U.S. DEPARTMENT OF ENERGY

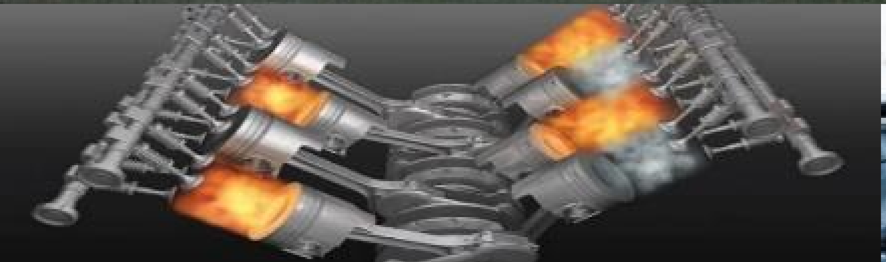
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Batteries and Electrification R&D

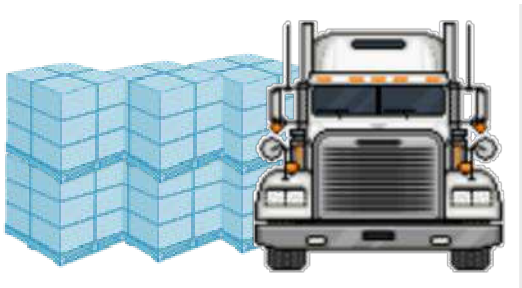
Steven Boyd, Program Manager

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.

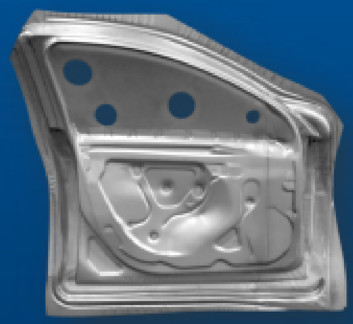
Source: TEDB, 2017

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

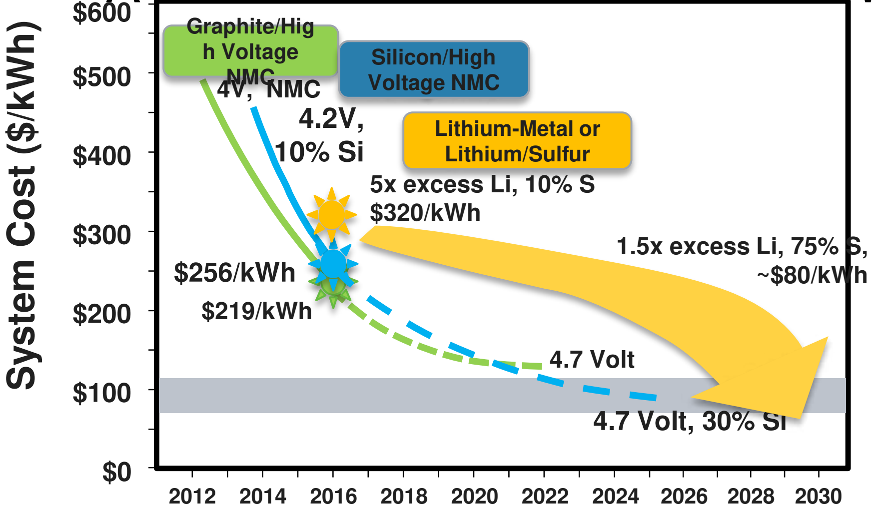
Batteries & Electrification	Advanced Combustion Systems & Fuels	Materials Technology	Energy Efficient Mobility Systems
			

Batteries and Electrification Program

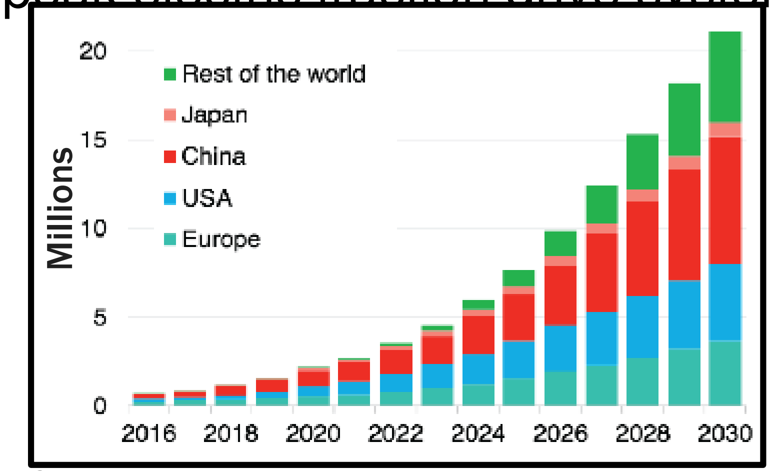
Enable a large market penetration of electric drive vehicles through innovative research and development:

- 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



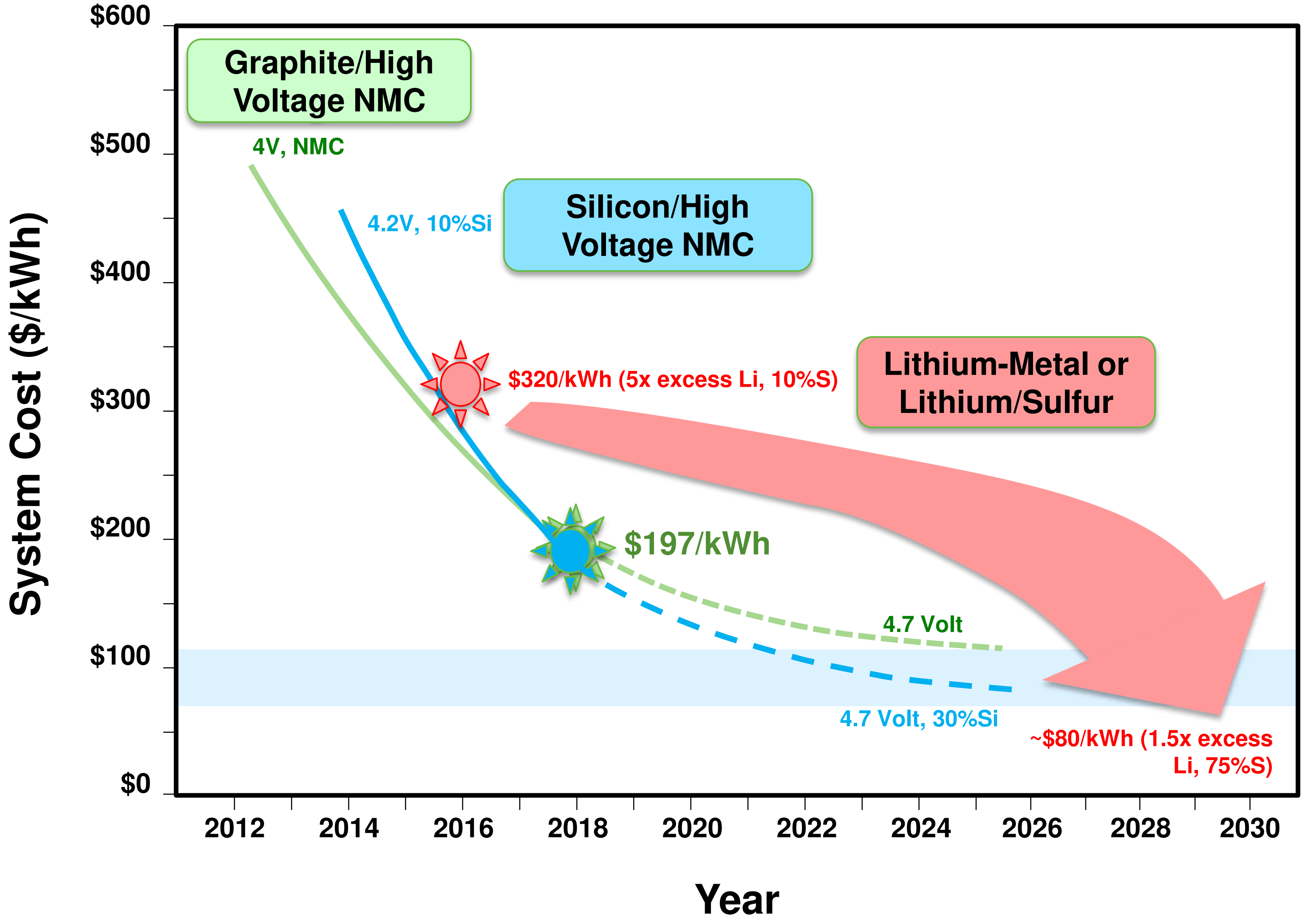
Global EV Forecast



Source: Bloomberg New Energy Finance

Batteries and Electrification (Batteries, Electric Drive, Grid/Infrastructure)	FY17	FY18	FY19
	$140,530,000	$160,000,000	$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

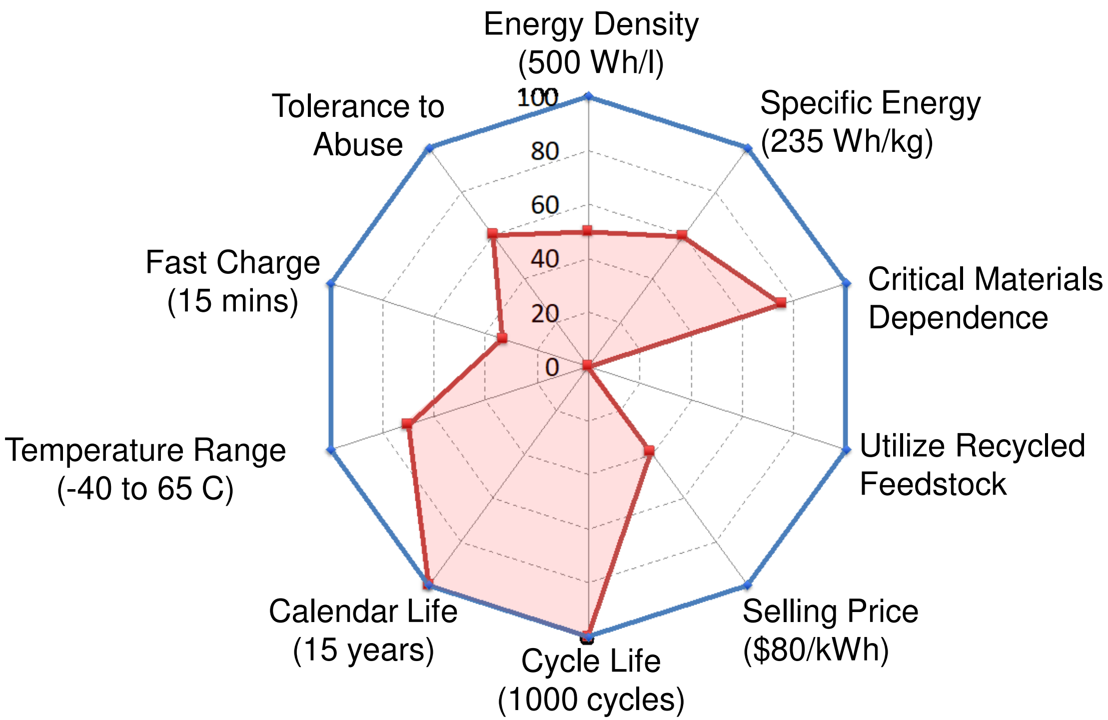
Silicon/High Voltage NMC

- 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

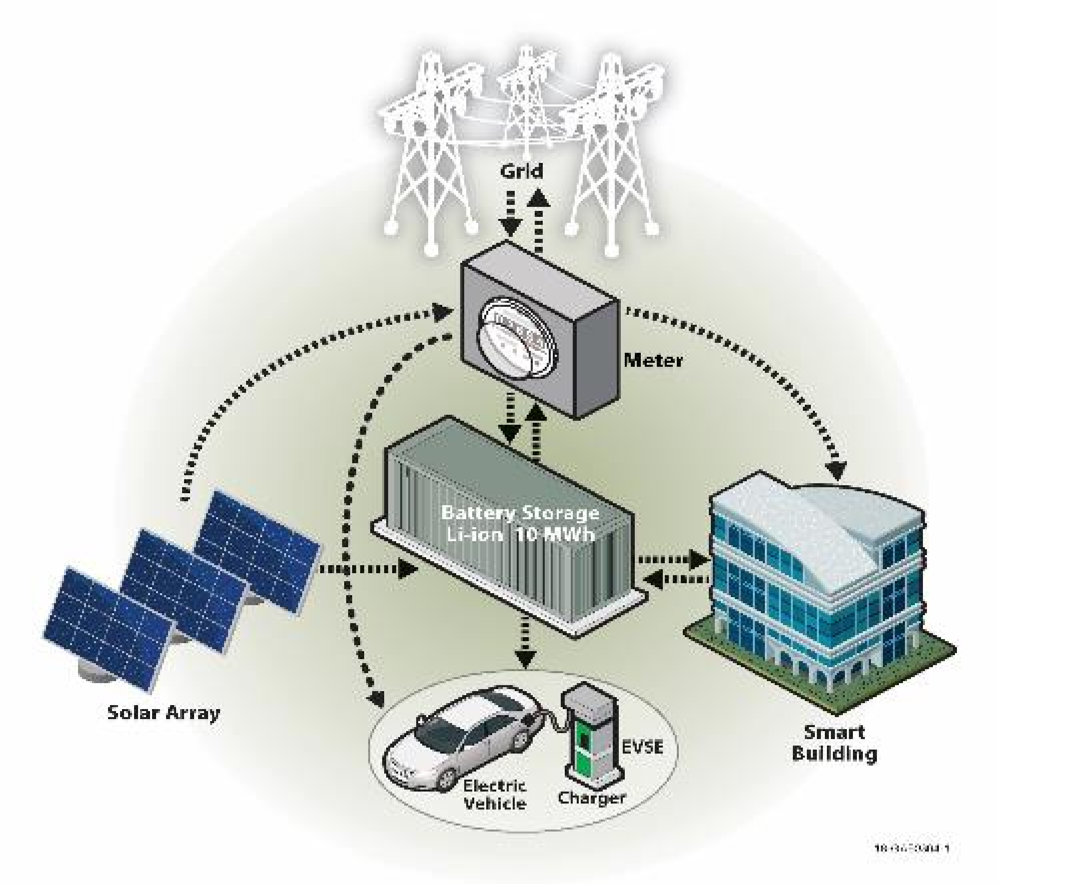
These three challenges will be the focus over the next 5 years

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.



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

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

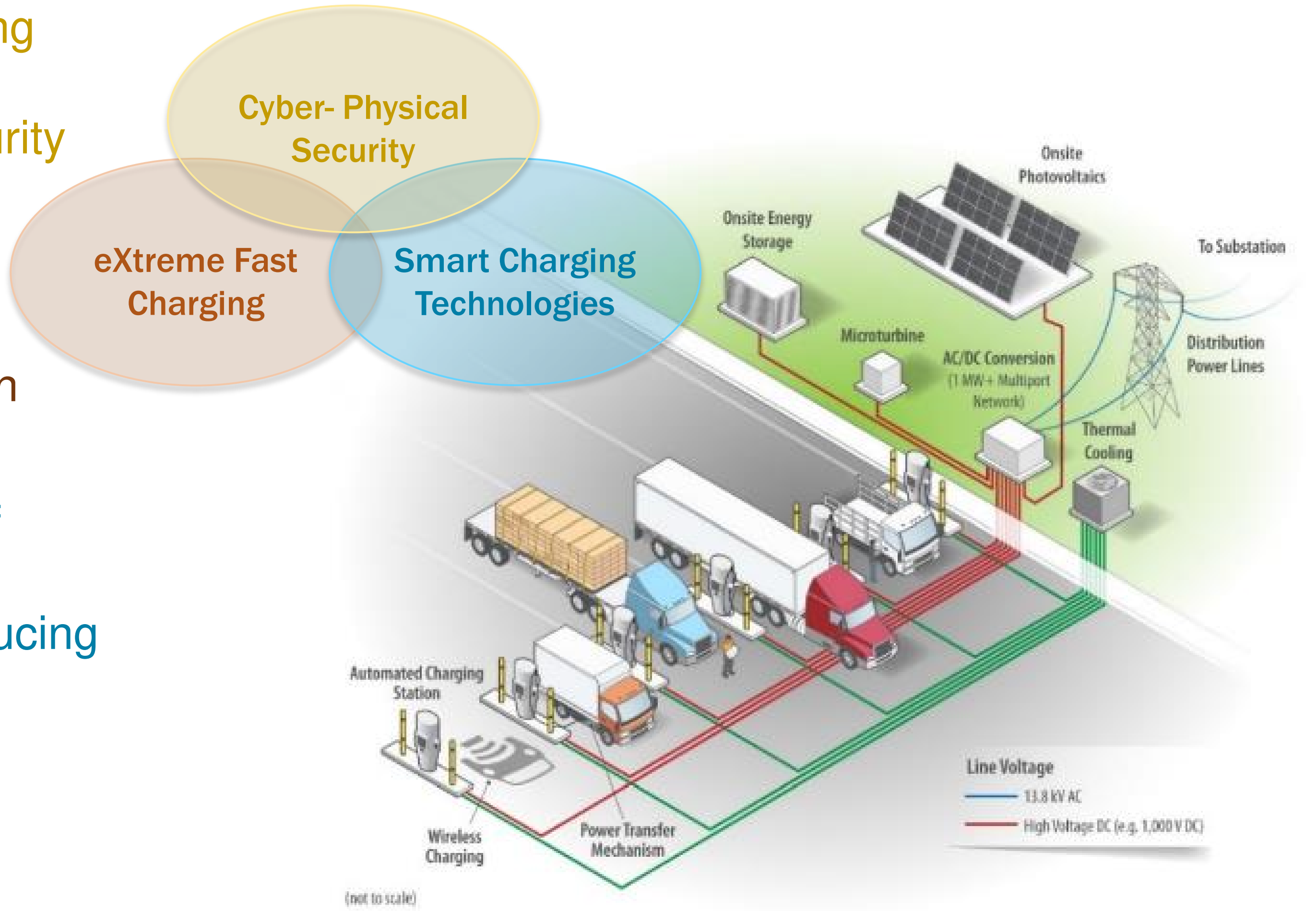
VTO – Electrification Activities

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

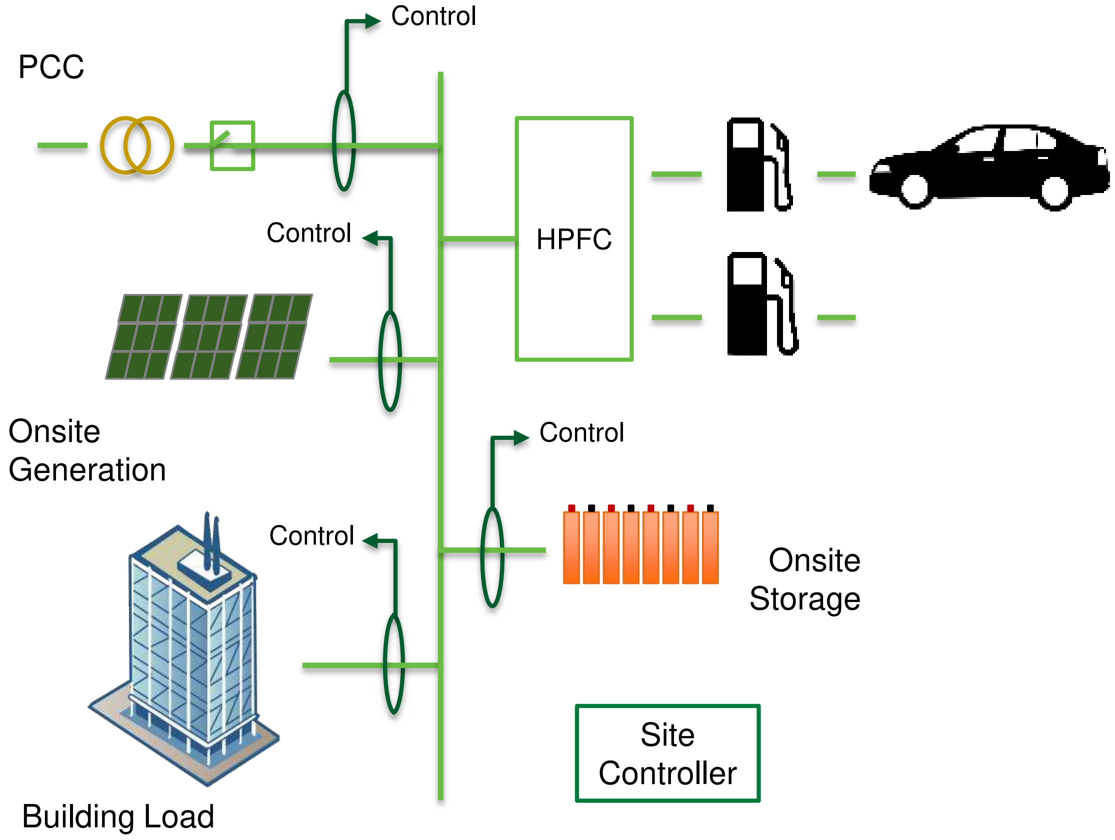
Buildings, Onsite Resources, and the Grid

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**

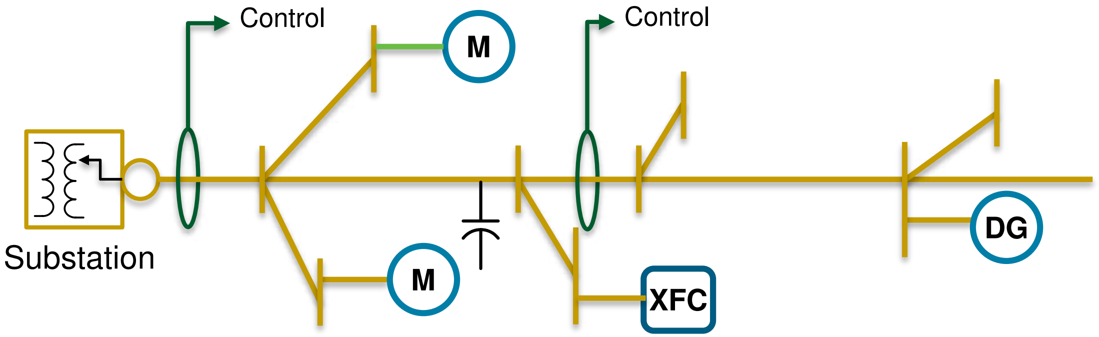
- **HPFC load** will vary depending on charging infrastructure and travel patterns
- Onsite **renewable generation** will be dependent on regional conditions
- **Building load** will be dependent on occupancy, building design, and is subject to seasonal weather variation

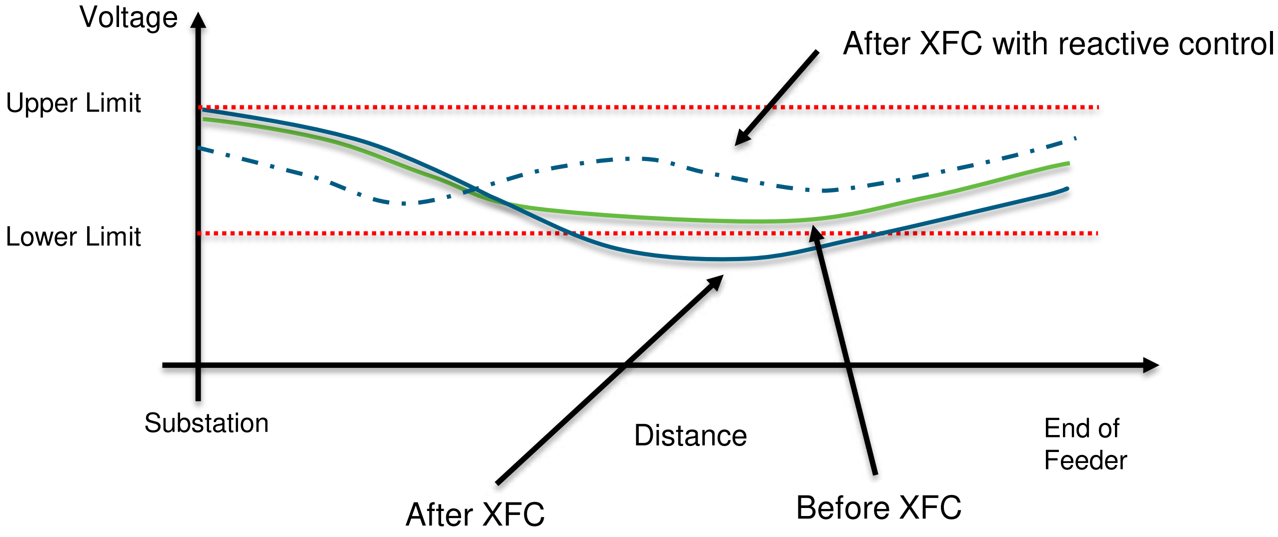
Control integration is required for energy system and microgrid management

- **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

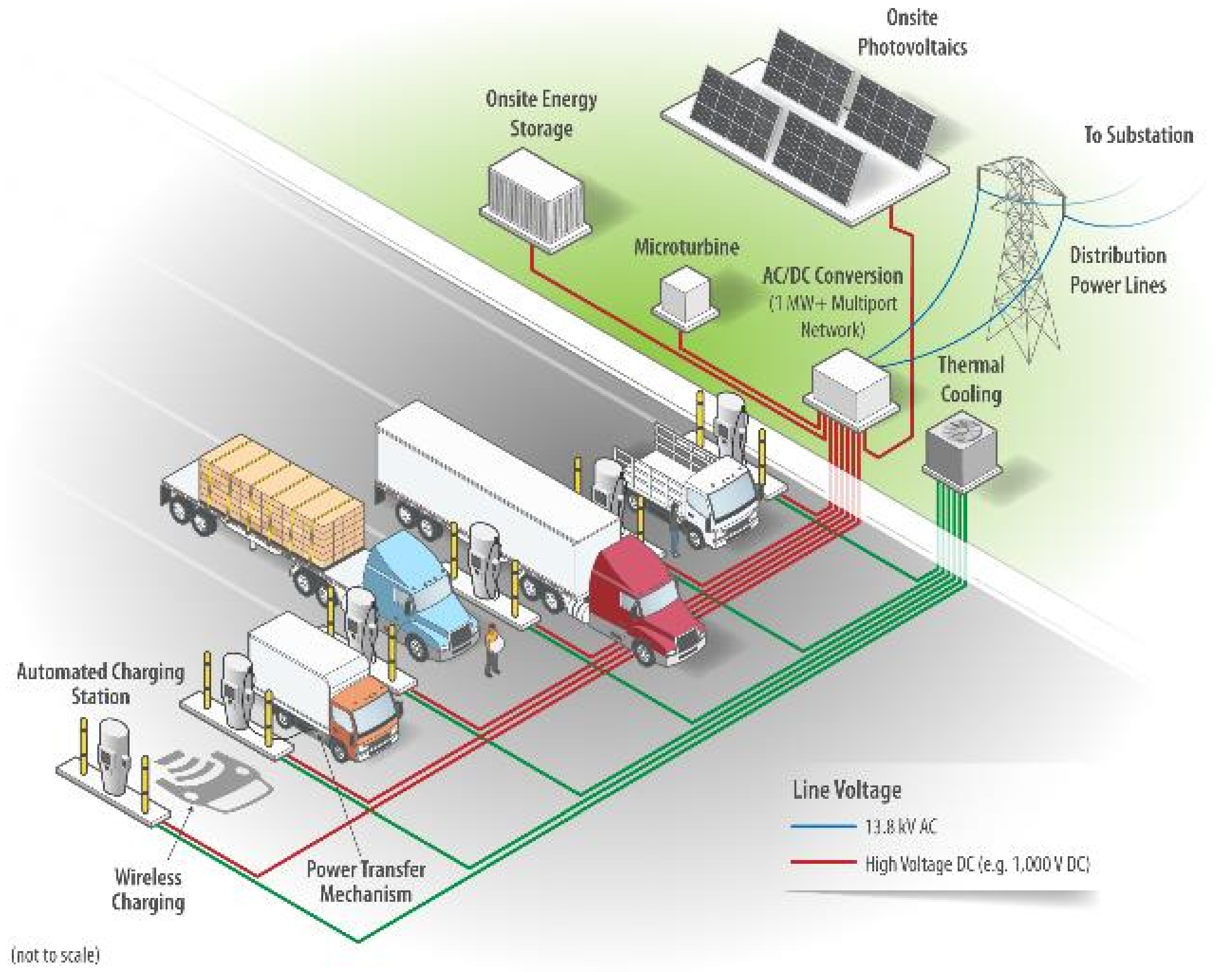
- What will be the **impact on voltage regulation hardware** from XFC installation
- Value of system efficiency and avoidance of line upgrades with **reactive XFC support**
- Capacity deferral opportunities through real power control at XFC sites to **avoid concurrent peak load** on the feeder

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

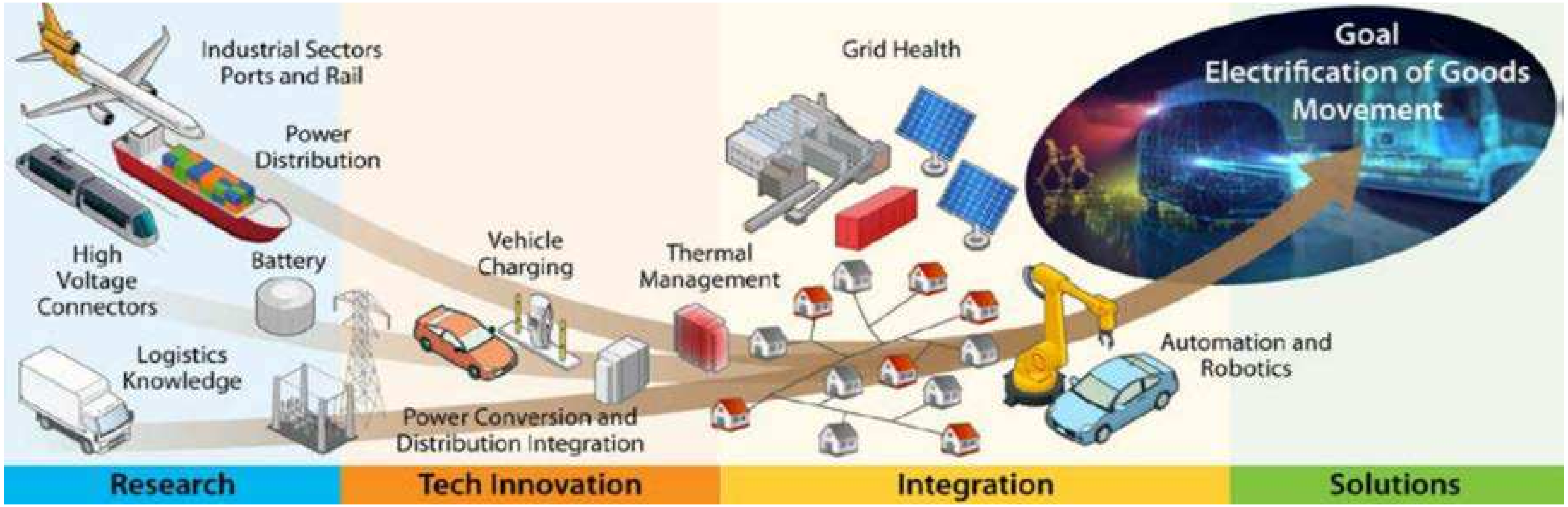
Extreme Fast Charging (XFC) Projects

- **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)

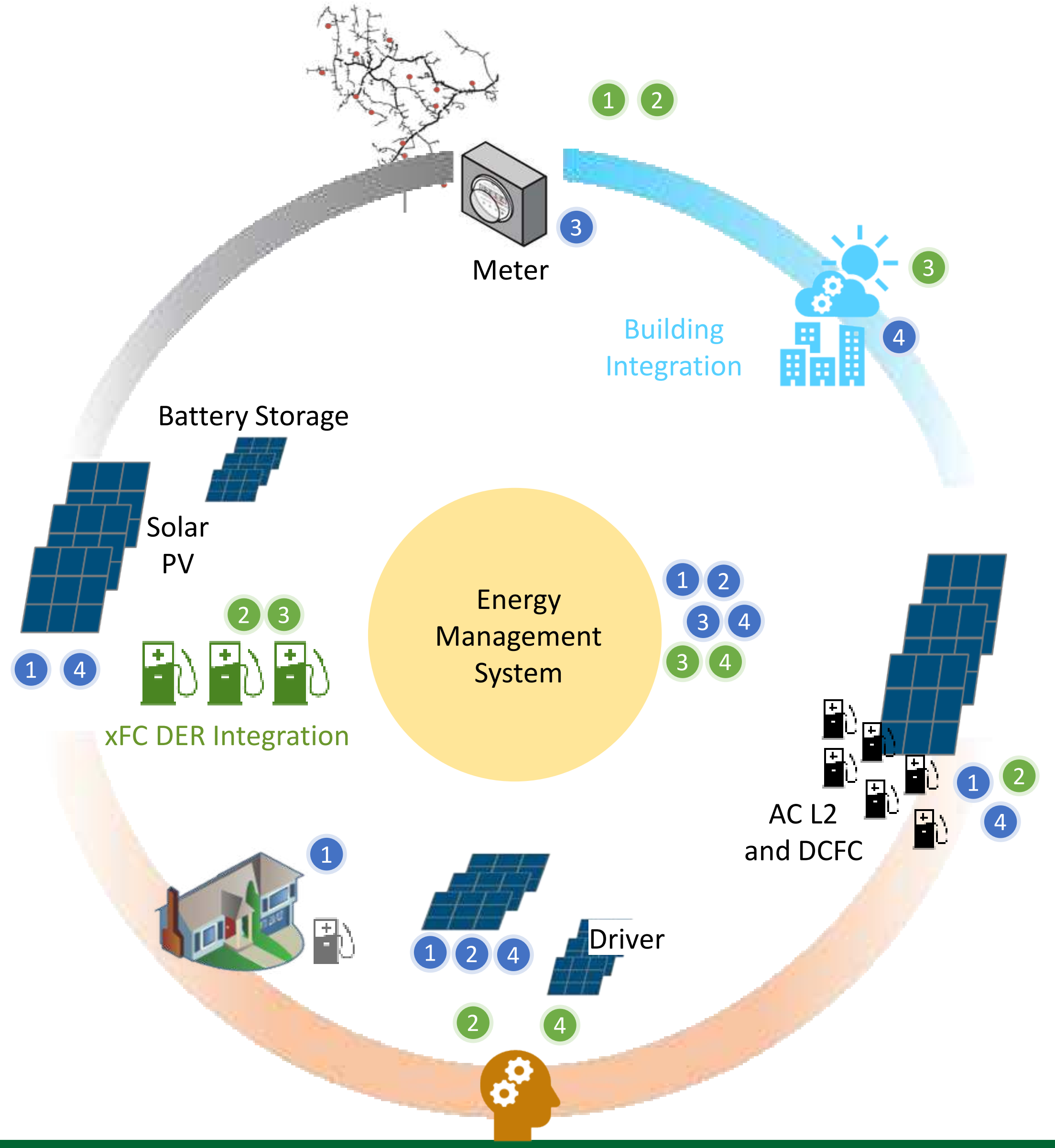
smaRt Electric vehicle CHArging for a reliable and Resilient Grid

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



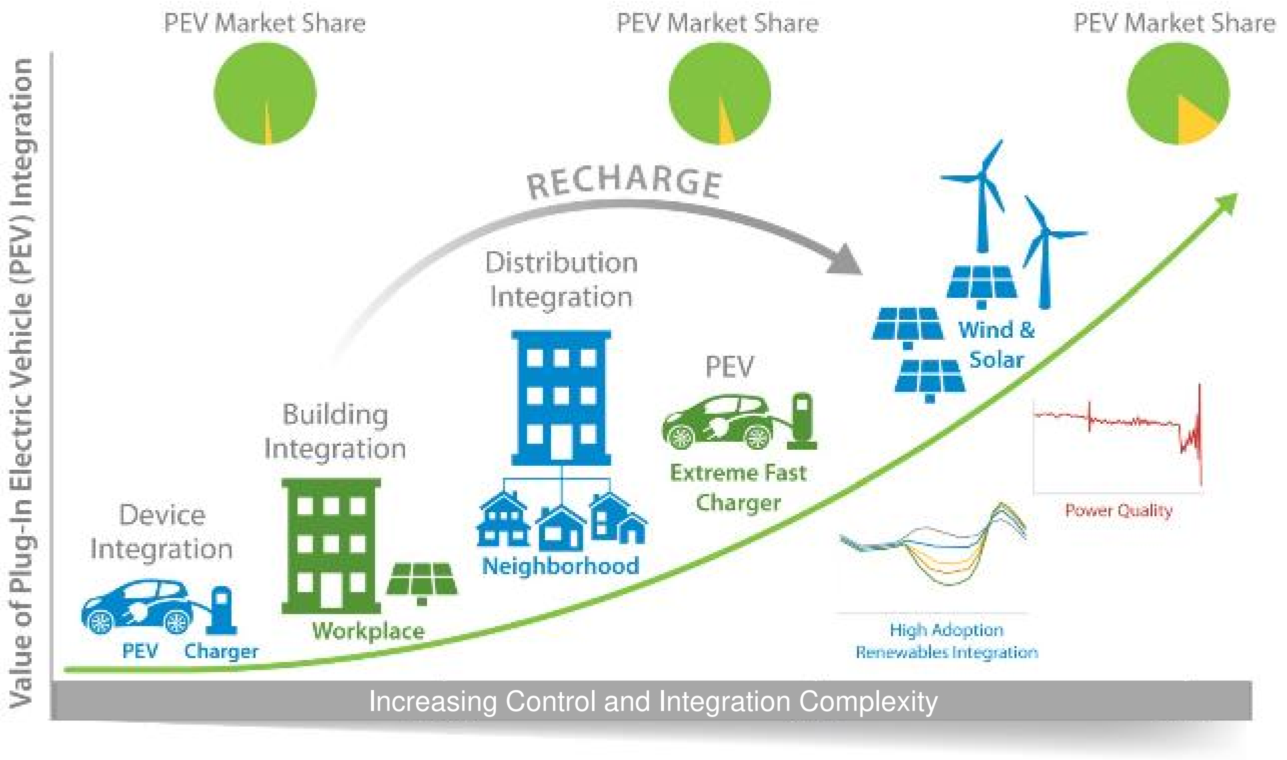
Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)

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**.



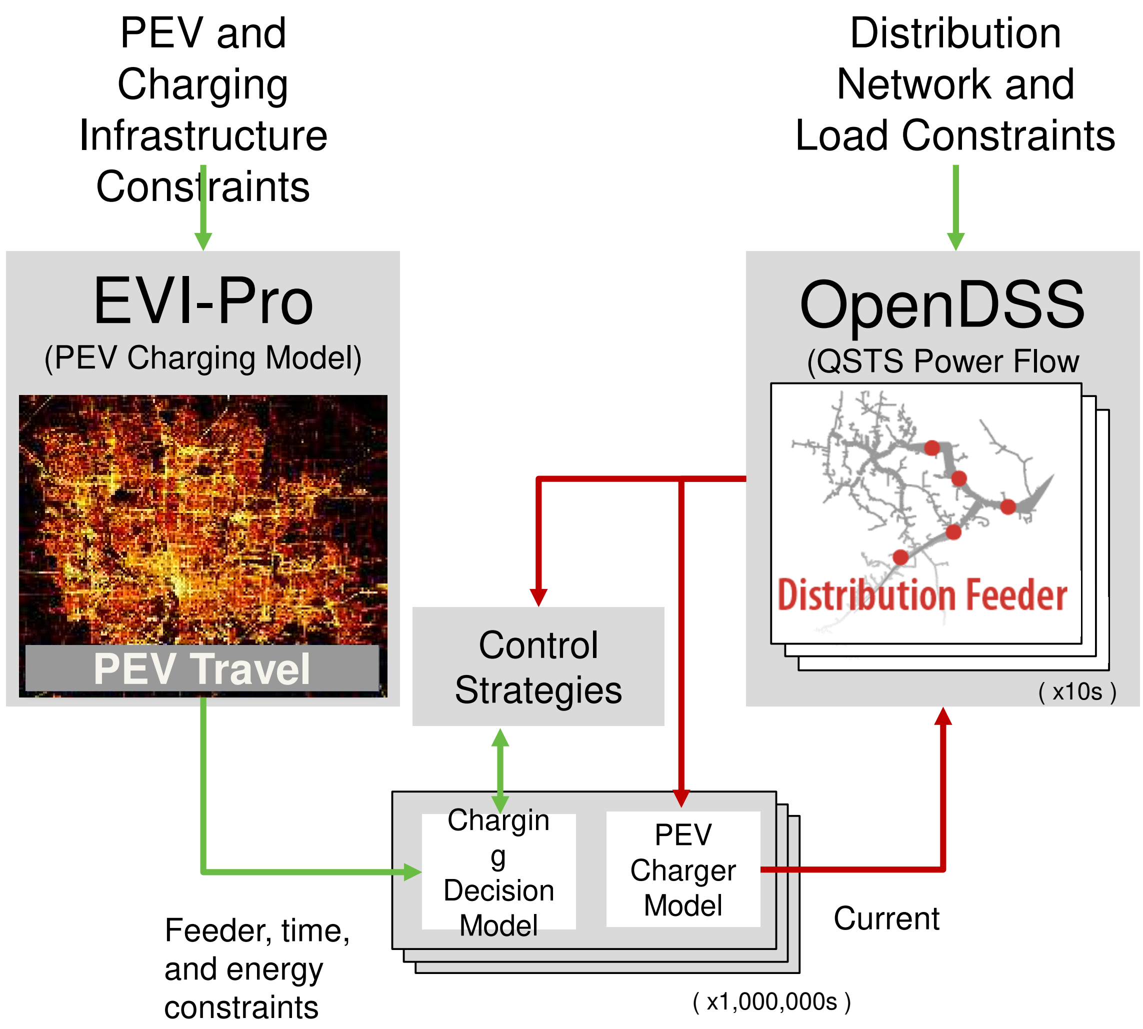
Specifically, this project will accomplish the following objectives:

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.

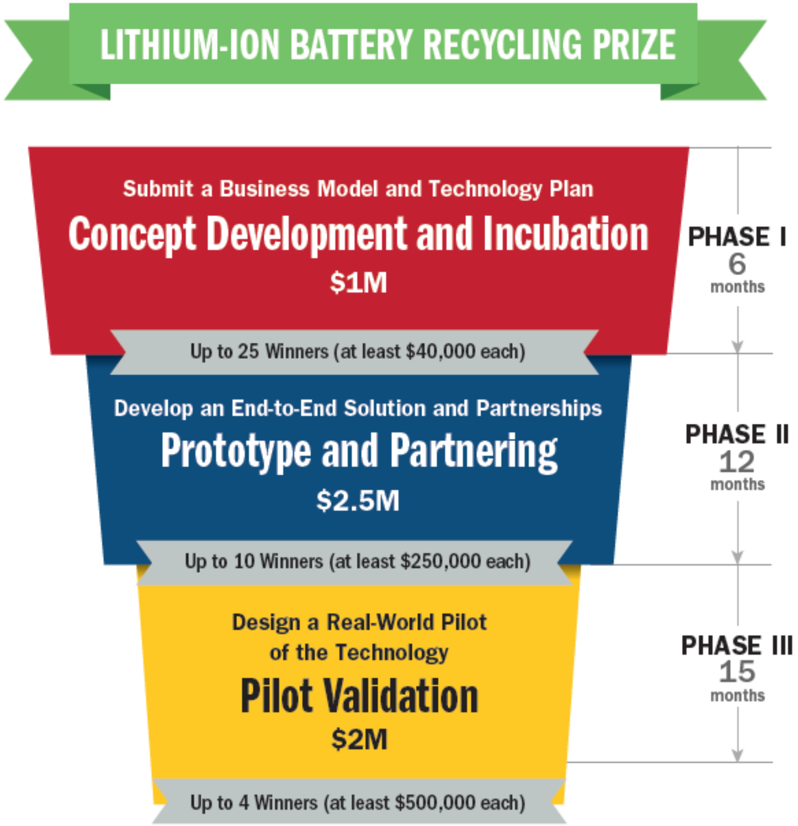


Battery Recycling Prize

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.



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VEHICLE TECHNOLOGIES OFFICE
ADVANCED MANUFACTURING OFFICE

NREL Transforming ENERGY

To enter the competition, visit AmericanMadeChallenges.org/BatteryRecycling

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

Tuesday, June 11

Time	Advanced Combustion Engines (ACE) – Regency E	Technology Integration (TI) – Theater	Electrification Technologies (ELT) – Regency B	Materials Technology (MAT) – Regency A	Battery R&D (BAT) – Potomac	Energy-Efficient Mobility Systems (EEMS) – Washington
7:00 AM	Continental Breakfast					
8:00 AM	ACE054	TI000	ELT000	MAT124	BAT337	EEMS056
8:15 AM						EEMS057
8:30 AM	ACE013	TI086	ELT089	MAT125	BAT252	
8:45 AM						EEMS011
9:00 AM	ACE012	TI087	ELT208	MAT118	BAT253	
9:15 AM						
9:30 AM	ACE006	TI088	ELT209	MAT119	BAT374	EEMS058
9:45 AM						
10:00 AM	ACE084	TI089	ELT210	MAT120	BAT183	
10:15 AM						Panel Disc
10:30 AM	Break					
11:00 AM	ACE005	TI090	ELT211	MAT146	BAT375	EEMS035
11:15 AM						
11:30 AM	ACE010		ELT212	MAT117	BAT376	EEMS007
11:45 AM						
12:00 PM	ACE125		ELT213	MAT101	BAT377	EEMS019
12:15 PM					BAT378	
12:30 PM	Lunch					
2:00 PM	ACE126		ELT214	MAT147	BAT379	EEMS039
2:15 PM				MAT148		
2:30 PM	ACE017		ELT215		BAT380	EEMS044
2:45 PM				MAT122		
3:00 PM	ACE015		ELT216		BAT381	EEMS040
3:15 PM				MAT149	BAT382	
3:30 PM	Break					
4:00 PM	ACE004		Panel Discussion	MAT127	BAT265	EEMS043
4:15 PM					BAT266	
4:30 PM	ACE127			MAT143	BAT264	EEMS023
4:45 PM					BAT263	
5:00 PM				MAT150		
5:15 PM				MAT151		
5:30-7:30 PM	Poster Session I – ACE, BAT (Part 1), EEMS, ELT					

Wednesday, June 12

Time	Advanced Combustion Engines (ACE) – Regency E	Fuel and Lubricant Technologies (FT) – Regency F	Electrification Technologies (ELT) – Regency B	Materials Technology (MAT) – Regency A	Battery R&D (BAT) – Potomac	Energy-Efficient Mobility Systems (EEMS) – Washington
7:00 AM	Continental Breakfast					
8:00 AM			ELT082	MAT139		EEMS016
8:15 AM						
8:30 AM	ACE022	FT037	ELT092	MAT138	BAT338	EEMS017
8:45 AM						
9:00 AM	ACE023	FT067	ELT093	MAT136	BAT339	EEMS033
9:15 AM						
9:30 AM	ACE085	FT069	ELT094	MAT137	BAT340	EEMS059
9:45 AM						
10:00 AM	ACE033	FT070	ELT095	MAT131	BAT371	EEMS020
10:15 AM						
10:30 AM	Break					
11:00 AM	ACE118	FT071	ELT202	MAT152	BAT383	EEMS027
11:15 AM				MAT153		
11:30 AM	ACE027	FT072	ELT201	MAT132	BAT384	EEMS034
11:45 AM						
12:00 PM	ACE119	FT073	ELT200	MAT133	BAT385	EEMS060
12:15 PM					BAT386	
12:30 PM	Lunch					
2:00 PM	ACE056	FT074	ELT190	MAT154	BAT387	EEMS037
2:15 PM						
2:30 PM	ACE032	FT075	ELT189	MAT155		EEMS061
2:45 PM					BAT388	
3:00 PM	ACE128	FT076	ELT191	MAT134		EEMS062
3:15 PM						
3:30 PM	Break					
4:00 PM	ACE129	FT077	ELT158	MAT156	BAT108	EEMS041
4:15 PM				MAT142		
4:30 PM	ACE130	FT078	ELT187			EEMS045
4:45 PM				MAT165	BAT317	
5:00 PM			ELT188			
5:15 PM						
5:30-7:30 PM	Poster Session II – BAT (Part 2), VAN					

Thursday, June 13

Time	Advanced Combustion Engines (ACE) – Regency E	Fuel and Lubricant Technologies (FT) – Regency F	Electrification Technologies (ELT) – Regency B	Materials Technology (MAT) – Regency A	Battery R&D (BAT) – Potomac	Energy-Efficient Mobility Systems (EEMS) – Washington	Vehicle Technologies Analysis (VAN) – Theater
7:00 AM	Continental Breakfast						
8:00 AM			ELT198	MAT157	BAT276	EEMS029	VAN000
8:15 AM					BAT327		
8:30 AM	ACE001		ELT199	MAT126	BAT326	EEMS032	VAN026
8:45 AM					BAT272		
9:00 AM	ACE131		ELT205	MAT158	Panel Discussion	EEMS028	VAN028
9:15 AM							
9:30 AM	ACE132		ELT206	MAT129	BAT330		VAN019
9:45 AM					BAT230		
10:00 AM	ACE133	FT079	ELT207	MAT144	Panel Discussion		VAN021
10:15 AM							
10:30 AM	Break						
11:00 AM	ACE121	FT086	ELT197	MAT069	BAT312		VAN023
11:15 AM					BAT322		
11:30 AM	ACE123	FT080	ELT235	MAT159	BAT365		VAN029
11:45 AM					BAT389		
12:00 PM		FT081	ELT204	MAT160	Panel Discussion		VAN031
12:15 PM							
12:30 PM	Lunch						
2:00 PM	ACE100	FT082	ELT239	MAT161	BAT054		
2:15 PM				MAT162	BAT309		
2:30 PM	ACE101	FT083	ELT240	MAT163	BAT329		
2:45 PM				MAT164	BAT091		
3:00 PM	ACE102	FT084	ELT241	MAT057	Panel Discussion		
3:15 PM							
3:30 PM	Break						
4:00 PM	ACE103	FT085	ELT236		BAT370		
4:15 PM			ELT237		BAT225		
4:30 PM	ACE124		ELT238		BAT085		
4:45 PM			Panel Discussion		BAT226		
5:00 PM					Panel Discussion		
5:15 PM							
5:30-7:30 PM							

Thank you

Steven Boyd
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