

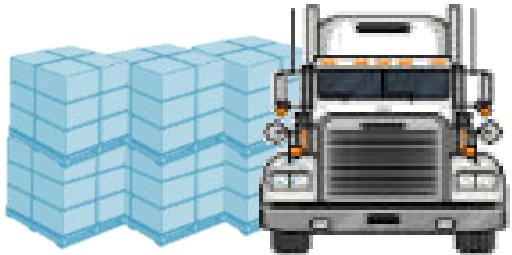
Batteries and Electrification R&D

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

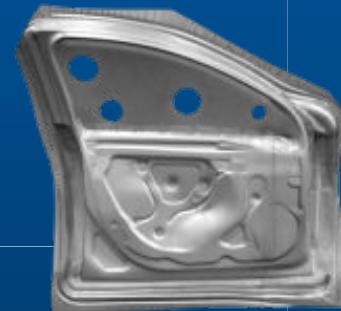
Batteries & Electrification



Advanced Combustion Systems & Fuels



Materials Technology



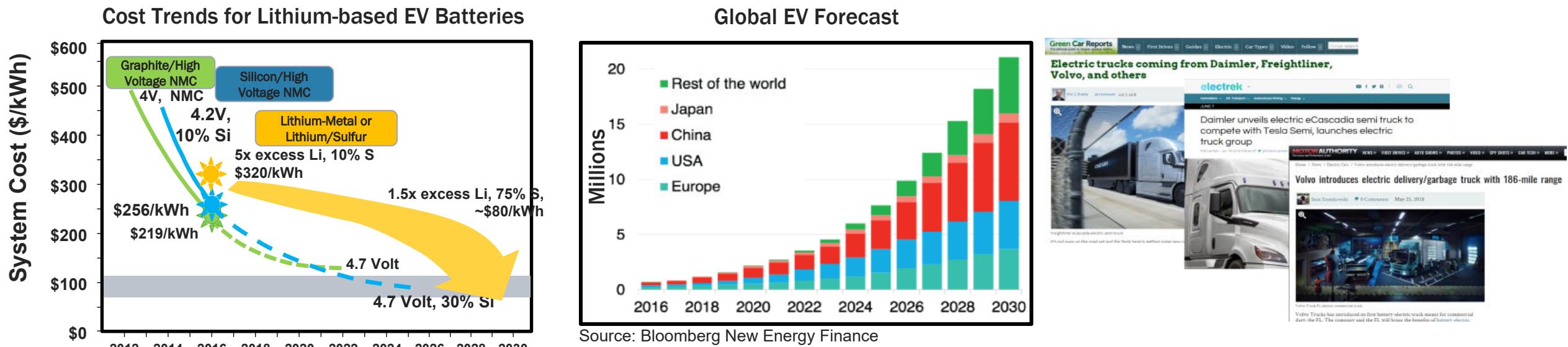
Energy Efficient Mobility Systems



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



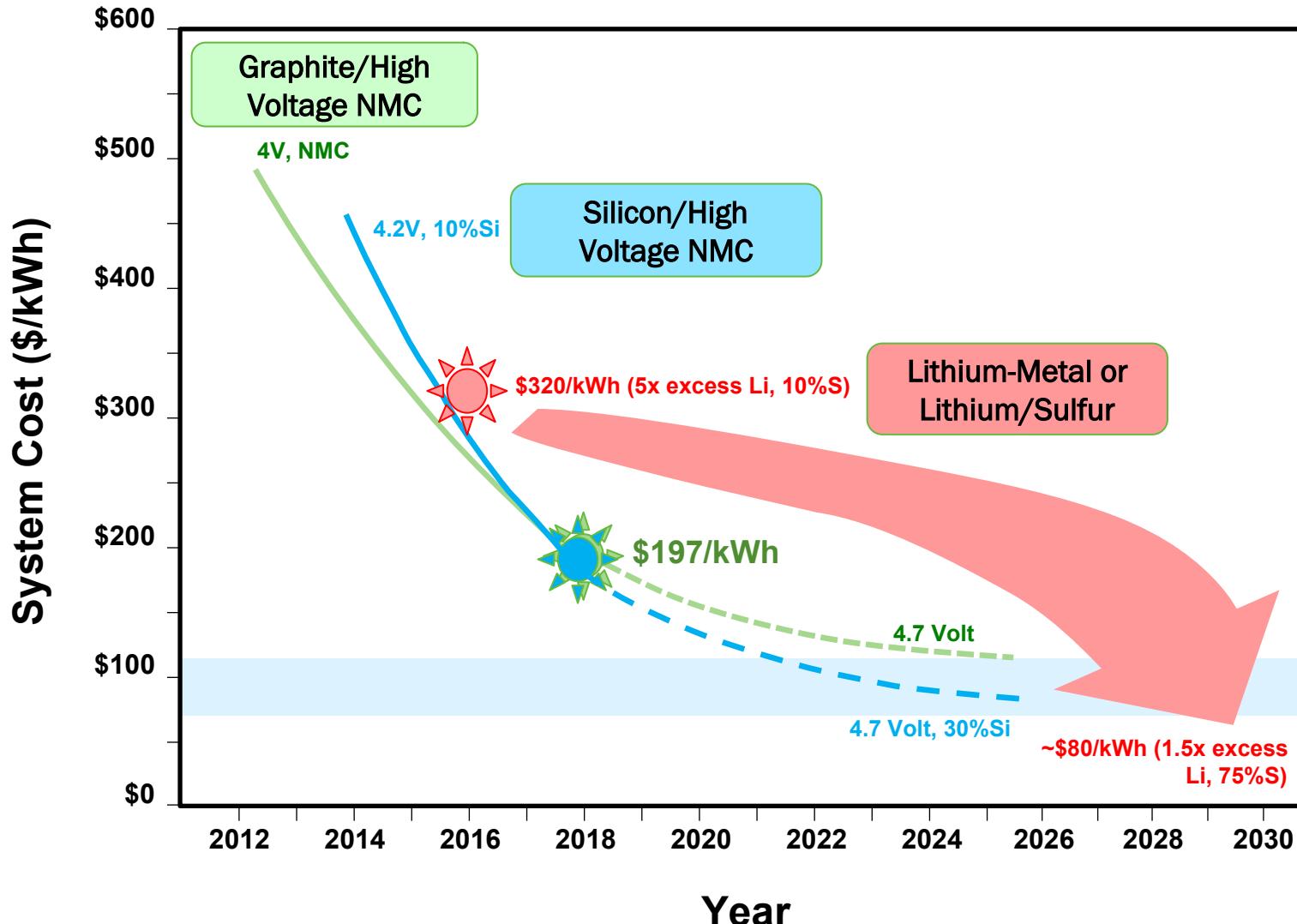
Batteries and Electrification (Batteries, Electric Drive, Grid/Infrastructure)

FY17 \$140,530,000

FY18 \$160,000,000

FY19 \$163,200,000

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

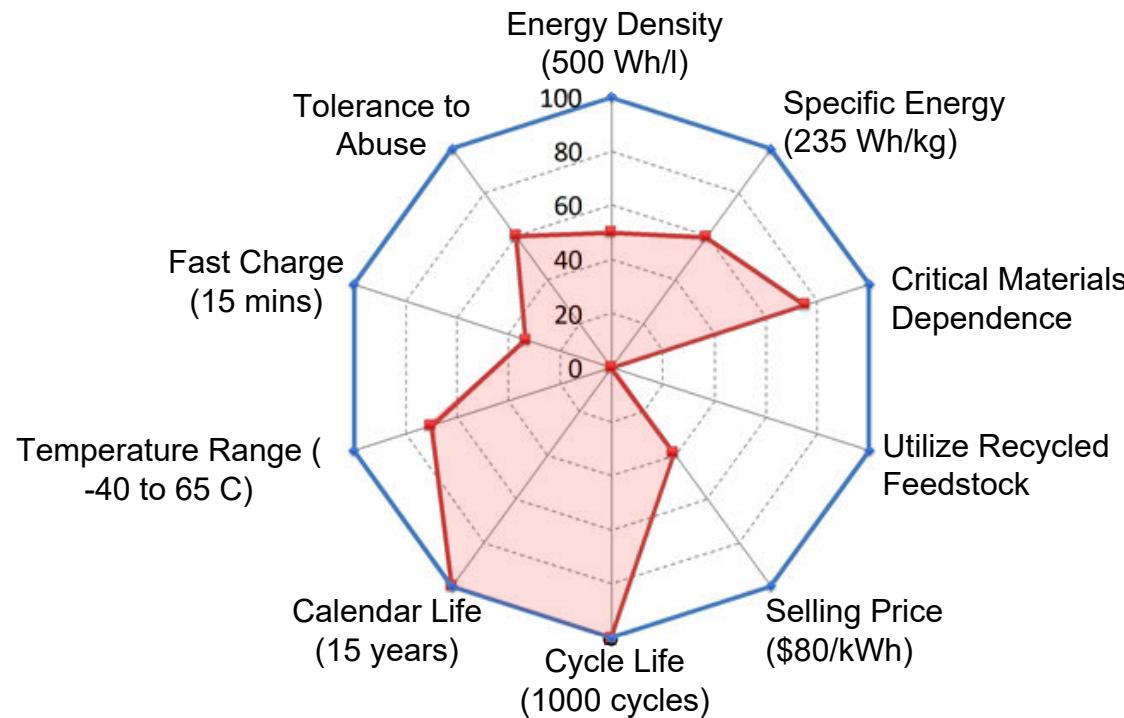
Silicon/High Voltage NMC

- 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

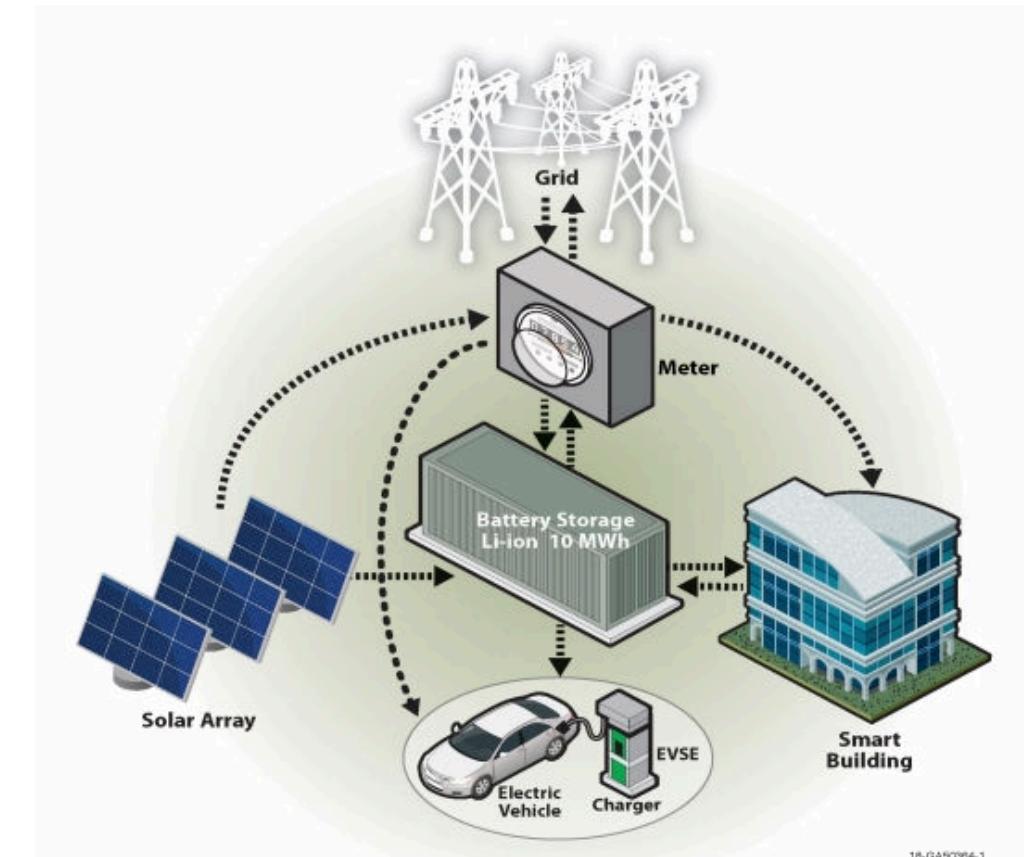
These three challenges will be the focus over the next 5 years

Behind-the-Meter-Storage (BTMS)

In partnership with the Buildings Technology office
and Solar energy Technology office

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 reliability and resilience.



18-GA90364-1

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

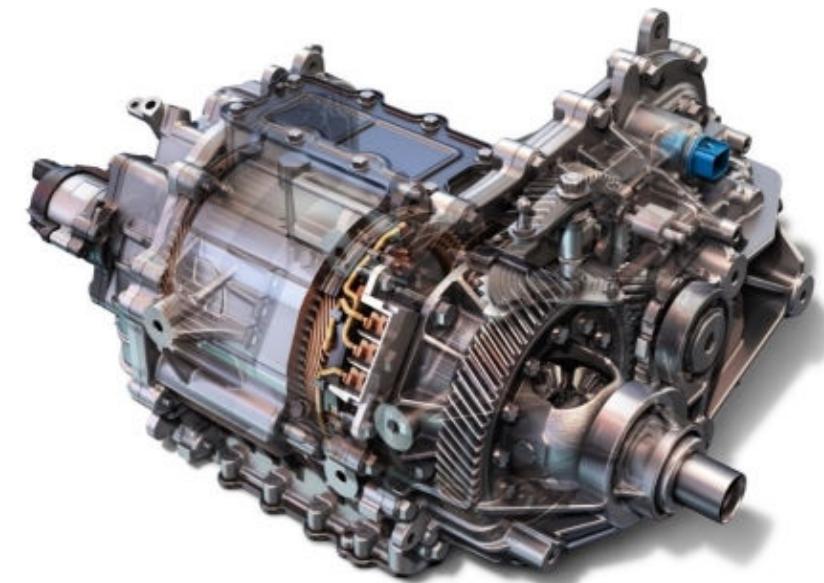


3 Liter Volume

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

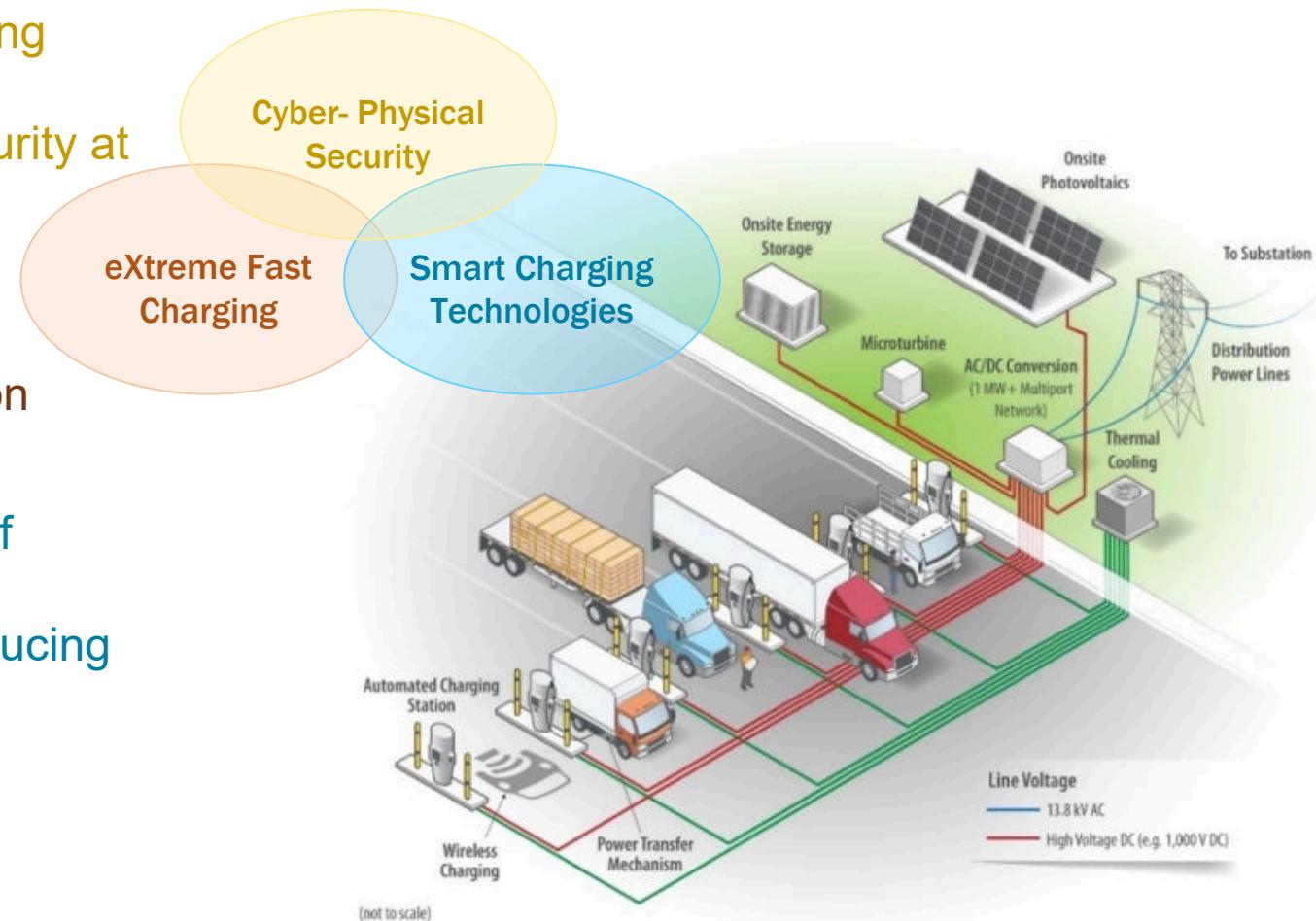


| Electric Traction Drive System Targets | | | |
|--|------|------|----------------------|
| Year | 2020 | 2025 | |
| Cost (\$/kW) | 8 | 6 | 25% cost reduction |
| Power Density (kW/L) | 4.0 | 33 | 88% volume reduction |

VTO – Electrification Activities

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

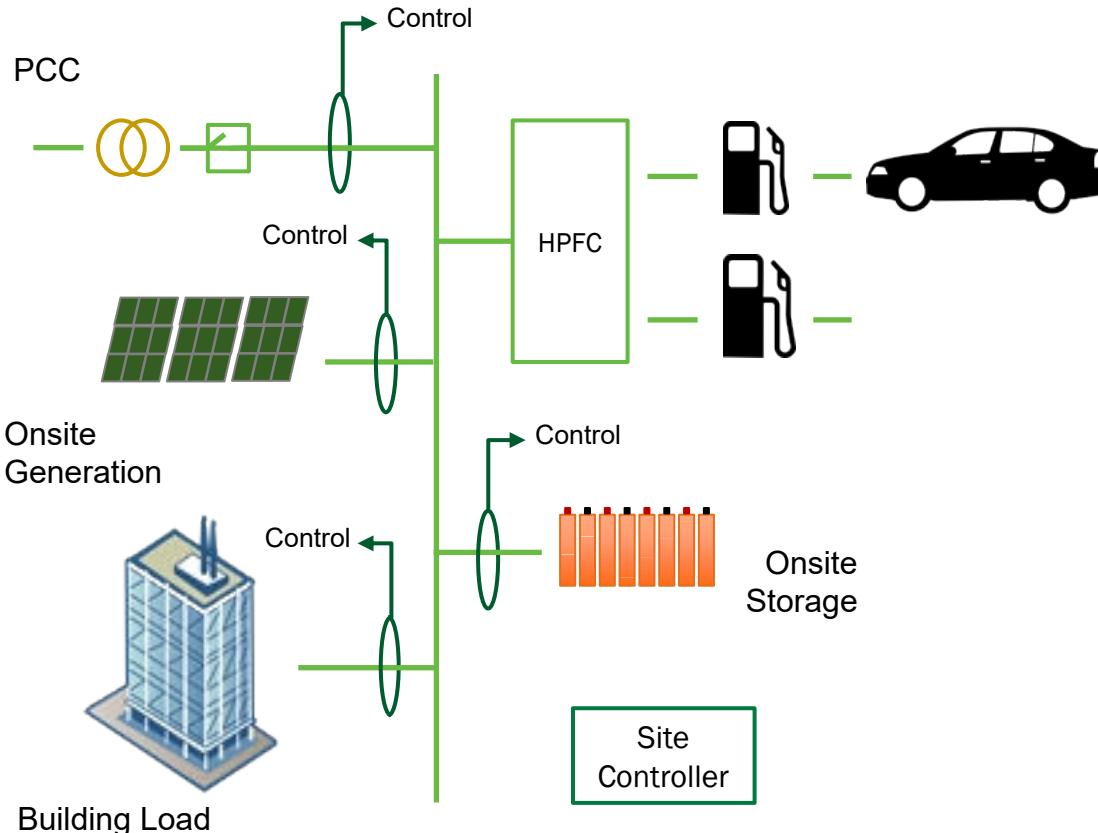
Buildings, Onsite Resources, and the Grid

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**

Extreme Fast Charging (XFC) Challenges and Gaps

Site Optimization and Resilience



Load and generation estimation is required for optimal energy storage integration

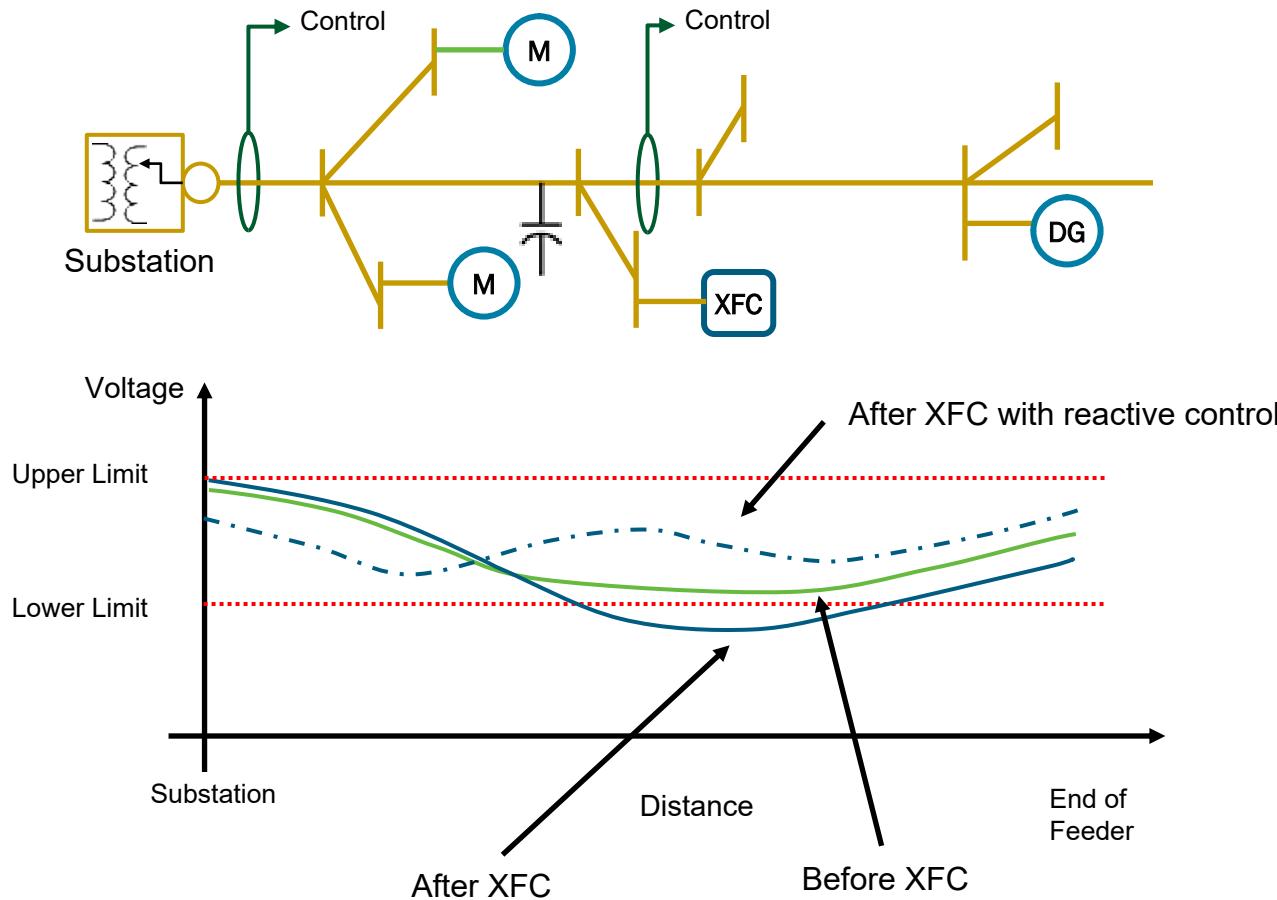
- **HPFC load** will vary depending on charging infrastructure and travel patterns
- Onsite **renewable generation** will be dependent on regional conditions
- **Building load** will be dependent on occupancy, building design, and is subject to seasonal weather variation

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

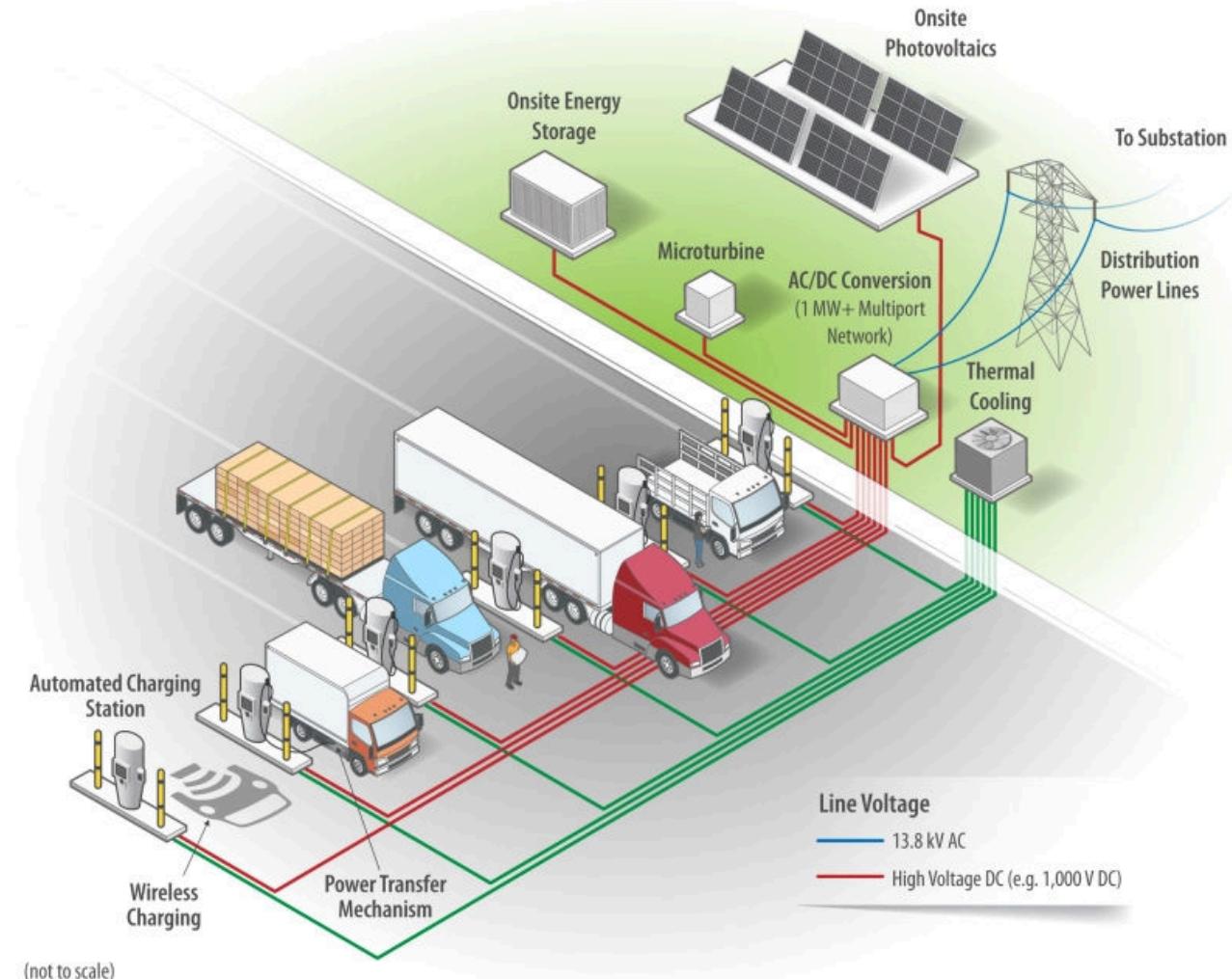
- What will be the **impact on voltage regulation hardware** from XFC installation
- Value of system efficiency and avoidance of line upgrades with **reactive XFC support**
- Capacity deferral opportunities through real power control at XFC sites to **avoid concurrent peak load** on the feeder

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

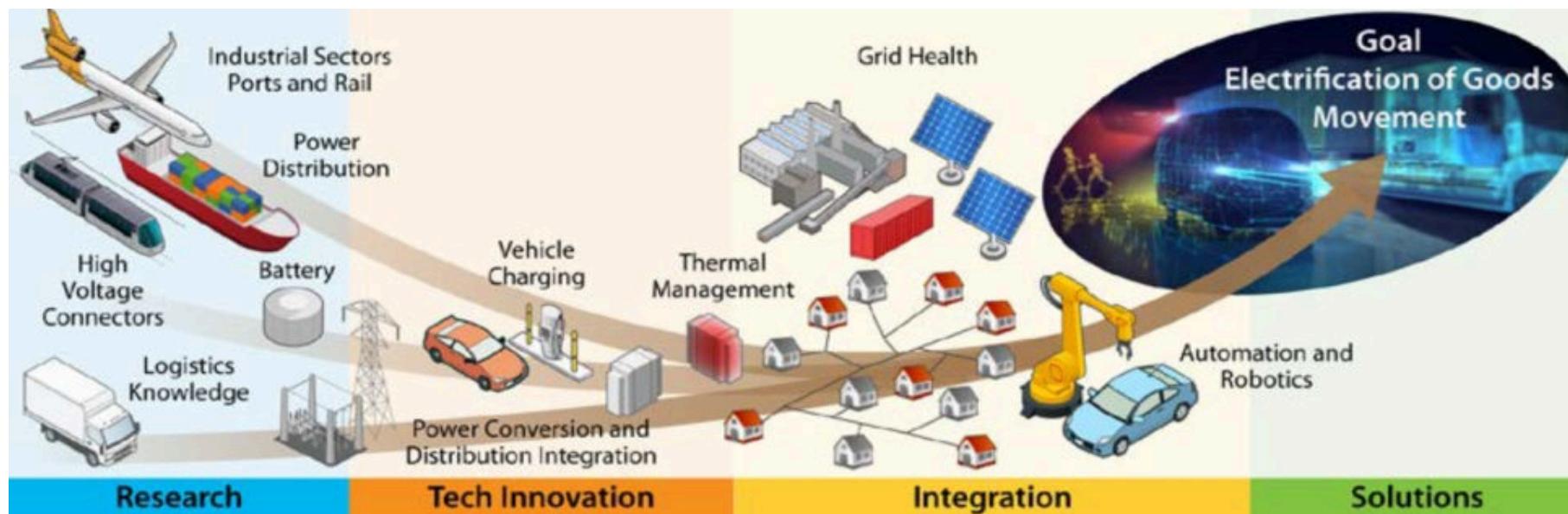
Extreme Fast Charging (XFC) Projects

- **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)

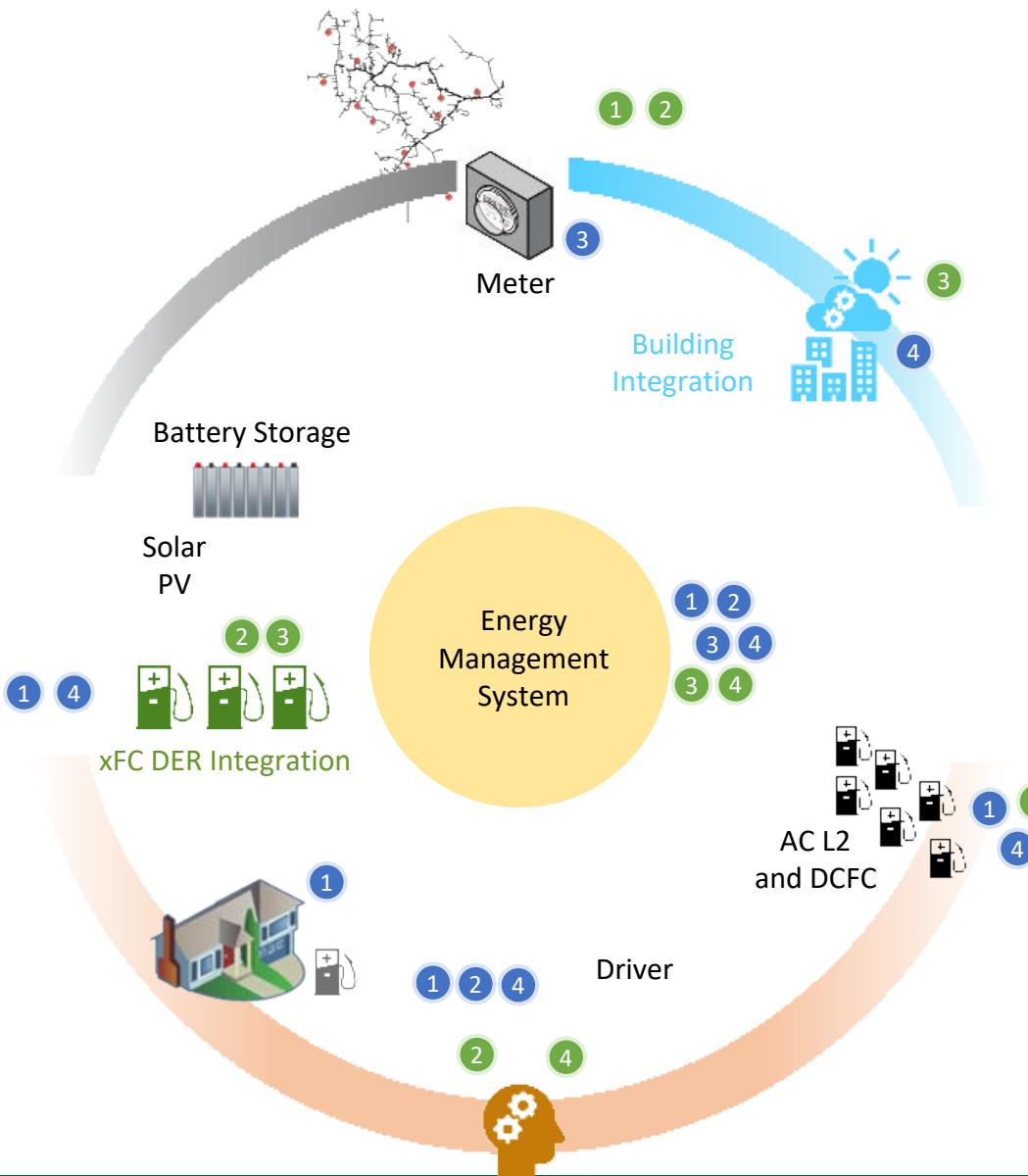
*smaRt Electric vehicle CHArging for a
reliable and Resilient Grid*

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

TIMESTEP
Sub-second to hours



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

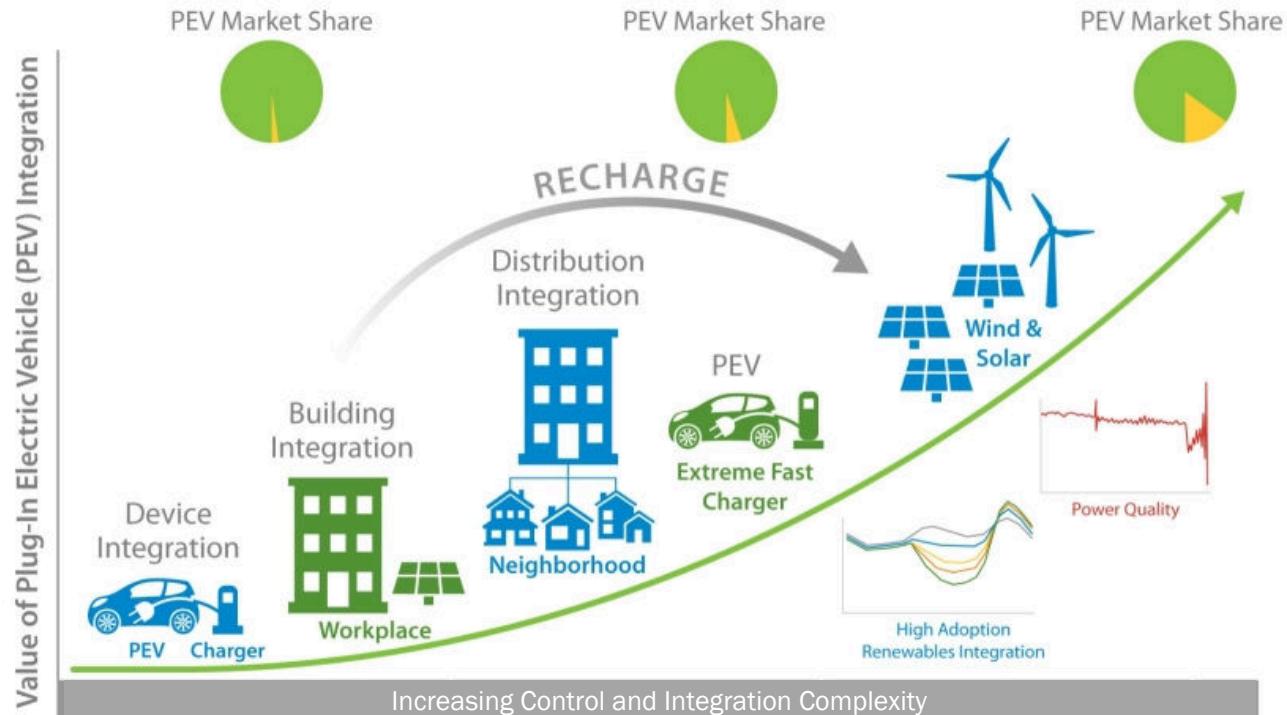
- ① Simulation and controls development to minimize distribution impacts
- ② Regional modelling for distribution operations & capacity planning
- ③ Forecasting-enhanced charging integration with buildings and DER
- ④ Predictive and interactive charge decision making

TIMESTEP
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**.



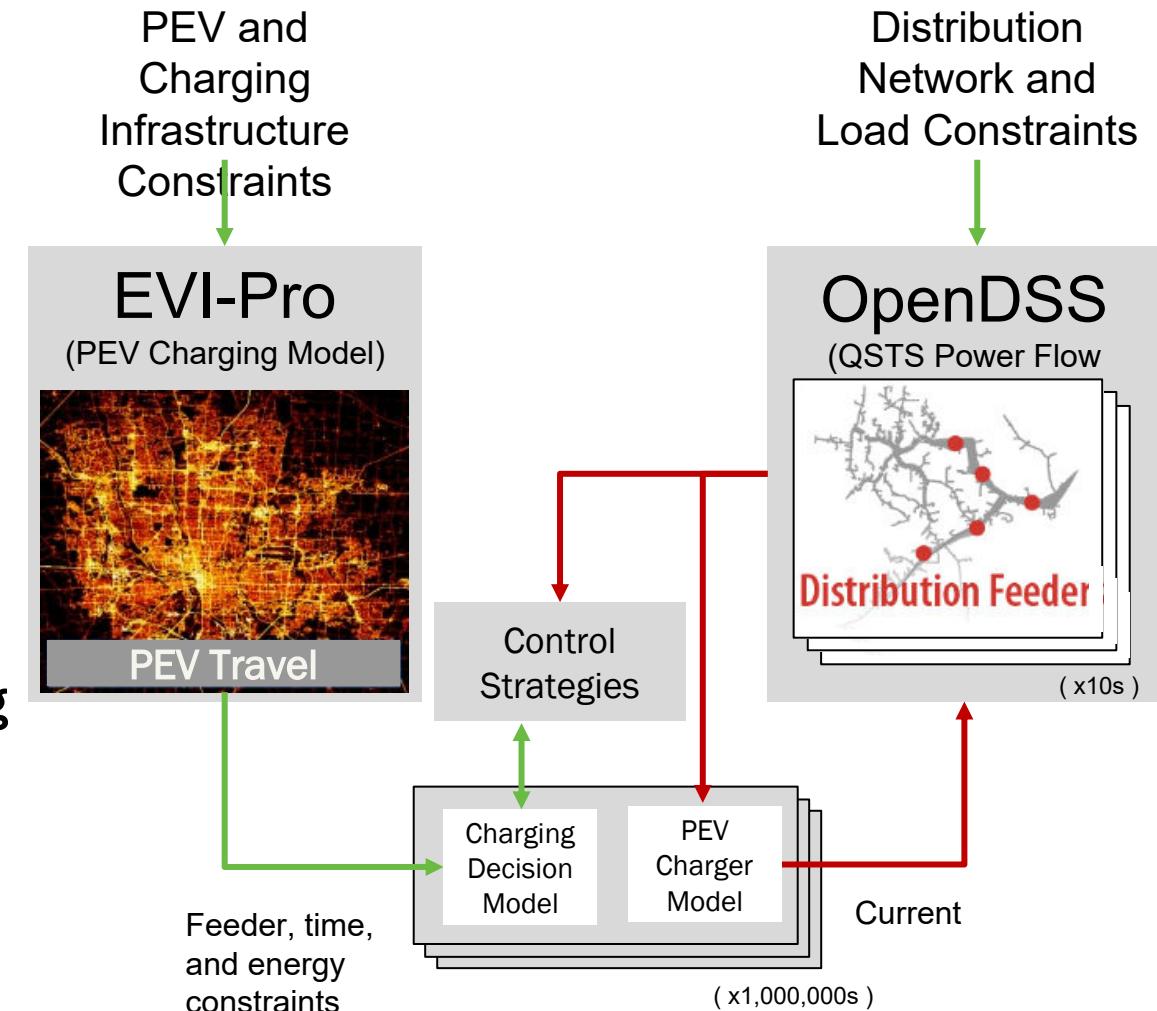
Specifically, this project will accomplish the following objectives:

- 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.

Smart Charge Management

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.



2019 Annual Merit Review

2019 ANNUAL MERIT REVIEW

The U.S. Department of Energy (DOE) Vehicle Technologies Office will hold its 2019 Annual Merit Review (AMR) on June 10-13, 2019, at the Hyatt Regency Crystal City hotel in Arlington, Virginia.

| ORAL TECHNICAL SESSIONS | | | | | | | | | | | | | | | | | | |
|-----------------------------------|---|------------------------------------|----------------------------|-------------------|--|-----------------------------------|--------------------------------------|------------------------------------|----------------------------|-------------------|--|-----------------------------------|--------------------------------------|------------------------------------|----------------------------|-------------------|--|-------------------------------------|
| Advanced Combustion Engines (ACE) | Technology Integration (TI) | Electrification Technologies (ELT) | Materials Technology (MAT) | Battery R&D (BAT) | Energy-Efficient Mobility Systems (EEMS) | Advanced Combustion Engines (ACE) | Fuel and Lubricant Technologies (FT) | Electrification Technologies (ELT) | Materials Technology (MAT) | Battery R&D (BAT) | Energy-Efficient Mobility Systems (EEMS) | Advanced Combustion Engines (ACE) | Fuel and Lubricant Technologies (FT) | Electrification Technologies (ELT) | Materials Technology (MAT) | Battery R&D (BAT) | Energy-Efficient Mobility Systems (EEMS) | Vehicle Technologies Analysis (VAN) |
| Regency E | Theater | Regency B | Regency A | Potomac | Washington | Regency E | Regency F | Regency B | Regency A | Potomac | Washington | Regency E | Regency F | Regency B | Regency A | Potomac | Washington | Theater |
| Tuesday, June 11 | | | | | | | | | | | | | | | | | | |
| Continental Breakfast | | | | | | | | | | | | | | | | | | |
| 7:00 AM | ACE054 T1000 ELT000 MAT124 BAT337 EEMS056 | | | | | | | | | | | | | | | | | |
| 8:15 AM | ACE013 T1096 ELT089 MAT125 BAT252 EEMS057 | | | | | | | | | | | | | | | | | |
| 8:30 AM | ACE012 T1087 ELT208 MAT118 BAT253 EEMS0511 | | | | | | | | | | | | | | | | | |
| 8:45 AM | ACE006 T1088 ELT209 MAT119 BAT374 EEMS058 | | | | | | | | | | | | | | | | | |
| 9:00 AM | ACE084 T1089 ELT210 MAT120 BAT183 EEMS058 | | | | | | | | | | | | | | | | | |
| 9:15 AM | Panel Disc | | | | | | | | | | | | | | | | | |
| 10:30 AM | Break | | | | | | | | | | | | | | | | | |
| 11:00 AM | ACE005 T1090 ELT211 MAT146 BAT375 EEMS055 | | | | | | | | | | | | | | | | | |
| 11:15 AM | ACE010 T1091 ELT212 MAT117 BAT376 EEMS007 | | | | | | | | | | | | | | | | | |
| 11:30 AM | ACE125 T1092 ELT213 MAT101 BAT377 EEMS019 | | | | | | | | | | | | | | | | | |
| 11:45 AM | BAT378 | | | | | | | | | | | | | | | | | |
| 12:00 PM | Lunch | | | | | | | | | | | | | | | | | |
| 12:15 PM | ACE126 T1093 ELT214 MAT147 BAT379 EEMS039 | | | | | | | | | | | | | | | | | |
| 12:30 PM | ACE017 T1094 ELT215 MAT148 BAT380 EEMS044 | | | | | | | | | | | | | | | | | |
| 12:45 PM | ACE015 T1095 ELT216 MAT122 BAT381 EEMS040 | | | | | | | | | | | | | | | | | |
| 1:00 PM | ACE128 T1096 ELT217 MAT149 BAT382 EEMS060 | | | | | | | | | | | | | | | | | |
| 1:15 PM | BAT385 | | | | | | | | | | | | | | | | | |
| 1:30 PM | BAT386 | | | | | | | | | | | | | | | | | |
| 1:45 PM | Break | | | | | | | | | | | | | | | | | |
| 2:00 PM | ACE126 T1097 ELT218 MAT127 BAT265 EEMS043 | | | | | | | | | | | | | | | | | |
| 2:15 PM | ACE004 T1098 ELT219 MAT128 BAT266 EEMS043 | | | | | | | | | | | | | | | | | |
| 2:30 PM | ACE127 T1099 ELT220 MAT129 BAT264 EEMS023 | | | | | | | | | | | | | | | | | |
| 2:45 PM | ACE130 T1100 ELT221 MAT130 BAT263 EEMS045 | | | | | | | | | | | | | | | | | |
| 3:00 PM | ACE131 T1101 ELT222 MAT131 BAT265 EEMS045 | | | | | | | | | | | | | | | | | |
| 3:15 PM | ACE132 T1102 ELT223 MAT132 BAT266 EEMS045 | | | | | | | | | | | | | | | | | |
| 3:30 PM | ACE133 T1103 ELT224 MAT133 BAT267 EEMS020 | | | | | | | | | | | | | | | | | |
| 3:45 PM | ACE134 T1104 ELT225 MAT134 BAT268 EEMS020 | | | | | | | | | | | | | | | | | |
| 4:00 PM | ACE135 T1105 ELT226 MAT135 BAT269 EEMS020 | | | | | | | | | | | | | | | | | |
| 4:15 PM | ACE136 T1106 ELT227 MAT136 BAT270 EEMS020 | | | | | | | | | | | | | | | | | |
| 4:30 PM | ACE137 T1107 ELT228 MAT137 BAT271 EEMS020 | | | | | | | | | | | | | | | | | |
| 4:45 PM | ACE138 T1108 ELT229 MAT138 BAT272 EEMS020 | | | | | | | | | | | | | | | | | |
| 5:00 PM | ACE139 T1109 ELT230 MAT139 BAT273 EEMS020 | | | | | | | | | | | | | | | | | |
| 5:15 PM | ACE140 T1110 ELT231 MAT140 BAT274 EEMS020 | | | | | | | | | | | | | | | | | |
| 5:30-7:30 PM | Poster Session I – ACE, BAT (Part 1), EEMS, ELT | | | | | | | | | | | | | | | | | |
| | Poster Session II – BAT (Part 2), VAN | | | | | | | | | | | | | | | | | |

Thank you

Steven Boyd

Program Manager, Batteries and Electrification

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