U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

VEHICLE TECHNOLOGIES OFFICE

Electric Vehicle, Battery, and Charging Infrastructure Update

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March 9, 2020

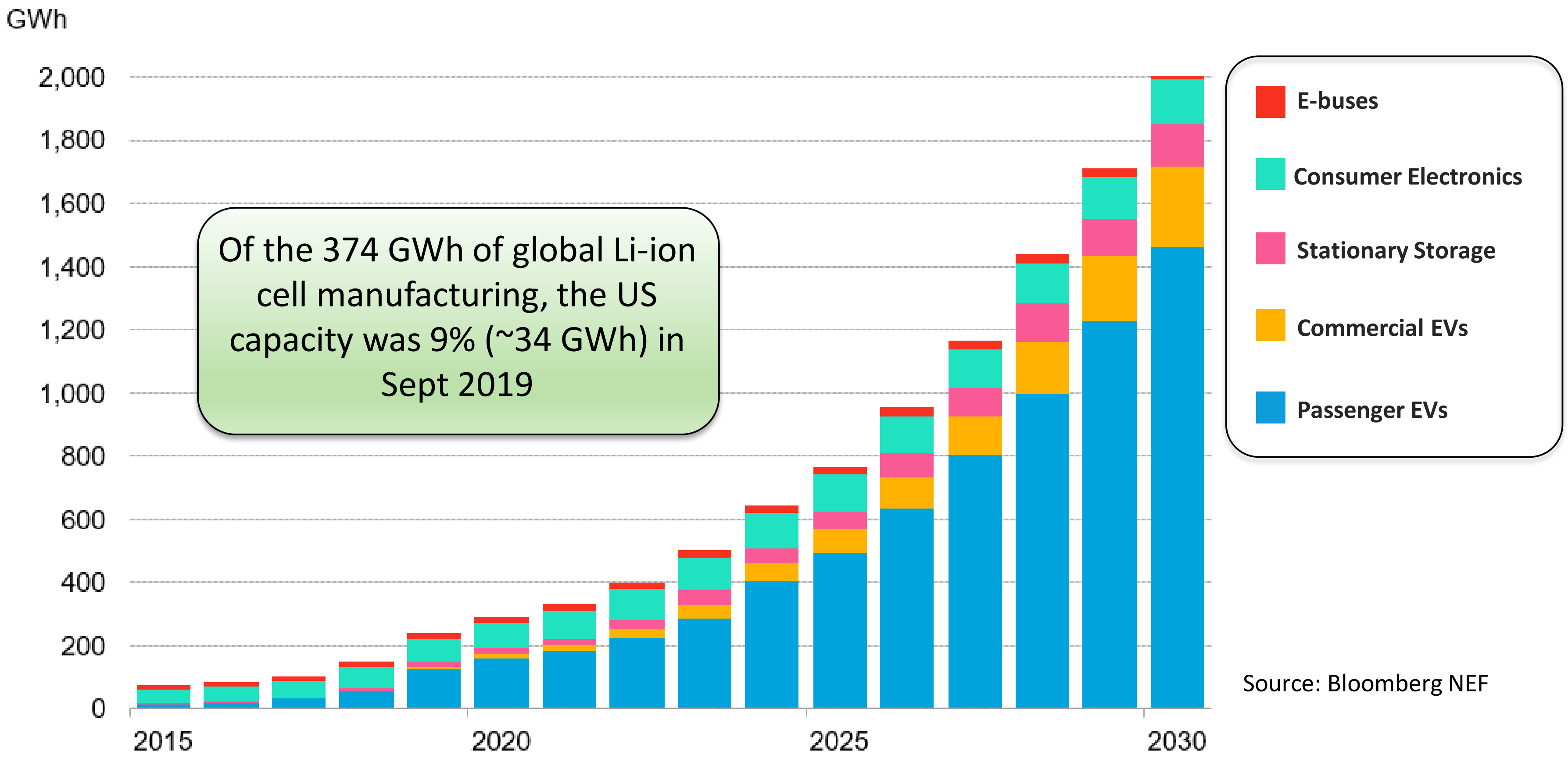
Electric Vehicle Economic Impact

- **U.S. PEV sales (**Cumulative: 1,443,627[1])
  - 2019 Sales: 325,839
  - PEV Models sold: 43[+1]
- **>70% of 2018 U.S.-sold EVs were manufactured in the U.S.**
  - 8 of the 10 top-sellers
- **U.S. manufacturing jobs associated with electrification[2]**
  - 2016: 258,000
  - 2030 Projected: >600,000 (6.5% of sales)
- **Consumers benefits[4]**
  - The average cost to drive an EV: $0.03/mile (for gasoline, it is $0.11/mile)
- **98% of electricity used in the U.S. is domestically generated**

OEM	Models (2019 Sales)[5]	Made
TESLA	• Model 3 *(154,832)* • Model S *(15,084)* • Model X *(19,424)*	*USA*
GM	• Volt *(4,915)* • Bolt *(16,310)*	*USA*
TOYOTA	• Prius PHEV *(15,084)*	*Japan*
HONDA	• Clarity PHEV *(10,690)*	*Japan*
NISSAN	• Leaf *(12,365)*	*USA*
FORD	• Fusion Energi *(7,451)*	*USA*
FCA	• Pacifica *(5,792)*	*USA*

1 Through September 2019
2 U.S. Department of Energy "2017 U.S. Energy and Employment Report (USEER)," January 2017
3 Of new Light-duty Vehicle Sales
4 Based on cost/kwh of electric energy: $0.12/KWh for electricity, $2.30/gallon for gasoline, and an average fuel economy of 23.6 mpg
5 Source: Wards, 2016; hybridcars.com, 2016

EVs will dominate the demand for Li-ion batteries



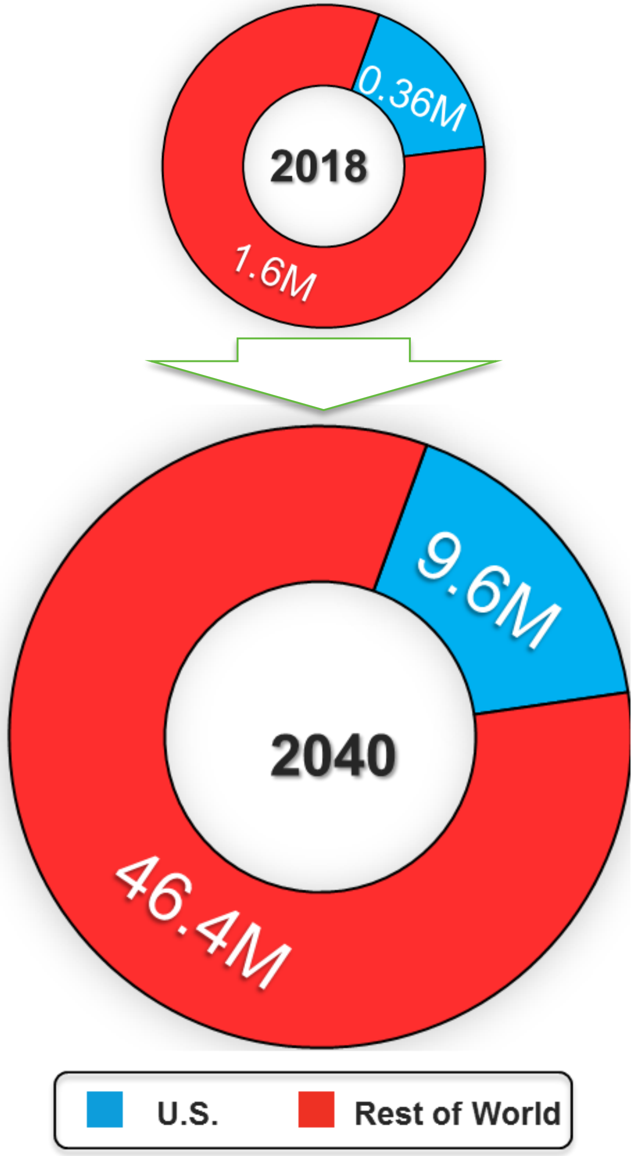
Of the 374 GWh of global Li-ion cell manufacturing, the US capacity was 9% (~34 GWh) in Sept 2019

Source: Bloomberg NEF

Lithium Battery development and production is a strategic imperative for the US, both as part of the clean energy transition and as a key component for the competitiveness of the US automotive industry

Anticipated Rise in Electric Vehicle Purchases

- **Global projection of annual passenger EV sales is 56M EVs in 2040[1]**
  - 17% (~9.6M EVs) of those sales will be in the US market
  - 9.6M EV's equates to approximately a $100 billion battery market
- **2018 markets[2] of similar size:**
  - Smart phones ($79 billion)
  - Gas stations ($110 billion)
  - Passenger Car/auto manufacturing ($112 billion)



[1]Source: Bloomberg NEF Long-Term Electric Vehicle Outlook 2019
[2]Source: IBIS World, Market Size Statistics - United States 2018 NAICS Reports

Industry EV Plans and Announcements

- Tesla became the top seller of luxury cars in the U.S.
  - In 2018, Tesla Model 3 sold more than 120,000 units.
- GM plans to double its allocated resources for EVs and autonomous vehicles in 2019-20.
- Ford plans to spend $11 billion on 40 PEVs over 2018 -2022.
- Mazda vehicles mix, by 2030, will be HEVs 95%, PEVs 5%.
- Daimler will develop >10 PEVs by 2022, with associated charging infrastructure ("ecosystem").
- Volvo will have five new full EVs in its lineup by 2021.
- Medium Duty/Heavy Duty vehicle manufacturers are entering the EV market.
  - Daimler deployed its first all-electric truck.
  - Volvo Trucks plans to begin demonstrations of all-electric VNR heavy-duty trucks.

Electric Vehicle Battery R&D

THREE MAJOR CHALLENGES

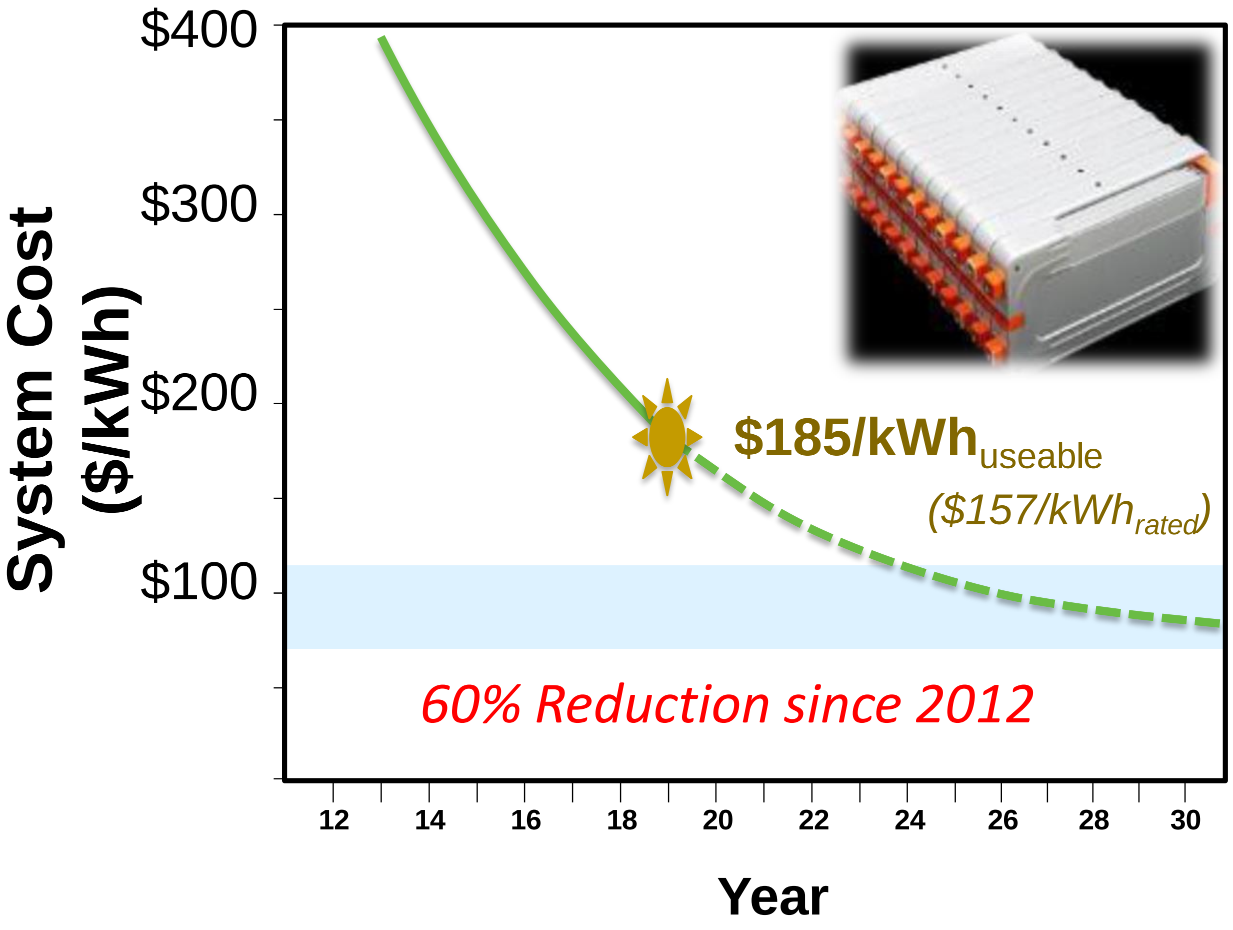
1. Further reduce battery costs (2X)

2. Eliminate dependence on critical materials

3. Develop safe batteries that charge in <15 minutes

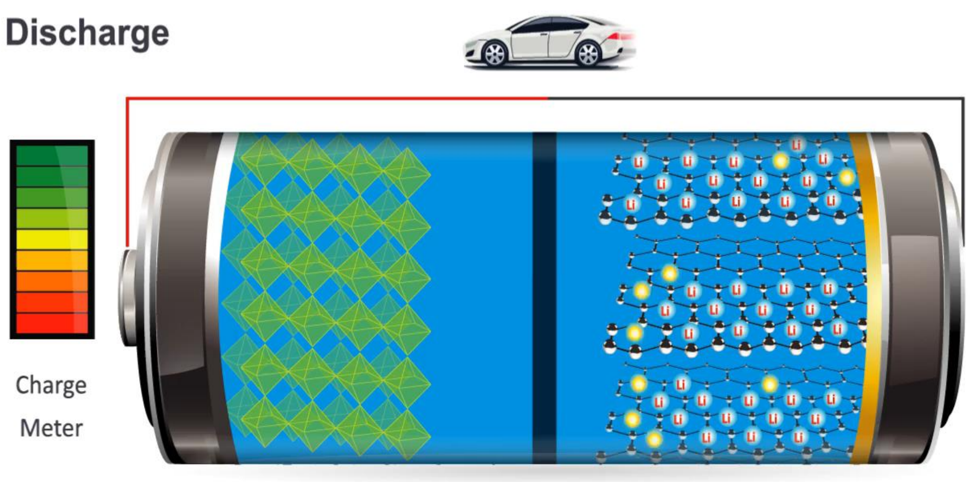
Battery Cost Reduction

Based on Useable Energy and production of 100k EV Packs/year



Cost Reduction

How Lithium-ion Batteries Work

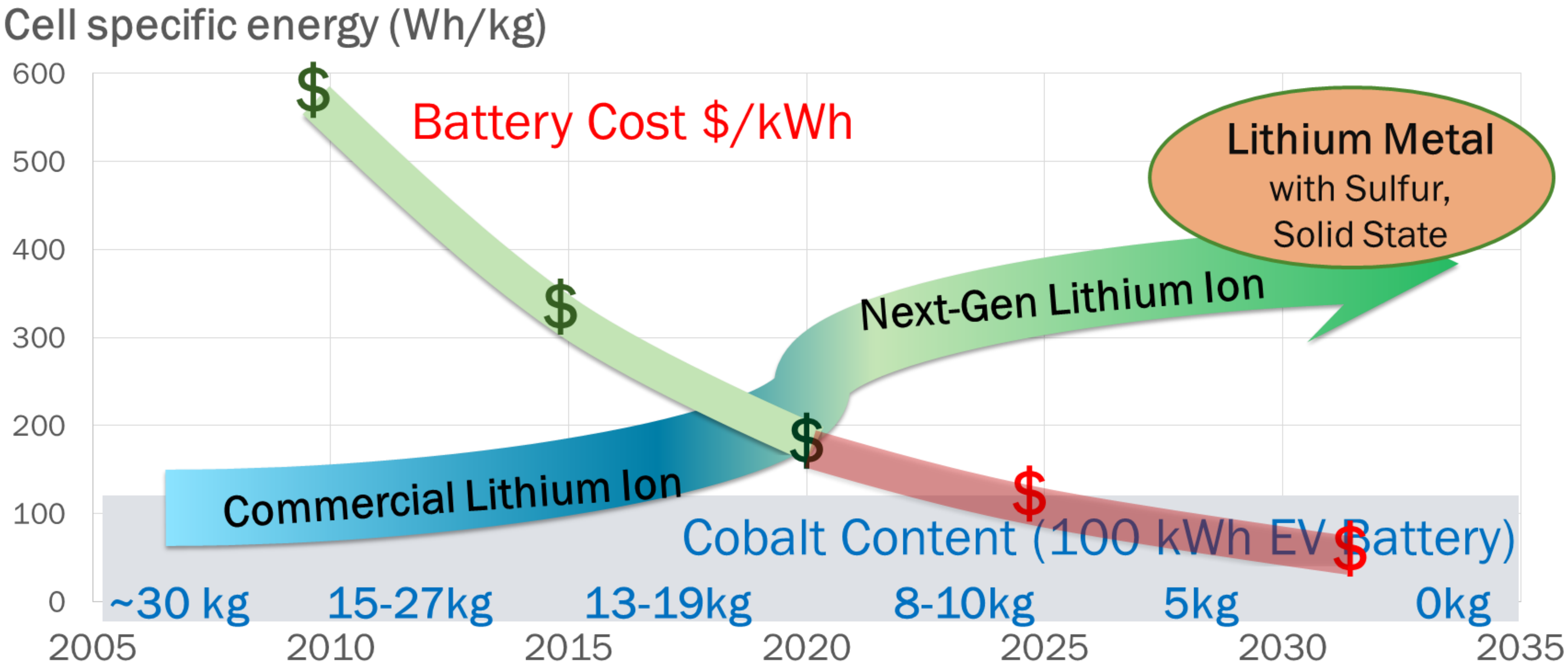


Low Cobalt Cathodes
or
"No Cobalt" Cathodes

New Liquid Electrolytes
or
Solid State Materials
or
Novel Polymer Separators

Silicon Anodes
or
Silicon-Composite Anodes
or
Lithium Metal Anodes

Lithium Battery Pathways and Cost Reduction



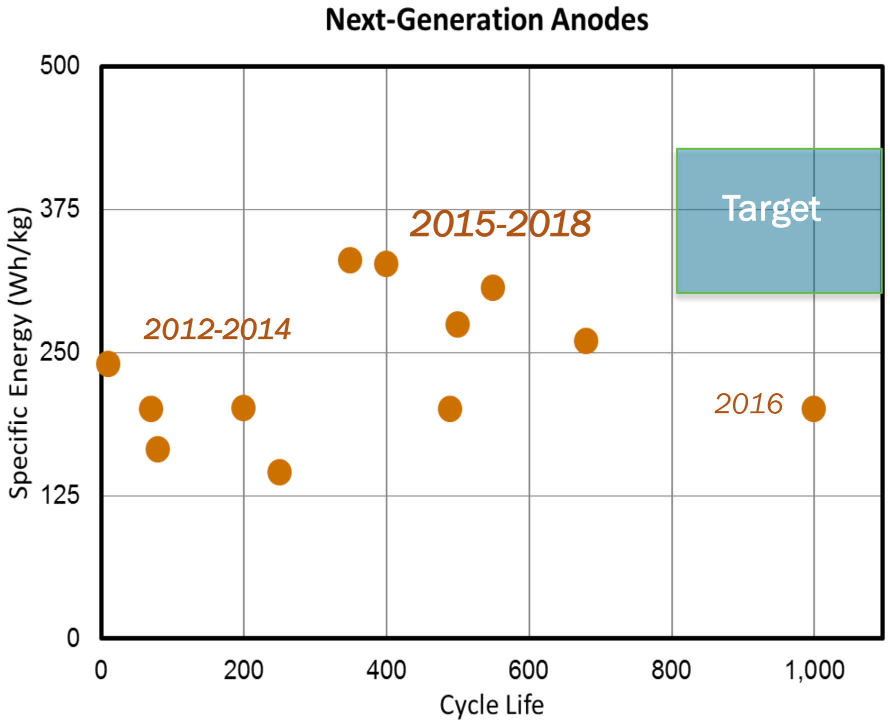
Cost Reduction + Fast Charge

Intermetallic Anodes (Silicon Composite Alloy)

Targets

- 1,000+ mAh/g
- 1000 cycles, 10+ years

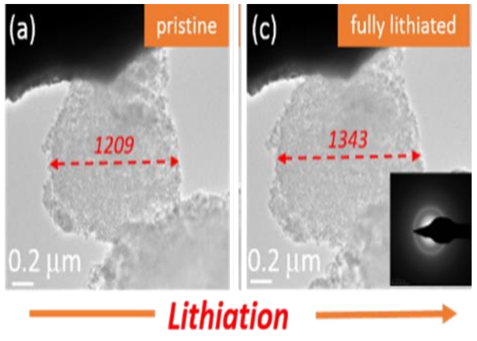
Cells tested provided by DOE-funded Developers



Challenges

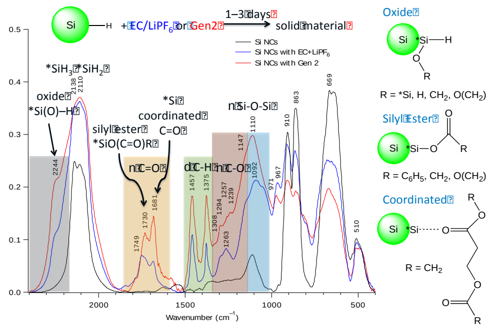
Key Issue: Cycle Life

- Silicon can swell >300% upon lithiation causing cracking and unwanted side reactions



Key Issue: Calendar Life

- Silicon surface is chemically and electrochemically reactive and byproducts do not fully passivate the silicon surface in a similar fashion to graphite.



Cost Reduction plus: Battery Materials Research (BMR)

Charter: Perform cutting edge research in new materials and conduct comprehensive modeling and diagnostic of materials and electrochemical cell behavior to address chemical and mechanical instabilities.

7 Topic areas, 51 research projects

- Modeling (11)
- Diagnostics (10)
- Liquid/Polymer/Solid State Electrolytes (10)
- Metallic Lithium (7)
- Sulfur Electrodes (7)
- Air Electrode/Electrolyte (3)
- Sodium ion Batteries (3)

Current Participants

National Labs (7)

Argonne National Laboratory
Brookhaven National Laboratory
Berkeley Lab
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
SLAC National Accelerator Laboratory
Lawrence Livermore National Laboratory

Academia (23)

BYU
Brown University
Carnegie Mellon University
Michigan State University
Michigan Technological University
Massachusetts Institute of Technology
NC State
PennState
Rutgers
Stanford University
Stony Brook University
UK
Michigan
University of Pittsburgh
University of Washington
Texas A&M University
University of Maryland
University of Wisconsin UW Milwaukee
Berkeley University of California
UC San Diego
The University of Texas at Austin
West Virginia University

Industry (2)

Daikin
GM

VTO Battery500 Consortium Team

BATTERY 500 CONSORTIUM

Strategic Goal

Develop and demonstrate cells with a specific energy of 500 Wh/kg and achieving 1,000 cycles

Harvest Maximum Capacity from Promising Battery Chemistries

- **High Nickel NMC-Li:** achieving >50% of theoretical capacity at cell level
- **Solid State Li-S:** solving polysulfide dissolution and Li degradation problems

National Laboratories

Pacific Northwest National Laboratory

- Pacific Northwest National Lab (PNNL)
- Brookhaven National Lab (BNL)
- Idaho National Laboratory (INL)
- Stanford Linear Accelerator (SLAC)

Universities

Binghamton University, The University of Texas at Austin, Stanford University, UC San Diego, University of Washington

Industry Partners

IBM, Stanford University, Tesla, USABC (United States Advanced Battery Consortium), NAATBatt (National Alliance for Advanced Technology Batteries)

Phase 2 Seedling Projects

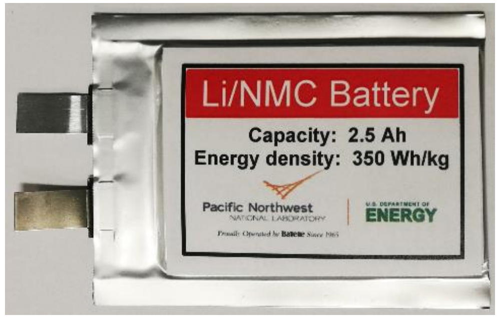
Cornell University, University of Houston, Berkeley Lab, PennState, University of Pittsburgh, University of Maryland, Texas A&M, Stony Brook University, GM, Navitas Systems

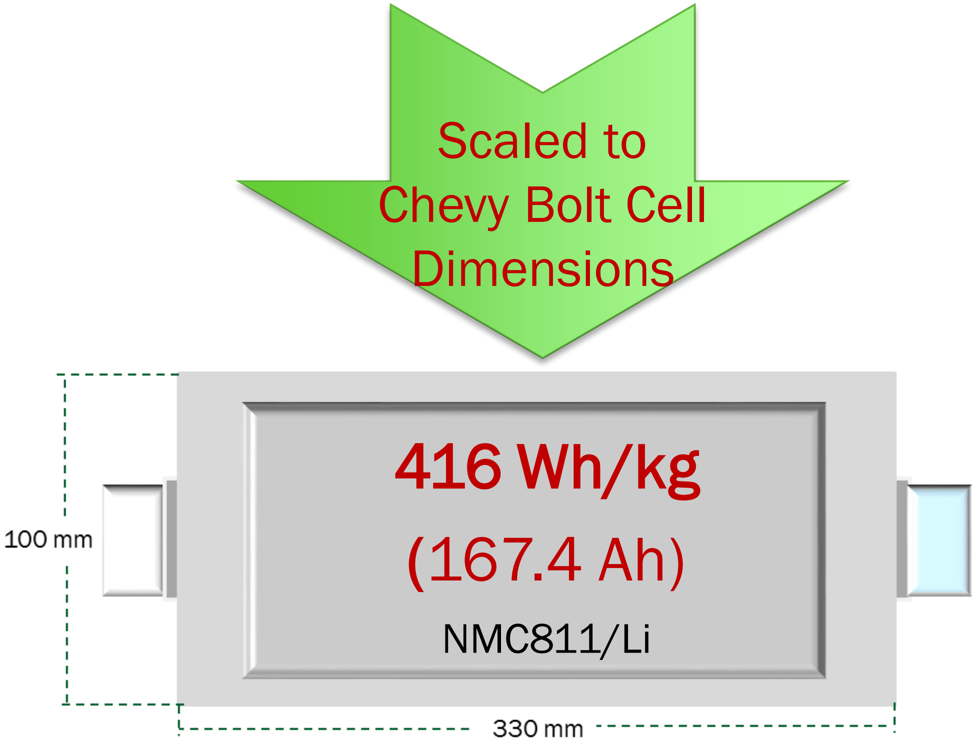
Lithium Metal Batteries: Major Accomplishments

Target: 500 Wh/kg and 1000 EV cycles

Demonstrated: 350 Wh/kg & > 350 cycles

the Battery500 Consortium Quarterly Review at UT Austin – May 2017



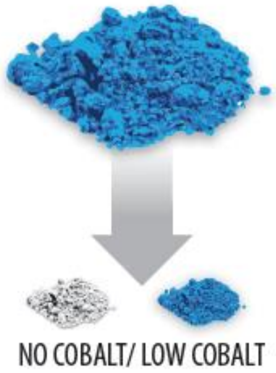


VTO Strategy to Mitigate Potential EV Battery Critical Material Impacts

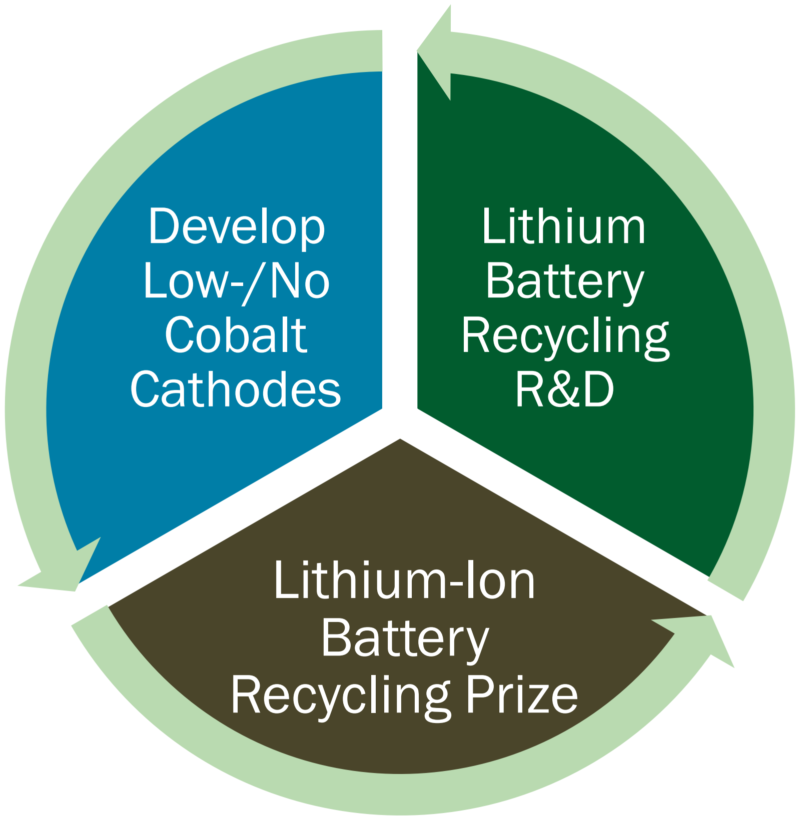
Low or No Cobalt Cathode R&D

19 kg

0-5 kg



Based on: 100 kWh battery pack and NMC622 cathode



ReCell
ADVANCED BATTERY RECYCLING

- Decrease recycling cost
- Recover critical and high value materials
- Reintroduce recovered materials into the material supply stream

AMERICAN MADE
BATTERY RECYCLING PRIZE
U.S. DEPARTMENT OF ENERGY

Demonstrate a process that has the potential to capture 90% of ALL lithium based battery technology in the U.S. (when scaled), including consumer electronics, stationary, and transportation applications.

Potential Material Supply from Recycled Li-Ion Batteries

	Natural Resources		Spent Batteries
One ton of battery-grade cobalt can come from:	 **300 TONS** OF ORE		 **5-15 TONS** OF SPENT LITHIUM-ION BATTERIES
One ton of battery-grade lithium can come from:	 **250 TONS** OF ORE	 **750 TONS** BRINE	 **28 TONS** OF LITHIUM-ION BATTERIES

Lithium Ion Battery Recycling R&D Center

MISSION: Decrease the cost of recycling lithium ion batteries to ensure future supply availability of critical materials and decrease energy usage compared to raw material production

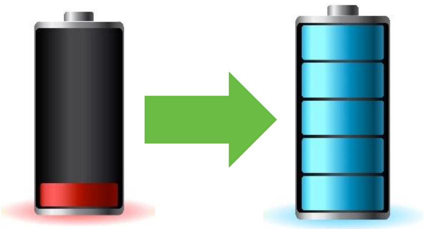
Direct Recycling

Cathode Separation

Binder Removal

Relithiation

Compositional Change



Recovery of Other Materials

Electrolyte

Graphite

Electrodes

Design for Recycle

Cell Design

Electrode Design

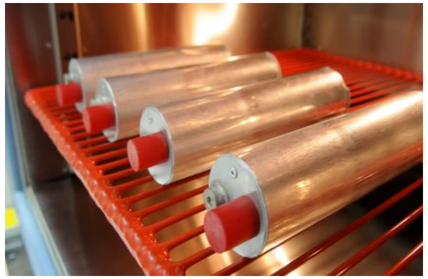
Alternative Binders

Characterization

Materials Analysis

Thermal Analysis

Advanced Characterization



Energy Secretary Rick Perry Announces the Battery Recycling Prize

January 17, 2019: At the Bipartisan Policy Center's American Energy Innovation Council

"America's dependence on foreign sources of critical materials undermines our energy security and national security," …

The Battery Recycling Prize will encourage American entrepreneurs to find innovative solutions to collecting, storing, and transporting discarded lithium-ion batteries for eventual recycling.

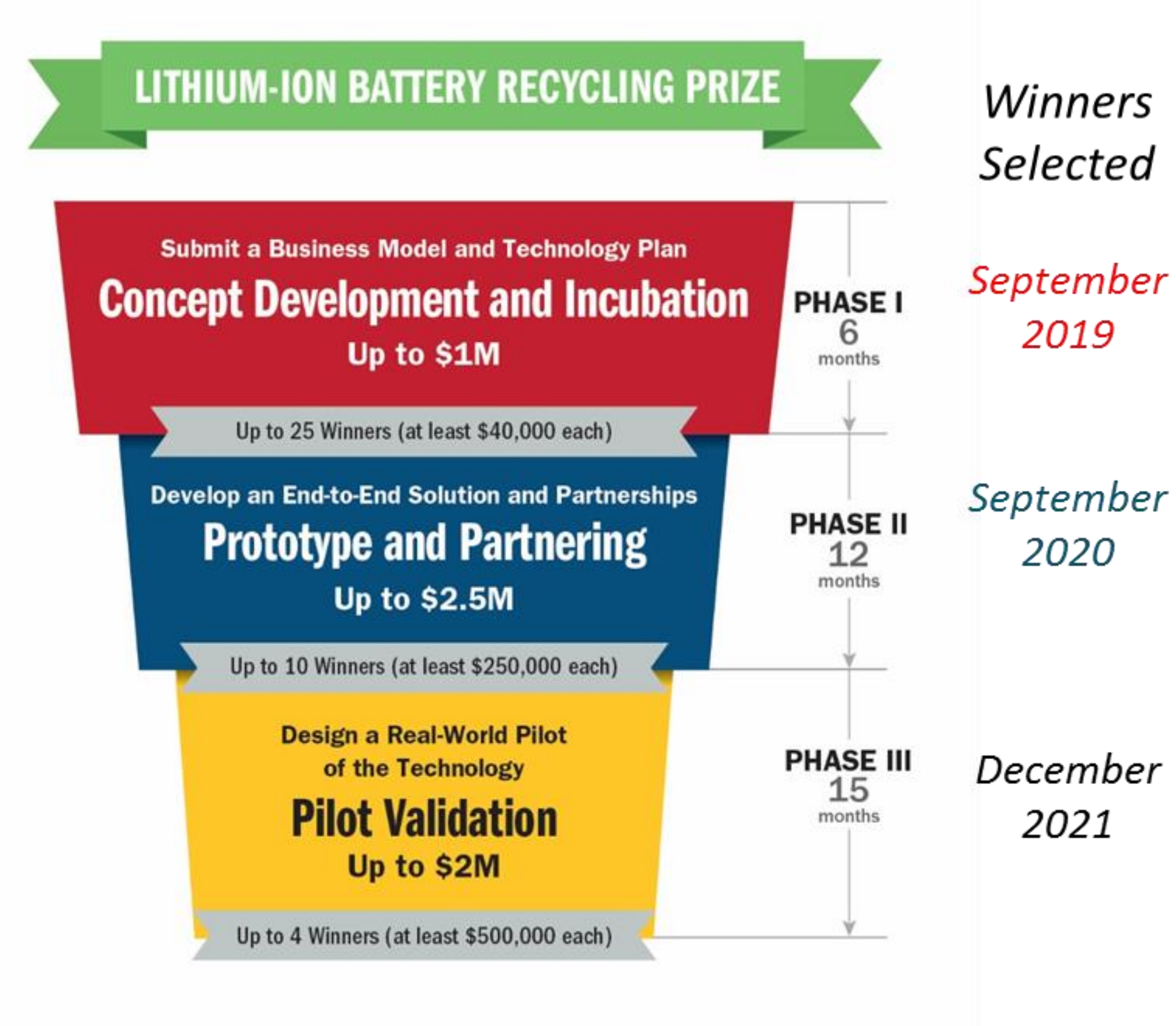
AMERICAN MADE
BATTERY RECYCLING PRIZE
U.S. DEPARTMENT OF ENERGY

A $5.5 million phased competition over three years

- Funded by DOE's Vehicle Technologies Office and DOE's Advanced Manufacturing Office

Battery Recycling Prize

Innovative Ideas for Collection, Storing, and Transporting Discarded Li-Ion Batteries



PRIZE GOAL

Demonstrate a process that has the potential to capture 90% of ALL lithium based battery technology in the U.S. (when scaled), including consumer electronics, stationary, and transportation applications.

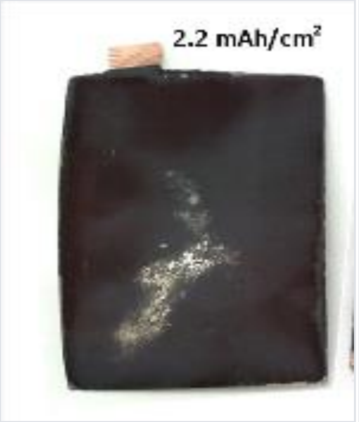
Prize will be administered on the HeroX platform
https://www.herox.com/BatteryRecyclingPrize

Extreme Fast Charging (XFC)

Combination of fast charge batteries and a network of high capacity chargers can;

- minimize range anxiety,
- promote the market penetration of BEVs,
- and increase total electric miles driven.

However, xFC can impact performance, life, safety, and cost of a cell

Type of Charging Station	**Tesla Super Charger (140 kW)**	**Extreme Fast-Charging (400kW)**
Time to charge (for 200 miles)	25 mins	10-15 mins
C-Rate	~2	4-6
Higher charge rates can increase the likelihood of plating		

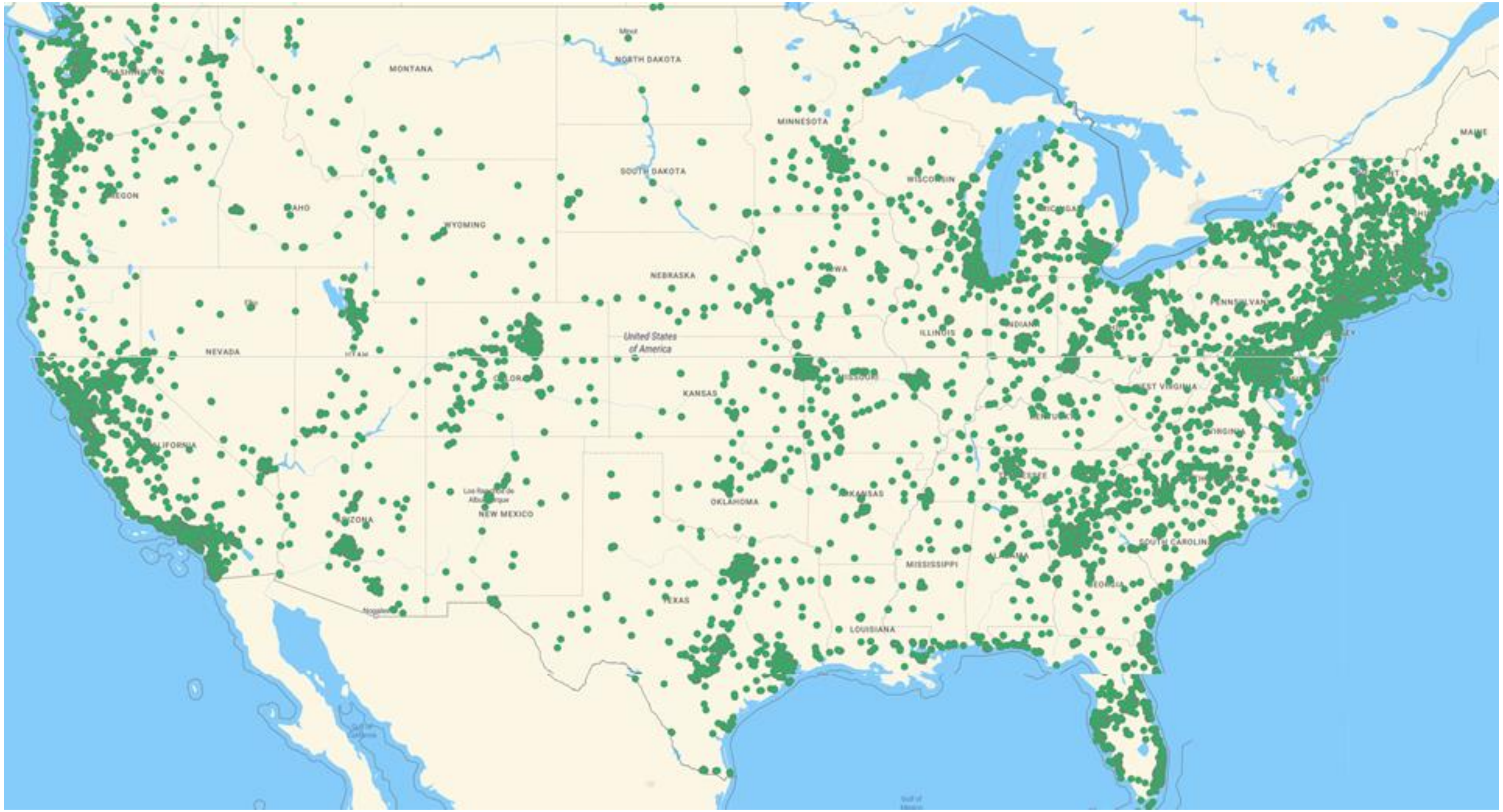
K. Gallagher, et al., J. Electrochem. Soc. 163 (2016) A138eA149

Charging Stations available

Number of Charging Stations			
Chargers	2017	2018	Change
AC Level 1 Chargers	1,300 (2,604)	1,031 (2,029)	-21% (-22%)
AC Level 2 Chargers	15,639 (38,264)	19,008 (48,818)	+22% (+28%)
Fast Chargers	2,232 (6,267)	2,620 (9,626)	+17% (+54%)
Superchargers (incl. in Fast Chargers)	394 (2,831)	594 (5,413)	+51% (+91%)
Totals	17,219 (47,135)	20,959 (60,535)	+22% (+28%)

* Excluding private chargers, data from the U.S. Department of Energy Alternative Fuels Data Center, accessed January 7, 2019.
http://www.afdc.energy.gov/fuels/electricity_locations.html

U.S. Electric Charging Stations (2018)



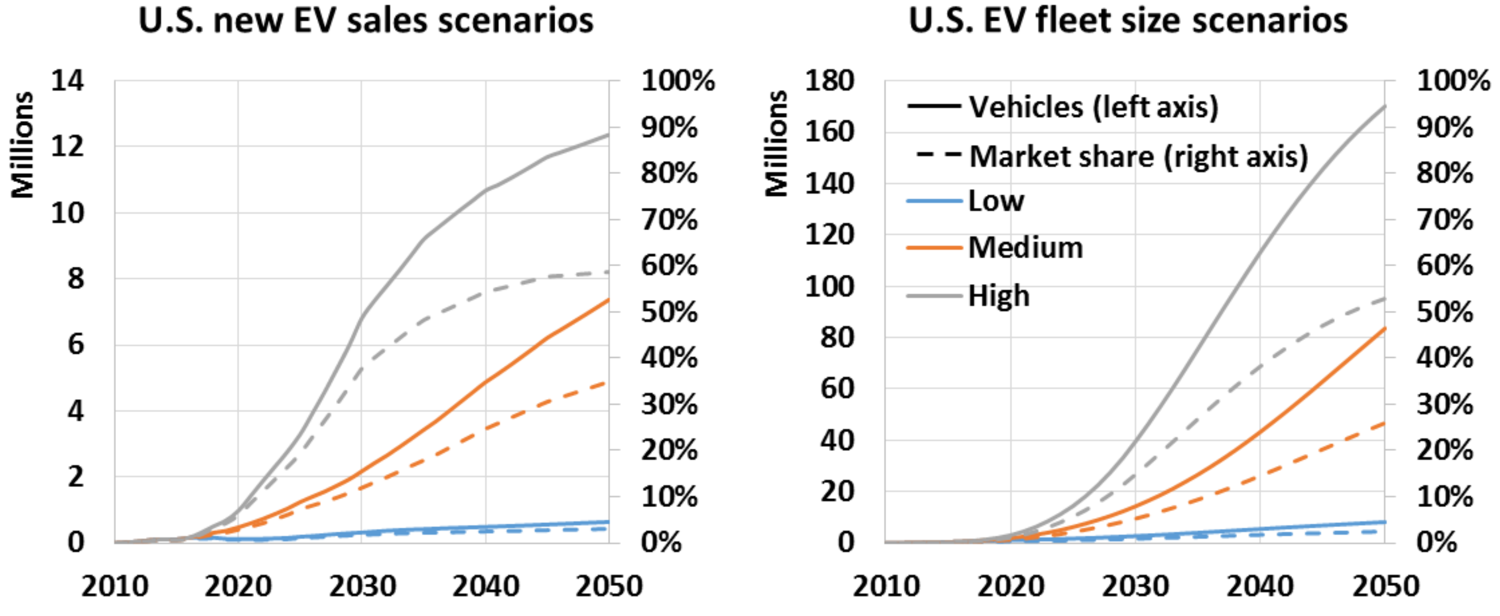
Source: http://www.afdc.energy.gov/fuels/electricity_locations.html

Summary Report on EVs at Scale and the U.S. Electric Power System

https://www.energy.gov/eere/vehicles/us-drive-partnership-plan-roadmaps-and-accomplishments

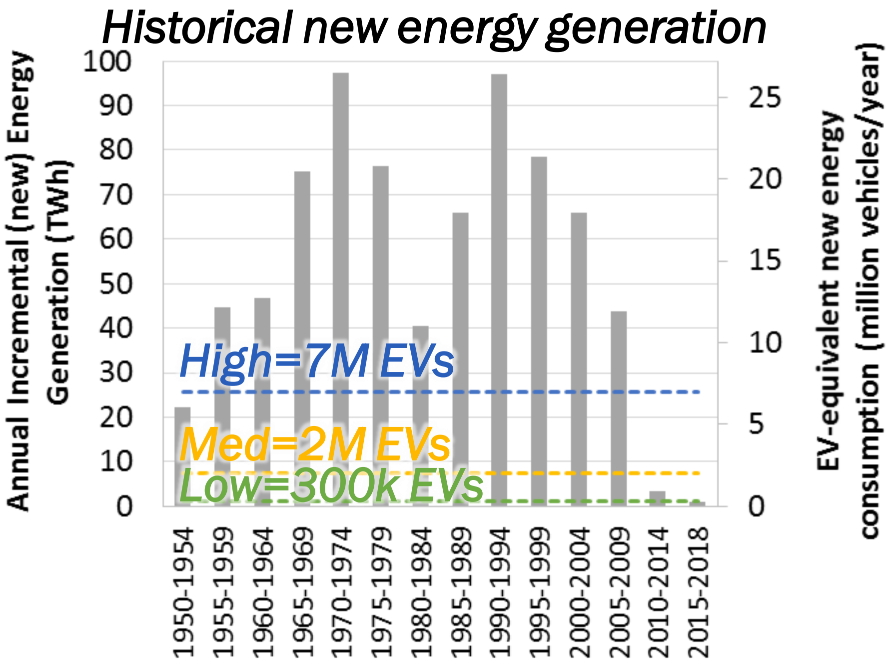
- Background: **The USDRIVE Executive Steering Group (ESG) directed ISATT to work with GITT** for a U.S. DRIVE-branded definitive statement/report leveraging that ISATT work
- Approach: **This report "examines a range of EV market penetration scenarios and associated changes to U.S. electric power system** energy generation and generation capacity."

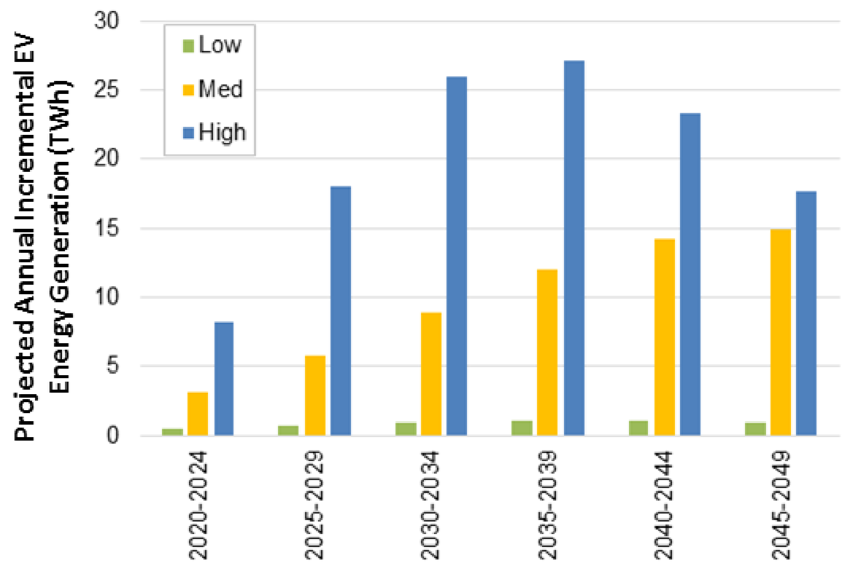
Input Assumption: U.S. EV Market Scenarios



Grid impact: key observations

- **Energy Generation (GWh)**: there have been sustained periods of time when the grid added in excess of 25 million vehicles-worth of generation per year*
- **Scenarios and year-on-year incremental new energy requirements**: high peaks at 27 TWh around 2035 and scenario peaks at 15 TWh in/after 2050





**Assuming 3.8 MWh per EV per year: 12,000 miles annually, consuming approximately 300 Wh/mi of AC load, and assuming 4.9 % system losses for transmission and distribution*

VTO-BTMS: Battery Requirements for Fast Charging

Battery Storage (DRAFT): **1–10 MWh** systems at **$100/kWh** able to cycle **2x/day** with a **4-h discharge** and lifetime of **20 yrs** and **8.000 cycles**

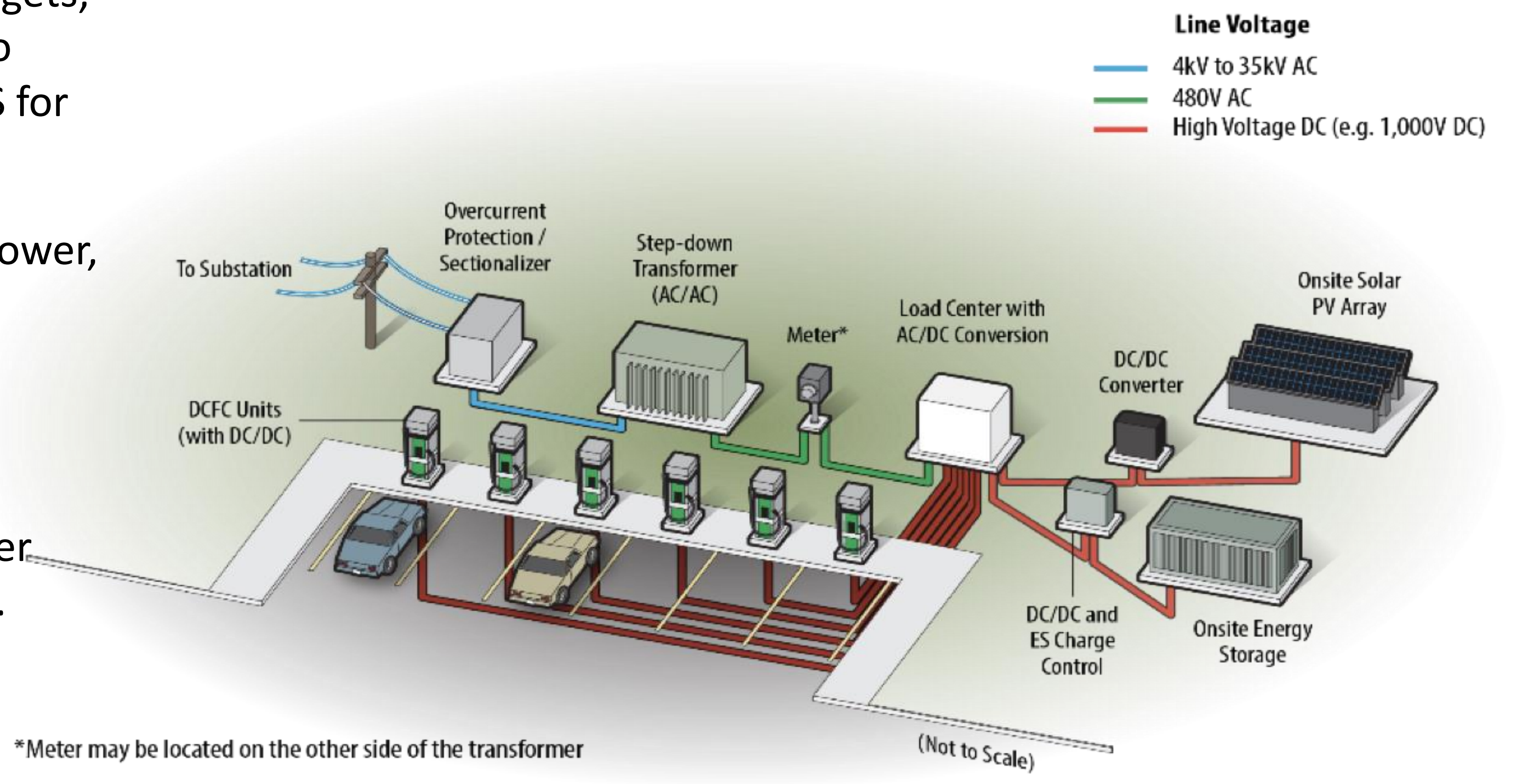
Clearly these are very high-level targets, and a major effort in FY19 will be to define the specific targets for BTMS for fast-charging and GEB applications.

Chemistry will dominate lifetime, power, and energy.

Balance-of-plant issues may dominate cost.

Thermal management of high-power systems will need to be considered.

No use of critical materials!



Thank You.