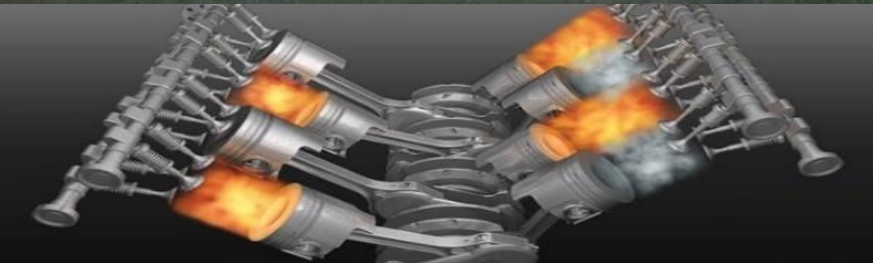


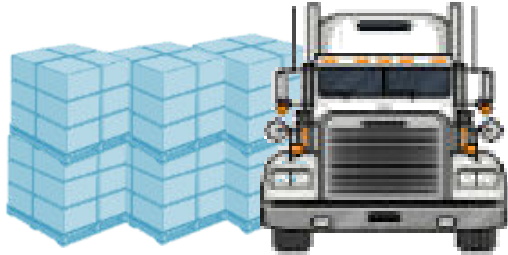
Batteries and Electrification R&D

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

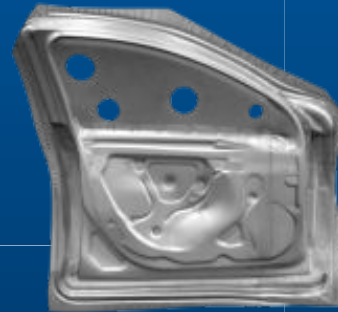
Batteries & Electrification



Advanced Combustion Systems & Fuels



Materials Technology



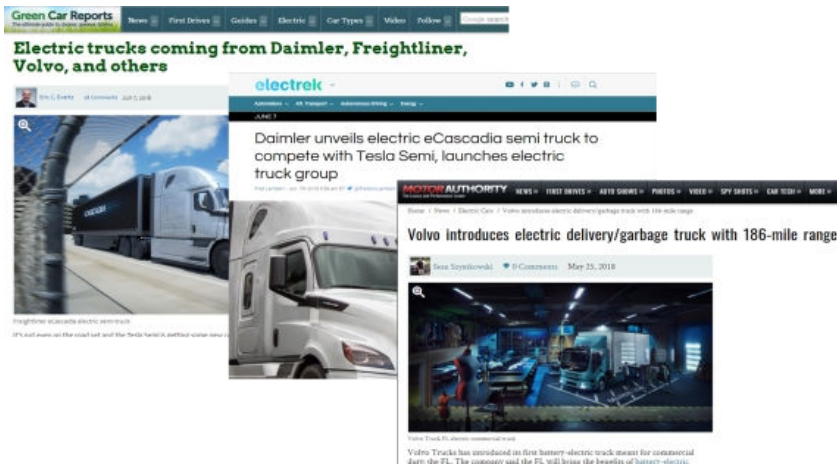
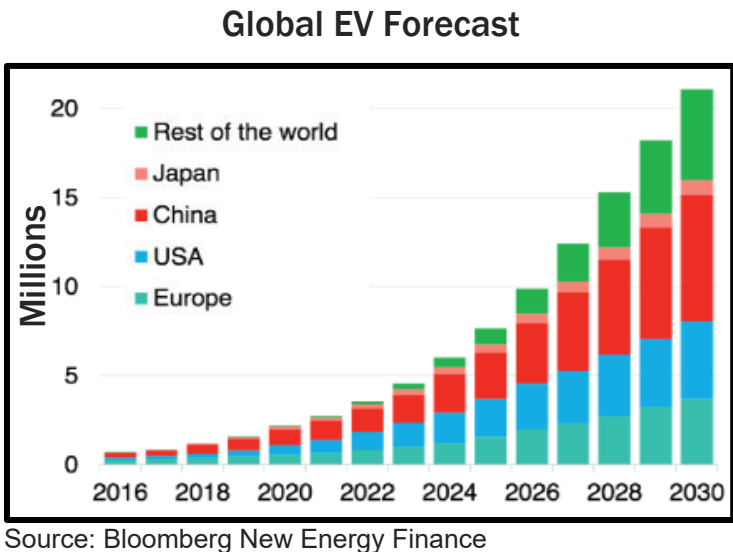
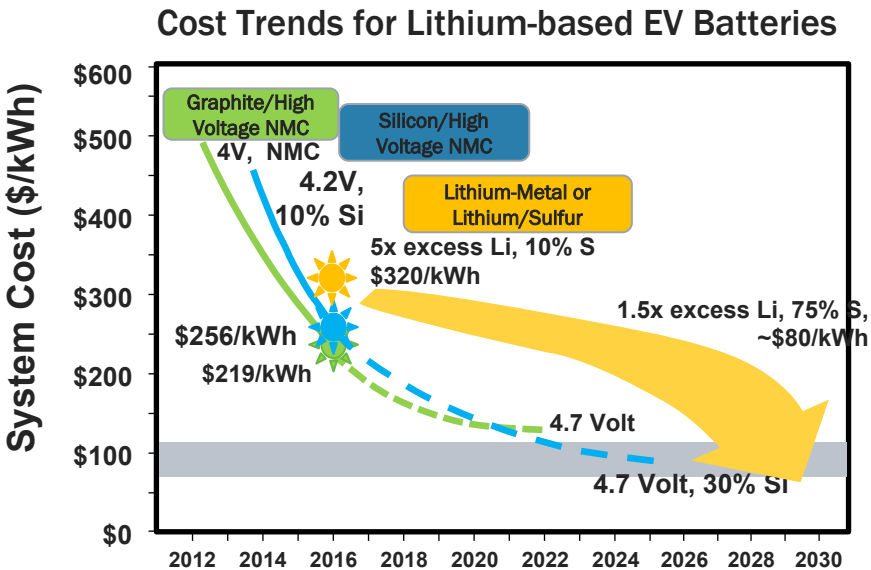
Energy Efficient Mobility Systems



Batteries and Electrification Program

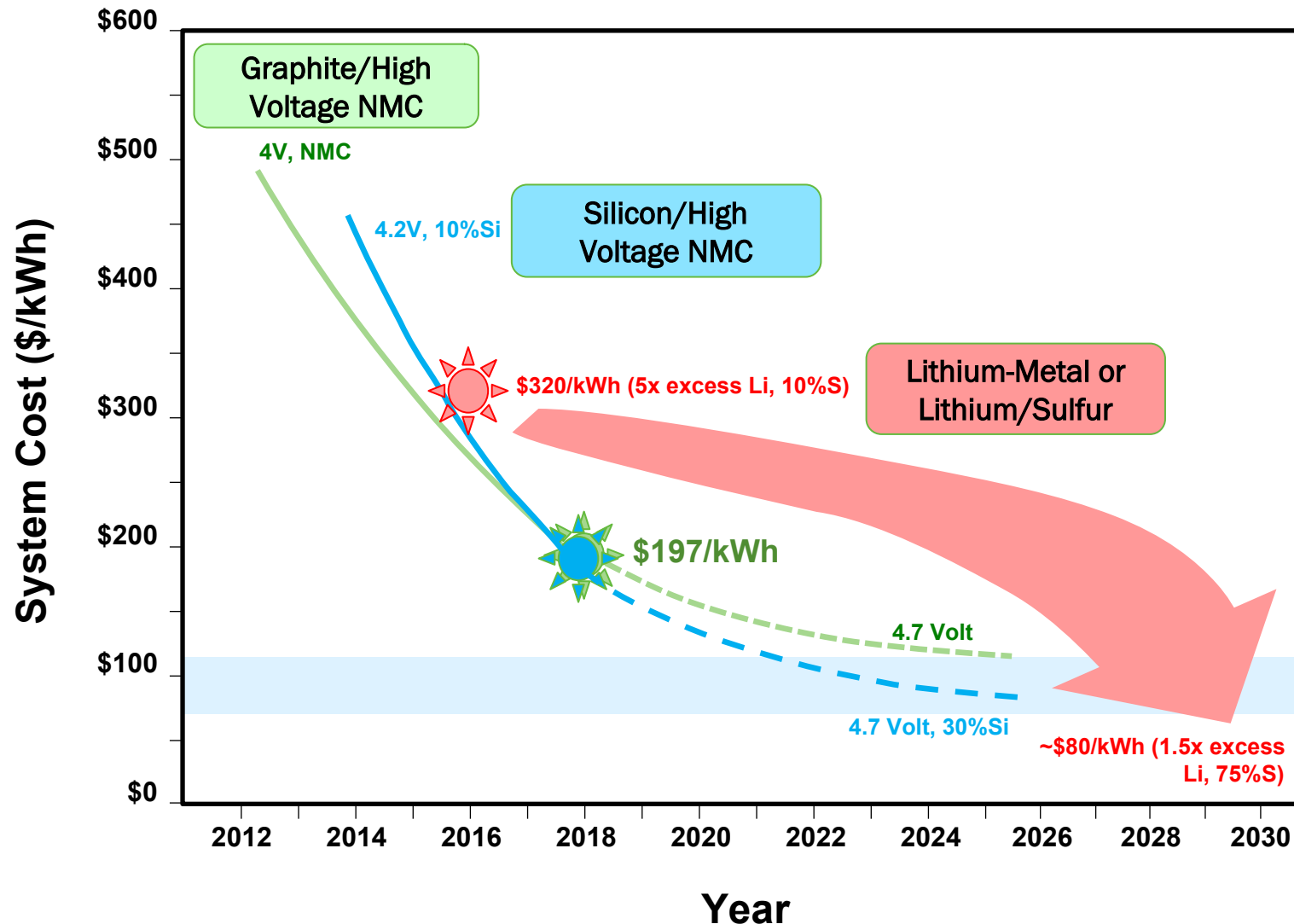
Enable a large market penetration of electric drive vehicles through innovative research and development:

- 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
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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

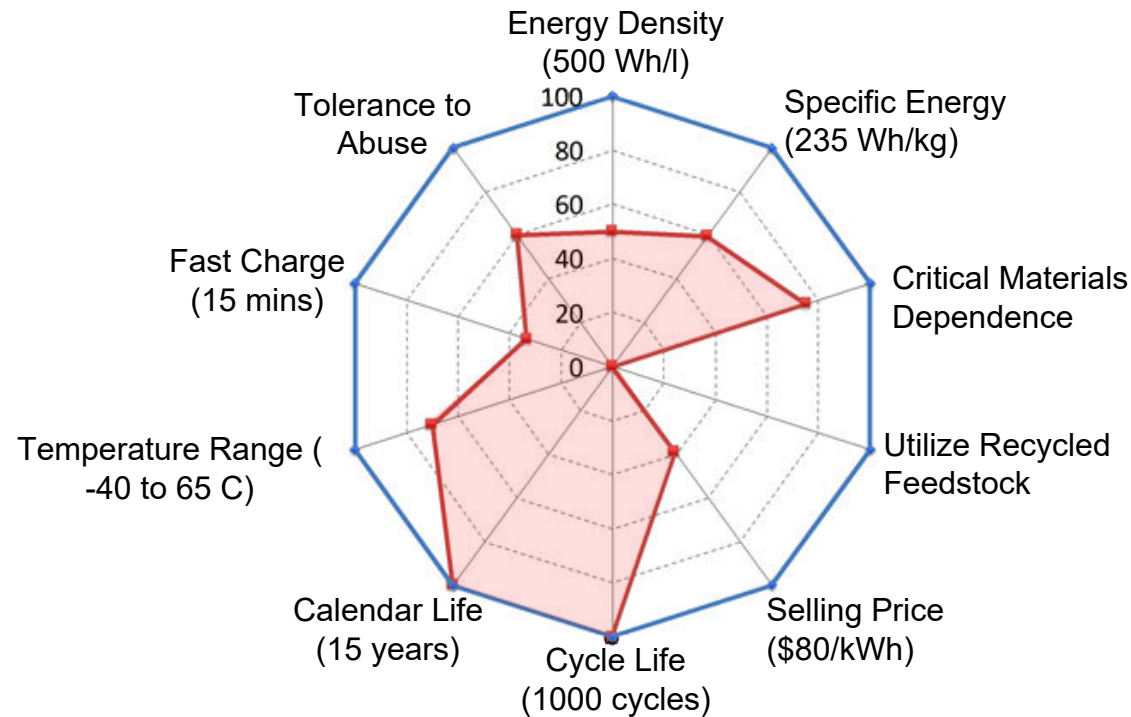
Silicon/High Voltage NMC

- 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

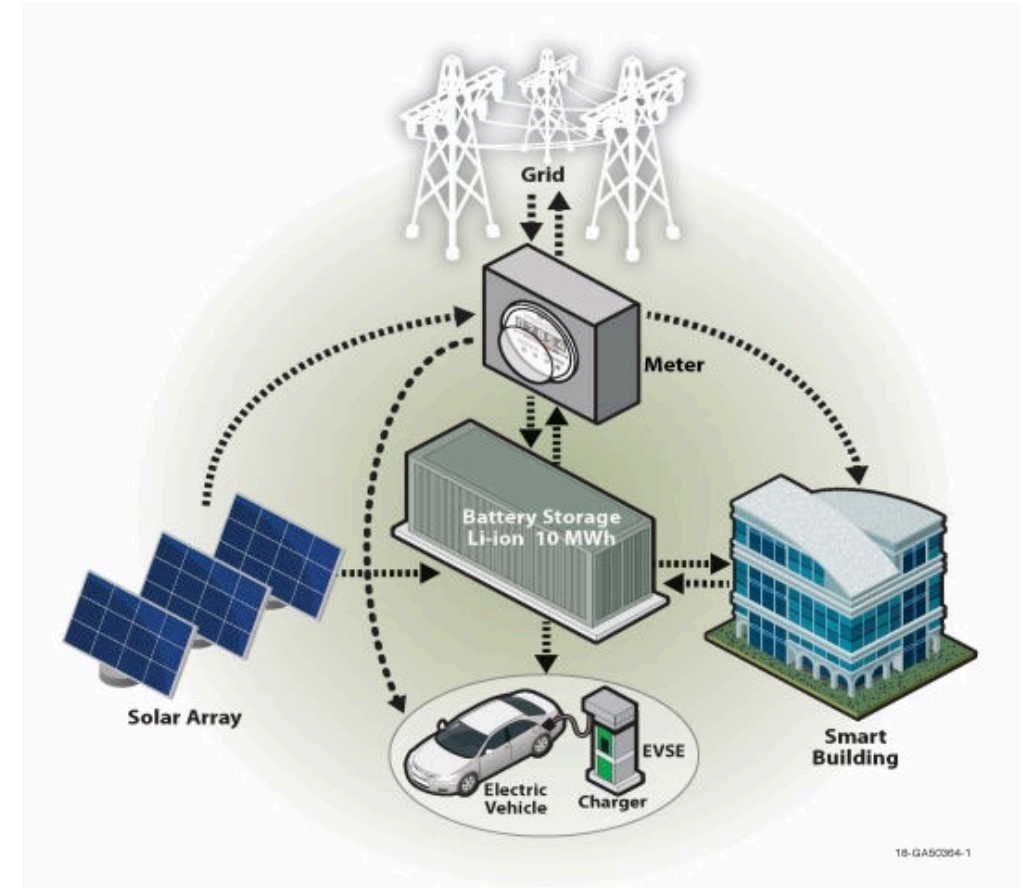
These three challenges will be the focus over the next 5 years

Behind-the-Meter-Storage (BTMS)

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

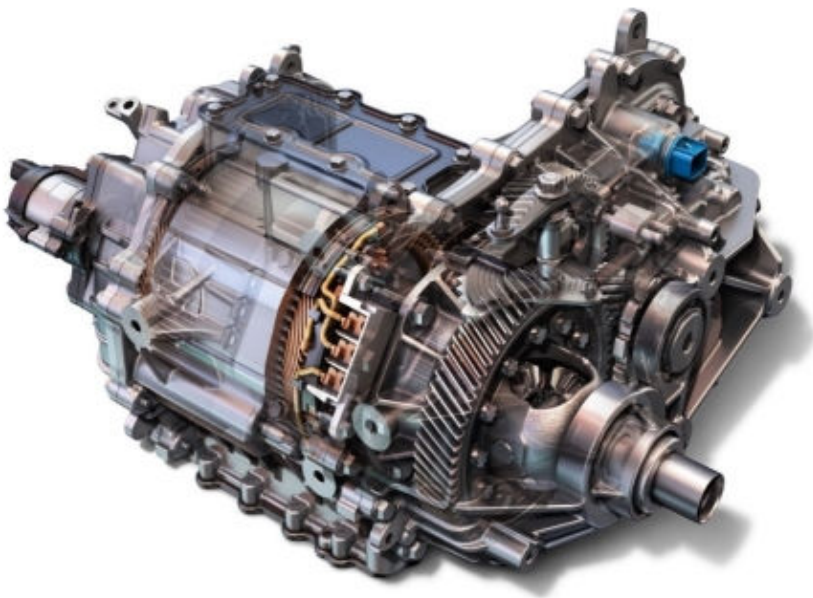


3 Liter Volume

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

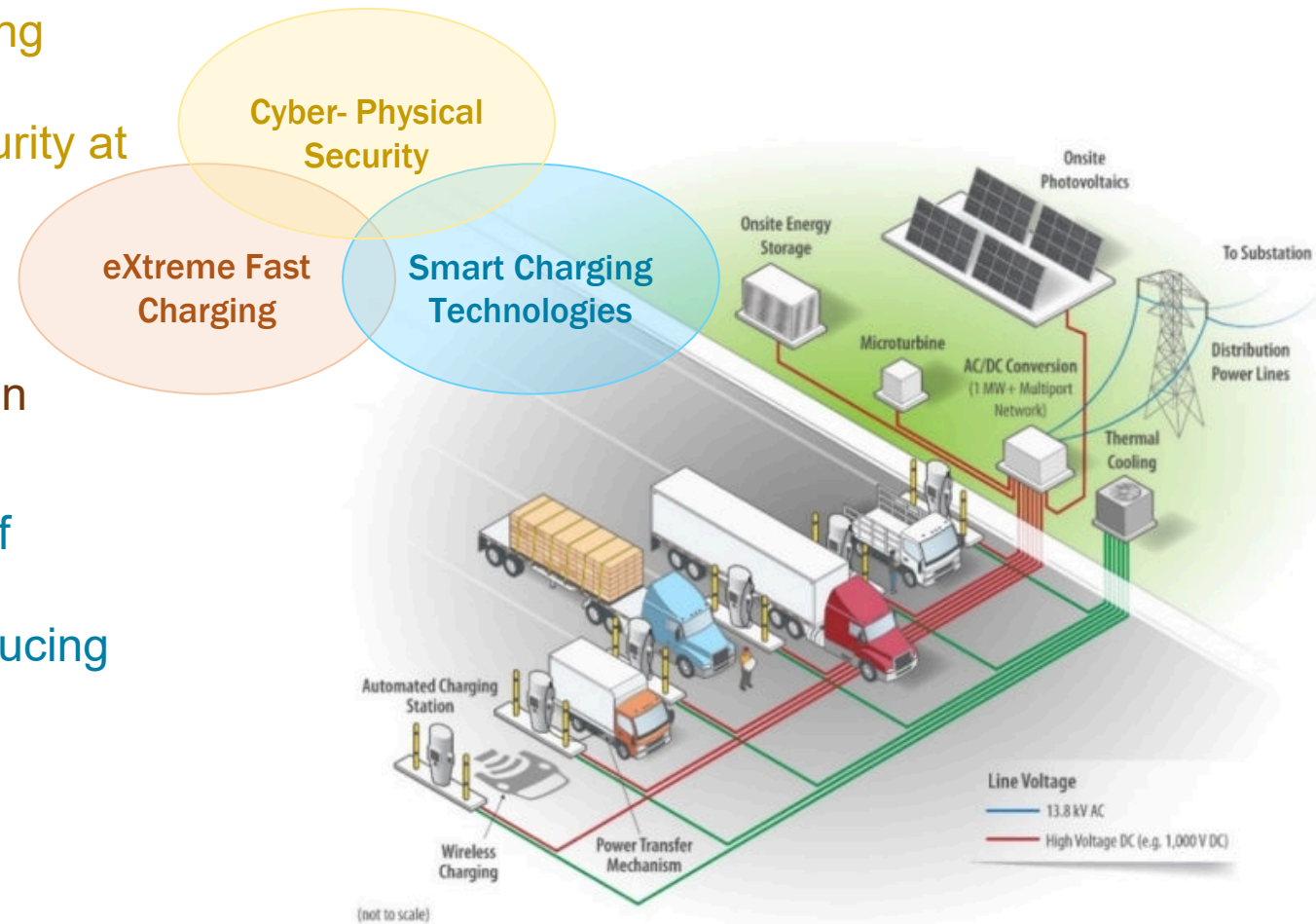


Electric Traction Drive System Targets			
Year	2020	2025	
Cost (\$/kW)	8	6	25% cost reduction
Power Density (kW/L)	4.0	33	88% volume reduction

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

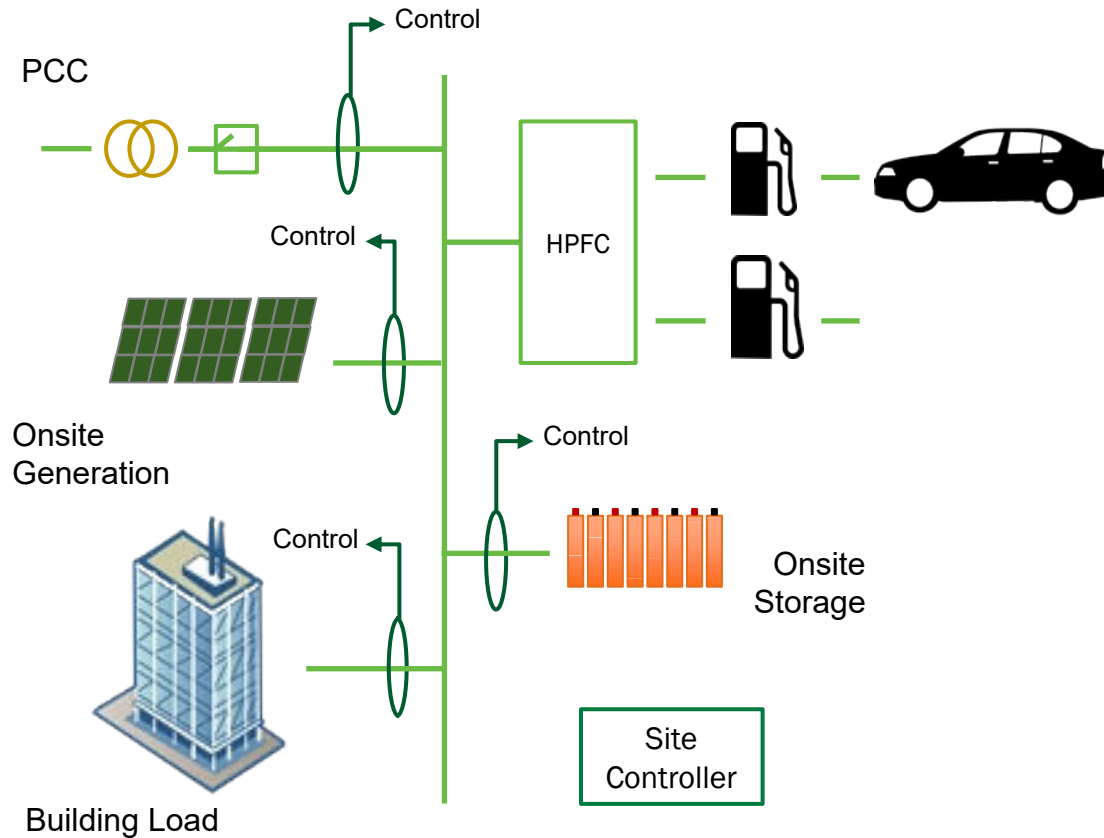
Buildings, Onsite Resources, and the Grid

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

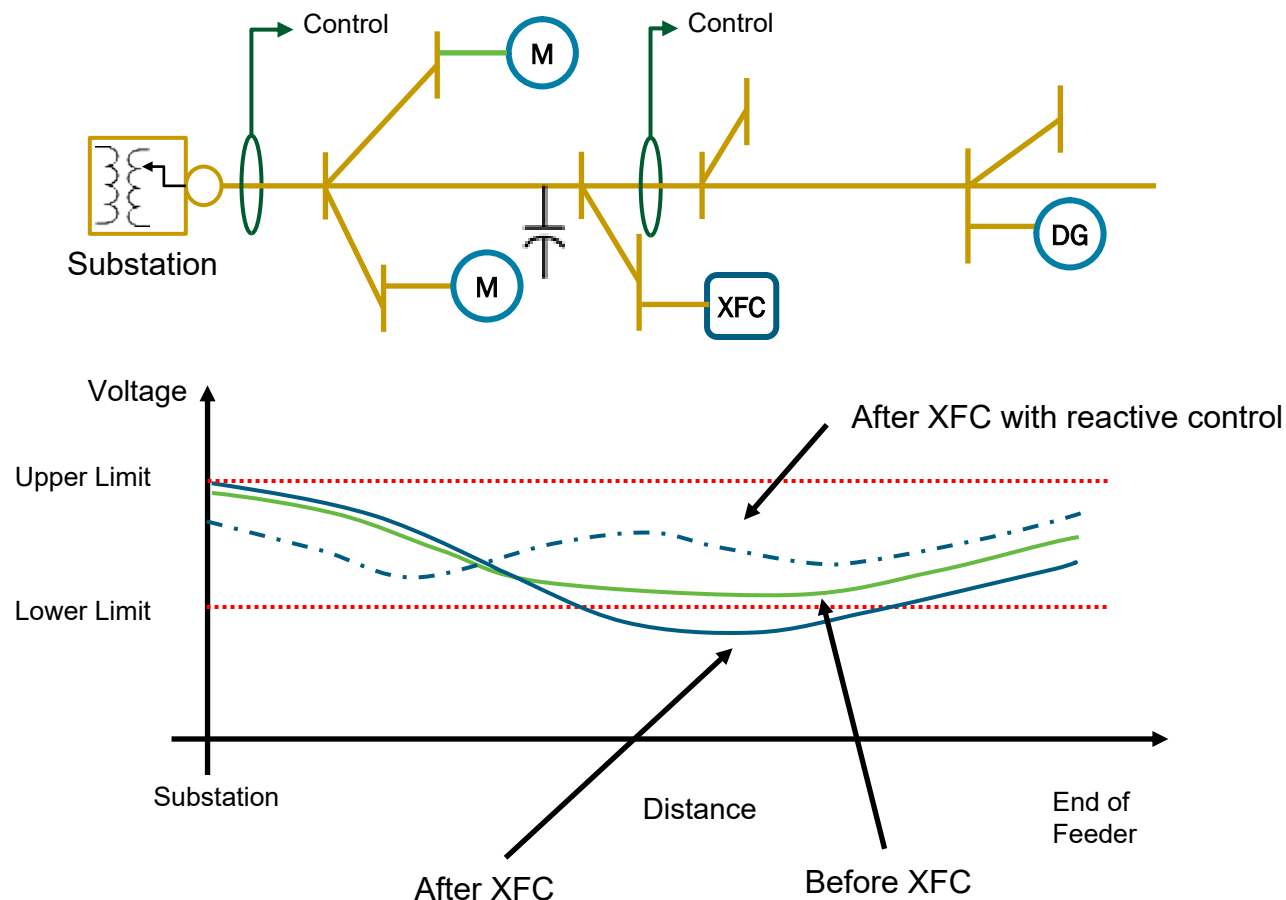
- **HPFC load** will vary depending on charging infrastructure and travel patterns
- Onsite **renewable generation** will be dependent on regional conditions
- **Building load** will be dependent on occupancy, building design, and is subject to seasonal weather variation

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

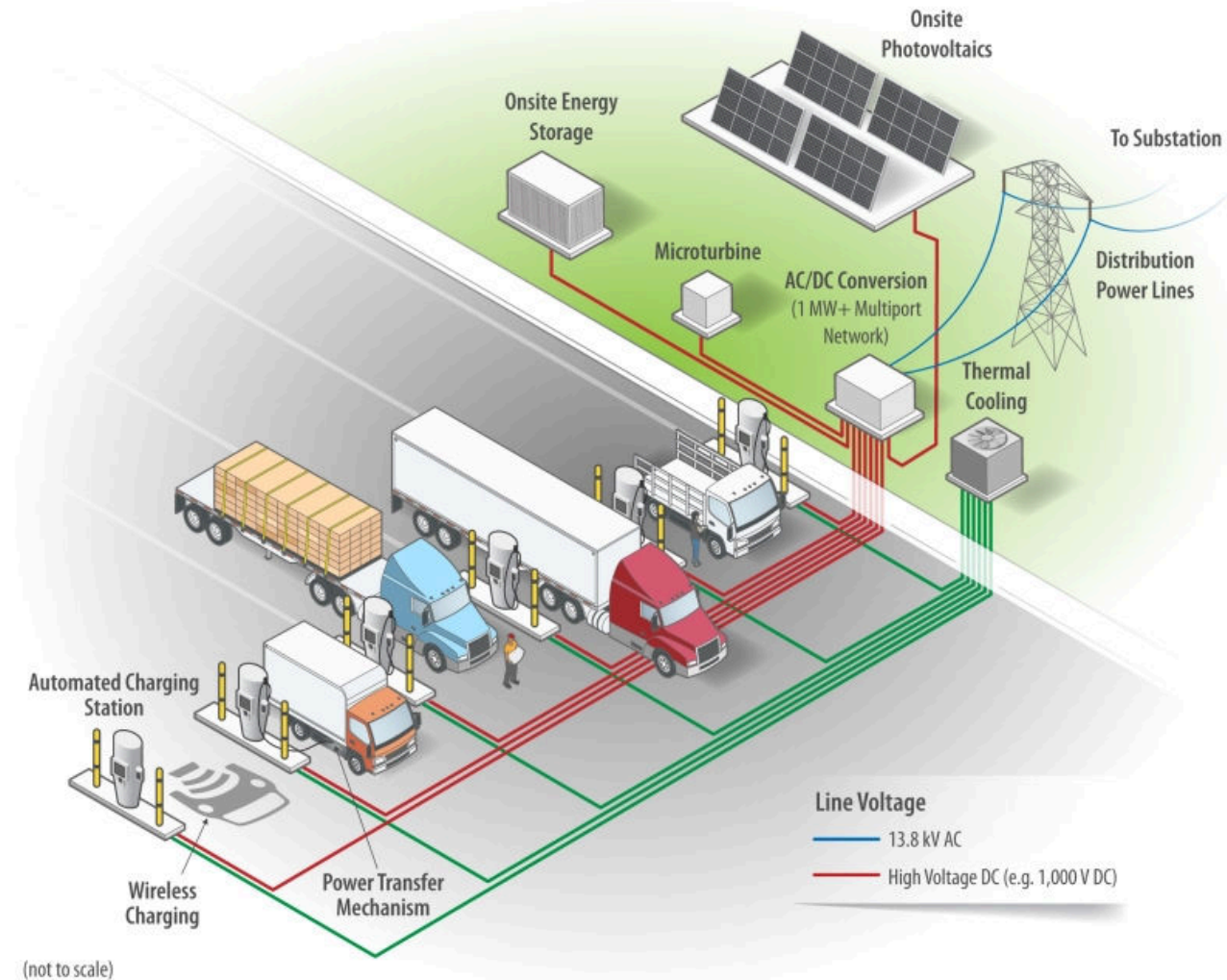
- What will be the **impact on voltage regulation hardware** from XFC installation
- Value of system efficiency and avoidance of line upgrades with **reactive XFC support**
- Capacity deferral opportunities through real power control at XFC sites to **avoid concurrent peak load** on the feeder

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

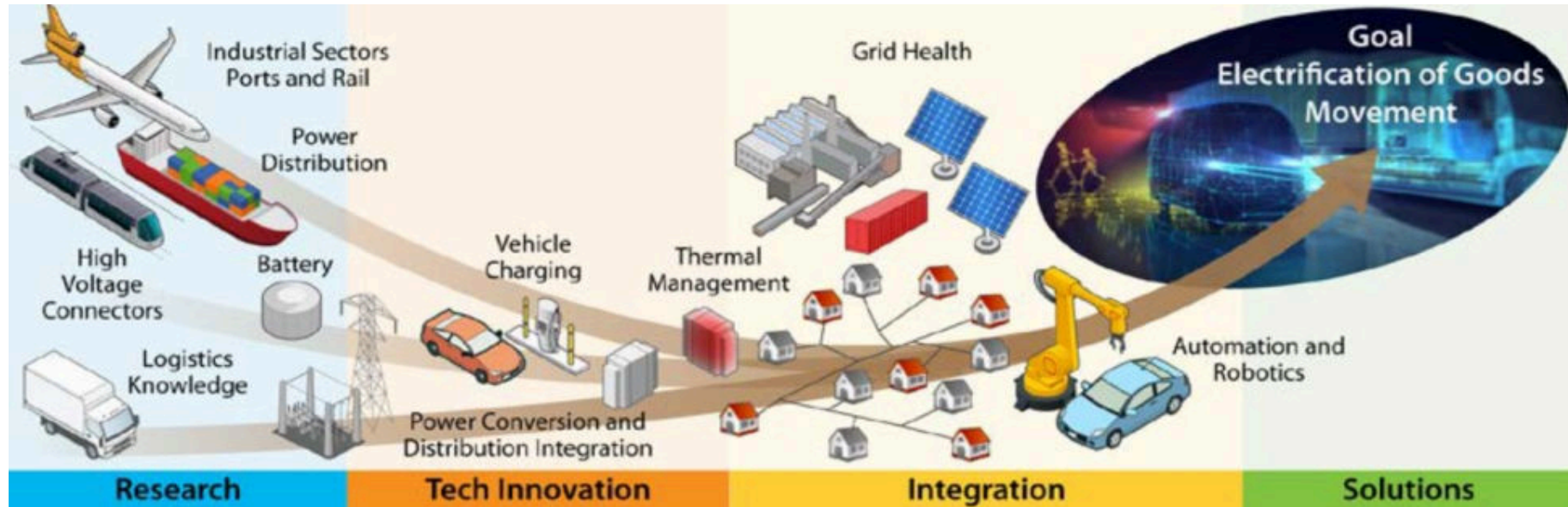
Extreme Fast Charging (XFC) Projects

- **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)

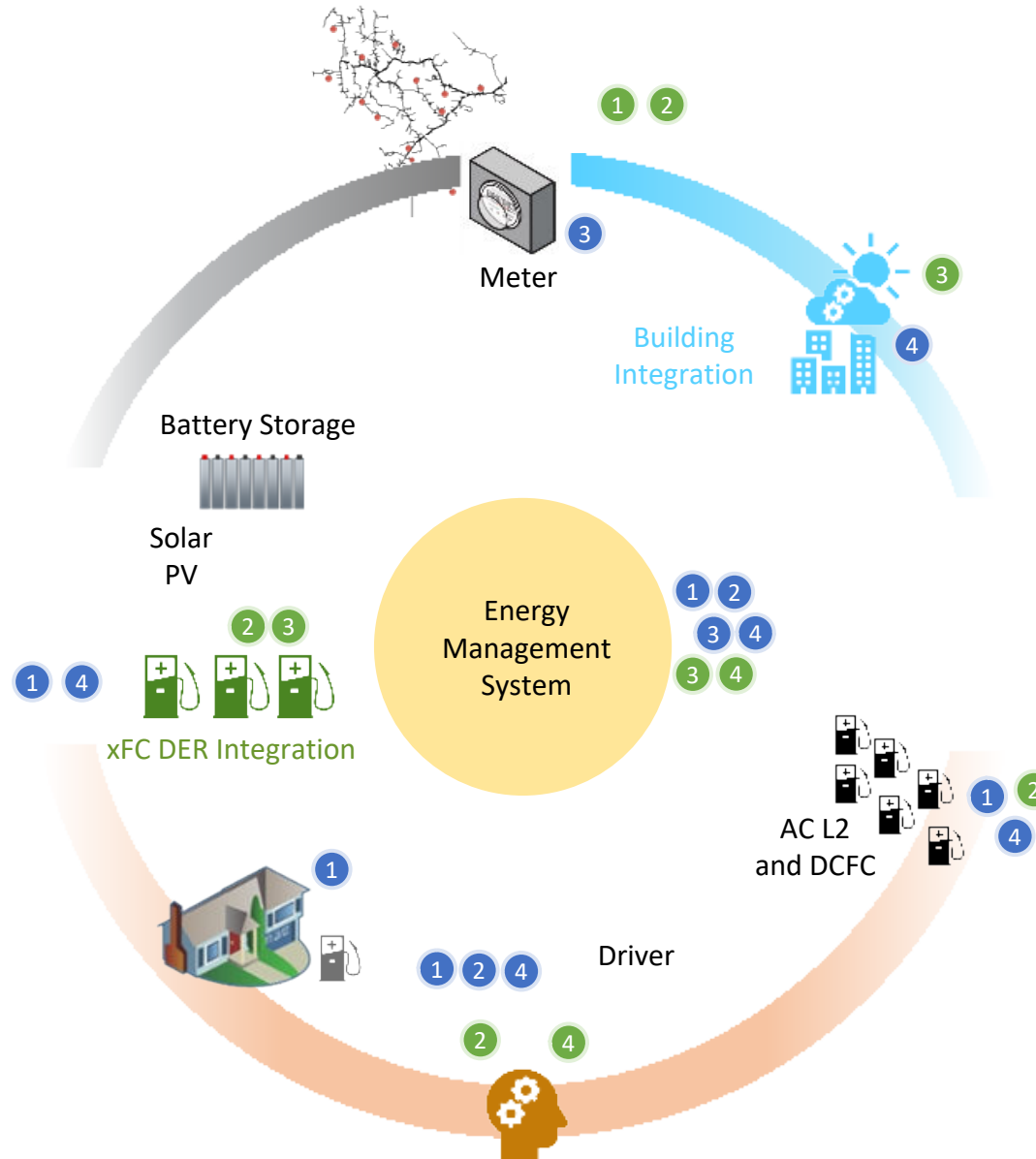
*smaRt Electric vehicle CHArging for a
reliable and Resilient Grid*

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)

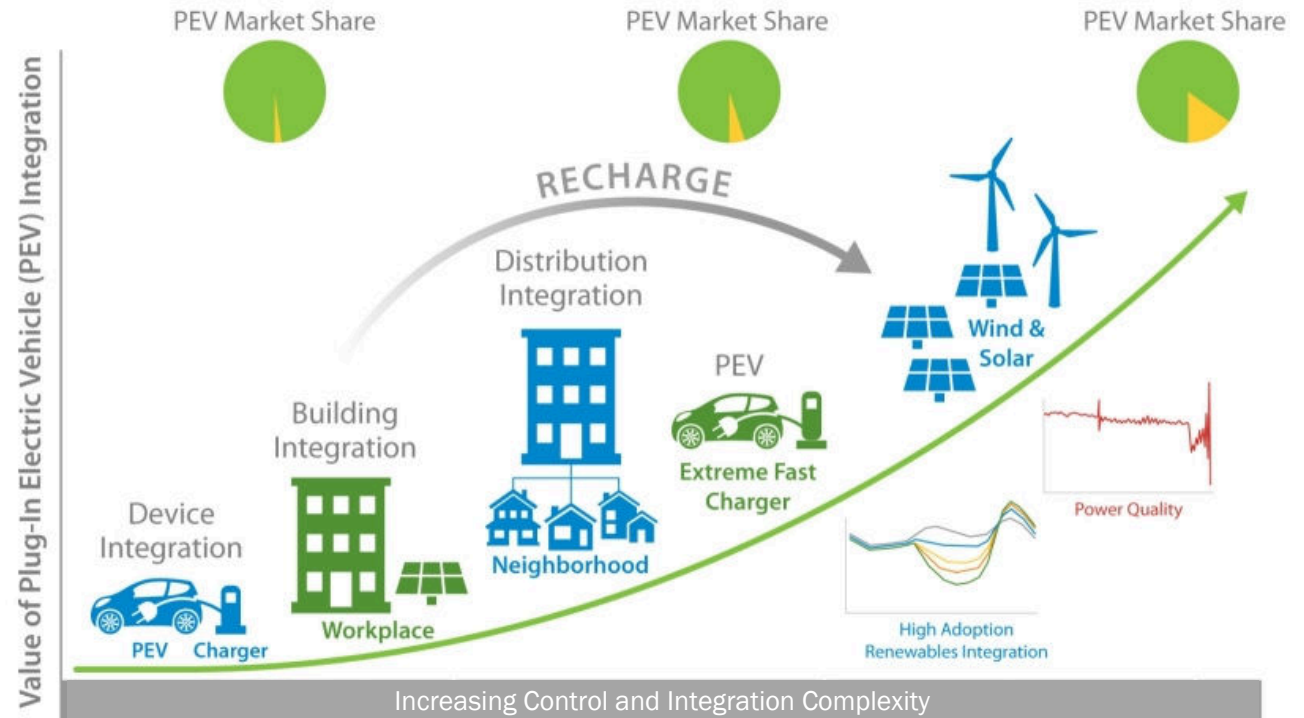
- 1 Simulation and controls development to minimize distribution impacts
- 2 Regional modelling for distribution operations & capacity planning
- 3 Forecasting-enhanced charging integration with buildings and DER
- 4 Predictive and interactive charge decision making

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.**



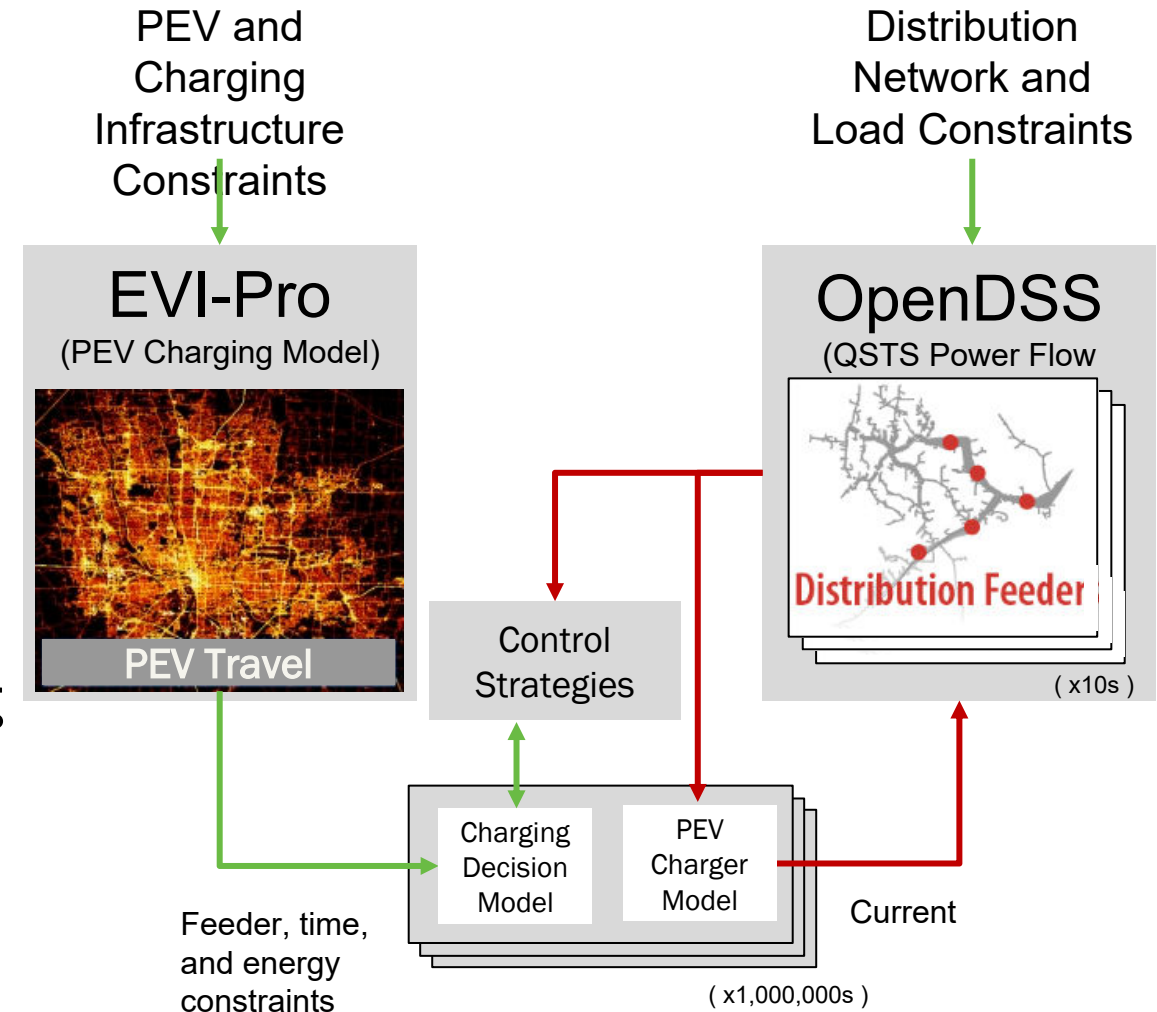
Specifically, this project will accomplish the following objectives:

- 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						Wednesday, June 12						Thursday, June 13						
	Continental Breakfast						Continental Breakfast						Continental Breakfast						
7:00 AM																			
8:00 AM	ACE054	TI000	ELT000	MAT124	BAT337	EEMS056			ELT082	MAT139		EEMS016			ELT198	MAT157	BAT276	EEMS029	VAN000
8:15 AM						EEMS057											BAT327		
8:30 AM	ACE013	TI086	ELT089	MAT125	BAT252		ACE022	FT037	ELT092	MAT138	BAT338	EEMS017	ACE001		ELT199	MAT126	BAT326	EEMS032	VAN026
8:45 AM						EEMS011											BAT272		
9:00 AM	ACE012	TI087	ELT208	MAT118	BAT253		ACE023	FT067	ELT093	MAT136	BAT339	EEMS033	ACE131		ELT205	MAT158	Panel Discussion	EEMS028	VAN028
9:15 AM						EEMS058													
9:30 AM	ACE006	TI088	ELT209	MAT119	BAT374		ACE085	FT069	ELT094	MAT137	BAT340	EEMS059	ACE132		ELT206	MAT129	BAT330		VAN019
9:45 AM						EEMS058											BAT230		
10:00 AM	ACE084	TI089	ELT210	MAT120	BAT183		ACE033	FT070	ELT095	MAT131	BAT371	EEMS020	ACE133	FT079	ELT207	MAT144	Panel Discussion		VAN021
10:15 AM						Panel Disc													
10:30 AM	Break						Break						Break						
11:00 AM	ACE005	TI090	ELT211	MAT146	BAT375	EEMS035	ACE118	FT071	ELT202	MAT152	BAT383	EEMS027	ACE121	FT086	ELT197	MAT069	BAT312		VAN023
11:15 AM						EEMS035				MAT153							BAT322		
11:30 AM	ACE010		ELT212	MAT117	BAT376	EEMS007	ACE027	FT072	ELT201	MAT132	BAT384	EEMS034	ACE123	FT080	ELT235	MAT159	BAT365		VAN029
11:45 AM						EEMS007											BAT389		
12:00 PM	ACE125		ELT213	MAT101	BAT377	EEMS019	ACE119	FT073	ELT200	MAT133	BAT385	EEMS060		FT081	ELT204	MAT160	Panel Discussion		VAN031
12:15 PM					BAT378						BAT386								
12:30 PM	Lunch						Lunch						Lunch						
2:00 PM	ACE126		ELT214	MAT147	BAT379	EEMS039	ACE056	FT074	ELT190	MAT154	BAT387	EEMS037	ACE100	FT082	ELT239	MAT161	BAT054		
2:15 PM				MAT148		EEMS039										MAT162	BAT309		
2:30 PM	ACE017		ELT215		BAT380	EEMS044	ACE032	FT075	ELT189	MAT155		EEMS061	ACE101	FT083	ELT240	MAT163	BAT329		
2:45 PM				MAT122	BAT381	EEMS040					BAT388					MAT164	BAT091		
3:00 PM	ACE015		ELT216	MAT149	BAT382		ACE128	FT076	ELT191	MAT134		EEMS062	ACE102	FT084	ELT241	MAT057	Panel Discussion		
3:15 PM																			
3:30 PM	Break						Break						Break						
4:00 PM	ACE004		Panel Discussion	MAT127	BAT265	EEMS043	ACE129	FT077	ELT158	MAT156	BAT108	EEMS041	ACE103	FT085	ELT236		BAT370		
4:15 PM				MAT127	BAT266										ELT237		BAT225		
4:30 PM	ACE127			MAT143	BAT264	EEMS023	ACE130	FT078	ELT187	MAT142		EEMS045	ACE124		ELT238		BAT085		
4:45 PM					BAT263					MAT165	BAT317				Panel Discussion		BAT226		
5:00 PM				MAT150					ELT188								Panel Discussion		
5:15 PM				MAT151															
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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