Batteries and Electrification R&D

Steven Boyd, Program Manager
Vehicle Technologies Office
Mobility is a Large Part of the U.S. Energy Economy

- **11 Billion Tons of Goods**
- **Over 3 Trillion Miles**

Transportation is the 2nd largest expense for U.S. households.

- **70%** of petroleum used for transportation.
- **85%** of it used for on-road vehicles.

Source: TEDB, 2017
EERE’s Vehicle Technologies Office (VTO)

VTO develops advanced transportation technologies that:
- Improve energy efficiency
- Increase domestic energy security
- Reduce operating cost for consumers & business
- Light/Medium/Heavy Duty Vehicles

R&D Focus Areas

- Batteries & Electrification
- Advanced Combustion Systems & Fuels
- Materials Technology
- Energy Efficient Mobility Systems
Batteries and Electrification Program

Enable a large market penetration of electric drive vehicles through innovative research and development:

- Reduce the cost of electric vehicle batteries to less than $100/kWh and decrease charge time to 15 minutes or less, with the ultimate goal of $80/kWh.
- Address the charging infrastructure and electricity grid challenges to enable a 15-minute or less charge.
- A high power density 3L, 100 kW peak electric traction drive system at a cost of $6/kW.

Cost Trends for Lithium-based EV Batteries

<table>
<thead>
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<th>System Cost ($/kWh)</th>
<th>2012</th>
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Global EV Forecast

Source: Bloomberg New Energy Finance

Batteries and Electrification (Batteries, Electric Drive, Grid/Infrastructure)

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<tr>
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<th>FY17</th>
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<td>Batteries,</td>
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<td>Grid/Infrastructure</td>
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Cost Trends for Lithium-based EV Batteries

**Graphite/High Voltage NMC**
- 2012: 4.0 Volts and ~180 mAh/g NMC
- 2017: 4.4 Volts and ~200+ mAh/g NMC

**Silicon/High Voltage NMC**
- 2014: 4.2 Volt NMC and <10% Silicon
- 2017: 4.4 Volts NMC and >10% Silicon

**Lithium-Metal or Lithium/Sulfur**
- 2016: 5x excess Lithium, 10% Sulfur
  - Projection assumes cycle life, cell scale-up, and catastrophic failure issues have been resolved
- Need: 1.5x excess Lithium, 75% Sulfur
Focused Research on Bridging the Gaps

1. Eliminate dependence on critical materials
2. Further reduce battery costs (initial and life cycle)
3. Develop safe batteries that charge in <15 mins

These three challenges will be the focus over the next 5 years
Behind-the-Meter-Storage (BTMS)

Develop innovative, critical materials free, battery storage technology (in the 1-10 MWh range) that will reduce cost & eliminate potential grid impacts of high power EV charging systems and enable localized storage of PV generation, and increase building energy-efficiency.

- **Battery Storage:**
  - Only non-critical materials chemistries considered
  - Investigate candidate chemistries to meet draft requirements such as LFP, LNMO, LTO, Solid-State, Others
  - Novel cell designs

- **Non-battery component evaluation and development.**
  - Power electronics, Controls architecture / strategy, and communication systems for enhanced grid interconnectivity.

Draft BTMS Battery Target
- $100/kWh
- 8000 cycle
- 20 year life
Electric Drive Technologies Research Consortium

**Current Status**

$1800*  
($12/kW 2015 Target)

Chevrolet Bolt

20+ Liter Volume

**2025+**

$900  
($6/kW 2025 Target)

Future EV Design Concepts

3 Liter Volume

*Based on 2016 Bolt 150 kW system*
Electric Drive Technologies Research Consortium

Traction drive system (motor + inverter), 100 kW peak power rating

- Voltage increase from 300 V to 600-800 V nominal
- Smaller electric drive systems enable greater vehicle electrification across small, medium, and large vehicle segments
- WBG based power electronics and Non-Heavy Rare Earth electric machines (reduced critical materials need)
- Ames, NREL, ORNL, SNL and 10 universities

<table>
<thead>
<tr>
<th>Electric Traction Drive System Targets</th>
<th>Year</th>
<th>2020</th>
<th>2025</th>
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<tr>
<td>Cost ($/kW)</td>
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<td>8</td>
<td>6</td>
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<tr>
<td>Power Density (kW/L)</td>
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25% cost reduction
88% volume reduction
Electrification R&D addresses challenges in Cyber-physical security, extreme fast charging, and Smart charging to support EVs at Scale.

- Cyber-physical security of EVs and charging protects our critical infrastructure
- R&D supports advanced EV charging security at the Grid edge
- XFC infrastructure enables EVs to charge similar to today’s vehicles refuel.
- R&D supports advanced energy conversion from the Grid.
- Smart charging EVs enable efficient use of locally produced energy.
- R&D supports advanced strategies for reducing cost of electricity delivery.
Ultra-High Power Fast Charging or Extreme Fast Charging (XFC):

Integrating EVs with Buildings, Onsite Energy Resources, and the Grid
Extreme Fast Charging (XFC) Challenges and Gaps

Buildings, Onsite Resources, and the Grid

What technology solutions will support integration of convenient XFC charging into the grid at a cost comparable to L1/L2 charging that is reliable and resilient?

• Site optimization of XFC with onsite
  – Distributed energy resources (DER) such as energy storage or photovoltaics (PV)
  – Commercial buildings, and/or other large flexible loads

• Resilient energy supply through onsite generation that utilizes alternative fuels with the potential to operate in a microgrid.

• XFC site control technologies for distribution system operation that mitigate capacity expansion, line upgrades, and voltage management
Load and generation estimation is required for optimal energy storage integration

- HPFC load will vary depending on charging infrastructure and travel patterns
- Onsite renewable generation will be dependent on regional conditions
- Building load will be dependent on occupancy, building design, and is subject to seasonal weather variation

Control integration is required for energy system and microgrid management

- Interoperability of communication and control across multiple sectors
- Resolving multi-objective optimization across the building, transportation, and grid interface that is open yet cybersecure
Extreme Fast Charging (XFC) Challenges and Gaps

Distribution System Operation

The value of reactive and real power control for the XFC site will need to be understood

- What will be the impact on voltage regulation hardware from XFC installation
- Value of system efficiency and avoidance of line upgrades with reactive XFC support
- Capacity deferral opportunities through real power control at XFC sites to avoid concurrent peak load on the feeder

How does the addition of XFC affect stability of the distribution system control

- Impacts of load that is fast ramping, highly variable, and a constant power device
- Integration requirements for onsite generation to support microgrids and support system resiliency
Extreme Fast Charging (XFC) Projects

- **North Carolina State University team** will develop and demonstrate a 1000 Volt XFC system with a combined 1 MW output power (350 kW per stall) using a solid-state transformer and circuit breakers.

- **Missouri University of Science and Technology** will charging system that connects directly to a 15 kV class distribution feeder and incorporates energy storage as a buffer to minimize grid impacts.

- **Electric Power Research Institute**, in a collaborative approach with two different equipment manufacturers, will develop an XFC system offering “DC as a service”, providing renewable energy resources integration and management.
Extreme Fast Charging (XFC) – Beyond 1+MW

- Address challenges associated with Multiport MW-scale charging infrastructure for MD/HD EVs
- Create hardware and system models as well as power and charge control methods and hardware
- Develop solutions with stakeholder input to enable 1+ MW charging systems for MD/HD EVs to maximize utilization
Smart Charge Management

(RECHARGe)

smaRt Electric vehicle CHArging for a reliable and Resilient Grid
Smart Charge Management

**Smart Vehicle-Grid Integration**

1. Vehicle role for home and workplace energy management
2. Controls for grid integration (GMLC use cases)
3. Optimal control on customer side for grid resilience and stability
4. Enabling technologies and tools development

**Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)**

1. Simulation and controls development to minimize distribution impacts
2. Regional modelling for distribution operations & capacity planning
3. Forecasting-enhanced charging integration with buildings and DER
4. Predictive and interactive charge decision making

**TIMESTEP**

- Sub-second to hours
- Minutes to weeks
Smart Charge Management

The RECHARGE project will determine how **PEV charging at scale** should be managed to avoid negative grid impacts, allow for critical strategies and technologies to be developed and increase the value for PEV owners, building managers, charge network operators, grid services aggregators, and utilities.

Specifically, this project will accomplish the following objectives:

1) Quantify the effects of uncontrolled charging to understand how increased PEV adoption may negatively impact the grid
2) Analyze the effectiveness of multiple control strategies in mitigating negative grid impacts introduced by PEVs at scale
3) Rank the benefits and costs of the control strategies in avoiding grid upgrades, providing grid services, and improving resiliency
4) Overcome technical barriers to implementing high-value control strategies.
Several existing modeling and analysis tools will be integrated to analyze the interaction of PEVs at the facility, distribution network, and transmission system levels:

- Quantify the effects of uncontrolled charging to understand how increased PEV adoption may negatively impact the grid.
- Analyze the effectiveness of multiple control strategies in mitigating negative grid impacts introduced by PEVs at scale.
- Rank the benefits and costs of the control strategies in avoiding grid upgrades, providing grid services, and improving resiliency.
- Overcome technical barriers to implementing high-value control strategies.
Battery Recycling Prize

The Lithium-Ion Battery Recycling Prize is a $5.5 million prize competition to support American entrepreneurs as they develop transformative approaches and technology ideas to collect, sort, store, and transport spent and discarded lithium-ion batteries cost effectively and efficiently for eventual recycling and recovery of critical materials.

The Battery Recycling Prize is composed of three progressive prize competitions that are structured to provide the resources, environment, and partnerships necessary to create new solutions and develop them from concepts to early-stage prototypes and processes to pilot-scale validations.

This work is funded by the U.S. Department of Energy Vehicle Technologies Office, within the Office of Energy Efficiency and Renewable Energy, in collaboration with the Advanced Manufacturing Office and administered by the National Renewable Energy Laboratory.

To enter the competition, visit AmericanMadeChallenges.org/BatteryRecycling
Thank you

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