EV Everywhere: -
A Grand Challenge in Plug-In Electric Vehicles -

Initial Framing Document -

White Paper to Explore -
A Grand Challenge in Plug-In Electric Vehicles -

DRAFT

Disclaimer: The purpose of this paper is to facilitate discussion among participants in the "*EV Everywhere* Grand Challenge" Workshops. This paper does not represent, reflect, or endorse an existing, planned, or proposed policy of the U.S. Government, including but not limited to the U.S. Department of Energy. The U.S. Department of Energy does not guarantee the accuracy, relevance, timeliness, or completeness of information herein, and does not endorse any sources used to obtain this information. As such, this paper is not subject to the Information Quality Act and implementing regulations and guidelines.

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I. Introduction

The *EV Everywhere* Challenge is a U.S. Department of Energy (DOE) "Clean Energy Grand Challenge" with the goal of enabling U.S. companies to be the first in the world to *produce plug-in electric vehicles (PEVs) that are as affordable and convenient for the average American family as today's gasoline-powered vehicles* within the next 10 years. President Obama announced the *EV Everywhere* Challenge on March 7, 2012. The goal of the aggressive *EV Everywhere* Grand Challenge is to enable American innovators to rapidly develop and commercialize the next generation of vehicle, component, and charging infrastructure technologies to achieve sufficient PEV cost, range, and charging infrastructure to assure widespread PEV deployment without subsidies. Broad deployment of PEVs will dramatically decrease American dependence on foreign oil, will provide stable and low fuel prices for American families with the convenience of plugging in at home, and will reduce the environmental impact of the transport sector. Winning the *EV Everywhere* Challenge will also put the U.S. in the lead to manufacture and export the next generation of advanced PEVs and PEV components, creating high paying manufacturing jobs and stimulating the American economy.

PEVs can offer consumers significant advantages over gasoline-powered vehicles, including savings on fuel costs, added convenience, and reduced maintenance costs. Electricity is cheaper than gasoline to power a vehicle – generally equivalent to less than $1 per gallon of gasoline equivalent – and consumers are able to conveniently fuel up at home. Electric vehicles can also offer the same or better driving performance compared to today's gasoline-powered vehicles. Furthermore, recent analysis by DOE in its inaugural Quadrennial Technology Review shows that EVs can achieve a dramatic reduction in petroleum energy use and a significant reduction in life-cycle greenhouse gas (GHG) emissions.

The purpose of this paper is to facilitate discussion among the public and participants in the "EV Everywhere" Grand Challenge workshops. The paper has not been submitted for peer review and is not intended to be a definitive resource on the topics addressed. DOE expects that discussions at public information exchanges will provide additional information and perspectives on the topics addressed below.

II. Scope

For the purposes of this Initial Framing Document, we put forward the following initial key parameters for the *EV Everywhere* Challenge:

- 5-passenger mid-size vehicle
- Majority of vehicle-miles-traveled powered by electricity under standard drive cycles
- 5 year simple payback vs. equivalent gasoline powered vehicle
- "Vehicle range/charging infrastructure" scenarios where the majority of consumers are willing to consider purchasing the PEV as a primary vehicle
- No reduction in grid reliability

To frame the discussion of the *EV Everywhere* Challenge, DOE is considering three specific framing "Vehicle/Infrastructure" scenarios, namely:

1. - A plug-in hybrid electric vehicle with a 40-mile all-electric range (PHEV-40) with limited fast-charge infrastructure;
2. - An all-electric vehicle with a 100-mile range (AEV-100) with significant intra-city and inter-city fast charge infrastructure; and
3. - An all-electric vehicle with a 300-mile range (AEV-300) with significant inter-city fast charge infrastructure.

Each of these framing "Vehicle/Infrastructure" scenarios would provide a majority of vehicle-miles-traveled powered by electricity, but the vehicle costs and the infrastructure costs (both public charging and home charging) would be quite different in each scenario.

Key Participants

Dramatic improvements in PEV performance and cost will require a well-coordinated effort across all of the DOE complex and with America's most innovative researchers and companies. Innovations in PEV technology occur as a result of fundamental investigations carried out at national laboratories and universities supported by the DOE Office of Science, through translational research sponsored by ARPA-E, and through applied research and development at labs, universities and industry supported by the DOE's Office of Energy Efficiency and Renewable Energy (EERE). Innovations coming from R&D on pre-competitive technologies will be transferred to and implemented by industry participants as a business case develops for these technologies through the US DRIVE public/private partnership (Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability)[1].

III. Considerations for Widespread Consumer Adoption of Plug-In Electric Vehicles

Where we are today

The 2011 DOE Quadrennial Technology Review concluded that electric drive vehicles (HEVs, PHEVs, and AEVs) offer a significant opportunity to reduce petroleum consumption, lower greenhouse gas emissions, reduce air pollution, and build a competitive U.S. industry within the next decade. Electric drive vehicles in which the majority of miles driven under standard drive cycles can be powered with electricity include plug-in hybrid electric vehicles (PHEVs) and battery-powered all electric vehicles (AEVs).

American automakers and automotive suppliers are currently pioneering the way forward in getting the first wave of electric vehicles into the hands of a significant number of U.S. drivers. But today, the prices of these cars are still out of reach for the majority of American families. The Tesla Roadster, with a range greater than 200 miles, was the first production automobile to use lithium-ion batteries, and more than 2,000 cars have been sold since 2008. Tesla is utilizing a DOE loan to bring the full-sized Model S battery electric sedan with 160-mile range to market in 2012. In 2010, GM delivered the first mass produced PHEV (Chevrolet Volt) and Nissan delivered the first mass produced AEV (Nissan Leaf). PHEV and AEV models are scheduled to beintroduced by Fisker, Ford, and others.

DOE is supporting the establishment of manufacturing capability for batteries and electric drive components through Recovery Act grants. By 2015, manufacturers will have the domestic capacity to produce batteries at a production rate of 500,000 units per year (based on 10 kWh average battery size). DOE is also supporting early adoption of PEVs by conducting technology validation through vehicle testing and data collection, public outreach through the Clean Cities/Clean Fleets programs, and infrastructure development through Recovery Act funded deployment of 13,000 PHEVs and AEVs and 23,000 chargers in more than 20 cities around the country.

Electric Vehicle Purchase Decisions

Vehicle purchase decisions are the result of many factors. For individual consumers, "identity statements" and style play central roles. Electric vehicle attributes such as instant torque, quiet drive and home recharging may be attractive to many purchasers. At present, there is limited data to evaluate the role of these factors in electric vehicle purchase decisions in the years ahead.

One constraint on electric vehicle adoption is likely to be the additional purchase price associated with battery costs. Reducing those costs will likely speed adoption. Additional amounts paid at purchase will likely be recovered over time, since the cost of driving a vehicle on electricity is often much less than the cost of driving a vehicle on gasoline. As battery costs come down, the "payback period" associated with the additional purchase price of an electric vehicle will likely shorten. At present there is limited data on the impact of shorter payback periods on consumer purchase decisions, but shorter payback periods may also help speed consumer adoption.

With that in mind, the following may be helpful:

- Current hybrid electric vehicles, which use no grid electricity, currently have a payback period of about 2-6 years. DOE estimates that the current payback time for a third-generation mid-size hatchback Prius HEV is 2 years, based on gasoline at $4/gallon, 15,000 annual miles, and a $2,180 price difference between a third-generation Prius hatchback and a comparably equipped Toyota Camry automatic. Similarly, DOE estimates the payback time for a Ford Fusion hybrid, compared to a comparably equipped Ford Fusion SEL 4-cylinder, is 2.4 years using the assumptions above.[2]

- Edmunds compared the mid-sized Leaf priced at $36,050 ($28,550 after including the $7,500 federal tax credit) with the compact gasoline-powered Nissan Versa (priced at $19,656) and calculated a subsidized payback period of 7 years at $4 per gallon.[3]

- U.S. EPA estimates the Nissan Leaf's annual fuel cost at $612 while the Nissan Versa's annual fuel cost is $1,860. (EPA estimates are based on 45% highway and 55% city driving, over 15,000 annual miles; gasoline price of $3.72 per gallon and electricity price of $0.12 per kWh.)[4] Thus, the EV's annual fuel saving under these assumptions is $1,248. Under these assumptions, over a five-year period, the fuel savings would offset a purchase price premium, before discounting for present value, of $6,240. Thus, for *EV Everywhere* to achieve a 100-mile EV with affordability comparable to a conventional vehicle, the unsubsidized purchase price would need to be reduced by about $10,000 from $36,050 currently to $25,896 as a first approximation.

DOE welcomes feedback and any data on the importance of the above factors in vehicle purchase decisions.

Regulatory and Policy Factors

Regulatory and policy issues can have a large impact, either positive or negative, on the deployment of PEVs. The *EV Everywhere* Challenge will seek to identify and address critical regulatory and policy barriers that affect the rate of deployment of PEVs.

Some of the key policy issues that may impact PEV adoption include:

- Increased CAFE standards for light-duty vehicles through 2025
- Advanced Technology Vehicle Manufacturing (ATVM) loan program
- Manufacturing tax credits (48c)
- Federal and State tax credits for vehicle purchases
- Government fleet EV/PHEV purchases
- HOV lane access and/or preferential parking for PEVs

Some of the key regulatory issues that can impact PEV affordability and convenience include:

- Vehicle and infrastructure safety regulations
- Charging infrastructure permitting
- Standardization of vehicle components for safety and charging
- Standardization of electric vehicle supply equipment (charging standards)

IV. Preliminary Technical Targets

The *EV Everywhere* Grand Challenge statement establishes a vehicle-level framework in which the necessary technology progress to "win" this Grand Challenge can be evaluated. Dramatic advances will be required in batteries, power electronics, motors, lightweight materials and vehicle structures, and fast-charging infrastructure technology.

Affordability and the 5-year payback period identified in the Grand Challenge imply a method for relating up-front vehicle purchase cost and subsequent fuel expenditure during vehicle operation, and, most importantly, the role that technology progress can play in that relationship. Specifically, according to the preliminary Grand Challenge key parameters, the technologies supported through the *EV Everywhere* Grand Challenge should enable sufficient range/rechargeability to eliminate daily PEV driving limitations and must reduce the initial PEV cost such that any incremental cost above today's equivalent gasoline-powered vehicles is more than compensated by fuel savings (using electricity in an PEV is much less costly than using gasoline in a conventional vehicle) over a standard passenger vehicle drive cycle in 5 years or less.

Target-Setting Methodology

EV Everywhere specifically targets dramatic performance and cost improvements in several platform technology areas: batteries, electric motors, power electronics, light-weight materials and vehicle structures, and fast-charging technologies. A combination of performance improvement and cost reduction across these technologies will result in electric vehicles that satisfy the Challenge of an affordable (5-year payback) and convenient electric vehicle within 10 years. DOE's Vehicle Technologies Program (VTP), with input from U.S. DRIVE industry partners, developed a framework within which one can evaluate the degree to which the portfolio of these technologies must progress—in both performance and cost terms—to satisfy the 5-year *EV Everywhere* payback challenge.

To estimate the point at which a combination of technology progress across the *EV Everywhere* portfolio achieves the payback challenge, a three-step analysis was developed.

1. - In step 1, technology development experts first forecast the likely progress possible within each technology pipeline. This expert elicitation yields a set of three scenarios—a low technology scenario (i.e., one without significant DOE support), a middle technology scenario (i.e., an expected outcome aligned with current technology progress), and a high technology scenario (i.e., the most aggressive technology progress possible over time).
2. - In step 2, Argonne National Laboratory's *Autonomie* Vehicle modeling and simulation software combines these likely performance and cost outcomes at the component technology level into possible vehicle-level cost and performance outcomes.

3. - Finally, in step 3, these vehicle-level outcomes facilitate a comparison of initial vehicle cost and subsequent fuel expenditure (assuming the Annual Energy Outlook 2011 High Oil Case projections for future fuel prices) such that a payback period relative to a baseline gas-powered vehicle can be calculated.

A schematic depicting the flow of information through this three-step model is shown in Figure 1 below:

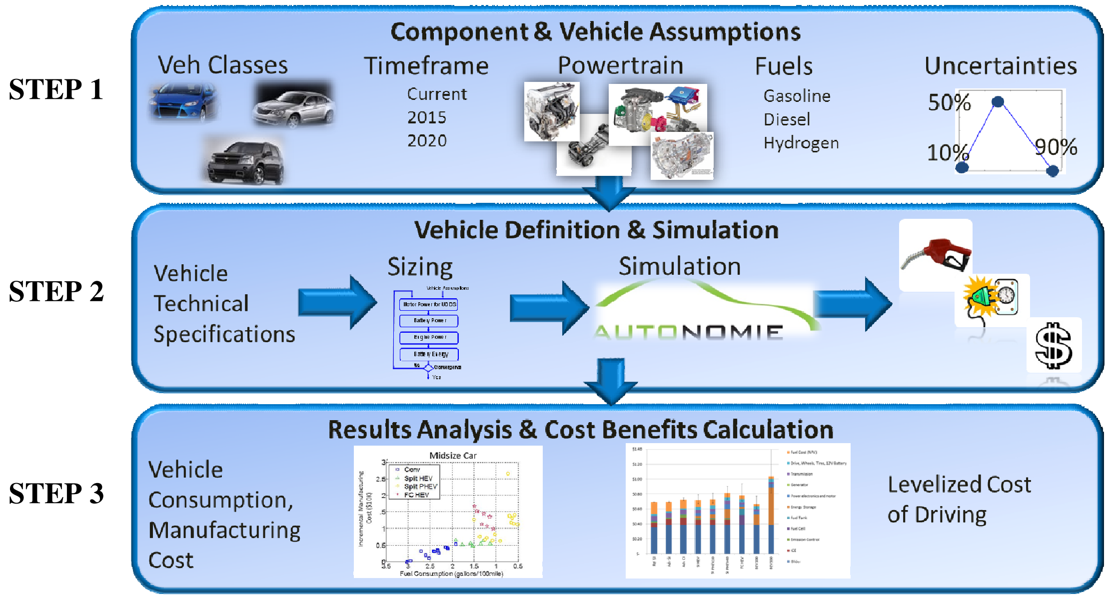


Figure 1. Autonomie model flow of information: from expert elicitation (component and vehicle assumptions at three levels of uncertainty) through the Autonomie model (vehicle modeling and simulation given a set of vehicle technical specifications) to results analysis and cost benefits calculation

The set of component technology performance and cost assumptions that together yield the 5-year payback period established in this Challenge is the portfolio of technology targets which *EV Everywhere*-supported technologies shall strive to achieve. These values are listed by component technology in the Tables 1 – 4 below.

Table 1. Batteries and Energy Storage 2022 Targets *(based on EV Everywhere 5-year payback analysis)*

		Current Status	PHEV40	AEV100	AEV300
Battery Cost	$/kWh (usable)	650	190	300	110
Pack Specific Energy	Wh/kg	80-100	150	180	225
Pack Energy Density	Wh/L	200	250	300	425
State-of-Charge Window	%	50	80	90	90

Table 2. Electric Motors and Power Electronics 2022 Targets *(based on EV Everywhere 5-year payback analysis)*

		Current Status	PHEV40	AEV100	AEV300
System Cost	$/kW	20	5	14	4
Motor Specific Power	kW/kg	1.2	1.9	1.3	1.3
Power Electronics Specific Power	kW/kg	10.5	16	12	16.7
System Peak Efficiency	%	90	97	91	98

Table 3. Vehicle Lightweighting 2022 Targets *(based on EV Everywhere 5-year payback analysis)*

		Current Status	PHEV40	AEV100	AEV300
Vehicle Lightweighting	%	n/a	29	3	30
Lightweighting Cost	$/lb-saved	n/a	3.30	3.30	3.30

Table 4. Vehicle Charging Infrastructure 2022 Targets *(based on EV Everywhere 5-year payback analysis)*

		Current Status	PHEV40	AEV100	AEV300
Charger Cost	$/kW	150	35	140	25
Charger Efficiency	%	91	99	91	99

V. Additional Requirements

We propose the following other key requirements for the *EV Everywhere* Challenge:

- **Secure Materials Supply at Scale:** Technologies should be based on materials without major supply/availability barriers and risks when deployed at large scale. This is required to meet cost goals, to eliminate foreign material resource dependence, and to ensure large-volume scalability.
- **Safety:** Technologies/solutions should meet all applicable safety and environmental standards and must meet or exceed Federal Motor Vehicle Safety Standards (FMVSS) and SAE–J2929 Battery Safety Standard.
- **Recycling:** Technologies should also be capable of full recycling. Recycling can provide a financial value and thereby contribute to overall affordability and sustainability, can conserve material resources, and can reduce the costs and environmental concerns of vehicle and component disposal at end of life.
- **No Reduction in Grid Reliability:** The charging technologies and charging infrastructures considered must be deployable without compromising the reliability of the electric grid and local distribution networks.

VI. *EV Everywhere* Grand Challenge Framing Process

Over the next few months, the Department of Energy will be organizing a series of *EV Everywhere* public information exchanges across the country to inspire and recruit the best and brightest American scientists, engineers, and businesses to tackle this electric vehicle grand challenge.

The first *EV Everywhere* public meeting will serve as an initial Framing meeting to obtain stakeholder input on the overall concept, proposed scenarios, and high-level strategy.

Subsequent follow-on Focused Topical public meetings may include the following topics:

- Factors in Consumer Adoption of PEVs
- Charging Infrastructure Requirements (including fast-charging, grid management, and hardware issues)
- Batteries – Manufacturing, Pack Innovation, Electrochemistry
- Power Electronics and Motors
- Lightweight Vehicle Materials and Structures

Key Questions to be addressed at Public Meetings

FRAMING MEETINGS

1.) What PEV vehicle architecture(s) should *EV Everywhere* focus on?
2.) What PEV cost, range, and charging capabilities are required for a majority of American consumers to be willing to purchase a PEV? How important is 5-year payback to widespread adoption?
3.) What regulatory and policy barriers must be overcome for widespread adoption of PEVs?
4.) What should be the focused topics, discussions, and outcomes for each follow on technology workshop?
5.) What are some high-impact "out of the box" new ideas and approaches for accelerating the adoption of PEVs?

TECHNOLOGY INFORMATION EXCHANGES

1.) What component performance and cost is required to achieve the *EV Everywhere* Challenge?
    a. - Battery Packs (and Cells)
    b. - Power Electronic Systems
    c. - Motor Systems
    d. - Lightweight Vehicle Structures and Materials
    e. - Fast Charging Capability
    f. - Charging Infrastructure
2.) What are the most promising candidate technologies to achieve these goals and what specific technology breakthroughs will be required?

Appendix A

Batteries and Energy Storage

- Overview
- Current DOE Battery R&D Technical Targets
- Current DOE Battery R&D Plans

Overview

The cost and performance of batteries are key factors determining the commercial growth of electric drive vehicles. Improvements in battery technology offer the potential to dramatically reduce the capital cost premium of electric vehicles over gasoline-powered vehicles. Key historical milestones in battery development for automotive applications include nickel-metal hydride batteries in the 1990's, which helped pave the way for introduction of hybrid electric vehicles; and lithium-ion batteries, first introduced commercially in 1990 for consumer products and then for vehicle applications in 2009. The development of these innovations was supported in part by DOE-sponsored work at US universities, national laboratories, and industry.

Some of the accomplishments from the DOE's Battery R&D programs include the following:

- The nickel metal hydride batteries used in the Toyota Prius and many other H*EVs* are based in part on technology licensed from DOE-sponsored research and development.
- Hybrid electric vehicles on the market from BMW and Mercedes are using Li-ion technology developed under projects with Johnson Controls–Saft (JCS).
- Li-ion battery technology developed in part with DOE funding at Compact Power Inc. (now named LG Chem Power) is being used in GM's Chevrolet Volt. LG Chem Power has also been selected for the upcoming Ford Focus EV battery.
- DOE supported A123Systems in the development of their cathode material and battery cells. A123Systems will supply Li-ion batteries for the GM Spark, Fisker Karma EV, and Navistar.
- A next generation lithium-ion cathode material developed at Argonne National Laboratory has been licensed by General Motors and LG Chem for use in the Chevrolet Volt, with additional licenses to materials suppliers BASF, Toda America, and Envia Systems. Eaton announced that it would use batteries from LG Chem Power for future Eaton hybrid drive heavy vehicles.

Recovery Act Battery Manufacturing Initiative

Almost all lithium-ion batteries, primarily for consumer electronics, are manufactured in Asia. In 2008, 98 percent of advanced hybrid vehicle batteries were made in Asia. In 2009, DOE initiated 20 projects to establish domestic battery manufacturing facilities, co-funded by a $1.5 billion investment under the American Recovery and Reinvestment Act, covering the supply chain from battery materials and components, cell and pack assembly, and battery recycling.

Production started in 2010 at several plants. The Recovery Act has positioned the US to capture a significant share of the worldwide market for EV batteries, projected to grow to $8 billion by 2015.[5] The Recovery Act cost-shared grants are enabling companies to build the capacity to produce 500,000 EV batteries annually (assuming 10 kWh average size) by 2015. This represents capacity sufficient to meet the requirements for projected U.S. EV production

Existing DOE Battery R&D Goals and Technical Targets

As the global competition to develop and manufacture the PEV battery of the future has accelerated, the DOE has ramped up its investment in battery R&D from $25 million in 2006 to $160 million in 2012. DOE-funded research has helped bring down lithium-ion battery costs from $1000/kWh in 2008 to roughly $650/kWh today.[6] DOE's goals are to continue to drive down battery cost to $300/kWh by 2015, and $100-150/kWh by 2020, with the higher battery cost ($150/kWh) identified as that needed for market introduction of PEVs to early adopters and the lower battery cost ($100/kWh) needed for broad market acceptance. A set of specific performance targets for electric drive vehicle batteries is listed in the Table 5 below. These targets were derived from modeling and hardware-in-the-loop simulations of batteries operating in EDVs under multiple drive cycles.

In order to address consumers' concerns about vehicle range and charge time, the Department has also recently established a "10 miles per minute" battery fast charge goal. This is a preliminary goal that may be revised based on further consumer acceptance studies.

Table 5. Current Status and Existing Technical Targets for Batteries for PHEVs and AEVs (Pre *EV Everywhere* Targets)

DOE Energy Storage Goals	**PHEV 2012 Status**	**PHEV 2015 Target**	**AEV 2012 Status**	**AEV 2020 Target**
Equivalent Electric Range, miles	10-40	10-40	200-300	200-300
Discharge Pulse Power (10 sec), kW	~40-70	38-50	80-120	80-120
Regenerative Pulse Power (10 sec), kW		25-30	40	40
Recharge Rate, kW		1.4-2.8	50	5-10
Available Energy, kWh	3.4-11.6	3.4 - 11.6	40-60	40-60
Calendar Life, years	8-10	10-15	TBD	10
Cycle Life, deep cycles	3000-5,000	5,000	TBD	1000
System Weight, kg	60-175	60-120	500-750	300
System Volume, liters	40-100	40-80	200-400	133
Operating Temperature Range, C	-10 - 40	-30 to 52	0 - 40	-40 to 60
Production Cost at 100,000 units/year	<$650	$300/kWh	<$650	$100-150/kWh

DOE Battery R&D Plans

The waterfall chart in Figure 2 below highlights the strategy to achieve the 2015 targets. R&D emphasis will enable cost reductions in the research areas depicted. For example, the chart depicts the primary areas for further reduction are pack hardware (red), cell materials cost (green), and electrode processing (blue). The illustration on the right side of the chart depicts the potential benefits of significantly increasing the energy density of battery cells and the importance of material improvements.

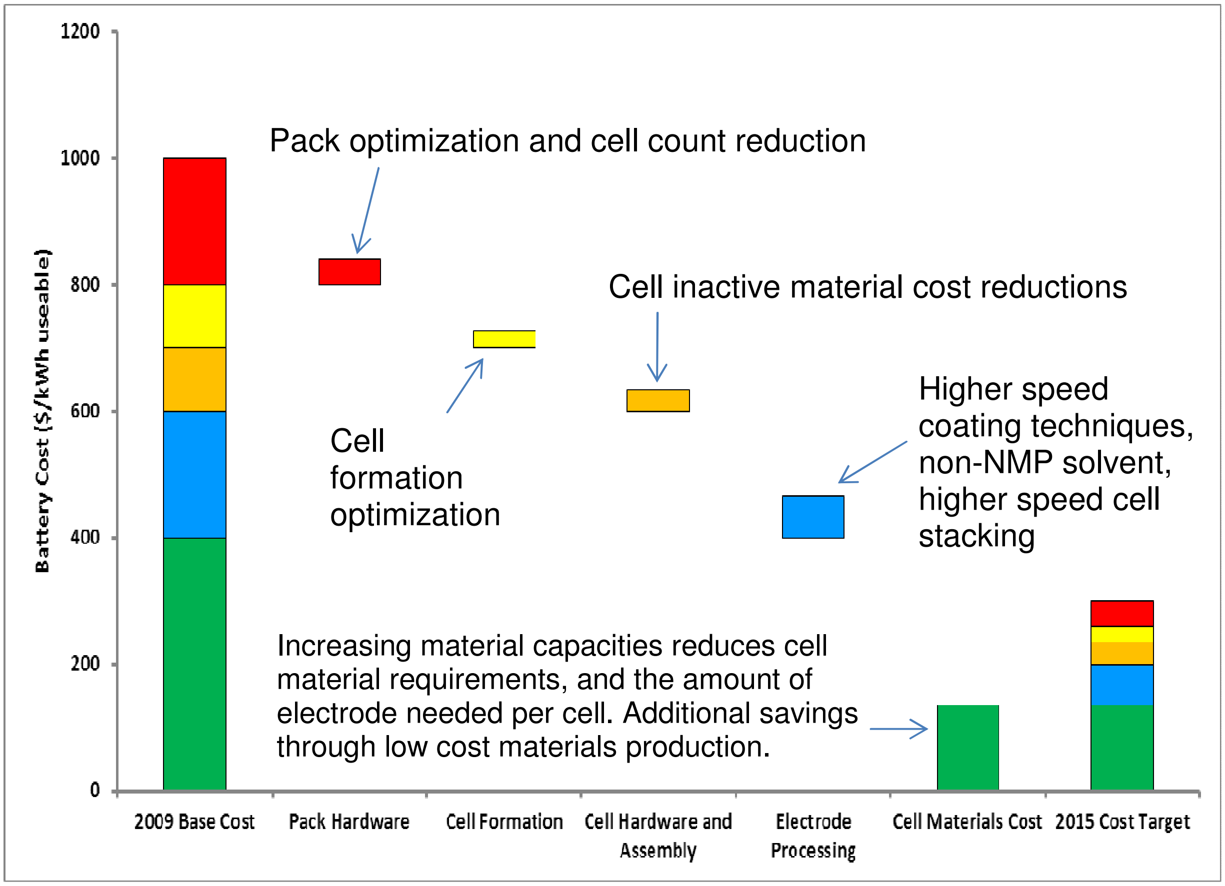


Figure 2. A waterfall representation of major cost drivers and potential cost reductions for lithium ion batteries designed for electric drive vehicle applications

Battery technology is very far from its theoretical limit. In the near-term (2012-2017), within existing lithium-ion technology, there is an opportunity to double the battery pack energy density from 100 Wh/kg to 200 Wh/kg through the use of new high-capacity cathode materials, higher voltage electrolytes, and the use of high capacity silicon or tin-based intermetallic alloys to replace graphite anodes. For example, Envia has recently demonstrated a cell with a specific energy of 400 Wh/kg using high capacity cathode and silicon-carbon anode materials. This shows what may be possible, but much more research and development will be required to achieve the performance and lifetime required for deployment in PEVs.

In the longer term (2017-2027), battery chemistries "beyond Li-ion", such as lithium -sulfur, magnesium-ion, zinc-air, lithium-air, and other advanced chemistries offer the possibility of specific energies several times greater than current lithium-ion batteries, together with potential for greatly reduced battery cost. However, the significant shortcomings in cycle life, power density, energy efficiency, and/or other critical performance parameters currently stand in the way of commercial introduction of state-of-the-art "beyond Li-ion" battery systems and significant breakthrough-oriented R&D will be required for these new battery technologies to enter the market.

Future generations of Li-ion battery technology might be able to get us to our 2020 EV battery targets, but it may be difficult to optimize performance, cost, life, and safety simultaneously given the inherent tradeoffs, so a balanced investment approach is needed between advancing next generation Li-ion technology and investing in potentially very high energy new approaches beyond Li-ion. Major technical challenges and their potential pathway to overcoming these barriers are shown in the Table 6 below.

Table 6. Major Li-ion technology technical challenges and potential pathways to address them.

Barrier/Challenge	Potential Solutions
Reduce the cost and improve the performance of Li-ion battery technology	- Improve material and cell durability - Improve energy density of active materials - Reduction of inactive material - Improved design tools/design optimization - Improved manufacturing processes
Develop higher energy battery technology such as next generation lithium ion, lithium-sulfur and lithium-air • Issues with these materials include poor cycle life, low power, low efficiencies, and safety	- Improved electrolyte/separator combinations to reduce dendrite growth for Li metal anodes - Advanced material coatings - Develop new ceramic, polymer, and hybrid structures with high conductivity, low impedance, and structural stability
Improve abuse tolerance performance of battery technology	- Non-flammable electrolytes - High-temperature melt integrity separators - Advanced materials and coatings - Improved understanding of reactions - Battery cell and pack level innovations such as improved sensing, monitoring, and thermal management systems

Near-term applied R&D will focus on lithium-ion batteries, including *inter alia* the development of cells that contain high voltage (5V) and/or high capacity (>300mAh/g) cathodes; alloy or lithium metal anodes; Li/air, Li/S, and other advanced systems; and high-voltage electrolytes, and solid electrolytes which may enable Li-metal anodes. Additional research efforts will be devoted to: the development of additives to prevent overcharging; additives that form a good interface between the electrode and the electrolyte for improved life and fast charge capability;

and electrolyte formulations and additives for low-temperature operation. These are just a few areas of potential focus going forward. Pack level innovation will be supported by ARPA-E projects funded under the current FOA on battery management systems, which will include among other things sensors/sensing techniques and advanced control technologies. Battery system development will continue in cooperation with industry to validate requirements and refine standardized testing procedures. As batteries become larger, abuse-tolerance becomes more of a concern and enhanced thermal management becomes more important. A more detailed description of DOE battery R&D projects can be found in the DOE Fiscal Year 2011 Annual Progress Report for Energy Storage R&D[5] and in the 2012 Annual Merit Review.[6]

Advanced battery prototyping should be pursued to move more mature battery technologies closer to market entry through the design and development of advanced pre-production battery prototypes, and by better understanding their behavior in simulated drive conditions. The activity will provide valuable data regarding battery operation and the results will be used to drive down battery cost through optimization of battery cell and pack designs.

Market entry should be supported through the scale-up, pilot production, and commercial validation of new battery materials and processes. Battery materials and cell manufacturing R&D will evolve from loosely measured and controlled processes, to processes that have adapted significant automated and metrological methods.

Computer aided engineering (CAE) tools will be developed to accelerate design cycles, reduce the number of prototypes needed, reduce battery development cost and provide a competitive advantage to U.S. OEMs, suppliers, and battery manufacturers.

Standards for battery design, performance ratings, commonality in labeling, and safety standards should be developed. Major standards-setting organizations, battery manufacturers, automotive OEMs, and DOE need to speed the development and adoption of these standards.

Key Partners for *EV Everywhere's* Battery Effort

Dramatic improvements in battery performance and cost will require a well-coordinated effort across all of the DOE complex and with America's most innovative researchers and companies. Innovations in battery technology occur as a result of fundamental investigations carried out at national labs and universities supported by the DOE Office of Science, through translational research sponsored by ARPA-E, and through applied research and development at labs, universities and industry supported by the DOE's Office of Energy Efficiency and Renewable Energy (EERE)Innovations coming from R&D on pre-competitive technologies will be transferred to and implemented by industry partners as a business case develops for these technologies through the US DRIVE public/private partnership (Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability, formerly the FreedomCAR and Fuels Partnership). The US Advanced Battery Consortium (USABC) makes cost-shared, competitively awarded projects to industry to facilitate commercialization of pre-competitive technologies and introduce them into the marketplace.

Appendix B

Power Electronics & Electric Motors for Electric Traction Drives

- **Overview**
- **Current DOE APEEM Technical Targets**
- **Current DOE APEEM R&D Plan**

Overview

Current cost estimates for on-road electric traction drives are about $35/kW of peak power, translating to about $2,800 - $3,500 for current PEV inverter and motor systems. To achieve the affordability goal of *EV Everywhere*, these systems must achieve significant cost reductions. These cost reductions can be realized through R&D projects focusing on cost reduction and performance improvements of the materials, devices, and components used in electric traction drive systems. Currently, the DOE R&D cost target for 2022 is $8/kW, representing a 77% cost reduction from estimates of current on-road technology.

Current DOE APEEM Technical Targets

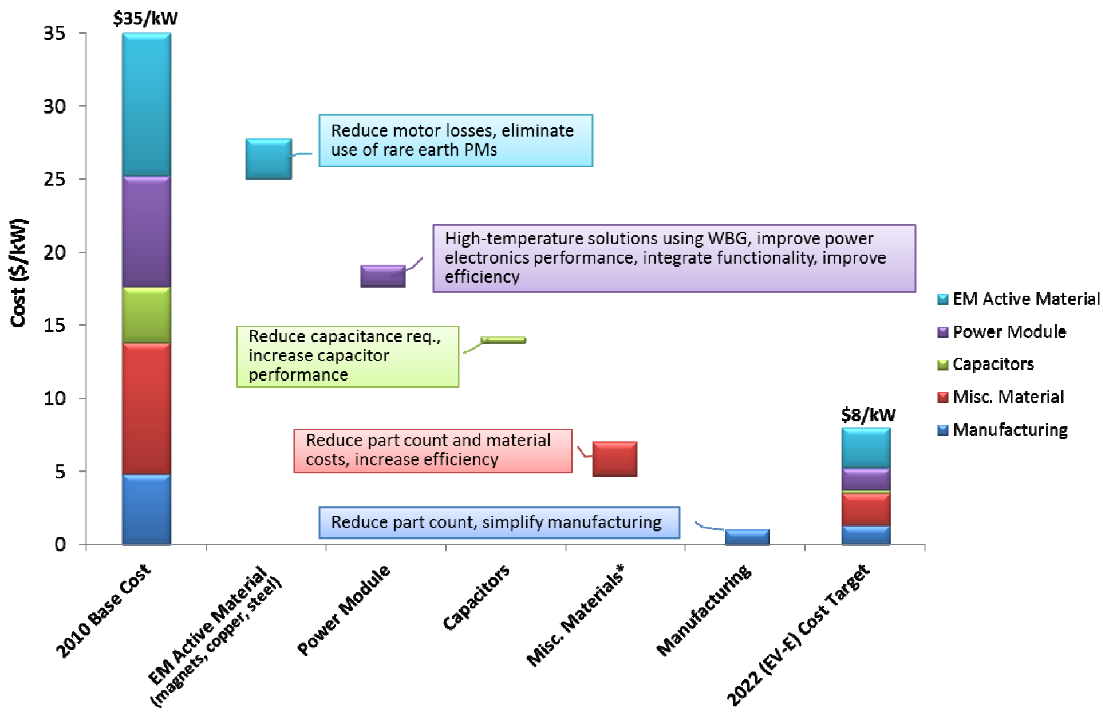
The current DOE Advanced Power Electronics and Electric Machines (APEEM) technical targets are listed in the Table 7. As previously mentioned, cost reduction is the main focus of these targets, while the associated specific power and power density numbers represent the improvements necessary to meet future automotive requirements. An increase in efficiency from 90 to 94% will marginally improve electric vehicle range, but more importantly these targeted efficiency improvements will decrease the amount of heat generation by 40%, enabling significant reduction in the cost, weight and volume of the cooling system.

Table 7. Technical Targets for Electric Traction Drive System (Pre *EV Everywhere* Targets)

	2010	**2012**	**2015**	**2022**
Cost, $/kW	< 19	<17	< 12	< 8
Specific power, kW/kg	> 1.06	>1.08	> 1.2	> 1.4
Power density, kW/L	> 2.6	>3.0	> 3.5	> 4.0
Efficiency (10%-100% speed at 20% rated torque)	> 90%	>91%	> 93%	> 94%

Current DOE APEEM R&D Plan

The waterfall chart below in Figure 3 highlights the strategy to achieve the 2022 targets and identifies critical areas of focus and what is necessary to achieve the targets. R&D activities will enable cost reductions in the research area depicted.



** Misc Materials*

Inverter: cold plate, drive boards, thermal interface material, bus bar, current sensors, housing, control board, etc.

Motor: bearings, housing, sensors, wire varnish and insulation, potting materials, shaft, miscelleneous materials.

Figure 3. A waterfall representation of cost savings in APEEM technologies

Emphasis on reducing weight and volume while increasing efficiency and reliability of electric drive components will be essential to achieving the *EV Everywhere* Challenge. DOE APEEM R&D activities going forward will address the challenges and barriers to realizing the cost and performance improvements necessary to achieve the *EV Everywhere APEEM* targets identified above. Proposed future efforts will include R&D in advanced materials, pre-competitive technology innovation, advanced motor and power electronics designs, and innovative thermal management technologies.

Although basic research is not a focus of the *EV Everywhere* Challenge, cutting-edge basic research discoveries will need to be exploited in several materials classes to achieve the *EV Everywhere* goals, including materials related to permanent magnets, non-rare earth magnets, advanced capacitors, thermal and electrical packaging, wide bandgap (WBG) semiconductors, motor laminations, and other areas. Figure 4 depicts the traction drive and power management components for vehicle electrification. Components may vary with OEM vehicle design.

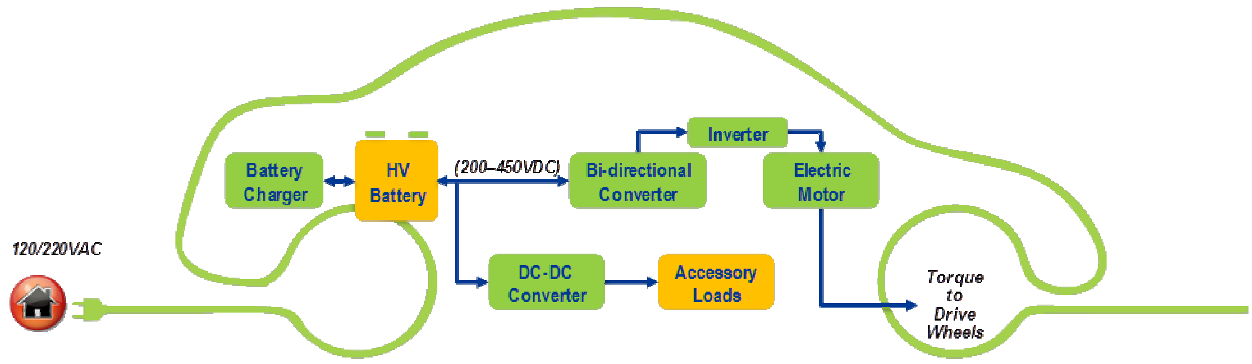


Figure 4. Traction drive and power management components for vehicle electrification.

The following focus areas outline the initially proposed DOE R&D strategy to achieve the *EV Everywhere* cost targets and performance targets:

Electric Motors- New low cost and highly efficient motor designs, alternative magnetic materials with reduced rare earth content, and improved motor manufacturing methods must be developed. Specifically, long-term emphasis must be given to non-rare earth motor architectures to reduce motor costs and ameliorate rare earth market uncertainties for the OEMs and their suppliers. Other motor issues important to suppliers are reliability and service life.

Power Electronics - Initially proposed areas of R&D focus include the development of affordable WBG devices, high-temperature capacitors, advanced packaging, high voltage operation, and new circuit topologies. Power electronics based on advanced SiC devices are currently under development and their usage will increase as suppliers mature their manufacturing processes leading to improved device yield and performance specifications. The promise of GaN-on-Si based devices will likely provide substantial performance improvements in terms of efficiency, operating temperature, and reliability relative to Si; however the status of GaN wafer and device technology is in its infancy compared to Si or even even SiC.

Thermal Management – Thermal management will be a key focus R&D area to achieve the *EV Everywhere* targets for the APEEM system. This R&D must address the areas of advanced low cost heat transfer technologies, thermal stress and reliability, and thermal systems integration. Effective heat transfer is critical for prolonging the life of semiconductor devices and improvements can lead to higher reliability and/or reduced die sizes by allowing smaller devices to handle higher loads, which can reduce overall costs.

Traction Drive System – This area of R&D will focus on integrating inverter and motor system technology, in addition to developing traction drive control strategies and innovative integrated system designs. Benchmarking will allow for technology screening and evaluation of current state-of-the-art systems and devices, while the development of integrated systems can leverage unique system benefits that enable part count reductions and performance improvements enabling cost reduction.

On-Board Chargers: The on –board charger is essential to *EV Everywhere*. Cost is the most significant challenge. The current status and current technical targets for on-board chargers are shown in Table 8.

Table 8. Current status and current technical targets for on-board chargers

3.3 kW Charger	2010	2015	2022
Cost	$900 - $1,000	$600	$330
Size	6-9 liters	4.0 liters	3.5 liters
Weight	9 -12 kg	4.0 kg	3.5 kg
Efficiency	90 – 92 %`	93%	94%

Appendix C -
Vehicle Lightweighting -

- **Overview**
- **Current DOE Lightweighting Technical Targets**
- **Current DOE Lightweighting R&D Plan**

Overview

Increased use of advanced lightweight materials can improve fuel economy, regardless of vehicle class or powertrain. For PEVs lightweighting can extend the range and/or reduce the cost of the battery by requiring less energy to overcome inertia In order to achieve these benefits, however, the use of lightweight materials, especially those with significant potential for reducing weight compared to standard steel must be affordable and meet the demanding performance requirements for vehicles. Two examples of materials that could provide large reductions in weight include both magnesium (potential to reduce 60%), and carbon fiber composites (50-60%). At a recent workshop on updating a roadmap for DOE VTP materials, industry experts provided input on stretch goals for weight reduction. Their input revealed that by 2022, compared to a 2006 baseline vehicle, lightweighting targets include the following: 35% for the body structure; 25% for the chassis and suspension; 10% for the powertrain, and 5% for the interior. Given the breakdown of weight in a typical passenger car, these changes would result in an overall vehicle weight reduction of about 20%, providing a significant increase in vehicle energy efficiency. With secondary compounding, for every 10% weight reduction of the vehicle, one should see an improvement in efficiency of 6-8%. Note that these targets were provided by industry from a workshop on developing our technology roadmap for both light weighting and propulsion materials . To achieve these targets, however, several technological challenges must be addressed.

Current DOE Lightweighting Technical Targets

At a recent workshop on lightweighting the light duty vehicle, including vehicles with all types of powertrains, industry experts provided input on a set of stretch goals for weight reduction targets as shown in Table 9. These targets represent a estimates developed with input from industry experts on maximum weight reduction possible for different time frames. Industry experts include OEMs, tier one suppliers, and material suppliers and manufacturers.

Table 2. Table of weight reduction for systems of the Light Duty Vehicle 2020 – 2050.

LDV Component Group	2020	2025	2030	2040	2050
Body	35%	45%	55%	60%	65%
Power-train	10%	20%	30%	35%	40%
Chassis/suspension	25%	35%	45%	50%	55%
Interior	5%	15%	25%	30%	35%
Completed Vehicle	***20%***	***30%***	***40%***	***45%***	***50%***

Current DOE Lightweighting R&D Plan

Industry can't yet reach these targets because many technology gaps inhibit our ability to realize them in a cost effective manner. Table 10 highlights the highest priority gaps for each of the systems in the vehicle. This high level view of the gaps serves to illustrate similarities in challenges common to the different vehicle systems. These technology gaps were identified by industry experts include OEMs, tier one suppliers, and material suppliers and manufacturers. The trend toward light weighting involves utilizing a multi-material design. A ubiquitous challenge in executing multi-material systems is the ability to join dissimilar materials cost effectively. In addition, the performance of lightweight materials needs to be improved while reducing costs. For example, the strength of advanced high strength steels needs to be increased while simultaneously improving the formability to enable low-cost manufacturing of lightweight, safety critical components. In order to accelerate progress here, we need better design and development tools.

Table 30. Technology gaps for systems of the Light Duty Vehicle.

System	Body-In-White & Cab	Propulsion	Chassis	Doors and Hatches
Joining of Multi-materials	X		X	X
Optimized material Performance with lower cost		X	X	X
Predictive Models	X			X
Optimized Manufacturing	X		X	
Design Tools	X			X
Cost and availability of Materials	X			
Corrosion				X

Improvement in the performance of each lightweight material while reducing cost is dependent upon not only low cost raw materials but also effective and energy efficient manufacturing processes. Industry feedback collected at the workshop indicates that challenging technology gaps exist in both raw material and manufacturing process capabilities. These gaps are listed in Table 41. This high level view of the gaps serves to illustrate similarities in challenges common among different materials. These technology gaps were identified by industry experts include OEMs, tier one suppliers, and material suppliers and manufacturers. Materials specific technology gaps include the lack of predictive models, the need for optimized manufacturing, and requirements for improved material performance. Additional challenges must be overcome in the performance of design tools, raw material supply for magnesium and other advanced metals, damage detection, and corrosion mitigation. A draft report from the 2011 workshop that includes targets and technology gaps will be available for comment later this summer.

Materials research under both the vehicles technology program and the Office of Advanced Manufacturing (OAM) are addressing some of these technology gaps now. While the role of

OAM seeks to support energy efficient manufacturing, by doing so the cost of raw materials and manufactured parts can be reduced.

Table 41. *Technology gaps for materials for use in the Light Duty Vehicle.*

Material	**Magnesium**	**Carbon Fiber**	**Carbon Fiber composites**	**Glass Fiber composites**	**Adv High Strength Steel**	**Aluminum**	**Advanced Metals – (Ti, Ni)**
Lack of Predictive Models	X	X	X	X	X	X	
Optimized Manufacturing (lower cost)		X	X	X	X	X	X
Optimized Perf (lower cost, improved strength)	X	X		X	X		X
Design Tools		X		X			X
Raw Material Supply	X						X
Multi-material Joining			X			X	
Damage Detection			X				
Corrosion	X						

For lighter-weight vehicle systems, a multi-material solution presents a flexible approach but requires the cost-effective joining of dissimilar materials and compatibility with a high-throughput factory environment. Research must also focus on improving the performance of lightweight materials, for example by increasing energy absorption of magnesium alloys that do not contain rare earth elements in crash events. Mg alloys that contain rare earth elements have excellent properties (ductility and crash energy mgmt.), however these alloys are expensive and the rare earth additives are not easily available. For improved lower cost solutions in Mg structures, we want equivalent or better properties in Mg alloys without using rare earth elements in the formulations.

Developing predictive tools that enable optimized designs of structural systems is also important to the lightweighting strategy. Predictive models can significantly accelerate the development of improved grades of lightweight materials, expand our understanding of how processing conditions impact mechanical performance, and support efficient designs by evaluating macroscopic behavior such as how carbon fiber composite structures absorb energy in a crash. Predictive models need to be validated for composites taking energy in a crash as currently these materials are overdesigned and too expensive for typical cars. We are working 1) to lower the cost of carbon fiber and 2) validating mechanical models that predict energy management under conditions of crash to minimize overdesign. Predictive modeling today is fairly crude and often only able to accurately predict properties in relatively simple steel and aluminum alloys. More complicated alloys and composites are difficult to model and so they are either not used or the components are overdesigned due to inaccuracy in the models.

Improved capabilities in predictive modeling support PEV weight reduction in two ways. They: 1) improve the designs of existing materials by improving the accuracy of models and eliminating over-design; and 2) increase the rate at which advanced material development and deployment can occur by replacing experimental iteration with computationally lead development that focuses on the most critical and optimized material formulations and conditions of manufacturing.

Cost reduction – of both raw material and manufacturing – is also critical. The manufactured cost of carbon fiber needs to reach $5/lb, and a domestic source of magnesium metal must be competitive compared to traditional steel in use today. Strategies for reducing costs to manufacture vehicle systems include design-for-manufacturing approaches that take advantage of lightweight materials and supersede evolutionary and non-optimized one-for-one parts substitution. In order to realize lower cost, new lightweight materials technologies require faster and more energy-efficient manufacturing techniques. In addition, efficient designs must enable consolidation of parts that reduces the need for joining. Methods to mitigate corrosion using low cost techniques are also needed.

The development of new material technologies which address these needs will enable improved performance in electric vehicles and support the *EV Everywhere* Grand Challenge. Continued focus on cost- effective reduction of vehicle weight is a critical element of transportation energy reduction and improved efficiency in the U.S. fleet.

Appendix D

Vehicle Charging Infrastructure

- **Overview**
- **Current DOE R&D Charging Infrastructure Targets**
- **Current DOE R&D Charging Infrastructure Plan**

Overview

In order to promote the widespread adoption of electric vehicles, sufficient and accessible charging infrastructure must be made available. While the majority of electric vehicle charging events currently take place at home using residential AC Level 1 or Level 2 charging equipment, the availability of public and commercial (such as workplace and retail) charging infrastructure may alleviate "range anxiety," increasing driver confidence and the overall utility of electric vehicles.

In the near term, plug-in hybrid vehicles with varying charge-depleting ranges (i.e., PHEV 10, PHEV-40) offer consumers the ability to shift vehicle-miles-traveled from petroleum to electricity, without requiring large-scale deployment of charging infrastructure. However, these vehicles may collectively create significant demand for public electric vehicle supply equipment (EVSE) so that owners may realize the full economic benefit electric transportation. If this "market pull" is realized, it could result in much greater deployments of EV charging infrastructure, both within cities, where it may promote adoption of BEV-100s such as those that are currently available, as well as between major metropolitan areas, where it could enable future all-electric vehicles (such as BEV-300s) to be the primary vehicle of choice for consumers.

Current DOE R&D Charging Infrastructure Targets

Electric vehicle charging stations are classified by the type of electricity provided by the infrastructure (AC or DC), as well as the power-level delivered. Currently, three types of EVSE are commonly available. AC Level 1 EVSE's operate from 120-volt supply and provide 1-2 kW charging power (approximately 4 miles equivalent range per hour of charge) at a cost below $1,000. AC Level 2 EVSEs operate from 240-volt supply and typically provide 7.2 kW or less, although SAE specifies AC Level 2 for up to 19.2 kW. (Most currently available P*EVs* are capable of charging at 3.3 kW, or approximately 11 miles equivalent per hour of charge.) Residential AC Level 2 EVSEs cost approximately $1,000-$2,000, while commercial units may be twice that. Installation costs vary significantly, from several hundred dollars for simple residential installations, to several thousand dollars when service upgrades and long conduit runs are required. Commercial installations may cost even more.

DC Level 2 chargers, more commonly known as DC Fast Chargers, provide 50 kW (20-30 minutes for an 80% charge for a BEV-100, or approximately 166 miles equivalent per hour of charge) or more, and may cost as much as $45,000 today, although Nissan recently announced plans to market a low-cost DC Fast Charger for less than $10,000. DC Fast Chargers include power electronics to rectify alternating current and supply DC directly to the vehicle, whereas AC EVSEs simply pass alternating current to the vehicle, where an on-board charger performs the AC-to-DC conversion. As power levels continue to increase in order to reduce charging times for electric vehicles, it is likely that the mass and expense associated with the power electronics will be moved off of the vehicle, resulting in DC charging becoming more commonplace.

Over 10,000 electric vehicle charging stations have been deployed with DOE financial support as of April 30, 2012. The vast majority of these charging stations were supported through American Recovery and Reinvestment Act (ARRA) funding under the Transportation Electrification initiative. In addition, a smaller number of charging stations have been deployed as part of programs undertaken by Clean Cities.

Current DOE R&D Charging Infrastructure Plan

With ARRA funding, DOE will install over 20,000 charging station by 2014, including approximately 200 dual-port DC Fast Chargers. Deployment of this infrastructure is taking place in residential, commercial (workplace/fleet), and public locations. Residential EVSEs are likely to provide the majority of charging events for EVs, and DOE has focused on residential and workplace/fleet charging. About two-thirds of the planned installations are in residential or workplace/fleet applications, with about one-third in public charging locations. The majority of these stations are AC Level 2 EVSEs, but approximately 1% are DC Fast Chargers – a ratio similar to that of all EV charging infrastructure nationwide.[7]

Through its Idaho National Laboratory, DOE is collecting and analyzing data from the ARRA Transportation Electrification demonstration projects, to improve understanding of how electric vehicles and support infrastructure are utilized and what the impacts and the grid may be, and to guide future EVSE deployments. The results of this analysis are made publicly available. One key finding that is already apparent is, although public charging infrastructure has a role, the primary delivery point for electricity for electric drive vehicles is the residential EVSE. For the two infrastructure-focused Transportation Electrification projects (ECOtality North America's "EV Project" and Coulomb Technologies' "ChargePoint America), the number of charge events at residential EVSEs far surpasses those at public charging stations.[8] Similarly, the percentage of time residential EVSEs are being utilized is several times greater than the utilization time for public EVSEs.

Additionally, DOE also supports other infrastructure-related critical enablers for EVs beyond EVSE deployment, such as:

- Codes & standards development
- Wireless charging systems
- Integration with a smart grid technologies

Through its National Laboratories, DOE supports development of standards related to electric vehicles through participation in standards development organizations such as the Society of Automotive Engineers (SAE). A comprehensive and consistent set of codes and standards addressing the interface between electric vehicles and charging infrastructure is essential for the market success of these vehicles. Critical efforts cover physical interfaces, power flow, communications, test procedures, and installation/permitting processes.

Wireless charging could be an enabler to enhance the consumer acceptance of electric vehicles. In the near term, static (stationary) wireless charging provides ease of use and convenience to the EV driver. In the longer term, dynamic (in-motion) wireless charging via an electrified roadway could provide additional propulsive energy, thereby increasing EV driving range, reducing requirements for the energy storage system, and greatly increasing the utility of electric vehicles while reducing costs.

Integration of electric vehicles, charging equipment, and the utility grid through smart grid technologies can mitigate the potential impacts of a large penetration of EVs connecting to the utility grid. Not only does this enable EVs to be managed as dispatchable load by utilities, it also allows consumers to set charge preferences based upon utility rates, and leverages synergies between EV demand and renewable energy supply. It also lays the groundwork to enable bidirectional power flow through vehicle-to-grid technologies, so that EVs may become an asset to the grid rather than a liability.

As automobile manufacturers introduce more electric vehicle models and charging infrastructure providers deploy additional charging stations, several challenges are emerging beyond the often cited “chicken-or-egg” problem that is traditionally associated with EV and infrastructure deployment. This includes such issues as:

- Fast charging standardization
- EVSE Permitting
- Infrastructure siting
- Demand charges
- Viable business models

Although the Society of Automotive Engineers published the SAE J1772 standard which has been adopted in North America for the conductive charge coupler for AC Level 1 and Level 2, standardization for DC Fast Charging has lagged behind. As a result, vehicles that are DC Fast Charge-capable have been introduced and sold in the U.S., compatible with the CHAdeMO quick-charge method employing a connector from Tokyo Electric Power Company (TEPCO) specified by the Japan Automobile Research Institute (JARI). DC Fast Charge infrastructure that is CHAdeMO-compliant is also being deployed. At the 2012 Electric Vehicle Symposium, SAE demonstrated a new J1772 “Combo Connector” to implement DC Fast Charging, and has garnered support from North American and European automotive manufacturers. Although no EVSE’s or vehicles utilizing this new connector are yet available, the imminent introduction of this technology into the marketplace may result in near term challenges as two incongruent standards exist.

Permitting for installations for electric vehicle charging infrastructure varies significantly regionally, and costs and delays associated with permits continue to be a barrier to charging station deployment. Although DOE efforts resulted in an EVSE permit template that could be adopted by the many authorities having jurisdiction (AHJs) over electrical permitting to streamline the permitting process, challenges remain in rolling out this single "model permit" in such a way that it is likely to be adopted by most AHJs around the country. Gaps remain in engaging stakeholders to ensure that permitting and inspecting procedures are efficient and do not hinder further EVSE deployment.

Additionally, the question of where to locate charging infrastructure – specifically, public charging stations – continues to be addressed by charging infrastructure providers as well as research and analysis organizations such as the Transportation Research Board of the National Academies and the University of California – Davis' Institute of Transportation Studies. While the infrastructure requirements for different vehicles (PHEV-10, PHEV-40, BEV-100, and BEV-300) will vary as described previously, optimal placement of charging infrastructure relative to vehicle deployments, regional characteristics, and traffic patterns require additional analysis. Although parallels are often drawn between the nearly 150,000 service stations and convenience stores that sell gasoline in the U.S. and the need for a similar number of public EV charging stations, the comparison is likely not valid given the different refueling paradigms alluded to earlier. (Drivers of conventional internal combustion vehicles typically do no refuel at home, whereas owner of EVs will do so the fact majority of the time.) The analysis suggested here will serve to distinguish these two topics and properly inform those interested in the EV infrastructure question.

Furthermore, demand charges pose a challenge to the deployment of fast charging infrastructure. Demand fees are imposed on large consumers of electricity by electric utilities to compensate the utility for the dispatchable resources required to supply that demand. DC Fast Chargers rated at 50 kW may be subject to demand charges of approximately $1000 per month, in addition to the energy charge for electricity delivered, posing a financial hurdle for site hosts and operators of DC Fast Charge infrastructure. While demand charges may be mitigated by energy storage collocated with DC Fast Chargers, this further increases capital costs.

Finally, a variety of business models are emerging as electric vehicle charging providers enter and mature in the EV infrastructure space. In addition to considerations of optimal EVSE placement and demand charges, these providers must create sustainable revenue streams from services provided in a way that does not rely on long term government subsidies. In many cases, it is difficult to create a viable business model for public charging infrastructure without significant utilization of infrastructure assets. Rate structures, provider/host/utility relationships, and additional services must be evaluated to determine how to best meet the requirements of EV owners.

A comprehensive set of policy initiatives could address some of the electric vehicle infrastructure challenges described above. Specifically, policies to help electric utilities manage the transition of a significant portion of our Nation's vehicle fleet to electric drive through smart grid technologies would allow grid-connected vehicles to be an asset to utilities as they engage in resource planning to meet electricity demand. Policy initiatives to remove the barriers to charging infrastructure deployment, such as disparate permitting procedures and confusion regarding sale of electricity (versus sale of time connected to an EVSE) could mitigate delays and implementation difficulties for charging station providers. Greater engagement between the renewable electricity generation community and the electric vehicle community could result in greater progress towards leveraging the supply and demand synergies between renewable generation resources and EVs. Such policies, in addition to efforts currently underway to assist cities and communities in planning for EVs and for sharing lessons learned with other regions, could make a significant impact on the successful deployment of adequate recharging infrastructure in order to sustain the full-scale market penetration of grid-connected vehicles through the next decade.

[1] http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/usdrive.html

[2] 2011 DOE Vehicle Technologies Market Report, ORNL-TM-2012/016, p26, http://cta.ornl.gov/vtmarketreport

[3] http://www.edmunds.com/industry-center/analysis/will-higher-gas-prices-boost-hybrid-ev-sales.html

[4] U.S. Environmental Protection Agency and U.S. Department of Energy (February 2012). "Compare Side-by-Side - 2012 Nissan Versa and 2012 Nissan Leaf". Fueleconomy.gov. http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=31715&id=32154

[5] DOE Fiscal Year 2011 Annual Progress Report for Energy Storage R&D, January 2012, http://www1.eere.energy.gov/vehiclesandfuels/resources/vt_es_fy11.html

[6] http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2012_merit_review.html

[7] http://www.afdc.energy.gov/afdc/data_download/download

[8] As of March 31, 2012, 91% of charge events in the EV Project occurred at residential EVSEs, while 9% occurred at publicly available EVSEs (http://avt.inl.gov/pdf/EVProj/EVProjInfrastructureQ12012.pdf). On average, residential EVSEs had a vehicle connected 34% of the time, while publicly available EVSEs had a vehicle connected 7% of the time.