construction requirements of the municipal or county building inspections organization before being served. Since the ideal location for many of the sites will be within street rights-of-way, however, a leasing arrangement with the municipality may be necessary. In addition, public policy around the resale of electricity by third parties in the city will need to be developed. For example, a third-party charging facility may be in an ideal site with little or no nearby competition. This could put the third-party charging entity in an unregulated monopoly position that could be detrimental to end customers. In spite of some potential issues, third-party charging stations will ultimately be an important part of making EVs successful.

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Metering EV Usage

Customers will certainly want to take advantage of any lower rates made available for charging vehicles. Most utilities already offer off-peak rates with special meters that track the time of use. Many utilities are also considering special off-peak rates for electric vehicles. In the long term, the smart grid will facilitate the tracking of electric vehicle usage for billing purposes and possibly for road taxes. Prior to implementation of the smart grid, another mechanism such as a second meter at the customer's premises, will be necessary to track vehicle energy usage at special EV rates.

Purchasing and Owning an EV

The utility industry should recognize that the purchase and ownership of an EV will require cooperation and coordination among several stakeholders. The ultimate aim is to make buying and owning an EV as positive an experience as possible. For the new vehicle owner to be satisfied, dealers, the purchaser, the local electric utility, electricians, and city or county building inspectors will all have important responsibilities. A few of these responsibilities are listed below.

Dealer Responsibilities

- ✔ Understand and communicate to potential buyers the vehicle specification, performance, and charging options.
- ✔ Clearly communicate to customers the entire process for preparing the home, place of business, and any additional locations for the charging option the customer expects to use.
- ✔ Provide information on how to contact each party involved in the process (utility, electrician, building inspection departments).
- ✔ Provide assistance and tell the customer where to go for help if problems arise in any part of the ownership experience.
- ✔ Provide warranty and repair service.
- ✔ Provide information on public charging options.

Purchaser Responsibilities

- ✔ Understand vehicle specifications, performance, and charging options.
- ✔ Determine available electrical outlet options at charging locations (e.g., at home and at the workplace).
- ✔ Meet with a utility representative to review existing service into the charging location and discuss any service upgrade requirements.
- ✔ Schedule an electrician who can make wiring modifications and install the EVSE.
- ✔ Understand how to safely charge the vehicle in a manner that avoids electrical and tripping hazards.

Utility Responsibilities

- ✔ Provide information to the dealer and new owner on how to contact the utility to start the process of preparing the place of charging to receive the plug-in electric vehicle.
- ✔ Provide a representative to assist the customer in understanding the charging options and the needed modifications in the home, business, or other place of charging.
- ✔ Complete any necessary service upgrades after the electrician has completed work and the building inspector has issued an approval.

Electrician or Electrical Contractor Responsibilities

- ✔ Become certified to install the EVSE and understand the circuit required to feed the EVSE.
- ✔ Complete the installation of the EVSE and obtain building inspection approval.

Building and Safety Responsibilities

- ✔ Provide information to the public on the applicable code requirements and the process of obtaining electrical permits, if needed.
- ✔ Issue electrical permit after all requirements are met.

Federal Incentives

The American Recovery and Reinvestment Act of 2009 (ARRA) provides energy incentives for both individuals and businesses. The new law modifies the tax credit for qualified plug-in electric drive vehicles purchased after 31 December, 2009. To qualify, vehicles must be newly purchased, have four or more wheels, have a gross vehicle weight rating of less than 14,000 pounds, and draw propulsion using a battery storing at least 4 kWh that can be recharged from an external source of electricity. The minimum amount of the credit for qualified plug-in electric drive vehicles is US$2,500, and the credit tops out at US$7,500, depending on the battery capacity. The full amount of the credit will be reduced with respect to a manufacturer's vehicles after the manufacturer has sold at least 200,000 vehicles.

Conversions of conventional vehicles to PHEVs receive tax credits of up to 10% of the cost of conversion. The new law provided a tax credit for plug-in electric drive conversion kits. The credit is equal to 10% of the cost of converting a vehicle to a qualified plug-in electric drive motor vehicle and applies to vehicles placed in service after 17 February 2009. The maximum amount of the credit is US$4,000. The credit does not apply to conversions made after 31 December 2011. A taxpayer may claim this credit even if the taxpayer claimed a hybrid electric vehicle credit for the same vehicle in an earlier year. A tax deduction of up to US$100,000 per location is available for qualified electric vehicle recharging property used in a trade or business.

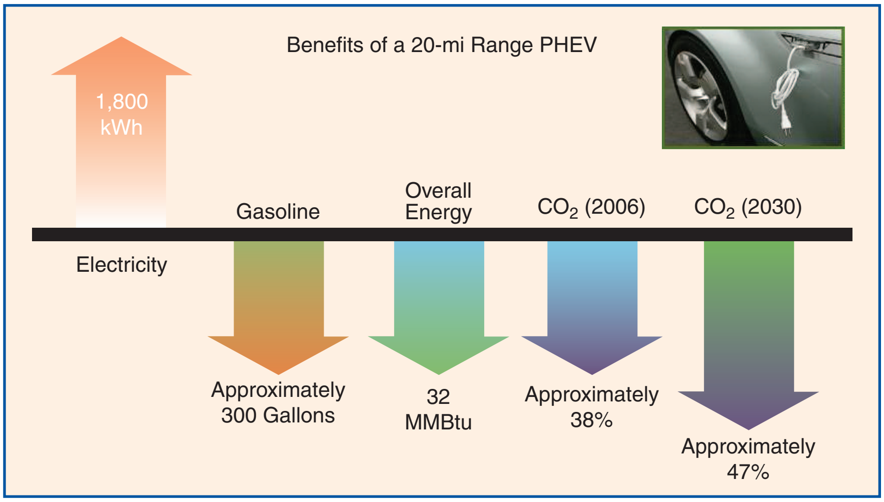

figure 2. EPRI summary of the benefits of a 20-mile-range PHEV [courtesy of Electric Power Research Institute (EPRI)].

Electric Vehicle Environmental Impacts

PHEV penetration could significantly reduce CO_2 emissions from the automotive sector and provide a net CO_2 benefit even when the associated power sector emissions are taken into account. Figure 2 shows an EPRI summary of the benefits from a 20-mile-range PHEV, including CO_2 reduction. Of course, in any particular situation the generation mix of the utility providing the electricity will determine the net impact. For example, a utility with a high penetration of nuclear and renewable energy would provide a greater net CO_2 benefit than a utility with primarily coal-fired generation. Air quality in urban areas will benefit the most from reductions in NO_x and volatile organic compounds emissions. Depending on the regional off-peak generation mix, emissions of NO_x, SO_2, and particulate matter could actually increase if they are not already subject to emission "caps."

Conclusions

Diminishing supplies of oil and environmental concerns are motivating policy makers to promote practical alternatives to the internal combustion engine. Advances in battery technology have already put practical electric vehicles within reach. Further advancements in manufacturing costs and storage capacity are needed, however, to make such vehicles appealing to the mass market. The increasing use of batteries for utility applications will certainly accelerate the required advancements in technology. In turn, the used batteries from vehicles (which can be classified in terms of how much of the original ability to hold a charge they retain) can also be used for residential backup service or for small local storage by utilities, thereby helping to reduce the vehicle's total cost of ownership. In any case, the future of batteries in vehicles and in electric utilities will have a strong synergy. All utilities will need processes for serving electric vehicles and integrating them into the system in a manner that moves as much load as possible during off-peak hours or allows for short interruptions of charging. For a few utilities, such as those in southern California, EV penetration will advance much more rapidly. For them, the urgency is great for developing the appropriate processes and approaches to integration as soon as possible.

For Further Reading

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