



POSITION STATEMENT

TRANSFORMING TRANSPORTATION BY DIVERSIFYING ENERGY SOURCES

*An Addendum to IEEE-USA's
National Energy Policy Recommendations*

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Board of Directors, 29 October 2015**

**Prepared by the
IEEE-USA Energy Policy Committee**

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SUMMARY

Today, more than 95 percent of the energy used in transportation comes from oil. The transportation sector consumes about 70 percent of all petroleum used in the United States. Oil will continue to be a major fuel for decades, but our ability to substantially reduce its use for transportation will be essential to reducing the national security risks inherent in dependence on a single energy source.

We need a radical transformation of the transportation sector, not only to reduce its complete dependency on oil, but also to reduce emissions in the transportation sector, particularly in large cities. Because transportation emissions are widely dispersed, it is impractical and uneconomical to capture and store transportation emissions. Hence, the principal option is substitution of alternate energy sources for oil.

IEEE-USA recommends a two-pronged effort: (1) to electrify transportation, focusing on plug-in electric and hybrid technologies; and (2) to pursue replacing conventional fuels with alternative liquid fuels or natural gas (for heavy-duty vehicles). Domestically produced electricity and alternative liquid fuels would give the United States the ability to maintain its economy and transportation system, regardless of what happens in the rest of the world.

Conventional hybrid vehicles have already demonstrated the capability to substantially increase fuel economy. The plug-in feature adds an option to substitute electricity for some or all of the gasoline used in the vehicles.

Electrifying Transportation: Plug-In and Hybrid Electric Vehicles

The electric infrastructure already in place is sufficient to permit on the order of 75 percent reduction in the dependence on liquid fuels, through greater penetration of plug-in electric vehicles (PEVs), including all electric and plug-in hybrid electric vehicles. In addition, very little oil is used to produce electricity in the United States, and the fuels used (nuclear, coal, gas and renewables) are primarily domestic. Therefore, electrification of vehicles would produce a direct and immediate substitute for oil along with commensurate benefits for national security and the environment. Electric motors are inherently more efficient than internal combustion engines. Motors do not consume energy while vehicles are stopped in traffic, and when paired with batteries, provide the opportunity to recover energy from braking. Current hybrid electric vehicle (HEV) technology, (e.g., Ford Focus, Toyota Prius, Honda Insight, and others) demonstrates the potential of this approach. Some of the improvements developed for electric and hybrid cars have migrated into and are now

improving conventional vehicle fleet efficiency.

Electrifying the transportation sector will increase transportation energy efficiency and reduce greenhouse gas and other emissions, even with the current generation fuel mix. Increased use of natural gas for generation is making the environmental advantage even more prominent. In addition, electrification opens up a clear pathway to near-zero “well-to-wheels” emissions in the transportation sector.

While the technical feasibility of PEVs is evidenced by the growing number of manufacturers, the market is still in its infancy. The current sales volume and maturity of plug-in vehicles are comparable to those of Prius in 2000, when it entered the U.S. market. Stable, predictable incentives, similar to those provided to help introduce conventional hybrids, are needed to expand this market and enhance economies of scale. These market development measures should be combined with further technology advances, particularly in battery systems, to improve cost competitiveness with conventional internal combustion technology.

IEEE-USA RECOMMENDS that federal, state and local governments, along with quasi-governmental and private sector organizations, develop and pursue a strategy to electrify transportation; including mass transit, passenger and commercial vehicles, buses and short- and long-distance rail by:

Efficiency and Deployment: Increasing transportation efficiency and promoting the rapid deployment of PEVs and HEVs through measures such as:

- Offering federal and state tax credits, rebates and other incentives for electric vehicle purchase
- Offering state and city incentives, such as commuter lane driving opportunities, and special parking privileges for consumers who drive PEVs and HEVs
- Accelerating U.S. Department of Defense development of HEV and PEV technology for military applications
- Offering city-, county-, or state region-sponsored incentives for PEV sharing
- Offering city and state license incentives for use of PEVs and HEVs as taxis
- Purchasing PEVs and HEVs by companies for employees use

Battery Charging Infrastructure: Promoting the development of battery charging infrastructure, and its deployment by cities, states, and businesses.

Battery R&D: Accelerating and diversifying federal and private sector R&D aimed at improving battery technology including:

- Increasing energy storage density
- Decreasing cost
- Increasing life
- Assuring safety
- Implementing rapid battery recharge or change-out strategies
- Identifying secondary markets for used batteries
- Recycling strategies

Grid Integration R&D: Continuing federal and utility-sponsored research on the integration of PEVs on the electric grid, developing and implementing industry consensus standards to realize full potential benefits.

Power Electronics and Electric Machine R&D: Accelerating and diversifying federal and company-sponsored R&D-- aimed at substantially reducing weight, volume and cost of power electronics (PE), and electric machines for PEVs including:

- Highly efficient PE interfaces, including integration with electric machines
- Wide band-gap semiconductor materials research
- Advanced, high-temperature PE packaging
- Enhanced PE reliability
- Alternatives to rare earth permanent magnet electric machines

Developing and Using Alternative Transportation Fuels

The fastest and most efficient way to reduce dependence on petroleum is to combine a strategy of rapid electrification, together with rapid development of alternative liquid fuels, to satisfy the continuing requirement for liquid fuels. Some alternative liquid fuels generate CO₂ emissions as great as conventional petroleum, but others may offer an opportunity to substantially reduce net CO₂ emissions. Some of the most significant issues with biofuels are water consumption and competition with food crops. It is, therefore, essential that these issues be fully understood as part of developing a broader perspective on this topic.

To help meet our transportation fuel demand from secure, domestic sources as soon as possible and at reasonable cost, IEEE-USA RECOMMENDS:

Fuel Flexibility: Passing federal legislation to mandate fuel flexibility in vehicles.

Biomass R&D: Pursuing federal R&D to convert sustainable biomass to transportation fuels that can be blended and distributed with gasoline

Fuel Distribution and Control: Promoting fuel flexibility in the fuel distribution system; and advanced control technologies to maximize efficiency, and minimize emissions across the spectrum of fuels

Government Vehicles: In all government procurement of light-duty vehicles, give preference to vehicles that offer three-way fuel flexibility, to use at least gasoline, ethanol and M60 methanol blends.

High EROI Fuels: Promoting the use of biofuels that offer a higher energy return on investment (EROI)

Natural Gas: Supporting comprehensive congressional legislation to promote greater use of natural gas in heavy-duty vehicles, so long as such legislation provides equal, or greater, stimulus to electrification and alternative vehicles

INTRODUCTION

The transportation sector is vital to our economy, but it is highly influenced by uncertainties in oil supply and cost. Today, about 95 percent of the energy used in transportation comes from oil.¹ Transportation is also the single largest U.S. petroleum user; it consumes about 70 percent of all petroleum used in the United States². Although oil will continue to be a major transportation fuel, our ability to develop effective substitutes for its transportation use will be essential to reducing the national security risks inherent in dependence on a single energy source. A single substitute would be an effective first step, but it is not sufficient. The United States should strive for **flexibility** -- the ability of vehicles and fueling systems to adapt quickly to rapid changes in technologies, price regulation and market conditions.

Many other reasons collectively suggest that complete dependence on petroleum for our transportation needs is unwise. Some of these reasons are summarized below:

- In 2014, the United States imported more than 25% percent of its petroleum needs, an amount comparable to ½ of the petroleum consumed in the form of motor gasoline.³ Even a relatively small fraction of personal transportation converted to alternative fuels would have a major impact on these imports. And though our dependence on foreign petroleum has declined since peaking in 2005, the funds spent for imported oil will continue to adversely affect the U.S. economy.
- Rapid growth of transportation needs in emerging economies will continue the upward pressure on oil demand and prices. Oil price increases would impact not only transportation, but also other sectors. About fifteen percent⁴ of U.S. petroleum is used for non-combustion purposes. The non-fuel uses include industrial feedstock for a variety of products such as plastics, detergents, and even aspirin.⁵
- Gasoline combustion is responsible for most precursors of urban smog. In addition, fuel combustion from transportation contributes about 30 percent⁶ of U.S. greenhouse gas emissions.

Consequently, a radical transformation of the transportation sector should aim to not only reduce its complete dependency on oil, but also to increase system efficiencies and reduce emissions in the transportation sector, particularly in large cities. Because transportation emissions are widely dispersed, it is unlikely that these emissions could ever be captured and stored. Hence, the principal option is to substitute alternate, cleaner, energy sources for oil.

¹ EIA *Monthly Energy Review*, May 2015, <http://www.eia.gov/totalenergy/data/monthly/pdf/sec2.pdf>

² Ibid, <http://www.eia.gov/totalenergy/data/monthly/pdf/sec3.pdf>

³ Ibid, <http://www.eia.gov/totalenergy/data/monthly/pdf/sec3.pdf>

⁴ EIA Annual Energy Review 2011, September 27, 2012; EIA *Monthly Energy Review* June 2015
<http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0115>

⁵ See, for example "A partial list of products made from Petroleum" at <http://www.ranken-energy.com/Products%20from%20Petroleum.htm>

⁶ *U.S. Greenhouse Gas Inventory Report: 1990-2013*, EPA April 2015

IEEE-USA recommends pursuing a portfolio approach to achieve the transformation away from oil, particularly substitution with electricity or alternative liquid fuels. Ideally, this would entail rapid deployment of vehicles which give the consumer the power to shift, from one day to the next, between petroleum, electricity, ethanol and new types of alternate liquid fuel, less expensive and more friendly to the environment than the high purity corn-based ethanol in common use today. Indeed, it should be noted that not all biomass fuels reduce carbon emissions; some applications may result in large increases of air emissions.^{7,8,9}

This document provides detailed background information and expands on the key actions and investments that IEEE-USA believes are necessary to reduce U.S. national security risks by transforming transportation.

⁷ See, for example, May 8, 2015, letter to EPA from Massachusetts Senators Markey and Warren (http://www.biologicaldiversity.org/programs/climate_law_institute/pdfs/EPABioenergyCleanPowerPlan_05-08-15.pdf)

⁸ T. Buchholtz and J. Gunn, "Carbon Emission Estimates for Drax biomass powerplants in the UK sourcing from Enviva Pellet Mills in U.S. Southeastern Hardwoods using the BEAC model," Spatial Informatics Group, May 27, 2015 (https://www.southernenvironment.org/uploads/audio/2015-05-27_BEAC_calculations_SE_hardwoods.pdf)

⁹ "Think Wood Pellets are Green? Think Again." NRDC issue brief IB:15-05-a, May 2015

ELECTRIFYING TRANSPORTATION: PLUG-IN ELECTRIC VEHICLES

One of the most effective avenues for reducing near-term oil use in the transportation sector is electrification. The electricity infrastructure is in place and the vehicles are already entering the marketplace. In addition to substituting for oil, electrification increases overall transportation system efficiency.¹⁰ If the electricity to run the vehicles is produced by nuclear, hydro, wind, or solar, no carbon dioxide is released in the electricity production and none while the electricity stored in the battery runs the vehicle. In fact, electric transportation improves overall energy efficiency and reduces greenhouse gas emissions even when electricity is produced from currently installed generation capacity mix.¹¹ Increased use of natural gas for generation is making the environmental advantage even more prominent. Electrification opens up a clear pathway to near-zero “well-to-wheels” emissions in the transportation sector.

IEEE-USA recommends developing and pursuing a general strategy to electrify transportation, including passenger and commercial vehicles, mass transit, buses, and short- and long-distance rail.

Hybrid electric vehicles (HEV) were introduced to the U.S. transportation market in 1999 and represent the first step towards electrification. While initially a rarity, by now they are a fairly common sight on the roads. These vehicles generate electricity on-board and use a small battery to supplement the gasoline engine, as needed, to increase its efficiency. Fossil fuel is the only energy source for this automobile. To substitute electricity for some, or all of, the fossil fuel (electrification) requires a new class of vehicles that can be charged by electricity through an electric plug. Several types of vehicles can use electricity directly as an energy source:

- Plug-In Hybrid Electric Vehicles (PHEV) – similar to conventional Hybrid Electric Vehicles (HEV), except for a larger battery and the ability to charge the battery directly from an electric socket
- Extended Range Electric Vehicles (EREV) -- electric drive vehicles with fuel-engine-driven generators capable of recharging their batteries
- Battery Electric-Only Vehicles (BEV) – all-electric drive vehicles, with no supplemental engine

The most important electrification target should be light-duty (LDV) and heavy-duty vehicles (HDV - primarily freight trucks, but also buses). These two uses represent about 60 percent and 20 percent of transportation energy use, respectively.¹² Target markets should include both individual-owned vehicles as well as fleets, (for example, delivery services, rental cars and buses).

¹⁰ See, for example, *Environmental Assessment of Plug-In Hybrid Vehicles*, Vol. 1: Nationwide Greenhouse Gas Emissions, EPRI-NRDC July 2007

¹¹ See, for example, *Advanced Energy Technologies for Greenhouse Gas Reduction*, AEE 2014; <https://www.aee.net/initiatives/epa-111d.html#epa-technologies-for-greenhouse-gas-reduction>

¹² *Annual Energy Outlook 2015*, DOE/EIA-0383(2015), April 2015

To date, more than 3.5 million HEVs (since 1999 market introduction)¹³ have been sold in the United States and about 330 thousand PEVs (since 2010 market introduction), including the almost 12,000 PEVs sold in May 2015 alone. Most major automakers have a PHEV/EREV or BEV vehicle either on the market or proposed. Through May 2015, conventional hybrids and PEVs accounted for three percent of 2015 vehicle sales¹⁴. The most energy efficient conventional hybrids cut gasoline consumption by around 30 percent compared with similar conventional cars.¹⁵ As outlined below, aggressive pursuit of further electrification can result in further increase of transportation energy efficiency, reduced maintenance costs, and reduced air emissions.

Plug-in electric vehicles (PEVs) operate some or all of the time in an electric mode using grid-supplied electricity generated from diverse domestic energy sources such as renewables, gas, coal, and nuclear. A PHEV/EREV uses only a modest sized battery for an all-electric range of ten to 40 miles.¹⁶ Because the average U.S. light-duty vehicle (LDV) is driven less than 40 miles a day and the average trip is about 10 miles,¹⁷ **PEVs could serve about half of U.S. LDV miles by electricity**. Electric-only vehicles completely eliminate the consumption of liquid fuels. In case of a sudden price shock or international crisis, most PEV users could continue to go to work and do essential shopping every day. Being able to sustain such activities, would substantially enhance the ability of the U.S. and OECD economies to cope with such events.

¹³ *U.S. HEV Sales by Model (1999-2014)*, May 2015, Alternative Fuels Data Center (U.S. DOE), <http://www.afdc.energy.gov/data/>

¹⁴ *Electric Drive Sales Dashboard*, Electric Drive Transportation Association. Available: <http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952>

¹⁵ See, for example, comparison of 2015 conventional and hybrid Honda Civic in city driving (<http://www.fueleconomy.gov>)

¹⁶ *Comparing Electric Vehicles: Hybrid vs. BEV vs. PHEV vs. FCEV*, Union of Concerned Scientists, February 2014 (<http://blog.ucsusa.org/comparing-electric-vehicles-hybrid-vs-bev-vs-phev-vs-fcev-411>); See also EPA, (<http://www.fueleconomy.gov/>) for data for individual vehicles.

¹⁷ *Survey Says: Over 40% of American Drivers Could Use an Electric Vehicle*, Union of Concerned Scientists, December 2013 (<http://blog.ucsusa.org/survey-says-over-40-of-american-drivers-could-use-an-electric-vehicle-338>)



Source: "Survey Says: Over 40% of American Drivers Could Use an Electric Vehicle," Union of Concerned Scientists, December 2013 (<http://blog.ucsusa.org/survey-says-over-40-of-american-drivers-could-use-an-electric-vehicle-338>)

PEVs make possible the conversion of many vehicle functions that are currently either mechanical or hydraulic to electricity because of on-board electric power that well exceeds what's available from a traditional alternator. Such conversions create new avenues for reengineering the car, including new efficiency improvements and reduction in moving parts, with an attendant reduction of owner maintenance costs. For example, electromagnetic valve lifters designed to keep the engine operating at its optimal point are practical in PEVs. Using electric motors and power electronics for the vehicle drive train can eliminate gear boxes and greatly simplify transmission design and vehicle maintenance. PEV drive trains also permit capture of energy that would normally be expended heating brake liners during vehicle slowing. In addition, the electric drive allows the vehicle's combustion engine to operate in a more efficient power cycle. In general, the technologies for PEV are much newer than those of internal combustion, and offer big opportunities for continued improvement, if market incentive and R&D are both accelerated.

Rail electrification offers further opportunities for zero-emission, zero-oil freight and passenger transportation. If high-traffic rail lines were electrified and powered in part by renewable energy sources, that investment would reduce nationwide carbon emissions and oil consumption. An obvious target is increased reliance on light rail, a form of urban rail public transportation that generally has a lower capacity and lower speed than heavy rail and metro systems, but higher capacity and higher speed than traditional street-running tram systems. The term is typically used to refer to rail systems with rapid transit-style features that usually use electric rail cars operating mostly in private rights-of-way separated from other traffic.¹⁸

¹⁸ See e.g., Light Rail, in Wikipedia. Retrieved 3 May 2012, from http://en.wikipedia.org/wiki/Light_rail

Amtrak operates the busiest intercity electrified corridor in the nation from Boston to Washington, D.C. through New York City. Many other electrified rail lines serve both regional commuters and freight. Electrification should also be extended to other parts of the country where passenger rail operations run on tracks owned by the freight railroads. The relationship with passenger rail operators enables partnerships that could take additional commuters out of their cars and onto trains.

The transportation electrification strategy must also recognize the challenges that have to be overcome before reaching a broad-based electrified transportation system. IEEE recommends the following solutions to overcoming these challenges:

- Promote the rapid deployment of PEVs and HEVs
- Promote the development of battery charging infrastructure, and its deployment by cities, states, and businesses
- Accelerate and diversify federal and private sector R&D aimed at improving battery technology
- Continue federal and utility-sponsored research on the integration of PEVs on the electric grid, developing and implementing industry consensus standards to realize full potential benefits.
- Accelerate and diversify federal and company sponsored R&D aimed at substantially reducing weight, volume, and cost of power electronics and electric machines for PEVs

Each of these recommendations is addressed in detail below.¹⁹

Promoting the rapid deployment of PEVs and HEVs

Light duty vehicles are mainly used for passenger transportation and come in a variety of body styles, such as cars, vans, SUVs, and pickup trucks. As of 2012, about 230 million such vehicles were registered in the United States.²⁰ Sales of new vehicles of this type range from seven million to 12 million per year,²¹ depending on economic and other conditions. At this rate it

¹⁹ A substantial amount of material included in this section has been extracted from the “IEEE Report to DOE QER on Priority Issues,” prepared by the IEEE Joint Task Force on Quadrennial Energy Review, September 5, 2014 (<http://www.ieee-pes.org/images/pdf/IEEE%20QER%20Report%20September%205%202014%20HQ.pdf> and <http://www.ieee-pes.org/images/pdf/IEEE%20QER%20Summary%20Report%20September%205%202014%20HQ.pdf>)

²⁰ Bureau of Transportation Statistics, National Transportation Statistics, Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances (Updated January 2015), http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html

²¹ Ibid, Table 1-12: U.S. Sales or Deliveries of New Aircraft, Vehicles, Vessels, and Other Conveyances (Updated October 2014),

would take at least 10 years to electrify one half of the vehicles, even if the entire new car market were to be converted to PEVs. This hypothetical scenario illustrates the magnitude of the challenge and the importance of a rapid and sustained effort. In 2012 the Obama Administration announced the *EV Everywhere Grand Challenge* with the goal to be the first nation in the world to produce plug-in electric vehicles (PEVs) as affordable and convenient for the American family as gasoline-powered vehicles by 2022.²²

Some are still concerned about the potential overload of the power grid due to wide-spread deployment of PEVs. These concerns are now much better understood. Early studies by PNNL²³ and ORNL²⁴ suggested that more than half of all LDVs could be powered by existing generation resources while more recent studies confirm that **eight to 12 million PEVs can be accepted into the current grid with little impact on generation and transmission**²⁵ as most charging would occur off-peak (if desirable, charging off-peak could be accomplished through a combination²⁶ of tariffs, built-in charging algorithms, demand limiters, or distributed controls).

However, **some of the existing distribution infrastructure may not be able to accept PEVs without some rework**. The peak demand imposed by the PHEV/EREV and BEV on the grid depends on the size of the on-board battery, the owners' driving patterns, the charging strategy, and the charger characteristics. A number of studies have developed and continue developing actual electricity use data, needed to establish the impact on the power system. Some of the readily available data includes The EV Project²⁷ indicating an average of 5 to 10 kWh/day. San Diego Gas Electric suggests a range of 6 to 8 kWh/day for PEV.²⁸ The more powerful chargers will result in much higher demand than that imposed by charging through a conventional plug. Several electric vehicles on one residential street could overload the local

http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_12.html

²² "EV Everywhere Grand Challenge: DOE's 10-year Vision for Electric Vehicles"

<http://energy.gov/eere/vehicles/ev-everywhere-grand-challenge-does-10-year-vision-plug-electric-vehicles>

²³ Kinter-Meyer, M., K. Schneider, and R. Pratt, Impact Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids. Part 1: Technical Analysis; Pacific Northwest National Laboratory, Richland, WA, 2007;

<http://energyenvironment.pnnl.gov/ei/pdf/Impact%20Assessment%20of%20PHEV%20on%20US%20Power%20Grid.pdf>

²⁴ Hadley, S. W., and A. Tsvetkova, Potential Impacts of Plug-In Hybrid Electric Vehicles on Regional Power Generation; ORNL/TM-2006/554; Oak Ridge National Laboratory, Oak Ridge, TN, 2008;

http://web.ornl.gov/info/ornlreview/v41_1_08/regional_phev_analysis.pdf

²⁵ Fang, X., S. Misra, G. Xue, and D. Yang, "Smart Grid - The New and Improved Power Grid: A Survey,"

Communications Surveys and Tutorials, IEEE (Volume: 14, Issue: 4) October 2012. Available:

http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6099519&sortType%3Dasc_p_Sequence%26filter%3DAND%28p_IS_Number%3A6341161%29

²⁶ TOU rates alone may not reduce demand because they don't induce load leveling. In fact, they may increase demand by clustering the start of many appliances to the start of the off-peak period.

²⁷ Education and EV Project Expansion FAQs, The EV Project, U.S. DOE and ECoality;

<http://www.theevproject.com/education.php>

²⁸ "The ABCs of plug-in EVs," SDG&E, 2011. Available:

<https://www.sdge.com/sites/default/files/documents/The%20ABCs%20of%20Plug-In%20EVs.pdf>

distribution transformer²⁹ unless demand management measures are implemented to enforce load diversity and prevent a possible overload. Ample experience already exists with success of such controls, which have been widely applied to off-peak heating and water heating.³⁰

Given the concerns, EPRI has analyzed distribution system impacts of PEV charging^{31,32} and concluded that:

- Diversity of vehicle location, charging time, and energy demand will minimize the impact to utility distribution systems
- Level 1 (standard residential voltage; no extra cost) charging generates the fewest distribution system impacts
- Higher power Level 2 (208 or 240 V) charging generates the strongest system impacts and is typically not required for most customer charging scenarios with light duty vehicles
- Short-term PEV impacts for most utility distribution systems are likely minimal and localized to smaller transformers and other devices where the available capacity per customer is already low
- Controlled or managed charging could defer system impacts for a significant period of time

EPRI concluded that potential stresses on the electric grid can be fully mitigated through asset management, system design practices, and at some point, managed charging of PEVs to shift the load away from system peak. A proactive utility approach of understanding where PEVs are appearing in their system, addressing near-term localized impacts, and developing both customer programs and technologies for managing charging loads is most likely to effectively and efficiently enable even very large-scale PEV adoption. This approach was born out by a series of field tests.

Electrifying transportation would have additional benefits beyond national security and energy independence – it represents a major potential area of economic development and growth. The need for charging stations alone represents creation of an entire new industry for producing, maintaining, and managing the charging infrastructure.

²⁹ Interview with S. Rahman, *Going Electric: Things to Consider* (The Institute, September 2011), <http://theinstitute.ieee.org/ieee-roundup/opinions/ieee-roundup/electric-vehiclespossibilities-challenges-and-their-impact>

³⁰ See, for example, IEEE Tutorial Course: Fundamentals of Load Management/89Eh0289-9-Pwr (1988)

³¹ *Transportation Electrification: A Technology Overview*, EPRI report 1021334, July 2011; http://www.smartgridinformation.info/pdf/4525_doc_1.pdf

³² Maitra, A., *Preparing the Distribution Grid to Embrace PEV*, September 2012 (<http://www.naefrontiers.org/File.aspx?id=35967>)

IEEE-USA recommends the following actions to promote deployment of PEVs and HEVs:

- Offering federal and state tax rebate incentives for electric vehicle purchase
- Offering state and city incentives, such as commuter lane driving opportunities, and special parking privileges for consumers who drive PEVs and HEVs
- Accelerating U.S. Department of Defense development of HEV and PEV technology for military applications
- Offering city-, county-, or state-, region-sponsored incentives for PEV sharing
- Offering city and state license incentives for using PEVs and HEVs as taxis
- Purchasing PEVs and HEVs by companies for employees' use

Development and deployment of battery charging infrastructure

The simplest form of battery charging infrastructure is standard electric plugs (Level 1 charging). Ready access to such plugs would meet the needs of almost half of U.S. drivers. Higher charging rates can be provided through Level 2 charging stations, which may use residential 240 V plugs, or high power commercial/industrial DC stations designed for rapid charging.³³

To help accelerate the adoption of the PEVs eight states have formed an electric vehicle compact³⁴. These states include California and New York and account for 28% of the total vehicle market in the U.S. The goal of the compact is to develop infrastructure, coordinated policies, codes and standards and a consumer market to put more than 3.3 million “zero-emission” vehicles on the roads in those eight states by 2025. This goal increase would be a tripling of the current pace of growth for electric vehicles. More than 1,000 public charging stations exist today and more than 14,000 are planned or under contract.³⁵ Plugshare offers pointers to more than 50,000 charging locations in North America³⁶, including many private chargers that the owners are willing to share with others who are traveling. On the West Coast, work is underway to provide a North to South fast charging infrastructure that will allow a driver to make the drive from Mexico to Canada without having to wait for regular charging times.³⁷ It is important to note that these “fast charging” stations are essential only for the BEV that cannot recharge from the onboard ICE. For the PHEV/EREV, fast charging is not really needed.

³³ See, for example, IEEE Transportation Electrification website (<http://electricvehicle.ieee.org/search-results/?q=charging%20options>) or DOE Alternative Fuels Data Center (http://www.afdc.energy.gov/fuels/electricity_infrastructure.html)

³⁴ “Multi-State ZEV Action Plan,” ZEV Program Implementation Task Force, May 2014. Available: <http://www.nescaum.org/topics/zero-emission-vehicles>

³⁵ Ibid

³⁶ PlugShare – EV Charging Station Map. Available: <http://www.plugshare.com/>

³⁷ “West Coast Electric Highway,” Washington State Department of Transportation. Available: <http://www.westcoastgreenhighway.com/electrichighway.html>

The challenge of charging infrastructure will need to be addressed at all levels of government and industry, because in most cases the features of residential, commercial, and industrial properties and of public streets are matters controlled by state and local governments.

IEEE-USA recommends that the following issues and opportunities be addressed:

- **Encourage state commissions to follow the California Public Utility Commission (PUC) example.** The California PUC concluded that electric vehicle service providers would not be regulated as public utilities, but would be subject to the Commission’s regulatory authority.³⁸
- **Building and zoning code issues related to residential charging stations in home garages and driveways.** Examples of these issues include electric service requirements for residences and zoning rules (or permissible neighborhood covenant restrictions) that govern placement and allowable locations for ancillary structures, such as charging stations, on residential properties and building properties and building and zoning code requirements for charging stations in parking lots and parking structures of commercial, industrial, and multifamily residential buildings.
- **Municipal deployment of charging stations along public streets** -- possibly incorporated into parking meters.
- **Expand opportunity charging options**, such as employer-provided plug-in opportunities. U.S. government facilities should lead by example.

Improving battery technology

Battery is a key component of electric vehicles and its cost is the principal barrier to rapid penetration of PEVs. There have been encouraging research announcements regarding battery technology and materials. As to materials, most of the world's lithium reserves are in Bolivia, Chile, China, therefore its supply is subject to political considerations. However, the lithium industry is expanding and new players like Australia have been moving quickly, using new technology. Lithium industry spokesmen have stated that the cost of lithium is no more than 1% of the cost of a lithium-ion battery pack³⁹, and that a ten-fold increase in price would open up new supplies much greater than any likely expansion of demand. There is a general agreement that Li-ion battery chemistry has a great potential for substantial cost reduction.

³⁸ California Public Utilities Commission, Rulemaking 09-08-009, Decision in Phase 1 On Whether a Corporation or Person That Sells Electric Vehicle Charging Services to the Public Is a Public Utility, Decision 10-07-044, July 29, 2010

³⁹ “Lithium Contained in Batteries Less than 1% of Cost” Technology & Rare Earth Metals (TREM), January 2011 (http://www.tremcenter.org/index.php?option=com_content&view=article&id=505:lithium-contained-in-batteries-less-than-1-of-cost&catid=105:latest-news&Itemid=476)

Some concerns have been voiced about environmental impacts of batteries, including concerns that, in some cases, the impact of batteries and battery production is so large as to negate the environmental benefits of electric transportation. In fact, production and disposal of Li-ion batteries for electric vehicles represent small contributions to life-cycle energy use and CO₂ emissions.⁴⁰ Of the materials used over the years in car batteries, nickel and cobalt are the most toxic, and therefore require the most care during handling and disposal. Over time, these toxic materials are being replaced by more benign and less expensive materials, which should reduce their environmental impacts. Similar changes in battery design and recycling options will continue as the industry searches for better performing and less expensive batteries.^{41,42}

Other materials concerns involve the need for rare earths in producing permanent magnet electric motors. However, alternatives are available in new motor technology (like switched reluctance motors and induction motors) that have higher average efficiency and do not require rare-earths. In past decades, issues of control limited the use of these cheaper and better engine designs, but several novel control technologies can overcome those problems. Companies such as Tesla and Toyota have demonstrated the required expertise and new engine technology.

Advances in battery performance and technology are required to reduce cost, increase power density, extend life, reduce the probability of hazardous failure and promote consumer safety.

- In the near term, improvements in engineering and management of lithium-ion battery systems are likely to deliver some of these needs. New fundamental university-based research is needed to improve our understanding of the interface between electronics and chemistry, as it determines battery lifetime and stability, and to apply new methods of intelligent control to maximize these variables in an adaptive way.
- For the longer term, novel battery chemistries, like metal-polymer, metal-air and silicon-air, could yield more dramatic advances in performance as well as a potential to make batteries from more common materials.
- As discussed below, in parallel with battery development, R&D is needed on power electronics for PEVs to reduce size and cost, improve fast-charging capability, and facilitate use of efficient motors (such as induction and switched reluctance technologies) that eliminate use of rare-earth materials.

Specific needs are to extend vehicle all-electric range; increasing energy storage density; decreasing cost; improving battery life and safety; and optimizing the associated power

⁴⁰ Dunn, JB; Gaines, L; Kelly, J.C.; James, C.; Gallagher, K. G., "The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction.", *Energy and Environmental Science* 8: 158-168 (2015)

⁴¹ "Application of Life-Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles," EPA 744-R-12-001, April 2013

⁴² Gaines, L., "The future of automotive lithium-ion battery recycling: Charting a sustainable course," *Sustainable Materials and Technologies*, Volumes 1–2, December 2014, Pages 2–7

electronics and controls. As with Li-ion, the R&D effort must remain cognizant of potential environmental issues that may arise in the course of battery production and disposal.

IEEE-USA recommends accelerating public and private sector battery R&D battery R&D focusing on:

- Increasing energy storage density
- Decreasing cost
- Increasing life
- Assuring safety
- Enabling rapid battery recharge or change-out strategies
- Identifying secondary markets for used batteries
- Recycling strategies

Integrating PEVs with the electric grid

With the appropriate technical and regulatory framework, the PEV batteries may also be able to provide services needed by the grid to balance the variability of wind and other variable and uncertain power resources. A consortium of eight automakers and 15 electricity utilities has been formed to address the PEV interface with the grid⁴³. As stated by GM⁴⁴:

“The first goal of this national effort to streamline EV charging is to develop a standardized Demand Response solution. Demand Response is the signal the utility sends to the energy management company which tells it just how much electricity is needed. While having a single EV plugged in to charge isn’t going to change the dynamics of electrical flow, once you have whole neighborhoods plugging in their cars every night after work, managing electricity becomes that much more important”.

It is expected that operational aspects of grid integration of PEVs will be handled mainly by the appropriate elements of the Smart Grid. The architecture being developed in the NIST-lead effort (<http://www.nist.gov/smartgrid>) identifies the actors and interfaces related to communications, control, metering, accounting, and settlement for PEV's.

PEV's are likely to have other technical impacts on the grid that will also need to be considered. For example, some utilities depend on overnight cooling of distribution transformers, cables and conductors to achieve reliability. As discussed earlier in this document, if overnight load levels remain high because of PEV charging, transformer reliability and lifetimes could be

⁴³ EPRI, *Utilities, Auto Manufacturers to Create an Open Grid Integration Platform for Plug-in Electric Vehicles*, July 2014; <http://www.epri.com/Press-Releases/Pages/EPRI,-Utilities,-Auto-Manufacturers-to-Crete-an-Open-Grid-Integration-Platform.aspx>

⁴⁴ *GM Joins National Smart Grid Consortium*, Clean Technica, August 2014; <http://cleantechnica.com/2014/08/06/gm-joins-national-smart-grid-consortium/>

affected. Data on transformer and distribution system loading will be required to manage the PEV charging at higher saturations. New intelligent systems will be needed to optimize performance and reliability, minimize cost, diversify the load, manage potential cold load pick-up surges, and coordinate generation pricing and user decisions.

An important consideration is that batteries are no longer suitable for vehicle use when their capacities fall below about 70 percent of design capacity. However, even at that level the batteries are suitable for use in stationary storage applications, and may eventually contribute to solving the need for large scale energy storage. Recycling of EV batteries is likely to be easier than lead-acid, but must be addressed.

Regulatory issues also affect the extent to which it will be possible to integrate PEVs with the electric grid. Without an effort to standardize the processes drivers will inevitably encounter problems as they travel between jurisdictions. Examples include:

- **Differences in rules for vehicle-to-grid relationships.** In some jurisdictions vehicles may participate in ancillary services markets. In other jurisdictions such markets may not exist. A vehicle roaming from one jurisdiction to another will encounter a variety of rules.
- **Lack of cross-jurisdictional arrangements for payment and settlement.** This especially applies to vehicles that roam from one jurisdiction to another.
- **Determination of whether charging infrastructure is a utility function or not.** Again, each jurisdiction makes its own rules. In some jurisdictions a vehicle owner may deal with a utility and in others the vehicle owner may need to make private arrangements. This issue is further discussed below.
- **Differences in possible market structures in various jurisdictions.** Some jurisdictions might allow aggregators, others might require them to meet minimum market participation size requirements, and still others might not allow them. Aggregators can act as critical intermediaries between vehicle owners and complex market structures.

The levels of grid interaction described above require increasing levels of communication and control. There are a number of elements involved in these functions, including:

- The vehicle
- The charging station
- The premises network (home, building, commercial or industrial site)
- The Load Serving Entity and/or aggregator that coordinates numerous loads for the grid
- Transmission and distribution grid operator
- Entities that manage accounting, billing, and settlement

Proper coordination among these elements will be needed to fully realize the benefits of vehicle-to-grid energy exchange functions. Some of that coordination will need to take place as often as every four seconds.

IEEE-USA endorses FERC's emphasis on electrification of transportation as one of the priority areas in its Smart Grid policy statement (<http://www.ferc.gov/whats-new/comm-meet/2009/071609/E-3.pdf>). This FERC policy resulted in electric transportation becoming a priority issue in the NIST Smart Grid efforts (<http://www.nist.gov/smartgrid/>). These efforts have resulted in:

- Defining a conceptual architecture for integrating communications, control and PEV's into the grid. For example, the architecture includes separate sub-metering of the PEV to support pricing arrangements and vehicle-to-grid accounting.
- Accelerating standards development to support PEV-related requirements.
- Identifying cybersecurity issues related to PEV communications and incorporating PEV standards into the Smart Grid Catalog of Standards after cybersecurity review.
- Identifying the significant privacy issues associated with PEV communications, control, and especially metering and accounting.
- Developing a draft four-stage roadmap for electric vehicle deployment, identifying the challenges and issues to be addressed to reach each stage-- including eliminating functionality barriers and advancements.

While it is important to integrate PEVs with the Smart Grid, such integration raises numerous cybersecurity and privacy issues that must be addressed. Examples include:

- Implementing Smart Grid cybersecurity requirements applying to PEVs.
- Implementing Smart Grid privacy requirements, involving access control or data tamper protection, as these requirements are developed in detail. Cybersecurity requirements (such as encryption protecting confidentiality) will accomplish some of the implementation requirements, but others will be specific to market arrangements.
- Supply chain integrity for the hardware and software that implements PEV communications and control, especially as it applies to interactions with the grid.
- Managing cryptographic keys for encrypting and authenticating PEV-related messages.
- Methods for secure PEV software upgrade, to support improvements in PEV integration and procedures for grid interaction.

- Implications of concerns about malicious access to on-board vehicle systems.

Examples of privacy issues include:

- Location and movement tracking--concern that a PEV could be tracked via an electronic "trail," opening up a variety of privacy issues common to numerous systems.
- Retention in back-end enterprise networks of information that includes sufficient personal identification to make it potentially suitable for numerous privacy-invading purposes. Examples of such back-end networks could include systems for billing and settlement as well as systems that retain grid operational history.
- Basic issue in PEV travel across jurisdictions of whether the vehicle roams or the driver roams, and the privacy impacts of being able to track them either individually, or both in conjunction.
- Cost and settlement infrastructure for roaming. There are numerous examples, such as credit cards, cell phones, and multi-jurisdictional toll road payment systems. However, such a system needs to be worked out for PEVs and its privacy implications evaluated.
- Identity theft, facilitated by misuse or intrusion on back-end systems, communications, or the devices in the PEV.

IEEE-USA recommends continuing federal and utility-sponsored research on integrating PEVs onto the electric grid, developing and implementing industry consensus standards to realize full potential benefits. Specifically:

- Improve grid communication and interoperability through timely development of Smart Grid standards and roadmaps
- Address cyber security issues
- Develop an institutional infrastructure for testing and certification of products for compliance with Smart Grid standards
- Resolve technical and jurisdictional issues associated with equipment and devices that operate across institutional, regulatory, and information architectural boundaries (e.g. grid spare parts)
- Put selected standard development on a “fast-track”. The U.S. Government and especially NIST have an important role in helping with this process. The standards and research needs include:

- **Physical grid equipment**, primarily at the distribution level. Experimental work is required to establish sizing and implementation guidelines.
- **Sensors** for PEV monitoring, both for charging and discharging the PEV back into the grid, along with supporting regulations.
- **Controls** that allow the utility (in addition to the customer), under an agreed to contract, to start and stop charging the PEV.
- **Security** of communications to and from any PEV and/or charging station.
- **Modeling and Forecasting** electrical demand with the increase in PEV and other distributed energy resources.
- **Garaging PEV** - Research on where PEVs are likely to be garaged both during the day and at night.
- **Natural disasters** - Using PEV batteries to support electric needs during natural disasters.

Pursuing Power Electronics and Electric Motor R&D

Successfully entering electric drive vehicles into the market place is a consequence of the convergence of technological advances in materials, semiconductor devices, power electronics, controls and batteries. For example, the technical feasibility of HEVs is primarily due to advances in power electronics and electric motors. Power electronics and electric motors that make up vehicles' electric drive system are essential to electrified vehicles and indeed all of transportation electrification. As such, improvements in these technologies (components and systems) can substantially improve efficiency, reduce vehicle weight, reduce petroleum consumption, and help meet economic, environmental, and energy security goals. For example, researchers in unified converter design have estimated that cost and weight of power electronics for PEVs could be cut in half or more, with aggressive development and deployment of that technology; other new options may be just as important, and compatible with unified design.

Power electronics, controls and the electric motor are significant systems cost components, as well as technical enablers. As costs have been an evolving moving target, a specific percentage of total costs is difficult to construct. Much of this data is business sensitive and proprietary. It also varies with the different categories of vehicles, HEV, PHEV/EREV and BEV as the battery changes in size from ~1 kWh to perhaps 100 kWh. **For today's HEV, the power electronics and electric motor probably contribute costs greater than the battery while the battery certainly dominates the cost in a BEV with substantial range.**

IEEE-USA recommends accelerating and diversifying federal- and private sector-sponsored R&D aimed at substantially reducing weight, volume, and cost of power electronics, and electric motors, including:

- Continued reductions in weight, volume and costs of complete systems
- More efficient power electronic interfaces, and integration with electric motors, protection and control systems
- Semiconductor materials and improved device performance research
- Advanced power electronics packaging and thermal management systems
- Enhanced device and power electronic system reliability
- Alternatives to rare earth permanent magnet materials and continued improvement in electric motor performance

DEVELOPING AND USING ALTERNATIVE TRANSPORTATION FUELS

In his State of the Union speech of 2007, warning about the consequences of US “addiction to oil,” George Bush argued that alternate liquid fuels could lead us relatively quickly to energy independence. After some filtering by Congress, his views were embodied in the Energy Information and Security Act (EISA) of that year, and in the Renewable Fuels Standards (RFS) that implement it. How to improve that bill and those regulations is still one of the key issues for policy today.

Jimmy Carter also selected a diverse group of alternate liquid fuels, called synfuels, as the core of his Project Independence effort of the 1970s. Both with Carter and with Bush, good intentions combined with difficulties in technical implementation led to many costs and inefficiencies. These inefficiencies tended to polarize the politics of this issue, and obscure the most important technical realities and opportunities in this sector. They also highlight the need to pay attention to the technical details.

Among the most important technical realities crying out for more attention are:

*** High purity ethanol made from food corn offers only a tiny fraction of the alternate fuels which could be used in US transportation.** There is growing public concern about how 40 percent of the U.S. corn crop now goes to supplying a small fraction of US liquid fuel demand, imposing costs on water and food supply far greater than what would be required by many other alternate liquid fuels. This concern is due, in part, to a specific provision in EISA and in RFS which sets aside a quota for this kind of ethanol fuel, shielding it from competition from other alternate liquid fuels. In the face of growing pressure to repeal RFS, due to these problems, it becomes ever more important to consider the possibility of reforming it instead, to allow more competition and efficiency in achieving Bush’s original goals or more.

*** The greatest and most reliable potential supply of alternate liquid fuels, with the least economic and environmental cost, lies in fuels like methanol or mixed alcohols which lead to high performance in cars designed to use it but which are too corrosive to use more than about five to 10 percent in blends of gasoline for today’s cars.**⁴⁵ While it is impossible for anyone to reliably predict the costs of competing types and sources of fuel, as they will fluctuate in the decades to come, it is clear that full flexibility in cars and trucks and in refueling systems would cost many times less than the price differences between fuels⁴⁶. It would have substantial value to the national security of the US and its allies, by reducing the damage which might occur in the worst case scenarios.

*** Fuel flexibility and electrification are not alternatives to each other. They are synergistic approaches that work best when combined together.** The greatest consumer choice, flexibility and security within reach today would come from deploying plug-in hybrid cars with an all-

⁴⁵ Olah, George A. "Beyond oil and gas: the methanol economy." *Angewandte Chemie International Edition* 44.18 (2005)

⁴⁶ <http://www.openfuelstandard.org/>

electric range of 20 to 40 miles and with a fuel system flexible enough to make use of gasoline, E85 ethanol fuel, and fuels as corrosive as M85. This kind of flexibility, GEM85, is less expensive to add in PHEV than in conventional cars, simply because the cost of gasoline engines, hoses and pumps is smaller in PHEVs than in conventional cars of the same size.

*** Unlike electrification, fuel flexibility for liquid fuels could be deployed very quickly, at much less cost per car than electrification or ability to use gaseous fuels like hydrogen or natural gas.** From January 2003 to May 2005, gasoline-ethanol (GE) flexible cars increased their market share in new light duty vehicles from less than five percent to well over 50 percent, in response to market conditions, such as a plentiful supply of ethanol⁴⁷. The technology for GEM85 flexibility is largely the same as that of GE flexibility, already well known to U.S. auto-makers, except for the need to purchase more durable materials in hoses, gaskets, engines and pumps, from existing catalogs. It is currently estimated that GEM85 flexibility in new cars would add less than \$100 per car today, but even lower costs could be obtained for GEM60 flexibility, which would already be enough to open up large new fuel markets and competition. The cost of GEM60 flexibility would mainly be the cost of using more durable gaskets and hoses, which would also benefit the consumer by improving safety and ability to tolerate moisture even when using petroleum as a fuel.

*** The farm industry would benefit substantially from greater fuel flexibility in cars, in fuel distribution systems and in RFS.** The revenue received today from corn ethanol is substantial, but much of that revenue goes to cover costs due to inefficiency, which also degrades the environment. For example, there is growing concern that runoff to the Gulf of Mexico may be causing dead zones in the ocean, which some environmentalists view as a greater threat than global warming (though the interaction of the two problems is especially worrisome). Farmers could get about twice as much fuel value per ton of biomass, and use lower grade nonfood biomass, if cars could make full use of mixed alcohols, and if the restriction in RFS on alternative biofuels could simply be eliminated. The technology of producing low-cost mixed alcohols, such as moonshine, has existed for generations, and could be deployed on a larger scale very quickly if market competition could be opened up. The complex restrictions in RFS were the product of a tradeoff between carbon dioxide concerns and national security, but the actual benefits of these restrictions to reducing CO2 emissions has been negligible. A more open, competitive market for biofuels would allow the development of new options which are the only serious hope for significant CO2 reductions in this sector.

*** A more diverse and competitive market for liquid fuels would also open up major opportunities and improve efficiency in the fossil fuel industry, for however long that industry remains a major part of the system.**⁴⁸ For example, industry analysts estimated that the cost per mile of fuel derived from natural gas is actually less when natural gas is converted to methanol than when it is used directly in vehicles, for a wide variety of vehicles and sources of natural gas. Large quantities of natural gas are still being vented, flared and wasted (adding

⁴⁷ Tom McDonald, California Energy Commission, Alcohol Fuel Flexibility: Progress and Prospects, 15th Annual Symposium on Alcohol Fuels (original source: ANFAVEA, Brazilian Motor Vehicle Association)

⁴⁸ <http://www.methanol.org/Energy/Transportation-Fuel/Methanol-Policy-Forum-2012.aspx>

to CO2 emissions without contributing to fuel demand) as a byproduct of oil production, especially in the Middle East. GEM flexibility would allow nations like Saudi Arabia to continue to supply the same high level of liquid fuel to world markets, by avoiding that waste and reducing the exhaustion rate of their oil.

*** The technical and environmental feasibility of using M85 fuels was established decades ago, but there is still room to improve efficiency through R&D.**

As discussed above, liquid fuel alternatives are needed to complement the benefits of electrified transportation and to extend the clean range of PEVs beyond the limits imposed by their battery capacity.

IEEE recommends the following:

- Passing federal legislation to mandate fuel flexibility in vehicles
- Promoting fuel flexibility in the fuel distribution system; and advanced control technologies to maximize efficiency, and minimize emissions across the fuels spectrum
- Pursuing federal R&D to convert sustainable biomass to transportation fuels, that can be blended and distributed with gasoline
- Government Vehicles: In all government procurement of light-duty vehicles, give preference to vehicles that offer three-way fuel flexibility, to use at least gasoline, ethanol, and M60 methanol blends
- High EROI Fuels: Promoting the use of biofuels that offer a higher energy return on energy invested (EROI)
- Natural Gas: Supporting comprehensive congressional legislation to promote greater use of natural gas in heavy-duty vehicles, so long as such legislation provides equal, or greater, stimulus to electrification and alternative vehicles

Each of these recommendations is discussed in further detail below.

Vehicle Fuel Flexibility, Fuel Distribution and Control

Vehicle fuel flexibility – The ability of a vehicle to operate with multiple fuels, such as gasoline, ethanol, methanol, natural gas, and others -- is a well understood technology in common use in many countries. Brazil is a leading country in modern deployment of this technology. Fuel flexible vehicles have been sold in the United States. In fact, the first flexible fuel vehicle was the Ford Model-T⁴⁹ although most modern US vehicles allow only up to a 10 percent ethanol blend. There is minimal impact on the cost of the vehicles, and the technology could easily be

⁴⁹ English, Andrew (2008-07-25). "Ford Model T reaches 100". London: The Telegraph. <http://www.telegraph.co.uk/motoring/main.jhtml?xml=/motoring/2008/07/25/mnmodel125.xml>. (Citation credit to Wikipedia)

provided as a standard feature of all vehicles. All that is needed to move toward nationwide fuel flexibility is a legal mandate to provide the technology in vehicles sold in the United States.

The Brazilian transition to FFVs was driven by the widespread availability of ethanol fuel, due to previous mandates from the government of Brazil. Without government intervention, a substantial “chicken and egg” problem arises (which market economists call a nonconvexity or barriers to entry problem) because consumers will not press for fuel flexibility when alternate fuels are not available, while fuel makers will not supply a fuel which few cars can use. By mandating flexibility and competition, the US can get to a better destination than what Brazil reached (more flexibility) at a much lower cost in government intervention. Crudely, if the cost of flexibility is less than \$100 per car, and if 17 million new cars are sold every year (as at present), the cost of flexibility would be well under \$1.5 billion per year, versus a fuel bill well over a hundred times as large. This cost is less than the new standards for digital television that Congress passed a few years ago, in a similar effort to open up the market to new products and new competition.

Various potential liquid fuels, as well as natural gas, have widely varying attributes regarding production requirements, costs, impacts on vehicle performance, the fuel distribution system, and emissions. For example, ammonia can be produced directly from natural gas or from water using electricity and has no carbon emissions when burned, but requires different characteristics of the vehicle engine and fuel distribution system. Also, the car’s NOx emissions would increase. We need to aggressively explore the universe of potential choices and their implications and focus the R&D accordingly.

Having fuel flexibility in vehicles has no value, unless alternative fuels are widely available. A flexible fuel distribution system must be in place as well, to deliver the alternative fuels to vehicles. Currently even diesel fuel is not widely available in some areas of the United States. Promoting alternative fuels’ availability could include a variety of incentives and mandates, but this challenge should be addressed as part of a fuel flexibility mandate. Fuel flexibility may also require advances in vehicle controls, to maximize efficiency and minimize emissions while using multiple fuels that may be mixed in vehicle fuel tanks.

IEEE-USA recommends that:

- Congress give priority to passing a new law similar in spirit to the Open Fuel Standard bill,⁵⁰ calling for at least GEM60 flexibility in all new cars, and requiring clear, colorful inexpensive labeling of both fuels and fuel intake doors, to encourage this market. To assure availability of alternate fuels the law should also address flexibility in the fuel distribution system.

⁵⁰ <http://www.openfuelstandard.org/>

Sustainable biomass R&D

Sustainability is a factor that must be incorporated into biomass use for fuel. Rational economic incentives would reduce the use of arable land be used for biofuel production. At the minimum, we should accelerate R&D to develop fuel production technology based on biomass⁵¹ that does not compete with food and does not increase water use. Some of the considerations include:

- The widely reported impact of food-based biofuel production on worldwide food prices. This impact is caused by tightening the market for food and switching farmland from production intended for food to production of biofuel feedstock. This switch is generally referred to as indirect land-use impacts.
- The greater productivity feasible with non-food-stock biofuel. For example, according to a report prepared for the Chesapeake Bay Commission,⁵² corn produces only 30 gallons of ethanol per acre per year, but a properly operated algae facility can produce fuel in the range of 3,000 to 5,000 gallons per acre per year.

Target fuels include both surface transportation fuels and aircraft jet fuel. The U.S. Department of Defense is particularly aggressive in planning to switch to renewable biofuels. The Navy and Air Force are testing biofuels for aviation and shipboard use and are planning to use at least 50 percent biofuels by 2020.⁵³

IEEE-USA Recommends pursuing R&D to convert sustainable biomass to transportation fuels.

Natural Gas

Extensive debates are ongoing about the economic and technical feasibility of carrying compressed natural gas, hydrogen or even ammonia in the tanks of large trucks or even cars, for use in direct combustion or in fuel cells. Because of the large externalities supporting government action on fuel flexibility, related to energy security and environmental security, IEEE does support rational incentives to encourage these alternatives, as well as the alternatives discussed above. However, a rational market-based approach requires that the incentives be essentially the same for these gasses as for upgrading gas stations for flexibility with liquid fuels, and for greater use of electricity. For electricity and for natural gas vehicles,

⁵¹ See, for example, SBE Special Section: *Lignocellulosic Biofuels - The Need for Biofuels*, Chemical Engineering Progress (CEP), March 2015; <http://www.aiche.org/resources/publications/cep/2015/march/sbe-special-section-lignocellulosic-biofuels-need-biofuels>

⁵² Chesapeake Bay Commission and Commonwealth of Pennsylvania, *Next-Generation Biofuels: Taking the Policy Lead for the Nation*, September 2008

⁵³ P. Molchanov, *Four-Star Biofuels: How the Pentagon is Outpacing Civilians in Gen2 Adoption*, Raymond James Associates Energy Industry Brief, March 19, 2012

incentives are called for, rather than mandates, simply because the cost per vehicle amounts to thousands of dollars in both cases. Incentives are also called for to encourage developing new technology in these sectors. Except for when fuel cells are used, there are more unmet opportunities for fundamental breakthrough technology in the electric sector, than in the others.

It is questionable whether use of a conventional PEM fuel-cell in place of the small gasoline engine like the Atkins engine used in the Prius hybrid would actually result in higher efficiency, if losses in storing gasses are considered, let alone the costs and/or emissions in producing hydrogen. However, there is some hope for breakthrough R&D to develop more efficient fuel cells compatible with high efficiency steam reformers converting methanol fuel to hydrogen on-board a vehicle.⁵⁴ Hydrogen and methanol both pose difficulties with the classic “chicken and egg” problem, the problem of who goes first – consumers, to buy cars which can use the new fuel, or suppliers, to supply the fuel in gas stations; however, with methanol, there is a pathway which costs far less, by using low-cost fuel flexibility in conventional cars to stimulate a supply of fuel. Electricity and natural gas are more widely available already, but technology to convert natural gas to hydrogen on-board a vehicle entails much larger losses and emissions than steam reformers for methanol.

IEEE recommends supporting comprehensive congressional legislation to promote greater use of natural gas in heavy-duty vehicles, so long as such legislation provides equal, or greater, stimulus to electrification and alternative fuel vehicles.

CONCLUSIONS

Electrified transportation and liquid fuel alternatives are complementary technology paths to diversifying transportation energy sources. The greatest consumer choice, flexibility and security within reach today would come from deploying plug-in hybrid cars with a fuel system flexible enough to make use of alternate liquid fuels. This kind of flexibility is less expensive to add in a PHEV than in conventional cars, simply because the cost of gasoline engines, hoses and pumps is smaller in PHEVs than in conventional cars of the same size.

The infrastructure for electric transportation is in place and the use of electricity for transportation comes with numerous attendant benefits, such as:

- Increased transportation energy efficiency
- Reduced urban smog
- Reduced greenhouse gas emissions

⁵⁴ P. Molchanov, M. Urquidi-Macdonald, A. Sen, Patrick Grimes, A. Tewari & V. Sambhy, Design and Test of a Carbon-Tolerant Alkaline Fuel Cell, <http://arxiv.org/abs/physics/0504130>

However, achieving significant penetration of these technologies requires a sustained effort aimed at resolving a number of research, engineering, and business issues. One of the most significant needs is developing less expensive, higher performance batteries.

Alternate liquid fuel options are available as well. However in selecting a strategic portfolio it is necessary to consider the following observations:

- High purity ethanol made from food corn offers only a tiny fraction of the alternate fuels that could be used in U.S. transportation.
- The greatest and most reliable potential supply of alternate liquid fuels, with the least economic and environmental cost, lies in fuels like methanol or mixed alcohols which lead to high performance in cars designed to use them but which are too corrosive to use more than about five to 10 percent in blends of gasoline for today's cars.
- The farm industry would benefit substantially from greater fuel flexibility in cars, in fuel distribution systems and in RFS.
- A more diverse and competitive market for liquid fuels would also open up major opportunities and improve efficiency in the fossil fuel industry, for however long that industry remains a major part of the system

ABOUT THIS IEEE-USA POSITION STATEMENT:

This statement, as approved by the IEEE-USA Board of Directors on 29 October 2015, was developed by IEEE-USA's Energy Policy Committee, as an addendum to IEEE-USA's Position Statement on the *National Energy Policy Recommendations*. It represents the considered judgment of a group of U.S. IEEE Members with expertise in the subject field. IEEE-USA advances the public good and promotes the careers and public policy interests of the 200,000 engineering, computing and technology professionals, who are U.S. members of IEEE. The positions taken by IEEE-USA do not necessarily reflect the views of IEEE, or its other organizational units.