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Western Governors' Association

Transportation Fuels for the Future

Electric

WGA Electric Team
January 8, 2008
Final Report

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The following report is based on the contributions of the individuals and organizations listed below. The Team members were chosen for their breadth of knowledge and industry or policy experience. The group was assembled with the goal of having a wide scope of interests including industry, academia and environmental analysis. The group also worked towards consensus viewpoints on the critical issues impacting the development of Electricity as an alternative fuel. This consensus model helped to achieve a balanced perspective on the challenges and potential solutions to further commercial development of this alternative transportation fuel.

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Electricity used as a transportation fuel provides multiple benefits to the Western states. Some of these benefits include increased energy security, reduced air pollution and economic growth.

Electricity can be produced from resources abundant within the Western region. The primary feedstocks for electric fuel are coal, natural gas, hydrological power, nuclear, wind and solar. Increased production of electric fuel will benefit the Western states by maximizing regional feedstocks and limiting dependence upon one critical resource base.

Emerging plug-in electric vehicles, particularly plug-in hybrids (PHEVs), have reinvigorated national interest in transportation powered from the electricity grid. National security and climate change concerns have further accelerated interest in displacing petroleum with electricity and/or other alternative fuels that are not derived from fossil fuels. Because the Western electricity grid has an insignificant amount of diesel generation, every electric fuel-mile driven corresponds to a significant reduction of petroleum-driven miles.

Immediate availability of electricity as a transportation fuel gives it an advantage over alternative technologies and fuels.

Electricity as a fuel has broad and beneficial interactions with other fuels, as well as energy production. Because hybrid vehicles are dual-fuel, they are compatible with biofuels, coal-to-liquid, hydrogen/fuel cells and non-conventional fuels. The electricity used to power these vehicles can be derived from a wide variety of sources, including renewable sources.

Developing appropriate energy storage devices (i.e. battery chemistry) to meet the requirements of electric vehicles has been a challenging endeavor. Cost, shelf life, safety and low-temperature performance are the key issues. The high cost of the battery and the integration of the battery into the vehicle are major challenges to the commercialization of PHEVs and Battery Electric Vehicles.

The transition to widespread use of electricity as a transport fuel in the Western states requires a long-term commitment from key parties, including utilities and government agencies. Recommendations for accelerating market deployment of electricity as a transport fuel are included in this paper.

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KEY RECOMMENDATIONS

Near-term (within 3 years)

- The Energy Independence and Security Act of 2007 has been signed into law and provides funding to the states for electric power research and development. In addition, Western states should prepare to match federal dollars, as disbursement may be conditioned upon state level contributions.
- Provide stable funding at the federal and state levels for battery research and development and distribute the results to the public as widely as possible.
- Support federal, state and local demonstrations of plug-in hybrid electric vehicles (PHEVs) by public and private entities.
- Revise government fleet purchasing programs to provide market certainty to manufacturers and promote technology demonstration.
- Include fleet purchase requirements that set fuel consumption and emission requirements to promote early purchases of PHEVs.
- At the state and local level (financial and regulatory agencies) provide incentives for consumers, including preferential tax treatment and parking benefits, such as plug-in parking slots with parking structures powered by renewable energy.
- Execute a review of individual state electricity infrastructure in partnership with the utility industry. This review will help outline system compatibility with electric drive market penetration in on- and off-road applications.
- Establish federal and state manufacturing incentives to mitigate the risk of new product development and promote domestic industry and employment.
- Establish regional coordination among utilities and public utility commissions to develop and implement an off-peak rate structure for vehicles that utilize fuel from the electricity grid and especially renewable energy.
- The Western region should promote federal law that begins the transition to a fuel-neutral system that allows electric transportation to compete in federal emission, petroleum and greenhouse gas reduction laws and incentives.

Mid-term (3-10 years)

- Utility analysis of their current infrastructure system with the development of a roadmap to prepare for mid- and long-term requirements
- Government/utility/developer/automotive analysis of what it means to have a future intelligent grid and how these systems communicate with each other
- Continue and extend state and local incentives to build markets and consumer acceptance for vehicles using electric fuel, including tax incentives for consumer and private fleet purchases and investment incentives for vehicle and advanced component manufacturers.
- Address the uncertainty associated with the new technology of new financing and insurance options, e.g., state-backed battery warranties that extend beyond current manufacturer warranties and utility financing for batteries.
- Commensurate with vehicle penetration, establish incentives for installation of private infrastructure, e.g., work sites, multi-family housing, etc.

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- Encourage the federal government to adopt a new class of vehicles with characteristics between a low speed vehicle (typically a battery electric) and a full-function passenger vehicle that can travel on freeways and highways.
- Support local government investment in public infrastructure, such as public lots with recharging units, with an emphasis on renewable-source re-fueling projects.
- Establish professional education and training infrastructure for engineers, mechanics, educators and first responders.
- Fund state-level research at university centers of excellence to address battery and power electronics maturity and cost issues.

Long-term (> 10 years)

- Convene a long-term WGA strategic Team to develop and disseminate an energy vision for 2050. The vision would include a state and regional blueprint for electrifying the transportation sector, including community planning, increased grid integration, and market penetration scenarios and impacts. The plan would include a comprehensive review of raw material available in the Western United States for advanced batteries and related technology.
- Implement state and regional business attraction programs; coordinate with members of Congress in efforts to promote investment in the electric drive vehicle-related industry within their states and regions.
- Increase state and federal cooperation with the automotive and battery industries to develop demonstration partnerships, such as deployment of prototypes and insertion of advanced batteries into fleets of demonstration vehicles.
- Increase state-level cooperation with utilities, mortgage companies and others to develop new mechanisms to mitigate the upfront cost of PEVs, such as financing through mortgage equity.

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Electric Fuel: An Introduction

Introduction and Definitions

Electrified transportation is the use of electrical power to run transportation vehicles and related facilities. Electrical power for transportation is expanding to include port facilities, medium-duty trucks, school buses and truck stops. Electricity is emerging to power cars and light-duty vehicles in the form of gasoline-electric hybrids and plug-in hybrid vehicles (PHEVs). Consumer benefits from electric-drive vehicles include greater conveniences; lower operating costs, quieter operation and lower maintenance costs.

Other benefits include the consumer satisfaction from driving a vehicle that makes such large contributions to addressing energy security, global warming and air pollution problems. Use of electricity reduces transportation pollutants that have serious impacts on human health, including particulates and volatile organic compounds. The environmental benefits and costs of using electricity as a fuel are explained in greater detail under the *Life Cycle Analysis* section of this paper.

Electric fuel provides both near- and long-term solutions to energy diversity and security to the Western states. Electricity as a fuel is defined as grid electricity used to charge batteries, which are used solely or in conjunction with another fuel to provide energy for traction in both land and marine applications, such as transporting people, handling material and services.

Greater use of electric fuel and alternative liquid fuels would add much needed diversity to the country's transportation fuel mix and reduce our vulnerability to oil shortages and price increases. Electric fuel, however, maintains a distinct advantage over alternative liquid fuels – an independent market structure not subject to the more volatile gasoline market, Convenience is another advantage of electric fuel, since refueling can be done at home, work or wherever there is access to an outlet. The cost of operation is less than that for gasoline-fueled vehicles, based on the current price of electricity being no more than 38 cents/kWh.[1,2].

Grid electricity is priced in accordance with public regulatory processes and typically includes the costs associated with generation, transmission and distribution. In numerous Western states, electricity is priced to reflect demand. Electricity consumption is discouraged during high load periods for both seasonal periods and times of day. Specific pricing of electric fuel has occurred in a small number of California utilities.

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[1] Kintner-Meyer, Michael; Schneider, Kevin; Pratt, Robert. 2006.
[2] California Energy Commission pure EV assumptions

Grid electricity pricing, transmission and production are regulated at both the state and federal levels to accomplish specific public policy objectives. Two examples of regulatory policies are time-of-use pricing of electricity and the incorporation of renewable energy into the fuel mix. Because electricity is widely available and well known, and because the public regulatory processes are mature, there are no regulatory barriers confronting the use of electric fuel. Regulatory processes could provide an incentive for the use of electric fuel based on community support for a reduction in petroleum-fuel consumption.

Electricity for Use in Plug-in Electric Drive Vehicles

Emerging plug-in electric drive vehicles, particularly plug-in hybrid electric vehicles (PHEVs), have reinvigorated national interest in transportation powered from the electricity grid. National security and climate change concerns have further accelerated interest in displacing petroleum with electricity and/or other alternative fuels that are not derived from fossil fuels.

Electric drive components and computer control systems are increasingly mature technologies and are in use today in hybrid vehicles. However, the advanced battery, the leading technology driver in on-road transportation necessary for large-scale plug-in electric drive vehicle availability, is still emerging. In particular, lithium ion batteries are showing promise in meeting the requirements of a plug-in electric vehicle driving cycle. Technological maturity has arrived for off-highway applications, especially in the material handling market.

Continuous technology development and validation is critical to ensure significant market penetration. Battery costs are also a significant market hurdle. Perhaps most critical will be establishing a value proposition for this higher cost item, while increasing production volume and domestic capacity.

Goods Movement

The use of electricity as a transportation fuel to replace some gasoline or diesel use produces very large reductions in fuel use due to the inherent energy efficiency of electric drive trains. For example, the State of California estimated that by 2010 it would have approximately 400,000 units of electric transportation and goods-movement equipment in operation, saving more than 63 million equivalent gasoline gallons or 72 million tons of CO_2 yearly[3]. Most of this equipment comprises industrial vehicles, including forklifts, industrial tugs, tow tractors, industrial sweepers and scrubbers. Also included in the transportation fuel category are neighborhood electric vehicles, electric-standby truck refrigeration units and golf carts. Opportunities for goods movement exist in four key applications: cold ironing, electric transport refrigeration units, truck stop electrification and electric forklifts.

[3] 2005 TIAX report for CalETC, "Electric Transportation and Goods Movement Technologies in California: Technical Brief", page 4-3.

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Cold Ironing

Large ocean-going vessels typically use on-board diesel engines to provide a ship's power while in port. Cold ironing or alternative marine power (AMP) allows the vessel to plug into the grid while in port, rather than running on its auxiliary engines. Cold ironing has the potential to generate significant reductions in emissions if applied to a wide range of vessels visiting a port. In California alone, cold ironing could provide a potential reduction of CO_2 emissions equaling 850,000 tons per year by 2022 and 131 million gallons of gasoline equivalent by 2020.[4]

Electric Transport Refrigeration Units (e-TRUs)

Electric transport refrigeration units (e-TRUs) are used to keep perishable goods cold during transit, either on land or at sea. Two general types of e-TRU technologies are currently in widespread use in the US: 1) diesel units with electric standby function attached to semi or bobtail trailers, and 2) pure electric ocean containers powered by ship generators at sea and by diesel generation sets while on land. True hybrid diesel-electric TRUs with full electric pull-down capability are a new technology that is common in Europe and is available in the U.S. from dealers. Hybrid e-TRUs provide substantial reductions in maintenance costs when operated in all-electric mode and can be expected to increase in popularity as their attractive lifecycle economics become more widely known. E-TRUs are a dual-mode technology because they use a diesel engine when the unit is moving.

Truck Stop Electrification (TSE)

Concerns about particulate emissions from idling sleeper-cab commercial trucks, along with the desire to reduce fuel costs associated with main engine idling, have led to increasing interest on the part of both truck operators and state and local governments in truck stop electrification. TSE is a dual mode technology because the diesel main engine is always functional. Two general types of TSE technologies are currently available: those relying upon on-board HVAC systems, and those using off-board HVAC systems, such as Idleaire packaging heating and cooling with ancillary services that include such as telephone, television and Internet access. Both on-board and off-board HVAC technologies have the potential to reduce air emissions associated with main engine idling, while also reducing fuel and maintenance costs for truck operators. Application of e-TRUs and TSE could provide an estimated CO_2 reduction of over 630,000 tons annually in California by 2022 and 61 million gallons per year of gasoline equivalent.[5] The potential in other Western states is over three times greater per unit, because in California the TSE is compared against a diesel auxiliary engine (not the main truck engine).

Electric Forklifts

Of the four technologies for moving goods, electric forklifts currently enjoy the greatest market share, particularly for smaller capacity lifts used for indoor operations. The adoption of electric forklifts has been in large part a natural market response to their

[4] 2005 TIAX report for CalETC, "Electric Transportation and Goods Movement Technologies in California: Technical Brief", page 6

[5] 2005 TIAX report for CalETC, "Electric Transportation and Goods Movement Technologies in California: Technical Brief", page 14

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significant advantages relative to internal combustion forklifts, including fuel savings, reductions in maintenance costs and suitability for narrow aisle operations. While the market for e-forklifts has been saturated in certain size ranges, potential exists for future growth in key market segments, including the downsizing of excessively large Class 4 and Class 5 forklifts and the replacement of heavy diesel forklifts typically used in outdoor operations (e.g., 8,000- to 10,000-pound lift capacity). The increased use of electricity in these areas is expected to be driven by improvements in battery technology, shifts to more powerful alternating current drives, and the spread of fast-charging technologies that offer the potential to minimize equipment downtime associated with the charging of larger capacity forklifts. Use of electric forklifts in California is expected to provide over two million tons of CO_2 reduction by 2022 and a reduction of up to 175 million gallons per year of gasoline equivalent.[6]

Other Technologies

While the above four technologies represent excellent near-term opportunities for substantial greenhouse gas and petroleum reductions, other technologies are being applied that could offer benefits, depending on the specific need for goods movement. Some of these technologies include light duty electric vehicles,[7] shuttle buses, airport utility vehicles, burden and personnel carriers, tow tractors, sweepers, burnishers, scrubbers, boats, mining equipment, bikes, scooters and other types of non-road equipment. In addition, electric light rail, electric trolley buses and electric freight rail are used today in the West, and high-speed rail, maglev or dual–mode–electric freight rail could be used.

Ongoing Research

The federal government, in particular the Department of Energy, is increasing its investment in battery and advanced power electronic systems research. Automotive and battery manufacturers are investigating PHEV, pure battery and fuel cell plug-in electric drive vehicles. Several national laboratories and the Electric Power Research Institute (EPRI) are focused on understanding operating systems and energy management to identify the most efficient design. Energy and environmental implications of grid-powered transportation, including grid capacity and carbon emissions, is the subject of several national and regional analyses.

New technology introduction presents a challenge to all stakeholders – manufacturers, regulators and consumers. To ensure that these challenges remain visible, and therefore solvable, it is important to establish some critical path milestones that can provide evidence of success. The electric fuel milestone chart on page ten is intended to provide a picture that can be used to measure progress toward the goal of electric transportation.

[6] I[6] 2005 TIAX report for CalETC, "Electric Transportation and Goods Movement Technologies in California: Technical Brief", page 420
[7] Commuter EVs, sports car EVs, neighborhood EVs, and "city" EVs.

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Potential

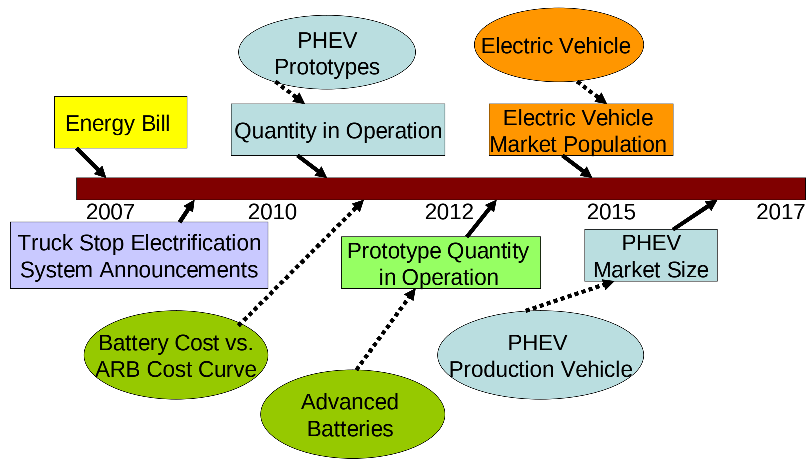
Introduction

The following section discusses the benefits and potential of electric fuel to society and the consumer. This paper emphasizes the balanced consideration of resource availability (energy security and supply impacts/limitations), delivery infrastructure (technology, access and cost), and downstream impacts (land and water use, air quality and global climate change). Attention is focused on the West where applicable.

The societal benefits of electric fuel are as follows:

- Significant displacement of petroleum with resources abundant in the West.
- Utilization of today's existing infrastructure, which is available nearly everywhere.
- Reduced air pollution and CO_2 emissions; electric fuel depends on a sector that is getting greener with time.
- De-coupling of electricity prices from petroleum markets, due to diversified and domestic production.

Electricity as a Fuel Tracking Milestones



Assumptions Supporting Each Milestone Item:

Energy Bill -- An energy bill is passed and signed into law in 2007 that focuses research and development dollars on electric transportation including federal fleet buys.

Truck Stop Electrification – This effort is continuing and driven by the US Environmental Protection Agency (EPA) and the private sector. Data that need to be tracked include the number of new starts at truck stops nationally, the number of OEM trucks offered with electric plug-in options, and the number of new trucks purchased with the option.

Battery Cost versus ARB Cost Curve: The California Air Resources Board (CARB) has published a projected cost curve for nickel metal and lithium ion batteries. It would be helpful to have a calculation that tracks the cost of batteries versus the curve.

PHEV Prototypes: OEMs have announced the build of PHEV prototypes. The key will be how many are in actual operation in the U.S. rather than in internal testing at a manufacturing warehouse.

Advanced Batteries: Advanced batteries are being introduced in “conversions” and in battery electric vehicles (BEVs), such as Tesla and the PHEV Sprinter. Quotes have been requested by the OEM for prototypes. Data tracking would capture the number of advanced batteries in running prototypes.

Battery Electric Vehicle (BEV): There is resurgence in interest in BEVs. The BEV market quantity should be tracked to include low-speed neighborhood vehicles, commuter cars, delivery vans and sports cars. Is there a true upswing that is attracting interest beyond the technical and environmental early entry buyer?

PHEV Production: Assuming PHEV production versions in 2010, what is the rate of market penetration? Does it exceed the hybrid growth rate? What is the make-up of the initial buyers? What does the marketing muscle supporting the introduction look like? How many have been acquired by government fleets? What is the market coverage: passenger cars, sport-utility vehicles, light-duty trucks, medium-duty trucks, etc.?

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Supply Sources and Infrastructure

Production of electric fuel depends on resources abundant to the states in the Western region. Primary feedstocks for electric fuel are coal, natural gas, hydrological power, nuclear, wind and solar. Diesel fuel is an insignificant part of electricity's primary energy portfolio in the West. The production of electric fuel will benefit the Western states by exploiting regional feedstocks and limiting an excessive dependency upon one critical resource base. The adoption of electric fuel reflects the diversity of the existing and future electricity grid.

Existing electricity infrastructure is sufficient and reliable for long-term supply for mass adoption of electric fuel. The electricity grid is built to accommodate peak load. The grid is underutilized except for a small number of hours. In the West, 46 percent of the vehicles can be PHEVs with little to no additional infrastructure investment.[8,9] It should be noted that the relative potential size of electric transportation fuel versus existing electricity generation is very small, particularly during the early market adoption period. According to an National Renewable Energy Laboratory report

> "…we conclude that large-scale deployment of PHEVs will have limited, if any, negative impacts on the electric power system in terms of additional generation requirements."[10]

The same conclusion can be extended to BEVs and goods movement applications.

Modest impacts of coincident loading of electric fuel demand and the overall electricity market can be mitigated through off-peak charging programs and smart demand management (i.e., curtailing charging through peak periods). The latter would allow for large-scale daytime charging leading to additional convenience and fuel savings for consumers without additional infrastructure needs.[11] As with all increasing load demands expected in future years, the increased demand for electricity for transportation can be planned and executed by the utility industry. Access to public "plug-in" locations, expanding fleet and employee parking, or expanding access at condominiums and apartments could expand charging opportunities beyond single-family homes. In addition, the coming smart grid and smart meters will make using this existing off-peak infrastructure even easier. For many goods movement applications, incremental electricity infrastructure investment is small to negligible for both operating cost and emission benefits. The exception is cold ironing, which would require transmission infrastructure investment in port areas and additional generation, but would also result in significant

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[8] Kintner-Meyer, Michael; Schneider, Kevin; Pratt, Robert (Pacific Northwest National Laboratory). 2006. Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilites and regional US Power Grids Part 1: Technical Analysis. Includes ERCOT, AZN&RMP, CNV, and NWP NERC Regions.

[9] Placeholder for EPRI-NRDC Report

[10] Short, W.; Denholm, P (National Renewable Energy Laboratory). 2006. Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles (Revised). TP-620-40293.

[11] Parks, K.; Denholm, P.; Markel, T. (National Renewable Energy Laboratory). 2007. Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory. TP-640-41410.

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emission reductions.[12] Total cost of service of electricity is anticipated to go down or remain unchanged due to mass use of electric fuel. The increase in infrastructure utilization drives down the total cost of electricity.[13]

In the long term, PHEVs and other electric vehicles (EVs) could provide a ready source of demand for power from intermittent renewable resources, such as wind and solar. Furthermore, the significant storage capacity in PHEV batteries can be used to firm up energy schedules of large wind-generation capacity, since the generation output from wind farms varies with wind availability. Intermittency of renewable resource poses a real challenge to the power systems' planning industry, particularly as the Western states pursue their aggressive renewable portfolio standards (RPS). The National Renewable Energy Lab recently quantified the greater market potential of this renewable resource when bundled with the PHEV storage capability.[14]

Reductions in Petroleum Consumption

Because the electricity grid in the Western states has an insignificant amount of diesel generation, every electric fuel-mile driven corresponds to a reduction of petroleum-driven miles. For battery electric vehicles, all miles driven are electric-fuel-based, thereby displacing all petroleum for that application. Due to their dual-fuel hybrid capability, PHEVs use both electric fuel and another fuel. While the second fuel can be ethanol, hydrogen or any other alternative fuel, the arguments made below are for gasoline hybrid vehicles equipped with larger batteries.

The amount of petroleum displaced depends on the size of the battery. PHEVs are referred to as PHEV-XX, where XX represents the number of all-electric miles the vehicle is capable of. For example, a PHEV-40 has an equivalent all-electric range of 40 miles. The vehicle will operate in all-electric mode at lower speeds and switch to a blended mode at higher speeds. After the battery reaches a pre-determined depth of discharge, the vehicle operates in standard hybrid drive mode. Additional benefits of electric and hybrid vehicles are auto-shut off when stopped and regenerative braking, which adds energy to the battery during operation. A PHEV-20 that is charged once per day will reduce the average household fleet petroleum consumption by 55 percent. If the vehicle has ready access to a charger throughout the day, gasoline consumptions of the average household fleet could be reduced up to 73percent.[15]

Reductions in CO2 and Urban Air Pollutants

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[12] AB 1007 Scenarios: Electric Drive Technologies

[13] Kintner-Meyer, Michael; Schneider, Kevin; Pratt, Robert (Pacific Northwest National Laboratory). 2006. Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and regional US Power Grids Part 2: Economic Assessment.

[14] Short, W.; Denholm, P. (National Renewable Energy Laboratory). 2006. Preliminary Assessment of Plug-in Hybrid Electric Vehicles on Wind Energy Markets. TP-620-39729.

[15] Parks, K.; Denholm, P.; Markel, T. 2007.

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Reductions in CO_2 and air pollutants (e.g., NOx, SO_2, PM10, etc.) depend on the source of the electricity. While arguments have been made for all coal-based or all renewable-based charging, the true impact of electric fuel vehicles is the incremental generation above the expected larger electricity market.

Electric drive will reduce overall emissions of volatile organic compounds, carbon monoxide, and greenhouse gases (GHGs). Total NOx, SOx and proposed mercury emissions will be capped for power plants nationwide, so they cannot rise even with increased electric load growth.

Reductions in the primary greenhouse gas, carbon dioxide, (CO_2) are anticipated from power plants could be in the 50% to 90% range by 2050, and this results in a PHEV 20 emitting 37% less GHG nationally than its conventional vehicle counterpart in 2050, according to the recent EPRI- NRDC study.[16] Total emissions, except for the particulates, are estimated to improve. Additionally, the urban environment is expected to become significantly cleaner. This is because electric fuel vehicles do not emit pollutants when driven in all-electric mode. The emissions are displaced to the smokestack of the resident utility. The shifting of many mobile sources to a handful of single-source polluters has two benefits: it takes emissions out of the urban air catchments and allows for easier emission reductions at these central facilities. For more details regarding this discussion, see the Life Cycle Analysis section of this paper.

Consumer Benefits

PHEVs can provide other unique comfort services, such as pre-heat or pre-cool (using a timer) for the vehicle's interior with the engine off and using a 120-volt outlet on the vehicle to run appliances with the engine off. Examples include appliances brought and used for camping, tailgate parties, mobile office, flea markets and other occasions. Finally, there is an interesting benefit to the automakers. Because there are so many different elements to designing PHEVs (architectures, design goals, pack sizes, etc.), there are many niches for each automaker to call their own. This is unique for an alternative fuel vehicle.

Pure EVs are over four times more efficient than their gasoline vehicle counterparts in using delivered energy (electric motor vs. internal combustion engine) and almost twice as efficient as hybridized fuel cell EVs. As a result, when there is competition for feedstocks (coal, natural gas, biomass, wind or solar), the EV or PHEV will use significantly less.

Electric transportation is also unique because it can use an underutilized existing infrastructure, which can be seen as an energy security asset. Better utilizing this existing asset will also put a downward pressure on electric rates. According to a report from the global assets management firm, Alliance Bernstein Electric, transportation is building on a trend that has occurred for the last 100 years: electrification of society.[17] This report calls PHEVs a "game changer," and expects "the shift to electric power to continue as

[16] "Environmental Assessment of Plug-In Hybrid Vehicles" Part I, pg 7
[17] Alliance Bernstein, June 2006. "The Emergence of Hybrid Vehicles."

electronics and electrical systems replace mechanical processes in an ever-expanding number of applications."[18]

Electric transportation is also a near- to mid-term technology that is widely expected sooner than fuel cells. However, the scale of transitioning to alternative fuels is so large that it will take decades to turn over the vehicle stock.

Markets

The potential markets for electric fuel are in:

- Light-duty passenger vehicles
- Medium- and heavy-duty vehicles
- Mass transit
- Goods movement applications

In light-duty applications, battery electric vehicles provide 100 percent electric-drive capability all the time. In light- to heavy-duty vehicles, electric fuel piggybacks on the commercially viable hybrid drive technology through plug-in hybrid electric vehicles. For these technologies, the potential is limited by battery costs versus value. There is on-going substantial research and media attention regarding PHEVs.

There are many demonstration programs across the U.S. regarding PHEVs. EPRI has numerous programs involving PHEVs, including the Daimler-Chrysler Sprinter program and the Eaton International PHEV bucket truck. There are a handful of after-market companies converting hybrid-electric vehicles into plug-in capable vehicles. These vehicles are in the prototype development stage, are expensive, not safety regulated and have limited availability. Large-scale production of electric fuel vehicles by car manufacturers is needed to reduce production costs, ensure reliability and safety concerns.

Additionally, the market penetration of electric-fueled vehicles is tied largely to battery costs. While operating costs are lower for most electric fuel vehicles, the savings do not offset the upfront cost of batteries.[19] As with other new technologies offered to the consumer, the value proposition must be established to offset the initial cost in order to enable significant market penetration. For more information regarding technology and cost barriers, see the *Barriers and Challenges* section of this paper.

Goods movement application is a viable and immediate application for electric fuels. For example, electric fuel can supply auxiliary services at ports, overnight truck stops and for warehouse operations (forklifts, on-site transportation). These markets are limited by investment and infrastructure.

The needs of mass transit and long-distance goods movement could be filled by electric and hybrid trains. Electric trains are used extensively in mass transit all over the world. Initial infrastructure costs are greater than diesel-powered trains. Despite being cleaner and

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[18] I Alliance Bernstein, June 2006. "The Emergence of Hybrid Vehicles." Pg 7
[19] Ibid. Kintner-Meyer; Schneider; Pratt

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quieter, the upfront infrastructure costs become onerous in cost-sensitive environments.[20] Hybrid trains utilize electric fuel during high-torque operation (hill climbs) and diesel for flat-ground operation. Again, the upfront cost of infrastructure limits the market potential of this technology.

Synergies with other Fuels

Electricity as a fuel has broad and beneficial interactions with other fuels, as well as energy production. Because PHEVs are dual-fuel vehicles, they are synergistic with biofuels, coal-to-liquid fuels, hydrogen/fuel cells and non-conventional fuels. The electricity used to power these vehicles can be derived from a wide variety of sources, including renewable sources. Lastly, the market for electric vehicles provides technical impetus for improving batteries that can be used in stationary power and other applications, such as power tools, which have energy efficiency benefits.

Electric vehicle hybridization is a general technology used to increase the fuel economy of vehicles. Hybrid vehicles are known to dramatically increase the fuel economy of gasoline and diesel vehicles (and to decrease pollution and noise). Hybridization allows the combustion engine to be sized for and operated at maximum efficiency. However, fuel cell vehicles are also hybrids that utilize a battery to support acceleration and regenerative braking. Hybridization also works for increasing the fuel efficiency of vehicles powered by unconventional fuels, including liquid natural gas, compressed natural gas and propane. Plug-in hybrids provide additional efficiency over hybrid electric vehicles by allowing further optimization of the combustion engine and by allowing liquid fuel replacement (by operating vehicle on electricity for 10-40 miles).

The pervasiveness of the electric utility grid provides widespread distribution of electric power, but also allows for widely distributed means for energy generation. This is especially beneficial for renewable energy sources such as wind, solar, geothermal, water and biomass, which are geographically distributed. These renewable energy sources can be converted locally to electricity and transmitted through the grid for use in vehicles. Of course, conventional fuels such as natural gas, nuclear and coal can also be used to generate electricity used as a fuel.

The flexibility of the grid to use a broad array of fuels provides a measure of stability and security to the economy. The use of local energy sources economically benefits the community providing the resource, as well as the region that uses the resource.

The use of electricity as a fuel will require the use of batteries for energy storage, which has major benefits for the electric utility grid. Batteries can be used for load leveling (consuming off-peak power), which makes the overall system more cost effective.

The emerging market for hybrid electric vehicles has encouraged the development of high-power lithium-ion batteries, and these batteries have found commercial application in

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[20] The Denver Post. RTD Needs to Reign in FasTracks Cost Hikes. May 22, 2007.

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power tools. The market for power tools is expected to grow dramatically as it spreads into lawn tools, such as trimmers, blowers and mowers. The use of these electrically powered tools reduces fossil fuel consumption as well as the concomitant pollution and noise.

Barriers and Challenges

Current Status

When compared with other emerging technologies being offered as alternatives to conventional transportation fuels, electricity is the one alternative with a comprehensive and complete distribution system. Electricity is readily available in the US to every potential transportation market. Electricity demand continues to grow approximately 1.5 percent per year based on population intensity and new technology introduction. Electric transportation, while potentially a significant load, remains very small when compared to the total electricity demand for homes and commercial and industrial applications. A substantial electric transportation market could be supported without increasing electrical generation capacity. [21]

Plug-in hybrid vehicles have achieved national interest due to the petroleum and CO_2 reduction potential. Electric drive components and computer control systems are mature technologies and are incorporated in today's hybrid vehicles. Advanced batteries, especially lithium ion, have shown strong promise to meet the requirements of a plug-in hybrid driving cycle, but the challenges of cost, lifespan, safety and low-temperature performance require solutions that are not market-ready at this time. Technology development and performance validation of advanced batteries must continue as the products are introduced and the operating systems are optimized.

Technical Barriers

Unproven Battery Technology

Developing appropriate energy storage devices (i.e. battery chemistry) to meet the requirements of PHEV/BEV vehicles has been a challenging endeavor. Cost, shelf life, safety and low-temperature performance are the key issues involved. The recent commercialization of lithium-ion batteries based on iron phosphate is encouraging, because this technology has much better abuse tolerance than other lithium-ion chemistries and may cost less than other batteries. However, the life of these batteries remains a major question (currently there is only a 2-year warranty) and the low-temperature performance is limited.

Advanced energy storage devices should be considered as systems consisting of cells and electronic controls, which include thermal management monitoring. Although the cells still require significant development, much progress has been made with electronic controls in terms of cost and capabilities.

[21] NREL. [0]

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PHEV and BEV vehicles require high-energy capability combined with high power, thus differentiating them from hybrid batteries that are currently in production. A number of companies have advanced battery technologies for the large formate energy storage needed for PHEV and BEV applications in various stages of development and testing. The challenge is battery maturity and the ability of the automotive industry to accept the long-term risk that commercialization of this technology poses. Key issues include: deep-cycle life, shelf life, impact of cold and hot weather on operating profiles, rate of charge acceptance, energy level available at the end of automotive life for secondary uses, vehicle management systems that maximize life and meet required manufacturer warranty concerns, and the battery warranty itself for such consumables as tires and brakes or as part of the emission control system). Ideally, the battery system will be a one-time, "life of the vehicle" investment.

We recommend review of the "Report of the CARB (California Air Resource Board) Independent Expert Panel 2007" report that was issued on April 13, 2007.

Battery Cost

The high cost of the battery itself and the integration of the battery into the vehicle are major challenges to the commercialization of PHEVs and BEVs. These issues have been addressed with some success by hybrid vehicle developers, such as Toyota with the Prius, but the problem of high battery cost is exacerbated in PHEVs and BEVs.

The questions to be addressed are:

1. When does battery cost impact the buying decision?
2. What is the value proposition necessary to overcome the battery cost?
3. What is the appropriate all-electric range that drives customer satisfaction?
4. What is the acceptable range in a battery electric vehicle?
5. Which range is reasonable for battery acquisition and integration cost?

Market research to answer these battery questions has been lacking. The exception is the consensus report by the Hybrid Electric Vehicle (HEV) Team, a three-year project in 1999-2001 that included automakers, national laboratories, CARB, EPRI, University of California, utilities and leading consultants.[22] This report found substantial market potential for PHEVs with 20 to 60 miles of all-electric range at a variety of battery prices. A 2001 study by the Electric Power Research Institute suggested a price threshold of $5,000 to $7,000 above an equal conventionally powered vehicle when life-cycle cost and benefits were understood.[23] Similarly, a study by the HEV Team determined that when life cycle cost and benefits were understood, a PHEV 20 with 20 miles of all-electric range had a price threshold of $4,000 to $6,000 above an equal, conventionally powered vehicle. [24] These prices resulted in market potentials of 47 and 35 percent respectively.[25]

[22] EPRI, 2001.

[23] Electric Power Research Institute, Report # 1000349, "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options"

[24] Electric Power Research Institute, Report # 1000349, "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options." Table A-7.

[25] Ibid. Table A-7

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Cost will ultimately depend upon manufacturing technology, production volume and material costs. These issues are currently being addressed by manufacturers in the U.S., Japan and China. "The projected costs for shorter range PHEV Li Ion batteries are about $3,500 - $4,000 in mass production; this is generally less than the fuel cost savings expected over the life of the vehicle…."[26]

Battery Manufacturing

Despite leading the world in alkaline and lead-acid battery markets, the U.S. does not have a strong market in advanced rechargeable battery industry. The advanced rechargeable battery manufacturing industry is primarily in Japan and Korea, with a strong movement to China. Recently, A123 has successfully designed a battery for power tools that is being assembled in China; this may be a new business model for U.S. companies.

Power Electronic Maturity and Cost Reduction

The emergence of the hybrid vehicle has eliminated the concern for power electronics for plug-in hybrid and battery electric vehicles. The key in this technology area for the U.S. and the Western states is "leap" technology improvements where one can see 40 to 60 percent efficiency gains, thus driving down component costs. An example of this technology is advanced on-board charger systems that are robust and show reduced cost.

Electricity Delivery Infrastructure Connectivity

Electricity infrastructure can be viewed in three timeframes:

- Near-term impact on the existing infrastructure as initial market penetration begins;
- Mid-term expansion of access to plugs for all and alignment with current smart metering/control that is being developed; and
- Long-term linkage between the intelligent grid of the future with smart vehicles and smart homes, which enables the vehicle as a distributed generator and potentially as an integral part of the power delivery system, providing spinning reserve and peak power requirements.

In the near term, especially when focused on off-peak, nighttime recharging, the current infrastructure is capable of handling a substantial number of electrically fueled vehicles. Even with a percentage of vehicles charging during the day, the system is fully capable of handling the additional load the same as the current new demand for population increases, new housing subdivisions and industrial expansion. It is a manageable load that can be calculated and planned.

The mid-term horizon may add some challenges to the utility to provide additional charging locations beyond home refueling. The issues appear to be more related to logistics and engineering in the areas of hardware (plug) and deployment of infrastructure needed for accurate billing. Wireless metering and billing technology may be applied to this issue.

[26] Report of the ARB Independent Expert Panel 2007, Executive Summary, April 13, 2007

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The long-term horizon presents a planning and communication challenge. If the U.S. is to remain competitive, the grid infrastructure will need to be modernized to enable our industries to be more energy efficient than countries with low-cost labor. This modernization permits the smart home to communicate with the smart device and ultimately with a vehicle that has communication capabilities to manage re-charge time and the ability to manage two-way power flows for home, community and regional electricity supply.

In some cases, infrastructure remains a barrier to non-road electrification. This issue is one of capital costs versus technology. Many of the complex systems, such as airports and ports, have not included the necessary electric infrastructure to support transportation electrification.

Societal Barriers

Accepting the issues and changing one's lifestyle are not always the same; therefore, it is critical from a societal perspective to address the value proposition for changing to an electricity-fueled transportation system. Technologies available for plug-in hybrids, battery electric vehicles and non-road electrification do not require a lifestyle change. PHEV technology can be applied to current production vehicles, drive the same total range, carry the same weight, have the same important amenities, and have the safety and appeal of current production.

In many cases, electric transportation in volume production has the following dilemma: the owner saves money in the long run, but is inhibited from making a purchase because of the higher up-front costs. Education alone does not seem to solve this barrier, based on the utilities' experience with promoting compact fluorescent light bulbs, energy efficient air conditioners and other energy efficient appliances. There is room for other policy interventions, including low-interest loans, loan guarantees and feebates. Beyond education, which is based on development of a strong value proposition, there are no evident societal issues that prevent a move toward transportation electrification.

Society is not the issue. The issue is a clear explanation of the value of electric transportation from an individual consumer's perspective. For example, electric refueling offers convenient charging at home, quiet all-electric drive, cabin pre-heat or pre-cool prior to departure, significantly reduced local pollution, and fuel cost savings. "The technical merits of PHEVs are clear – fuel economy can be improved substantially by either not using the engine (i.e., operating in an electric mode) or using it less (similar to today's hybrids, but allowing the battery to discharge throughout the day and recharge using off-peak electricity)." [27]

Regulatory

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[27] Summary Report, Discussion Meeting on Plug-in Hybrid Electric Vehicles, May 4-5, 2006, U.S. Department of Energy, Wash DC, Office of FreedomCAR and Vehicle Technologies, August 2006

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The regulatory challenge is to identify and execute the appropriate federal and state actions that enhance electric transportation, while eliminating cumbersome regulations that hinder electrification and maintaining a competitive society.

Following are examples of the regulatory environment that can impact transportation electrification.

Certification

To date, no certification process exists that captures the benefits of operating a portion of each day with the engine off. The complexity of this issue cannot be understated as the industry develops various energy management approaches that maintain battery life, extend all-electric range, manage engine start-up and capture regenerative braking.

Safety Standards

The National Fire Protection Association (NFPA) has addressed the safety of Electric fuel.[28] Additionally, Underwriters Laboratory (UL) has developed numerous safety specifications (Blue Covers) for vehicle charging and connection devices and equipment. The Society of Automotive Engineers (SAE) has developed numerous recommended practices for battery electric vehicles. Adherence to NFPA, NEC, UL, and SAE recommended practices is generally required for vehicles intended for unrestricted highway use.

Mobile Source Emissions

Rewarding consumers of electric transportation for their willingness to pay more for a new technology is important. Establishing the ability to obtain mobile emission credits for the purchasing organization can assist with this reward. Currently mobile emission credit procedures are complex, difficult to manage and very challenging to apply to stationary source emissions.

Road tax

The issue of road taxes will need to be addressed, as electricity becomes the fuel of choice. While capturing the re-charge data will not be difficult with modern communication systems, it will be important to analyze the impact of electric transportation on road conditions. For example, are they less abusive to roadways because they are lighter?

Non Road Applications

Cold Ironing

Many existing vessels have long operating lifetimes and fall outside traditional local and national regulatory authority. One technical barrier to the expanded use of cold ironing is the need to retrofit existing vessels to operate off 6.6 kV power.

Investment in berth-side transmission at affected ports is also necessary. Significant upfront costs (on the order of $1.5 million per vessel and $3 to $8 million dollars per berth retrofit) are required to take advantage of cold ironing, along with investments in new

[28] In NFPA 70, commonly referred to as the National Electric Code (NEC, article 625)

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power generation and transmission infrastructure. Cold ironing enjoys little or no operational savings associated with its use, potentially inhibiting its adoption in the private market. From a social benefit perspective, the adoption of cold ironing will result in substantial reductions in criteria pollutants in dense urban areas heavily impacted by port-related diesel pollution. Those benefits, which are not adequately accounted for in the free market, provide a strong basis for regulatory mandates for the adoption of cold ironing. For these reasons, public policy is expected to play an important role in promoting and coordinating investments in cold ironing.

Electric Transport Refrigeration Units (e-TRUs)
The limited duration of electric operation for most TRUs means that incremental capital costs are spread out over a more limited number of hours, degrading their lifecycle economics. As a result, incentives for the purchase of e-TRUs (such as grants to subsidize their incremental capital costs) provide one possible method of promoting their adoption. In addition, tougher emission standards for diesel TRUs (perhaps for new equipment based upon a "fleet average") could also support the penetration of electric technologies by raising the cost of incumbent technologies or requiring the purchase of low-emitting electric versions for existing fleets.

Electric Forklifts (e-forklifts)
Historically, there have been efforts to promote the use of e-forklifts, some of which continue to this day. Some electric utilities have offered incentives for the purchase of e-forklifts in order to benefit through increased electricity sales. While the private business case for e-forklifts is strong (particularly the significant lifecycle savings in high fuel-price scenarios), public policy may also be necessary to support their increased use. The significant incremental upfront costs of e-forklifts create a high hurdle to their adoption in small, cash-strapped operations. Policy instruments likely to support the increased use of electricity in forklift applications fall into one of two categories. The first of these categories includes efforts to bridge the upfront/lifecycle cost gap, either by providing incentives to cover incremental equipment costs or through a combined fee/rebate system ("feebates") designed to convert lifecycle savings into upfront costs/savings. The second category includes policies to monetize reductions in greenhouse gas emissions and petroleum use attributable to the use of e-forklifts. Improvements in battery charger efficiency will also improve the economics for electric forklifts.

Life-Cycle Environmental and Societal Impacts

Life-cycle assessments (LCA) are used to measure environmental and energy impacts of transportation fuels. There is considerable uncertainty associated with LCA assessments, and there is no expert consensus on what is the best analytic methodology. The analysis of a transportation fuel cycle--also known as a fuel cycle--is often reported in two distinct phases: well-to-tank (WTT) and tank-to-wheels (TTW). The well-to-tank phase includes resource extraction, feedstock production, refining, blending, transportation, and distribution. The tank-to-wheels phase includes refueling along with consumption and evaporation of the fuel. The compete fuel cycle analysis is referred to as a well-to-wheels (WTW) analysis.

The GREET model is the most publicly available and widely cited research tool for analysis of transportation fuel emissions and energy usage. GREET is used to make side-by-side comparisons across transportation technologies. Because GREET covers the entire transportation realm, it must make many reductionist assumptions regarding each technology. This is particularly true for the electricity sector. These assumptions limit GREET's ability to accurately represent the electricity marketplace and the overall SO_2 and NO_x emission constraints that are defined by the Clean Air Interstate Rule, which allow a regional cap and trade mechanism[29]. These complex dynamic feedbacks between the electric load from vehicles and the electric power system are generally analyzed with complex production cost models of the US power grid that find least-cost power plant dispatch strategies meeting current emissions constraints.

For example, GREET and other models use national averages for electricity and do not look state by state. In addition, they do not consider the marginal or incremental generation – typically off-peak – that serve PHEVs. These assumptions limit GREET's ability to accurately represent the electricity marketplace. This is particularly true for the electricity sector. For example, GREET and other models use national averages for electricity and do not look state by state. In addition, they do not consider the marginal or incremental generation – typically off-peak – that serve PHEVs. These assumptions limit GREET's ability to accurately represent the electricity marketplace. Also GREET does not model goods movements.

This section provides a synopsis of a rich body of work on sophisticated life-cycle analyses of electric vehicles and other electric applications for goods movement, including shore power for ships while in port (cold ironing), electric transportation refrigeration units, truck-stop electrification, and electric fork lifts. The four analyses presented are:

- The EPRI/NRDC analysis released July 19, 2007, examines nine scenarios for the potential GHG benefits for PHEVs. It also examines the air quality impacts using sophisticated modeling of the utility and transportation sectors and atmospheric modeling to examine a very conservative scenario with no GHG constraints.
- The California Energy Commission released a detailed analysis of the costs and petroleum reduction and GHG benefits of five types of electric transportation (attached Appendix 2) as part of a broad report performed in support of California's Assembly Bill 1007 (AB1007).[30]
- The National Renewable Energy Laboratory (NREL) Assessment of synergies between PHEVs and the wind energy markets using the Wind Deployment System (WINDS) model.[31]

[29] Clean Air Interstate Rule applies to 28 eastern states. Texas is the only state that must comply to the particulates-related rules, Federal Register, Vol 70, No 91 (May 12, 2005), 40 CFR Parts 51.
[30] Draft electric Storyline, May 2007, California Energy Commission draft AB 1007 report, and June 2007, final California Energy Commission full fuel cycle analyses for the AB 1007 report. .
[31] Short, W.; Denholm, P. (National Renewable Energy Laboratory). 2006. Preliminary Assessment of Plug-in Hybrid Electric Vehicles on Wind Energy Markets. TP-620-39729.

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- EPA is currently performing a comprehensive assessment of PHEVs and the impacts to the electric power system. This study is expected to be released in late summer of 2007.[32]

EPRI – NRDC study

The EPRI – NRDC study is the most sophisticated analysis of the benefits of electric transportation to date. It provides a valuable tool to better understand how the continuously improving power plants, location of the power plants, national carbon policy, and use of off-peak charging impacts the benefits of PHEVs.

Released on July 20, 2007,[33] the EPRI- NRDC study in two separate analyses covers:

- the potential greenhouse gas and petroleum reductions from large scale national deployment of PHEV 20s in 2050 under nine carbon constrained scenarios for 2050

- the air quality benefits from large-scale deployment of PHEV 20s in 2030 under a conservative status quo scenario with no constraints on carbon emissions. This analysis was the first to consider atmospheric conditions, location and timing of power plant emissions, national caps on NOx, Sox and mercury emissions from power plants, and the retirement / building of powerplants in the evaluation of ozone, particulate matter and other air pollutants. It also included emissions from the refineries, gas stations and other sources and considered that fact that cars and trucks are getting cleaner. The GREET model uses static assumptions and thus is not able calculate these type of refinements to the system.

The two EPRI – NRDC reports found that:

- widespread adoption of PHEVs can reduce GHG emissions from vehicles by more than 450 million metric tons annually in 2050 – equivalent to removing 82.5 million cars from the road.
- PHEVs can improve air quality nationwide
- There is an abundant supply of electricity for transportation: a 60 percent U.S. market share for PHEVs would use 7 to 8 percent of grid-supplied electricity in 2050.
- PHEVs brought nationwide air quality improvements including reductions in ozone and fine particulate matter; reduction in deposition of various pollutants such as acids, nutrients and mercury as well as improvement in visibility in national parks.

California Energy Commission AB1007 Report

Goods movement electrification opportunities exist in four key applications in addition to electric vehicles and PHEVs. They include alternative marine power for ships while in port, electric transportation refrigeration units, and truck-stop electrification for the hotel

[32] Michael Shelby, EPA, personal communication. A synopsis of this analysis will be included in the final version of this paper.
[33] www.epri-reports.org

load (heating and cooling of cab), and electric forklifts. In a 2005 report, the expected CO_2 emission reductions for California alone are estimated to be 1.2 million tons annually in 2010 for the e-TRU and the electric fork lifter applications (each).[34] The fundamental mechanism of the electrification applications in the goods movement category is the same as that for electric vehicles. Because of the inherent energy efficiency of electric motors, significant consumption of diesel fuel can be displaced.

The National Renewable Energy Laboratory (NREL) Wind Synergy Study

The NREL published a report discussing the synergy between the wind generation and the battery storage capability of PHEVs.

- The study was based on the WINDS model; a 136-region electric capacity expansion model that determined the least-cost generation technology to meet future loads.

The NREL study found that:

- Assuming a 50% penetration of PHEV-20 vehicles by 2050, and that these vehicles are able to feedback power to the grid, wind integration costs are reduced to economically increase wind penetration by 14%. Assuming the same penetration with PHEV-60 vehicles, wind penetration more than doubles from the status quo.

PHEVs can assist in the long-term integration of variable output resources like wind.

Reduction of Foreign Oil Dependency

Electric fuel is inherently domestic. The electrification of the transportation sector replaces petroleum fuel products (primarily gasoline) with coal and natural gas resources for the generation of electricity. Almost all of the coal burned in US power plants is domestic in origin. Natural gas imports were about 12% (2.6 trillion cubic feet in 2005) from neighboring Canada.[35] The petroleum-based generation except for Hawaii and Alaska are insignificant. Thus, for every electric vehicle (BEV or PHEV in the electric mode), 100% of the transportation fuel (pre-dominantly gasoline) can be replaced with primarily domestic energy resources. The EPRI – NRDC study found that by 2050, PHEV 20s with 60 percent of new vehicle sales could displace 3 – 4 billion barrels of oil compared to regular hybrids.

California Energy Commission (CEC): Electric Drive Technologies Storyline

The California Energy Commission (CEC) performed a comprehensive analysis of electric replacement opportunities for the transportation sector that determined the social benefits and cost associated with the expanded use of electric drive technologies [CEC, 2007]. This analysis focused on the opportunity specific for California, with California's transportation energy requirements and electricity generation mix. However, the key messages of this analysis are qualitatively applicable to other Western States as well. The CEC study used

[34] TIAX, 2005
[35] EIA, 2007b

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the GREET model modified for California. For example, based on prior studies it was assumed that electricity incrementally supplied would be 80 percent combined cycle natural gas and 20 percent renewables in 2012.

The electric drive replacement opportunities analyzed in this study included: 1) off-shore power supply of ocean-going vessels (cold-ironing), 2) electric transportation refrigeration units attached to semi trailers (e-TRU), 3) truck stop electrification for hotel services (e.g., HVAC), 4) electric forklifts, 5) PHEVs. The results of this study can be summarized as follows:

- The five electric drive opportunities have a total combined CO_2 equivalent emission reduction potential of 10.9 million tons in the most aggressive penetration scenario in 2022, which represents about 6% of reduction target (175 million tons in 2020) to meet the AB32 reduction requirements.

- The combined petroleum reduction potential is estimated to be 1000 million gallon of gasoline equivalent in 2022, corresponding to a 5% reduction of gasoline[36]

- Of the five electric drive opportunities, PHEVs contribute to about 70% and e-forklifts to about 15% of the benefits for both the petroleum dependence and GHG emissions reductions. This assumes a maximum penetration of 80% for the e-forklifts and a modest 8.4% penetration of PHEV in 2022[37].

- However, truck stop electrification benefits in other Western states would be much larger than in California – 5 times more per electrified truck stop space. This is because in Western States sleeper cab trucks can use their main engine to provide comfort to the driver, while in California they must use a diesel generator set or auxiliary power unit (which saves fuel).

- The life-cycle costs are attractive in all scenarios analyzed, and estimated to generate net savings over the life of the technology. The only exception is the cold-ironing application, which requires infrastructure investment at the port to service the vessels. Public policy will play an important role to promote and coordinate this investment.

- Incentives and/or mandates are necessary to achieve higher penetration rates beyond the "business as usual" case.

Life-Cycle Cost (LCC) of PHEVs and Electric Transportation

Market research has not traditionally been done to answer questions about PHEVs, batteries and other attributes. The exception is the consensus report by the EPRI HEV Team. As was mentioned above, this report found substantial market potential for PHEVs with an all-electric range between 20 to 60 miles regardless of the battery's cost. This

[36] Using estimates from Caltrans of about 25 billion gallon of gasoline in 2022. [Caltrans, 2006] page 15.
[37] Using 2.1 million PHEVs in the "Aggressive Growth" scenario defined in [CEC 2007] and 25 million registered autos in 2022 [Caltrans, 2006]

study also found that customers are willing to pay more for a PHEV20 or PHEV60 than a traditional power-assist hybrid with no all-electric range ($1,400 to $2,000 more).[38] While this study is seven years old, it has been supported by more recent, less sophisticated surveys of market interest. [39]

One of the greatest challenges for most alternative fuel vehicles is the higher up-front cost and the need for a new infrastructure system to be constructed. However, many types of electric transportation, such as electric forklifts using lead acid batteries, e-TRUs and truck-stop electrification, have substantial fuel and maintenance savings that can pay back these higher upfront costs, including the cost of infrastructure. This is shown in the appendix table 1 In fact, electric forklifts have been around for years and enjoy a 50 percent market share.

It appears unlikely that EVs and PHEVs can pay back the higher upfront costs in the early years, when advanced batteries are in low-volume production. Detailed studies on this are underway. However, a number of studies have examined the question of whether a PHEV20 in volume production can pay back its higher upfront costs with fuel and maintenance savings.

This question is complicated by several factors. Car and truck pricing is very complex and includes not only cost considerations, but also compliance with state and federal laws, competitive concerns, the ability to secure free advertising or a green brand and other customer considerations. In addition, the willingness of customers to pay more for a PHEV than a traditional HEV comes into play/ Examples of studies on life-cycle cost for PHEVs in mass production include EPRI 2003,[40] EVS 20 and EVS 22 papers,[41] an analysis by Mr. Hu, and the California Energy Commission Analysis shown in appendix.

<u>Ongoing Research</u>

The federal government, and the Department of Energy in particular, is increasing its investment in battery and advanced power electronic systems research. Automotive and battery manufacturers are investigating PHEV, pure battery and fuel cell plug-in electric drive vehicles. The national laboratories and EPRI are focused on understanding operating systems and energy management to identify the most efficient design. Energy and environmental implications of grid-powered transportation, including grid capacity and carbon emissions, is the subject of several national and regional analyses.

<u>Predicted Deployment/Use</u>

Initial production of consumer-available, plug-in electric drive automobiles is projected for 2010. Conversion kits to add an additional battery to a hybrid vehicle are available today. A limited number of battery electric vehicles are slated for delivery in 2008, with volumes projected to increase each succeeding year. In 2009, plug-in hybrid service vans and a medium-duty truck will be in production.

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[38] EPRI, Market Price, 2001
[39] EPRI, Market Price, 2001
[40] EPRI, Life Cycle Analysis, 2003
[41] EVS20 & 22, International Battery, Hybrid and Fuel Cell Electric Symposium and Exposition

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The production volumes and rate of commercial penetration will depend upon actions taken to address the technology and market hurdles of the emerging technology.

Suggested State, Regional and Federal Actions to Accelerate Deployment/Use of Electric Drive Technologies

Near-term (within 3 years)

In the near term, federal, state and local efforts should focus on proving technology; reducing cost barriers; supporting expanded manufacturing capacity; identifying infrastructure requirements and promoting consumer awareness of the range of electric vehicles, including plug-in electric, hybrid electric and pure electric vehicles.

- Provide stable funding at the federal and state levels for battery research and development and distribute the results to the public as widely as possible.
- Support federal, state and local demonstrations of plug-in hybrid electric vehicles (PHEVs) by public and private entities.
- Revise government fleet purchasing programs to provide market certainty to manufacturers and promote technology demonstration.
- Include fleet purchase requirements that set fuel consumption and emission requirements to promote early purchases of PHEVs.
- Fully recognize the fuel and emissions benefits of neighborhood electric vehicles that are used to displace conventional vehicles.
- At the state and local level (financial and regulatory agencies) provide incentives for consumers, including preferential tax treatment and parking benefits, such as plug-in parking slots with parking structures powered by renewable energy.
- Execute a review of individual state electricity infrastructure in partnership with the utility industry. This review will help outline system compatibility with electric drive market penetration in on- and off-road applications.
- Promote consumer understanding and market acceptance through state and regional consumer education campaigns about plug-in, electric-drive vehicles and their benefits.
- Establish federal and state manufacturing incentives to mitigate the risk of new product development and promote domestic industry and employment.
- At the state and local level, establish downstream retail incentives, such as automobile dealer tax credits and preferential advertising for advanced vehicle products, to promote local participation in the emerging market.
- Establish regional coordination among utilities and public utility commissions to develop and implement an off-peak rate structure for vehicles that utilize fuel from the electricity grid and especially renewable energy.
- The Western region should lobby for federal law to begin to transition to a fuel-neutral system that allows electric transportation to compete in federal emission, petroleum and greenhouse gas reduction laws and incentives.
- Learn from the 1990s experience with battery EVs and avoid multiple charging standards, have the same 120 v and 240 v standards apply to EVs and PHEVs, and keep the charger on the vehicle.

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- Seek niches for electric transportation, such as post office vehicles, low mileage city fleets, utility bucket trucks, etc.

Mid-term (3-10 years)

Assuming the technology progresses as projected in the near term, research and development will continue to be a priority in the mid term. However, additional areas of action that should accompany increasing commercialization include electricity infrastructure issues, support for large-scale investment in domestic production, and overcoming market hurdles and funding.

- Establish a technology strategy that aligns modernization of the electricity infrastructure with the communication and connectivity needs for an electric-drive market transformation. Key elements would include:
- Utility analysis of their current infrastructure system with the development of a roadmap to prepare for mid- and long-term requirements
- Government/utility/developer/automotive analysis of what it means to have a future intelligent grid and how these systems communicate with each other
- Automotive/utility alignment to ensure connectivity simplification with an emphasis on safety and ease of use
- Monitor vehicle technology development, deployment and real-world use to ensure expected reductions in fuel consumption and emissions are being realized.
- Continue and extend state and local incentives to build markets and consumer acceptance for vehicles using electric fuel, including tax incentives for consumer and private fleet purchases and investment incentives for vehicle and advanced component manufacturers.
- Address the uncertainty associated with the new technology of new financing and insurance options, e.g., state-backed battery warranties that extend beyond current manufacturer warranties and utility financing for batteries.
- Commensurate with vehicle penetration, establish incentives for installation of private infrastructure, e.g., work sites, multi-family housing, etc.
- Set up programs to reward the best dealerships and sales persons, as this is a weak link in the process, and may be as important as tax credits.
- Encourage the federal government to adopt a new class of vehicles with characteristics between a low speed vehicle (typically a battery electric) and a full-function passenger vehicle that can travel on freeways and highways.
- Support local government investment in public infrastructure, such as public lots with recharging units, with an emphasis on renewable-source re-fueling projects.
- Establish professional education and training infrastructure for engineers, mechanics, educators and first responders.
- Fund state-level research at university centers of excellence to address battery and power electronics maturity and cost issues.

Long-term (> 10 years)

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In the long term, assuming mid-term expectations are met, state and federal technology efforts should be directed toward expansion of plug-in electric drive across transportation platforms for on- and off-road markets; expanding development and deployment of advanced batteries in emerging battery electric vehicles applications; coordination of regional infrastructure and regulatory efforts; assessment of environmental and energy impacts; and building a sustaining knowledge base through education and training.

- Convene a long-term WGA strategic Team to develop and disseminate an energy vision for 2050. The vision would include a state and regional blueprint for electrifying the transportation sector, including community planning, increased grid integration, and market penetration scenarios and impacts. The plan would include a comprehensive review of raw material available in the Western United States for advanced batteries and related technology.
- Engage in ongoing Western interstate cooperation in developing coherent, technology-neutral regulations and measurement of environmental impacts, such as holistic approaches to reducing climate impact (not just carbon footprint) and interstate grid impacts of large-scale use of electric fuel (including demand management and infrastructure requirements).
- Implement state and regional business attraction programs; coordinate with members of Congress in efforts to promote investment in the electric drive vehicle-related industry within their states and regions.
- Increase state and federal cooperation with the automotive and battery industries to develop demonstration partnerships, such as deployment of prototypes and insertion of advanced batteries into fleets of demonstration vehicles.
- Increase state-level cooperation with utilities, mortgage companies and others to develop new mechanisms to mitigate the upfront cost of PEVs, such as financing through mortgage equity.
- Support establishment of an industry-wide collaborative to create manufacturing techniques to be applied to the U.S. manufacturing industry.

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APPENDIX
Assumptions of the GREET Model

In order to accurately asses WTW emissions, GREET makes critical assumptions about sources of energy generation and the calculation of energy emissions across the energy supply chain.

a) **Detailed emissions data for VOCs, CO_2, NOx, PM10, and SOx** were obtained from EPA emissions inventory data. There were limitations in the EPA data related to CH_4 and N_2O emission from fuel combustion; as a result, these particulates are not taken into account.
b) **Energy efficiency in GREET is calculated by taking the energy output divided by energy input,** including energy in both process fuels. For a given well-to-tank activity, energy input per unit of energy product output is calculated in GREET from the energy efficiency of the activity.
c) **Emission factors for VOCs, CO2, NOx, PM10, CH_4, and N_2O** for different combustion technologies fueled by different process fuels are continuously updated from the original sources, which consist of emission inventory information for point sources collected from state and local air agencies.[42] Data in this inventory are commonly used for air quality monitoring and human local air agencies.
d) **Combustion CO_2 emission factors (in g/mmBTU of fuel throughput) are calculated by using a carbon balance approach** in which the carbon contained in a process fuel is burned, minus the carbon contained in the combustion emissions of VOCs, CO, and CH_4 are assumed to convert to CO_2. The detailed formula for this calculation is available in the report titled:

   GM Study: Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems — A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions" http://www.transportation.anl.gov/software/GREET/publications.html

Limitations

In general, GREET follows widely accepted methods, but significant uncertainties and omissions remain, and current methods are not considered adequate by all experts.[43] No single approach may be able to address all concerns. For instance, there is an important trade-off between detail and breadth, typically manifested in the choice between detailed engineering-type, process-specific LCAs of limited extent and extensive economy-wide analyses of limited detail.[44] It is not clear how to resolve this tradeoff, and a highly detailed, economy-wide analysis may be impracticable. The present generation of transportation fuel LCA models, such as GREET, produce global warming intensity (GWI) values for each fuel pathway; but these values must be understood as both incomplete and, in many cases, highly uncertain.

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[42] EPA's AP-42 document (EPA 1995) and the NEI database.
[43] Delucchi 2004; Pennington, Potting et al. 2004; Rebitzer, Ekvall et al. 2004; International Standards Organization 2006.
[44] For an example of the latter, see Matthews and Small 2001.

The following two graphs provide a picture of estimated fuel economy and emissions associated with different fuel and engine technologies. These graphs were generated using a modified version of GREET for the California Air Resources Board. This provides an example of how each state can estimate emissions and efficiency of various alternative fuels. These results are relevant to California only. Individual states can reconfigure the model in order to reflect the power generation mix peculiar to their own state and come up with a visual representation of the costs and benefits of commercializing alternative fuels in their state.

Tables

Table 1

	Scenario*	2012			2017			2022		
		BAU	CEG	AG	BAU	CEG	AG	BAU	CEG	AG
Cold-ironing	Population (1,000s)	0.05	0.22	0.39	0.10	0.53	0.95	0.13	0.67	1.20
Cold-ironing	Petroleum Displaced (10^6 gge/yr)	12	34	55	21	66	111	25	78	131
Cold-ironing	GHG Reduction (10^6 tons/yr)	0.08	0.22	0.36	0.14	0.43	0.73	0.16	0.51	0.85
Cold-ironing	Upfront Costs (10^6 $/year)	$14.7	$36.2	$57.7	$23.7	$62.0	$100.3	$26.2	$70.2	$114.2
Cold-ironing	Operational Savings (10^6 $/yr)	($3.3)	($0.2)	$2.9	($2.8)	$7.6	$18.0	($2.0)	$11.8	$25.5
Cold-ironing	Lifecycle Costs (10^6 $/yr)	$18.0	$36.4	$54.8	$26.5	$54.4	$82.3	$28.3	$58.4	$88.6
e-TRUs	Population (1,000s)	5	10	15	9	17	26	11	20	29
e-TRUs	Petroleum Displaced (10^6 gge/yr)	2	4	7	4	8	12	5	9	14
e-TRUs	GHG Reduction (10^6 tons/yr)	0.02	0.04	0.07	0.03	0.07	0.11	0.04	0.09	0.13
e-TRUs	Upfront Costs (10^6 $/year)	$2.9	$7.8	$12.7	$6.4	$14.4	$22.3	$8.3	$17.1	$25.8
e-TRUs	Operational Savings (10^6 $/yr)	$3.2	$8.5	$13.7	$7.5	$16.2	$25.0	$9.8	$19.5	$29.3
e-TRUs	Lifecycle Costs (10^6 $/yr)	($0.3)	($0.6)	($1.0)	($1.1)	($1.8)	($2.6)	($1.5)	($2.5)	($3.5)
TSE	Population (1,000s)	11	17	22	15	23	31	17	26	35
TSE	Petroleum Displaced (10^6 gge/yr)	13	19	26	19	30	40	23	35	47
TSE	GHG Reduction (10^6 tons/yr)	0.14	0.20	0.27	0.21	0.31	0.42	0.24	0.37	0.50
TSE	Upfront Costs (10^6 $/year)	$6.5	$9.6	$12.7	$8.9	$13.5	$18.0	$10.0	$15.2	$20.4
TSE	Operational Savings (10^6 $/yr)	$31.7	$47.4	$63.0	$50.8	$77.6	$104.4	$59.6	$91.7	$123.8
TSE	Lifecycle Costs (10^6 $/yr)	($25.2)	($37.8)	($50.3)	($41.9)	($64.1)	($86.4)	($49.6)	($76.5)	($103.4)
e-forklifts	Population (1,000s)	49	63	77	58	73	88	61	77	92
e-forklifts	Petroleum Displaced (10^6 gge/yr)	12	83	155	13	92	170	14	95	175
e-forklifts	GHG Reduction (10^6 tons/yr)	0.13	0.98	1.83	0.16	1.08	2.01	0.16	1.12	2.07
e-forklifts	Upfront Costs (10^6 $/year)	$7.6	$48.5	$89.4	$8.9	$52.6	$96.4	$9.4	$54.3	$99.2

	Scenario*	2012			2017			2022		
		BAU	CEG	AG	BAU	CEG	AG	BAU	CEG	AG
	Operational Savings (10^6 $/yr)	$26.1	$166.2	$306.3	$30.5	$181.0	$331.4	$32.5	$188.1	$343.7
	Lifecycle Costs (10^6 $/yr)	($18.5)	($117.7)	($216.9)	($21.6)	($128.3)	($235.0)	($23.1)	($133.8)	($244.5)
PHEVs	Population (1,000s)	87	189	292	384	922	1,459	548	1,330	2,112
PHEVs	Petroleum Displaced (10^6 gge/yr)	28	61	94	120	285	451	169	409	648
PHEVs	GHG Reduction (10^6 tons/yr)	0.32	0.69	1.07	1.36	3.23	5.10	1.93	4.63	7.33
PHEVs	Upfront Costs (10^6 $/year)	$102.2	$158.4	$214.6	$286.8	$640.8	$994.9	$369.6	$897.3	$1,425.0
PHEVs	Operational Savings (10^6 $/yr)	$81.0	$176.9	$272.9	$353.8	$859.8	$1,365.9	$504.0	$1,240.8	$1,977.7
PHEVs	Lifecycle Costs (10^6 $/yr)	$21.3	($18.5)	($58.3)	($67.0)	($219.0)	($371.0)	($134.4)	($343.6)	($552.7)
Total	Population (1,000s)	153	280	407	466	1,035	1,605	637	1,453	2,270
Total	Petroleum Displaced (10^6 gge/yr)	66	202	337	177	481	784	236	626	1,015
Total	GHG Reduction (10^6 tons/yr)	0.68	2.14	3.60	1.89	5.13	8.37	2.53	6.71	10.88
Total	Upfront Costs (10^6 $/year)	$134.0	$260.5	$387.1	$334.6	$783.3	$1,231.9	$423.5	$1,054.0	$1,684.6
Total	Operational Savings (10^6 $/yr)	$138.7	$398.8	$658.8	$439.7	$1,142.2	$1,844.7	$603.8	$1,551.9	$2,500.1
Total	Lifecycle Costs (10^6 $/yr)	($4.7)	($138.2)	($271.7)	($105.1)	($359.0)	($612.8)	($180.3)	($497.9)	($815.4)

* BAU = Business-As-Usual Growth; CEG = Cost-Effective Growth; AG = Aggressive Growth
Note: BAU = CalETC Expected Scenario; AG = Achievable Scenario; CEG = mean of BAU/AG
Numbers in parenthesis represent negative values. Negative operational savings represent net costs

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