U.S. DEPARTMENT OF ENERGY

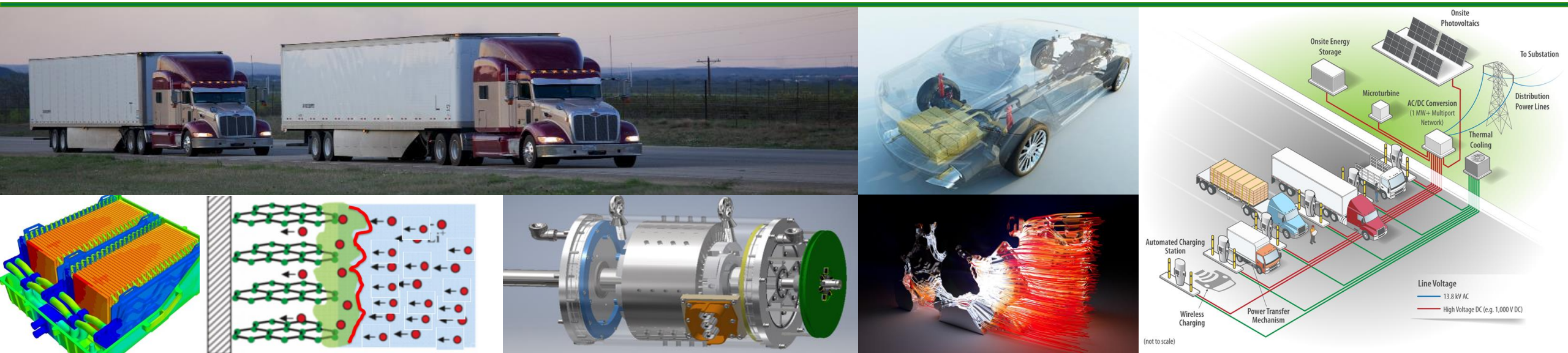
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Batteries and Electrification R&D

Steven Boyd

Program Manager, Batteries and Electrification R&D

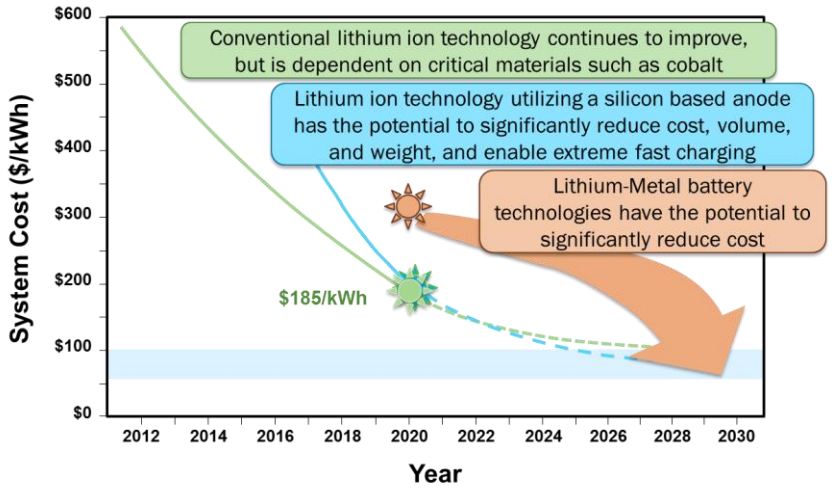
Vehicle Technologies Office

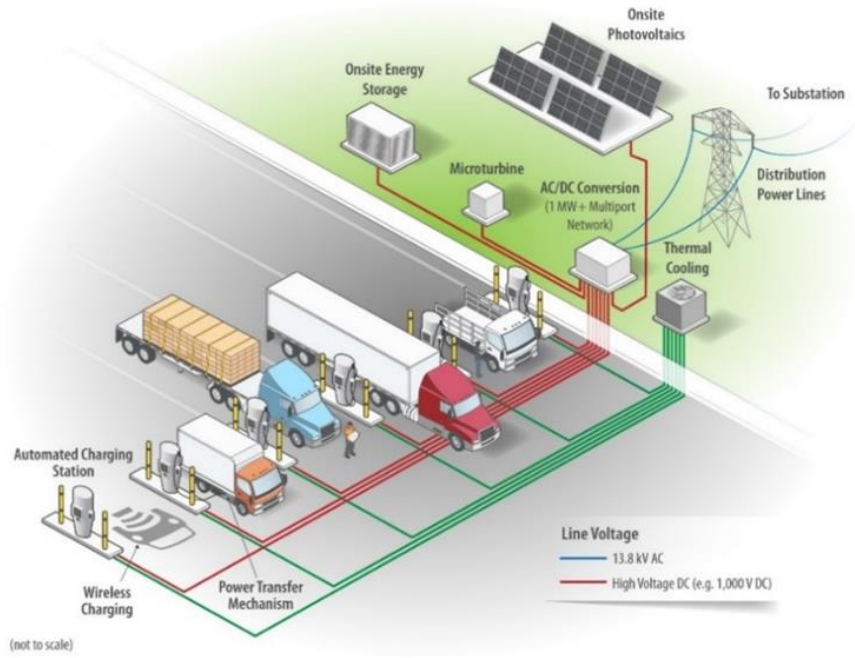


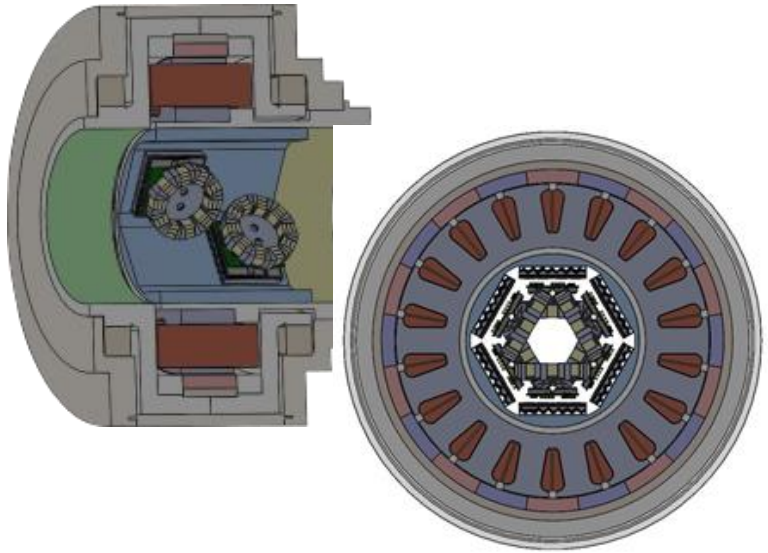
Batteries and Electrification Program

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







Who We Are and What We Do

Battery R&D

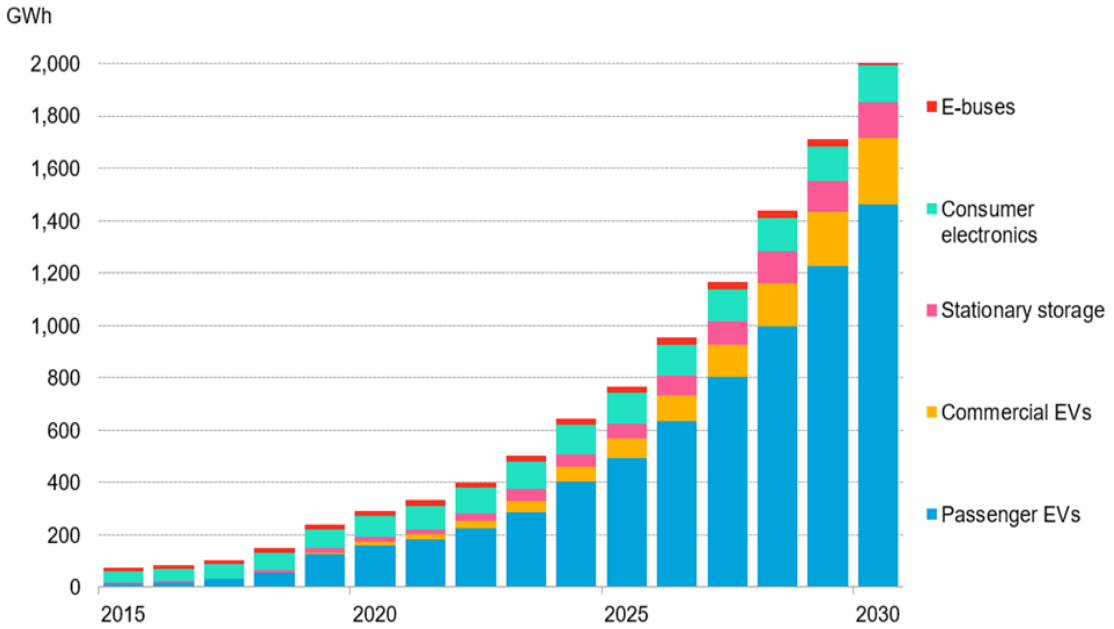
- Haiyan Croft – Battery Testing
- Brian Cunningham – Silicon Anodes and U.S. Advanced Battery Consortium — Tues BAT
- Tien Duong – Battery Material Research and Battery 500 — Thurs BAT
- Peter Faguy – High Voltage Cathodes, Battery Processing and Manufacturing — Wed PM BAT
- Samm Gillard – Battery Recycling, Extreme Fast Charging, Behind the Meter Storage — Tues PM/Wed BAT
- Simon Thompson – Solid State Batteries and Small Business Innovation Research

Electrification R&D

- Susan Rogers – Power Electronics, Electric Machines, Electric Drive Systems — Tues/Wed ELT
- Lee Slezak – Cyber-physical security, Extreme Fast Charging, Smart Charging — Wed/Thurs ELT

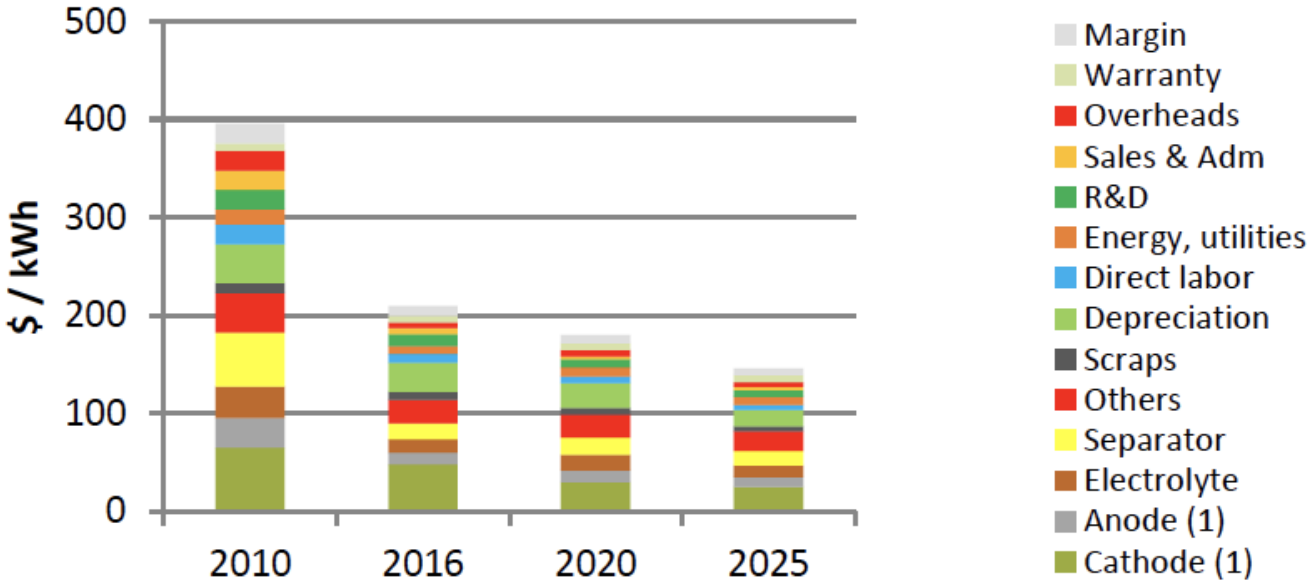
Headlines/Trends for Electrification

EV and associated Li ion market growth are projected to be very strong…



Bloomberg NEF Long-Term EV Outlook 2019

But projected market growth is dependent on further significant reductions in battery prices…



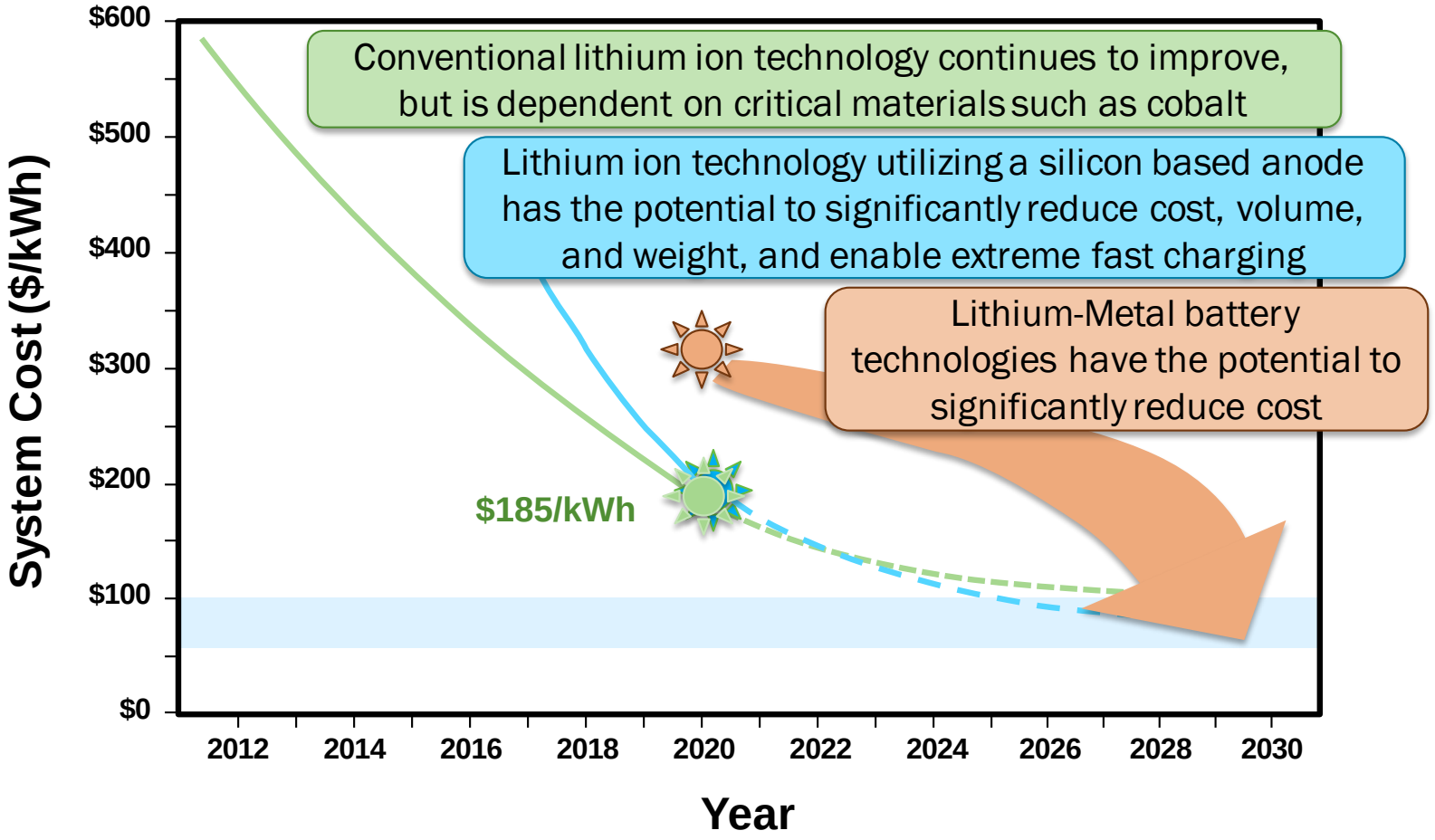
Avicenne The Rechargeable Battery Market and Main Trends 2016-2025,_September 2017

Recent EV Battery production announcements:

- GM and LG Chem JV investing up to $2.3B in Lordstown, OH for a 30GWh cell plant
- Tesla has invested ~$4B in its 20GWh plant in Nevada
- SK Innovation has announced a $1.5B project for two plants in Commerce GA for up to 10GWh of cells

Reducing Costs and Transitioning Technology for Batteries

VTO R&D has lowered the cost of EV battery packs to $185/kWh in 2019, an ~80% reduction since 2008 based on useable pack energy. Further cost reduction is needed in order for EVs to achieve cost competitiveness without Federal subsidies.



EERE VTO Battery technology is incorporated in over 15 hybrid and electric vehicles

Chevrolet Bolt

Electric Vehicle battery technology is being commercialized for stationary systems as well.

DOE VTO Battery R&D: Near, Next, and Long Term

Enhanced Li-ion
Graphite/NMC

Projected Cell Specific Energy, Cost
300Wh/kg, $100/kWh

Current cycle life	> 1000
Calendar life	> 10 years
Mature Manufacturing	Yes
Fast charge	No
Cost positive recycling	No

R&D Needs
- Fast charge
- Low temperature performance
- Low/no cobalt cathodes
- Cost positive recycling

Next Gen Li-ion
Silicon/NMC

Projected Cell Specific Energy, Cost
400Wh/kg, ~$75/kWh

Current cycle life	> 1000
Calendar life	~3 years
Mature Manufacturing	No
Fast charge	Yes, at BOL
Cost positive recycling	No

R&D Needs
- Enhanced calendar life
- Abuse tolerance improvement
- Low/no cobalt cathodes
- Cost effective and scalable pre-lithiation

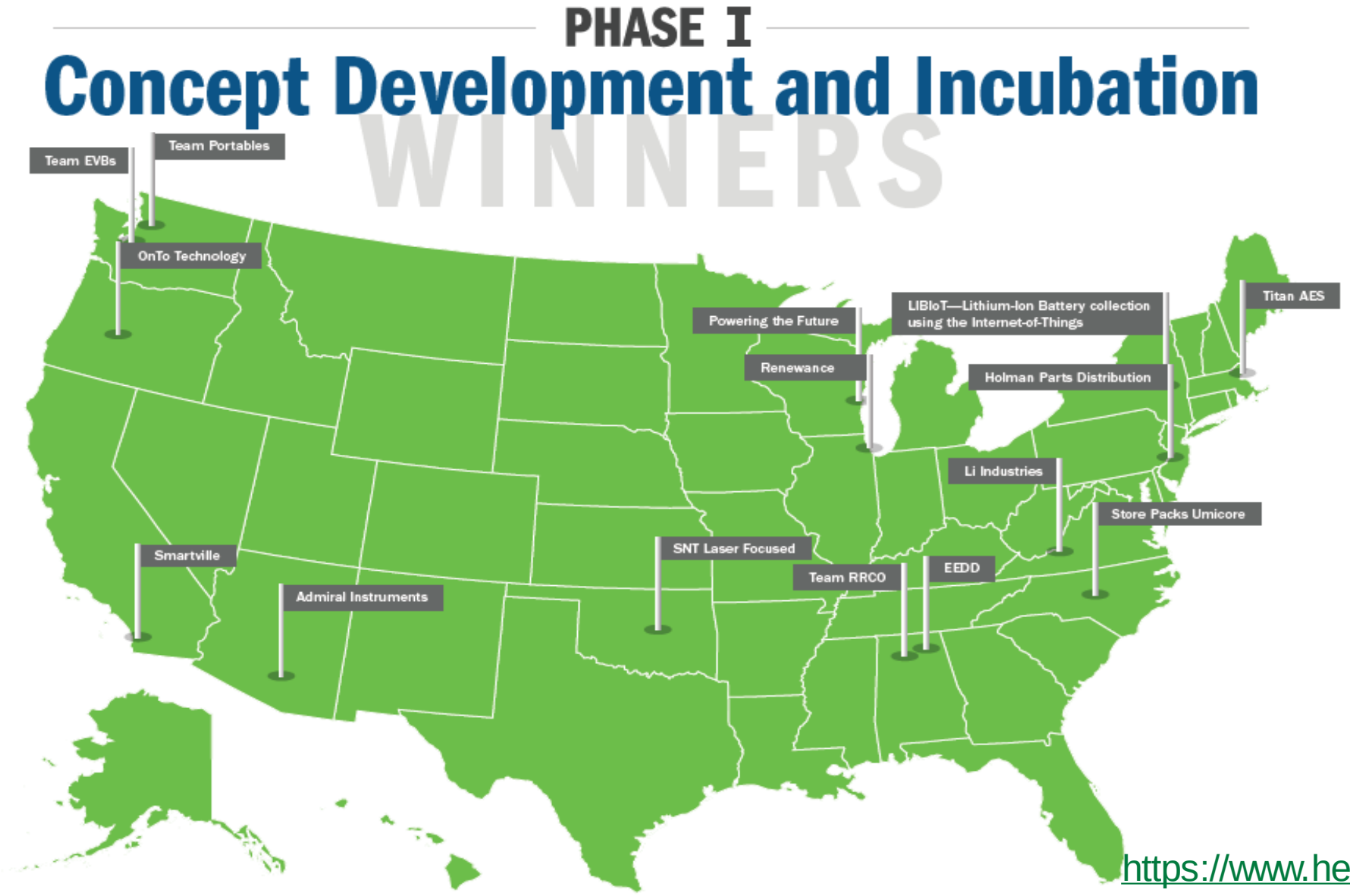
Lithium Metal
Li metal/NMC or Sulphur

Projected Cell Specific Energy, Cost
500Wh/kg, ~$50/kWh

Current cycle life	> 300
Calendar life	???
Mature Manufacturing	No
Fast charge	???
Cost positive recycling	No

R&D Needs
- Enhanced cycle and calendar life
- Protected lithium
- Dendrite detection and mitigation
- Cost effective manufacturing
- High conductivity solid electrolyte

Awarding Innovation: The Lithium-Ion Battery Recycling Prize



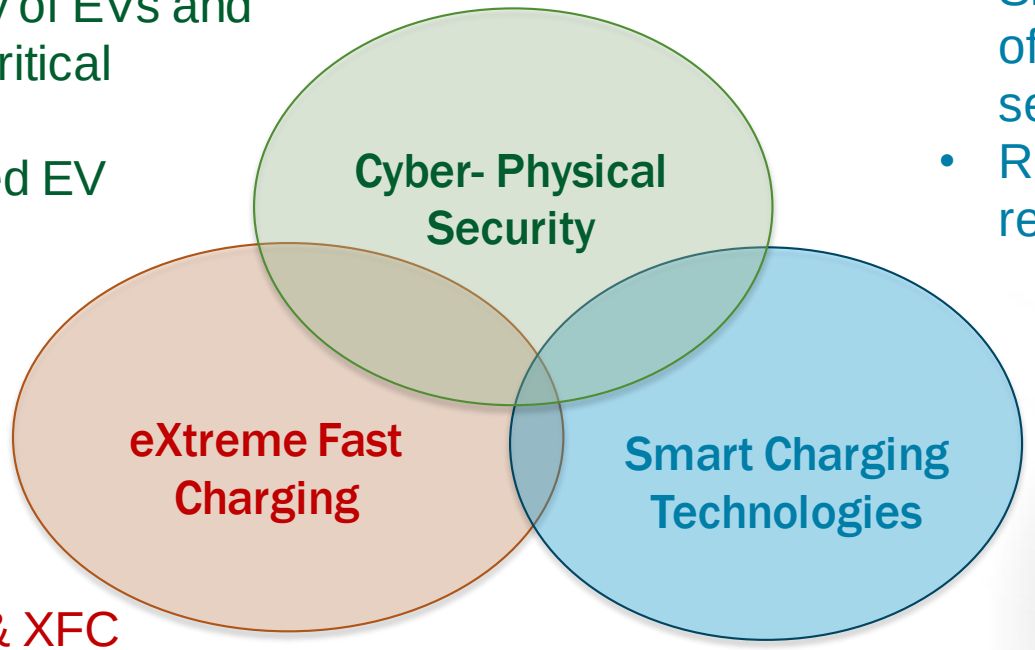
- 15 Phase I Winners were announced in September 2019
- Up to 10 Winners will be selected for Phase II November 2020
- Phase II is focused on prototyping and partnering

https://www.herox.com/BatteryRecyclingPrize

R&D for Electrification Enables Electric Vehicles at Scale

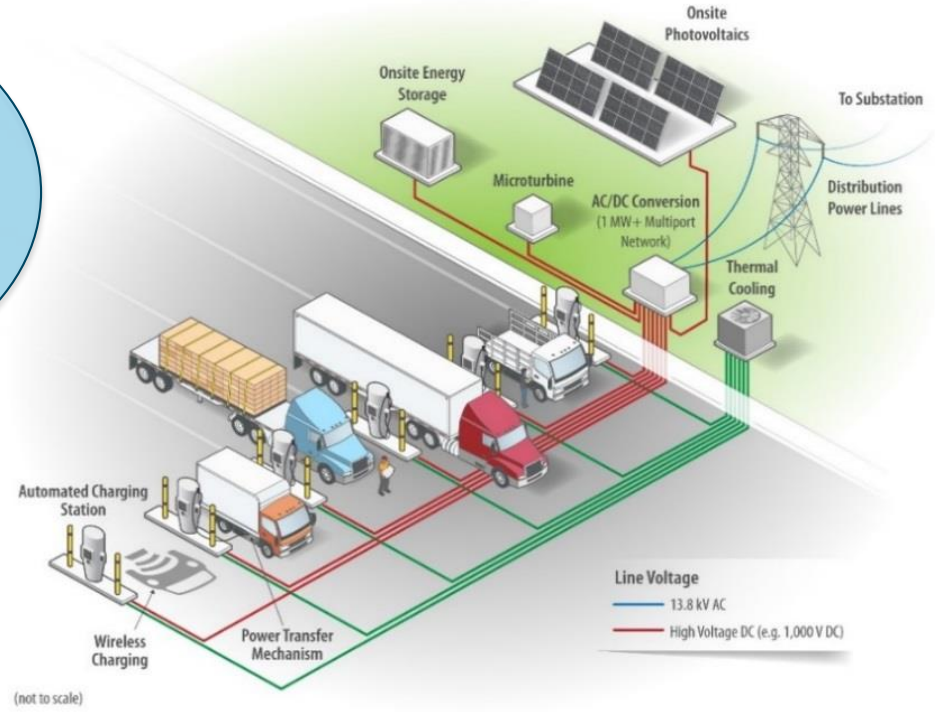
VTO's Electrification activities address challenges in Cyber-physical security, eXtreme fast charging, and Smart charging to support EVs at Scale.

- Cyber-physical security of EVs and charging protects our critical infrastructure
- R&D supports advanced EV charging security at the Grid edge



- High Power Charging & XFC enables higher utilization for LD, MD, & HD EVs.
- R&D supports advanced energy conversion from the Grid.

- Smart charging EVs enables efficient use of locally produced energy and grid services.
- R&D supports advanced strategies for reducing the cost of electricity delivery.

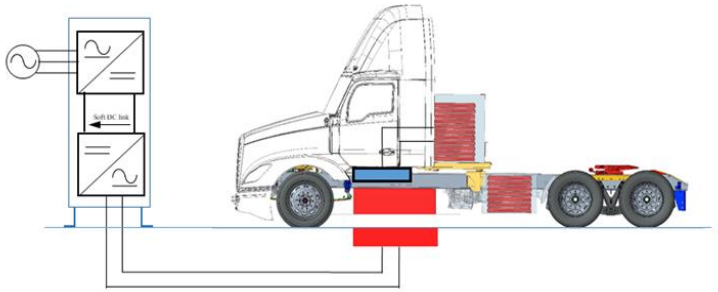


Rolling Out Electrification for Heavy Duty Vehicles

In coordination with High Power 1+MW Charging R&D, 4 new projects started in FY20 for RD&D on Class 7 & 8 Battery Electric Trucks with a daily range greater than 250 miles.

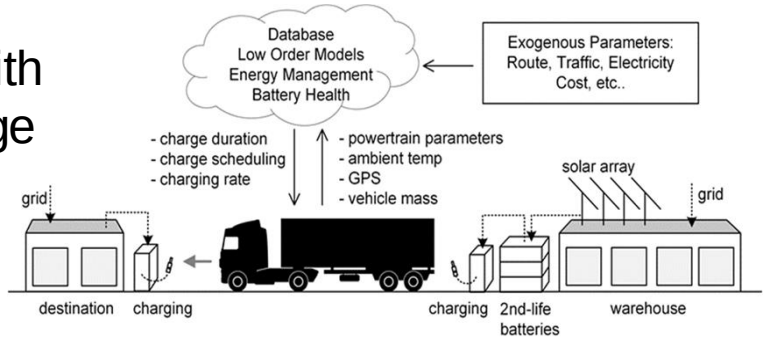
Kenworth

- 2 Class 8 UPS trucks with 200 mile range
- 1MW wireless charging enables 400 mile daily range



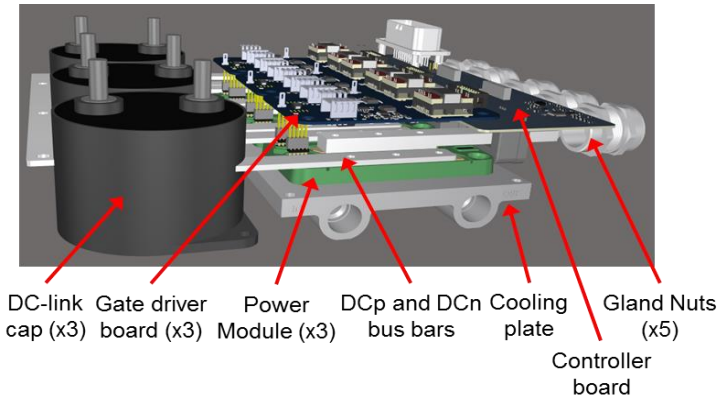
Volvo

- 2 Class 7 trucks with 250 mile daily range
- Intelligent Energy Management System



Ricardo

- 2 Class 8 trucks, 250mi regional delivery
- 250 kW WBG inverter
- 3 speed eAxles



Daimler Trucks NA

- 14 Class 8 trucks with improved performance over eCascadia 1.0
- >250 mile daily fleet demonstrations
- 2 speed eAxles

Voices of Experience – An EV Future Navigating the Transition

A joint Office of Electricity and Vehicle Technologies Office series of workshops with EV and Utility Stakeholders

Objectives

1. Explore what the transition to EVs will mean from different stakeholder perspectives
2. Understand the opportunities, potential pitfalls, and considerations for building the necessary electricity and charging infrastructure
3. Provide a consolidated overview of ongoing activities
4. Identify pre-competitive research needs or areas where the federal government's expertise, resources, or convening power could assist efforts

Underlying Goals

- Provide a forum to exchange ideas and share experience/knowledge
- Capture various perspectives
- Identify new pathways or uncover potential obstacles
- Provide high-level insights, considerations, and references
- Create a valuable resource for informing the conversation

Providing clarity on infrastructure requirements and policy needs to prepare for growing EV adoptions

Electric Drive Technologies Consortium R&D Targets

2015 Baseline
($1800, $12/kW)

Chevrolet Bolt

Oak Ridge National Laboratory
Sandia National Laboratories
NREL National Renewable Energy Laboratory
Ames Laboratory Creating Materials & Energy Solutions U.S. Department of Energy
Illinois Institute of Technology
Georgia Tech
Berkeley University of California
Virginia Tech
Purdue University
University of Arkansas
The Ohio State University
SUNY Polytechnic Institute
Wisconsin University of Wisconsin-Madison
NC State University
MAGNA
Illinois University of Illinois at Urbana-Champaign
United Technologies Research Center
Carnegie Mellon University
UNC Charlotte

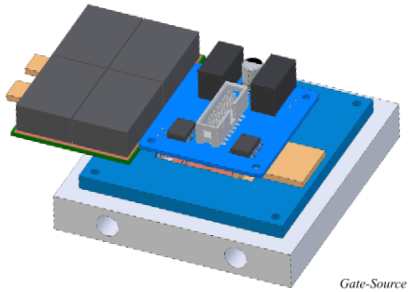
2025 Target
($900, $6/kW)

Future Mobility Design Concepts

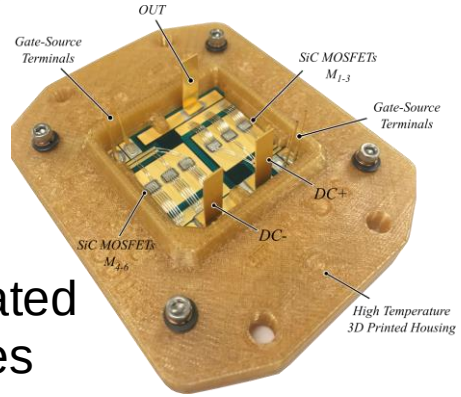
2025 Targets		
Cost	$ 900	50% reduction
Power Density	33 kW/L	843% increase
Reliability/lifetime	300,000 miles	100% increase

Electric Drive Technologies Consortium R&D Concepts

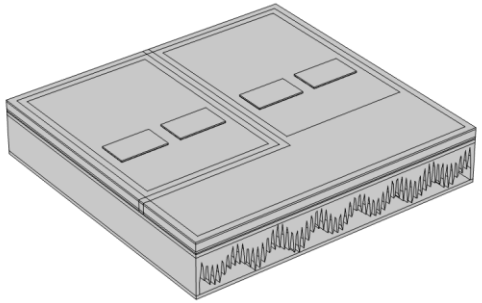
Keystone Project #1
Highly Integrated Power Electronics



SiC-based Segmented Inverter

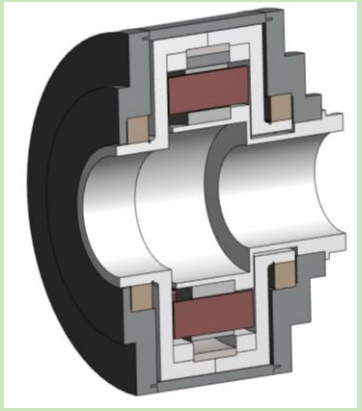


Half-Bridge Power Module based on Insulated Metal Substrates



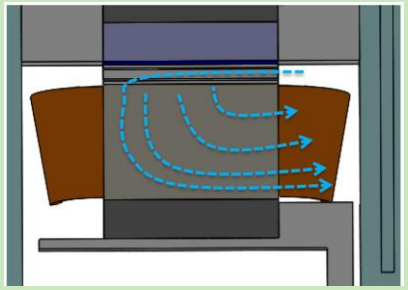
Genetic Algorithm Designed heat sink

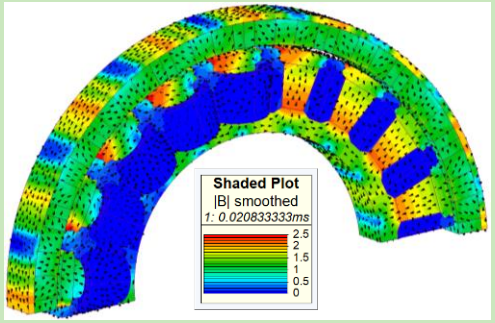
Keystone Project #2
High Speed Electric Motors



Heavy Rare-Earth-Free Dual Three-Phase Outer Rotor Traction Motor

Slot heat exchanger

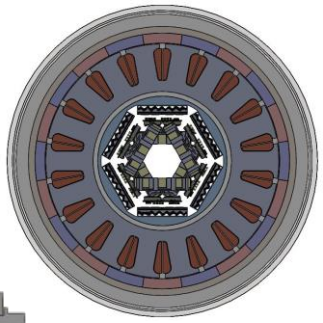


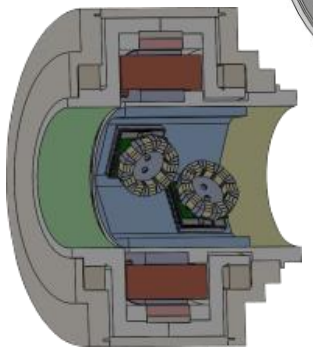


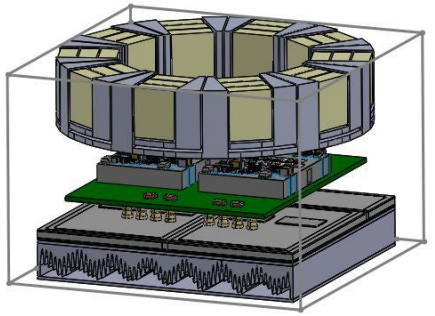
Electromagnetic design completed

Keystone Project #3
Integrated Drive Systems

Integrated Drive Concepts







Power Module for the Integrated Drive

21st Century Truck Partnership Electrified Technical Team

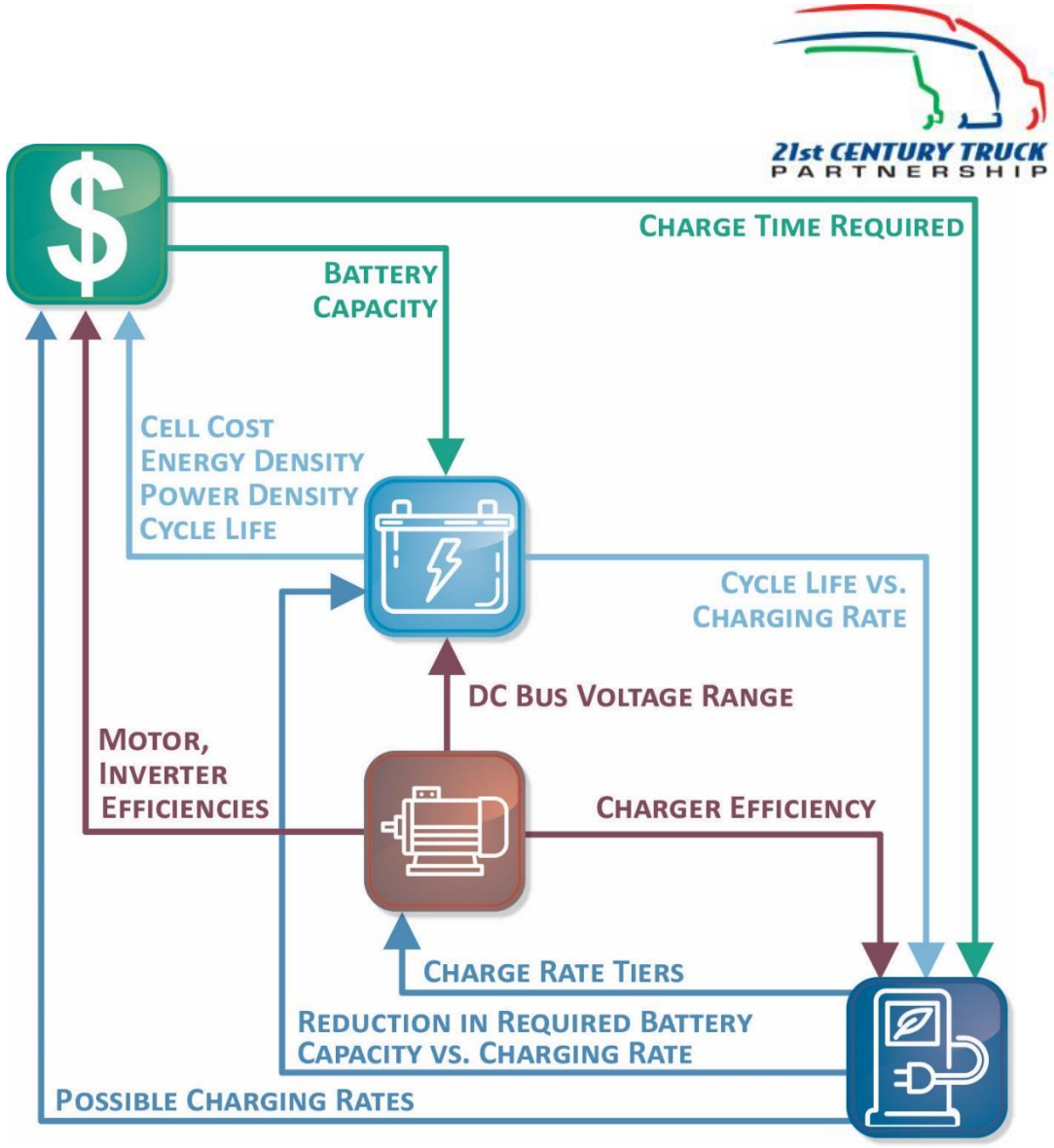
ELECTRIFIED TECHNICAL TEAM (ETT)

GOAL

Develop ***electrified powertrain options*** that meet commercial truck customer duty cycles at ***drastically reduced capital and operating cost***, harnessing high-performance computing to analyze and design ***scalable, modular systems*** for high-volume production

Tech Team Sub-working Groups

- Electrification Components
- Battery
- Powertrain System Architecture
- Infrastructure



Thank you

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