U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

EERE R&D Battery Critical Materials Supply Chain Workshop

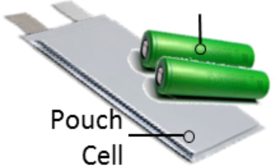
Day 1: Lithium

Day 2: Cobalt and Nickel

Day 3: Cathode Manufacturing

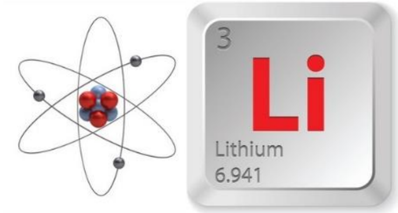
December 10-17, 2020

EERE Electric Vehicle Battery R&D



Raw Materials Production	Materials R&D and Processing	Cell R&D and Manufacturing	End of Life Recycling
EERE GTO	EERE VTO	EERE VTO	EERE VTO
EERE AMO	EERE AMO	EERE AMO	EERE AMO

Current DOE Efforts – Critical Materials Supply Chain Nexus

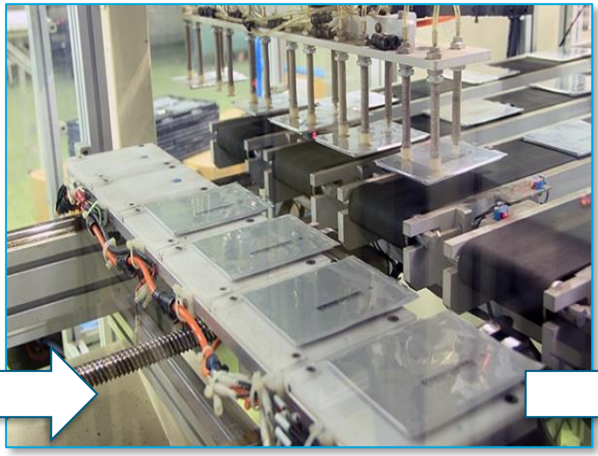


EERE seeks to demonstrate added value in regions where geothermal brines can deliver critical elements such as lithium.

Geothermal Technologies
SUPPLY

Advanced Manufacturing
PROCESS

Vehicle Technologies
MARKET



Uniting GTO, AMO, and VTO creates clear-path integration from supply to manufacturing to end-market, with improved efficiencies and economics.

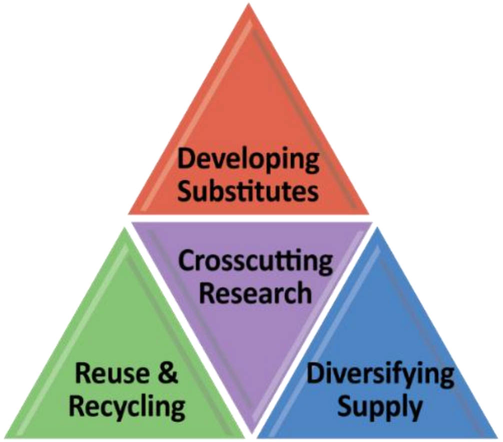
GTO R&D Highlights

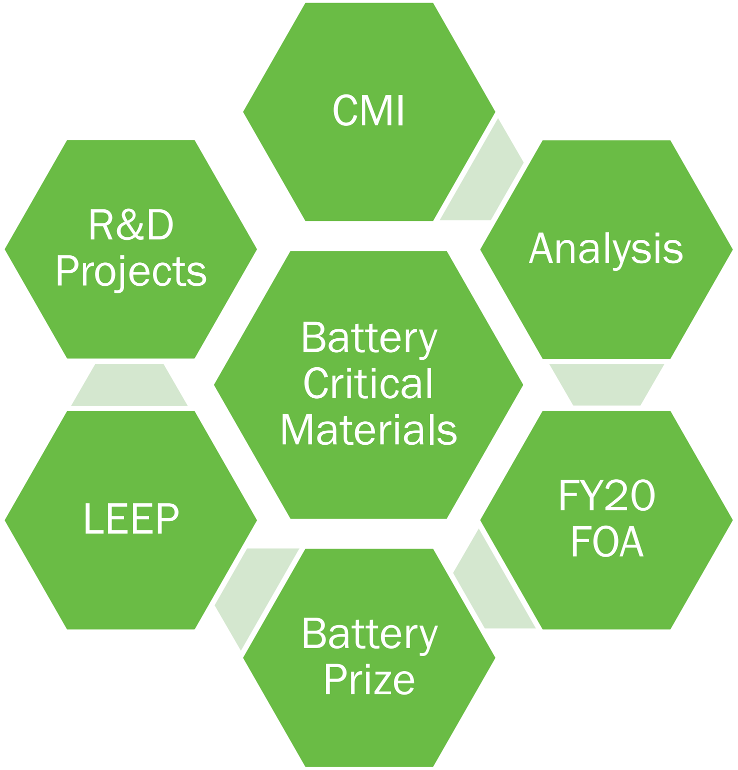
- **Geoscience Data Acquisition for Western Nevada (GeoDAWN)**
  - Collaboration between DOE and the U.S. Geological Survey
  - Collecting lidar and geophysical data to serve the dual purposes of identifying hidden geothermal resources and locating critical mineral deposits
- **Geo-Mining Study – National Renewable Energy Laboratory**
  - NREL study that found multiple avenues for mineral / mining exploration data to be leveraged towards the development of geothermal resources.
- **Geothermal Lithium Prize (proposed in President's FY21 budget)**
  - Goal: overcome critical technological barriers currently inhibiting our ability to produce cost-effective, domestic lithium from geothermal brines
  - Intends to leverage the combined power of American industry, academia, and our National Labs to identify and solve these key technical challenge

Advanced Manufacturing Office (AMO)

- **Critical Materials Institute (CMI), a DOE Energy Innovation Hub – Battery R&D**
  - Forward-osmosis technology to concentrate lithium chloride and sulfate chemistries for efficient conversion
  - Physical, chemical, and biochemical recycling approaches
  - Supported by cross-cutting R&D efforts like thermodynamic characterization

CMI Accelerating Energy Innovations
Critical Materials Institute





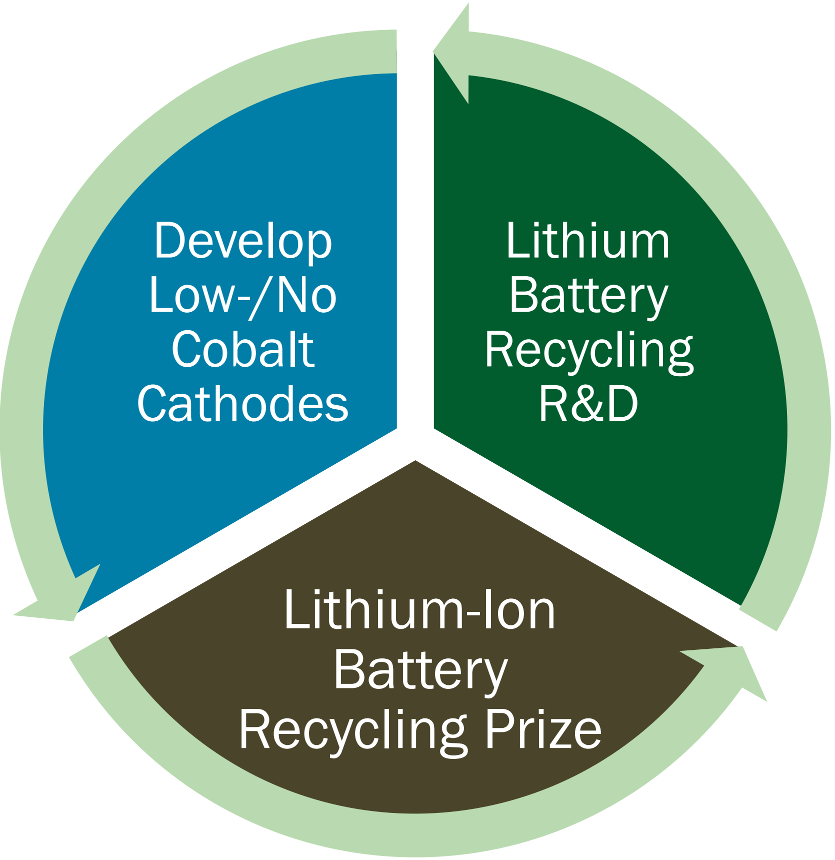
- **Energy Storage Cross-Cut with VTO**
  - FY19 FOA: 10 projects with ~$45M total funding to advance battery manufacturing
  - Lithium-ion Battery Recycling Prize (led by VTO)
  - Call for lab-industry partnerships to solve engineering challenges for advanced battery materials and devices

- **FY20 Critical Materials FOA**
  - Field validation and demonstration
  - Next-generation technologies
  - Announced anticipated in December

VTO: R&D to Mitigate Potential Critical Material Impacts

Low/No Cobalt Cathode R&D

**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

A $5.5 million phased competition over three years

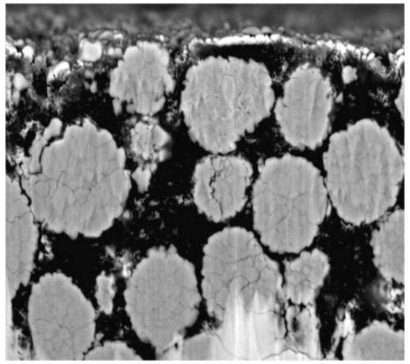
Innovative Ideas for Collection, Storing, and Transporting Discarded Li-Ion Batteries

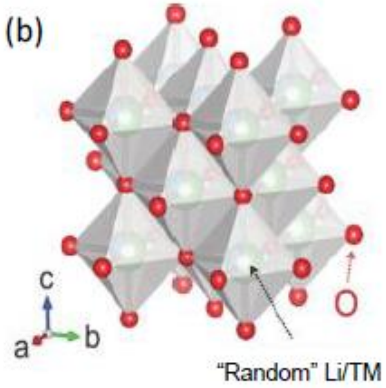
Request for Information (RFI)

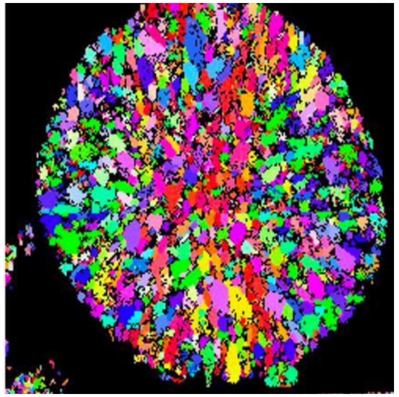
Battery Critical Materials Supply Chain R&D

- EERE sought feedback from stakeholders on issues related to challenges and opportunities in the upstream and midstream critical materials battery supply chains
- Specifically interested in raw minerals production and refining and processing of cathode materials including cobalt, lithium, and nickel*
  - Future Battery Chemistries and Material Supply
  - Economics and Battery Supply Chain
  - Lithium Powder Processing including Geothermal Brines
  - Cobalt and Nickel Processing

*Nickel is not a critical mineral commodity on the list published by the Secretary of Interior.







Goals of the Workshop Series

- Verify and expand on understanding of the state of the industry
- Determine R&D opportunities in the cathode materials supply and value chains – both short-term and long-term
- Identify gaps and barriers for advancement of innovative technologies
- Identify capital and technological considerations for scaling from pilot to commercial production, including metrics for success
- Understand certification of new materials, including purities and scales

Takeaways from the Request for Information

- **Short-term: materials needs similar to that of today**
- **Shift towards nickel-rich cathodes and solid electrolytes will change materials demand**
  - Recycling was cited as the most promising pathway in the near and medium term for major supply chain disruptions
- **Need to achieve higher cycling stability for longer life**
  - Single crystal cathode materials may have potential in this regard
- **Domestic supply chain gaps: raw material extraction through cathode manufacturing**
  - Limited domestic production (<1% of global total), yet significant domestic potential
  - Large cathode producers prefer 5-10kt to qualify new sources
  - Low market prices discourage expansion needed to keep pace with global demand
- **Adequate supply for planned Giga- and Tera-factories may be challenging in the short-term**
  - Gigafactory scales ideally qualify 2-3 different sources of raw materials

Takeaways from the Request for Information

- **Brines**
  - High reagent costs
  - Lead time to production is several years
  - Opportunity: adsorption or ion exchange-based approaches for geothermal brines
  - Major challenge: removal of impurities
  - Life cycle considerations: large land footprint, toxic and caustic reagents, substantial water use

- **Hard rock**
  - Low operating costs
  - Lead time to production is ~18 months
  - Opportunity: electrification of mining equipment and processes
  - Major challenge: permitting
  - Life cycle considerations: proximity to communities, toxic and caustic reagents, substantial water use, mine tailings

- **Conversion to LiOH**
  - Opportunity: recycling of hydroxide reagents
  - Opportunity: novel separation methods
  - Opportunity: colocation of refining processes with raw material extraction
  - Opportunity: electrochemical processes that eliminate intermediate conversion to Li2CO3

Takeaways from the Request for Information

- **Cobalt**
  - Major challenges:
    - Limited domestic low grade, raw material resources
    - High costs
    - Economies of scale for economic mining
    - Shift to low-cobalt chemistries
  - Life cycle considerations: environmental and health impacts of arsenic and sulfides
  - Opportunities:
    - Cost reduction: In-situ leaching
    - Highly selective solvents
    - Energy reduction of high temperature roasting
    - Process intensification to eliminate energy intensive processing steps e.g. smelting
- **Nickel**
  - Major challenges:
    - Limited domestic raw material resources
    - Permitting
    - High capital costs, but low nickel prices
    - Economies of scale for economic mining
  - Opportunities:
    - Sulfide bodies are ideal for Class I nickel production
    - Mapping and characterization of deposits
    - Process intensification to eliminate energy intensive extraction and processing steps
      - Direct electrochemical conversion of concentrates to sulfates
    - Recycling of spent batteries
    - Colocation of smelters

Takeaways from the Request for Information

- **Cathode material transportation is not a large supply chain consideration in general**
  - Beneficial colocation: processing of intermediates into products
    - High costs of sulfate transportation make colocation with cathode production desirable
    - Lithiated cathodes less likely to be shipped due to vacuum or N2 atmosphere requirements
  - Co-location could reduce supply risk, inventory and carbon footprint
- **Material Purities**
  - Purities may range from 98-99.5% but there is no industry standard
    - Heard from stakeholders on Day 1: >99.9% for Li_2CO_3 and >99.99% for LiOH
  - Shift to Ni-rich cathodes will necessitate increased purities
  - Variation in specs between cathode manufacturers adds complexity for raw and refined material producers
- **Magnetic and electrochemically active elemental impurities are considered the most problematic to cathode manufacturing**
  - In general, higher nickel content cathodes have lower impurity tolerance of precursors
  - Typically in the 50-200ppm range but magnetic material can be as low as 1000ppm