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DE-FE0032144: Utilization of Carbon Supply Chain Wastes and Byproducts to Manufacture Graphite for Energy Storage Applications

Tuesday, October 25th, 2022

U.S. DOE-NETL Resource Sustainability Project Review Meeting

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Ohio University

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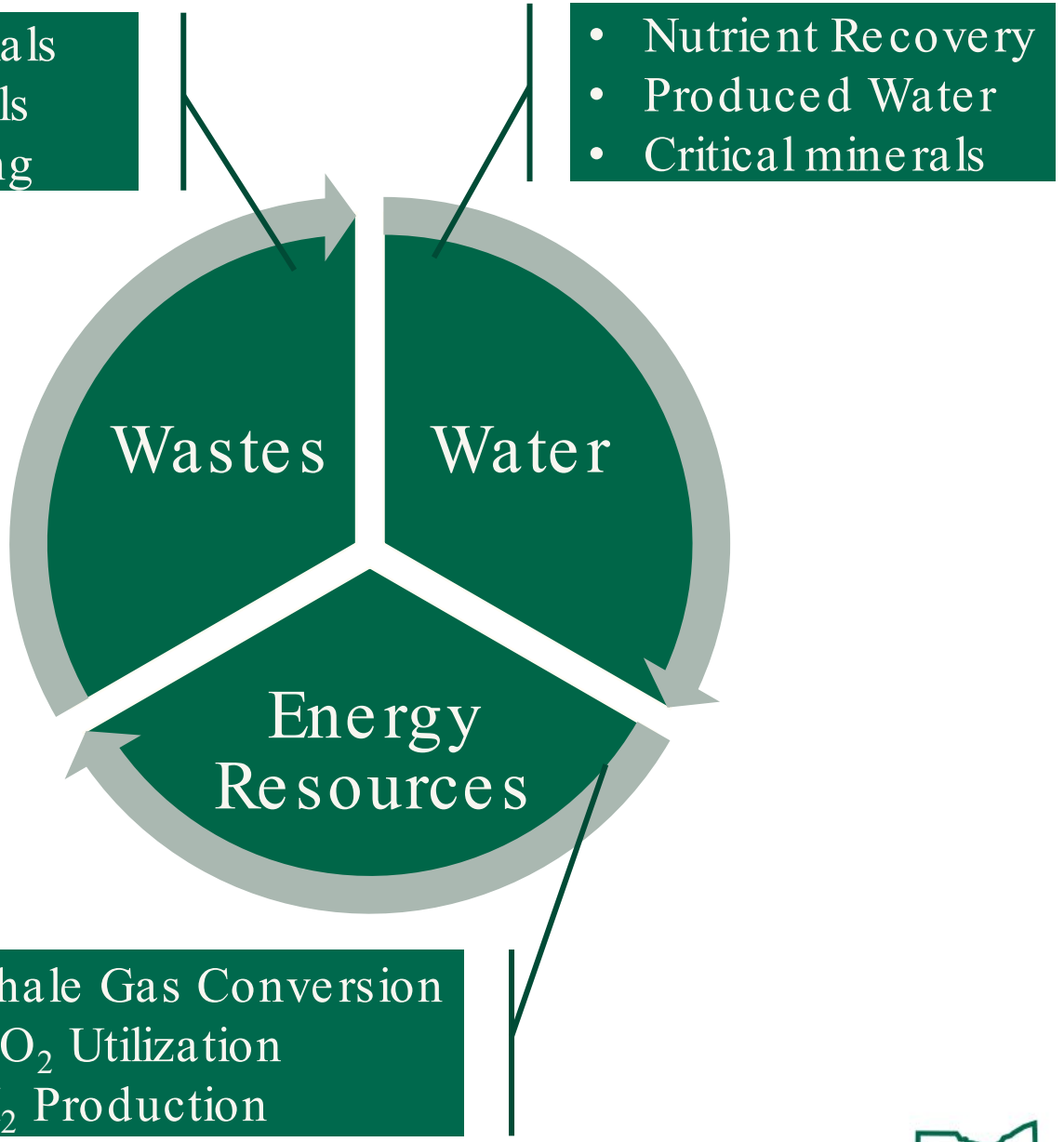
ISEE Overview

- Institute Facts
  - Faculty: 4
  - Staff: 4
  - Students: 16 Graduate; 20 Undergraduate
  - Space: 14,000 ft²
  - Over $25M in external research since 2008
- Research Capabilities
  - Thermocatalytic and electrochemical processes
  - Atomic and Process Simulations
  - Materials R&D
  - Techno-economic and lifecycle analyses



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Project Overview

Project Specifics

- DOE/NETL Cooperative Agreement No. DE-FE-0032144
- DOE Project Manager: Jason Montgomery
- Principal Investigator (PI): Jason Trembly
- Participants: GM, CONSOL Energy, CFOAM (CONSOL Innovations), Omnis Regenerative Energy, Koppers, and AEP

Project Budget

- Federal: $1,000,000
- Non-Federal: $250,000

Project Duration

- February 14, 2022– February 13, 2025

DOE-NETL Carbon Ore Processing Program

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OHIO Carbon Ore Research

- In the past 3 years, OHIO and industrial partners have developed CPC materials for decking applications
  - DE-FE0031809
- Successfully matured technology from TRL4 to TRL8
- Meets or exceeds ASTM and IBC requirements
- Performance advantages
  - Equivalent or greater strength
  - Greater resistance to oxidation
  - Lower flammability
  - Better price point
  - Lower embodied energy and emissions

Deck Constructed with CPC Boards

CPC Pricing with Commercial Products

Manufacturer	Product	Sales Price ($/linear ft)
DE-FE0031809	CPC	1.29
Trex	WPC	1.75-5.78
Choicedek	WPC	3.67
TimberTech	WPC	4.48-6.68

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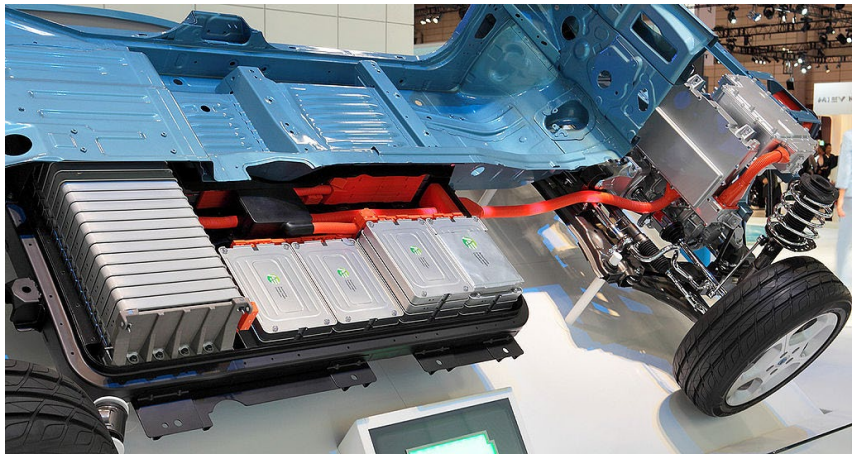
Background

- Electric vehicle (EV) market is significant and growing
- $162.4 billion in 2019; projected to grow to $800 billion by 2027
- Graphite is critical because it is used as the negative electrode material
- There are currently no operating graphite mines in the United States; dependence on foreign sources
- United States Geological Survey lists graphite as a material critical to U.S. security.
- Only 9% of global LiB manufacturing capacity in the U.S.
- Current process to convert flake graphite from mines to graphite suitable for LiBs wastes up to 70% of the graphite – battery grade graphite is $3,000 – $10,000/tonne
- New IRA critical mineral requirements



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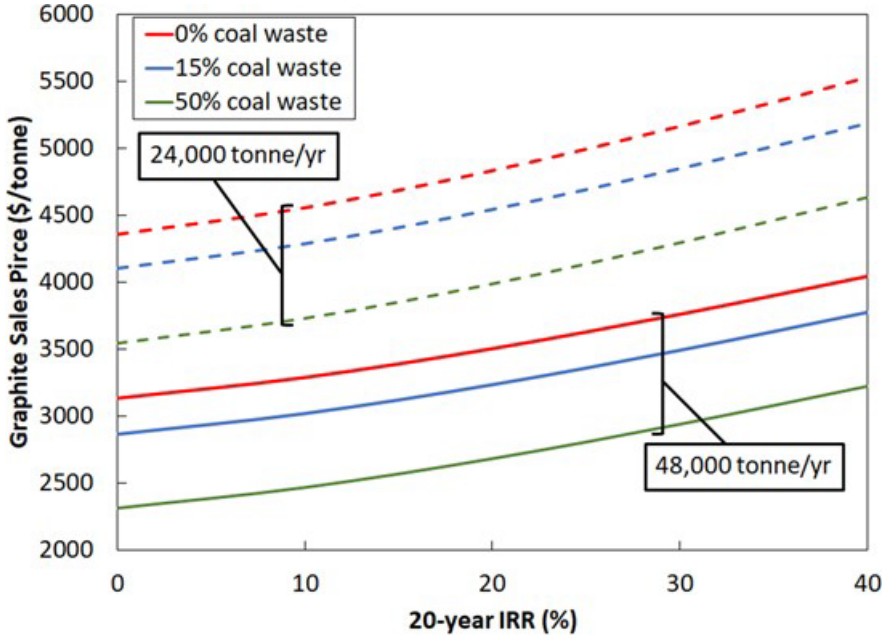
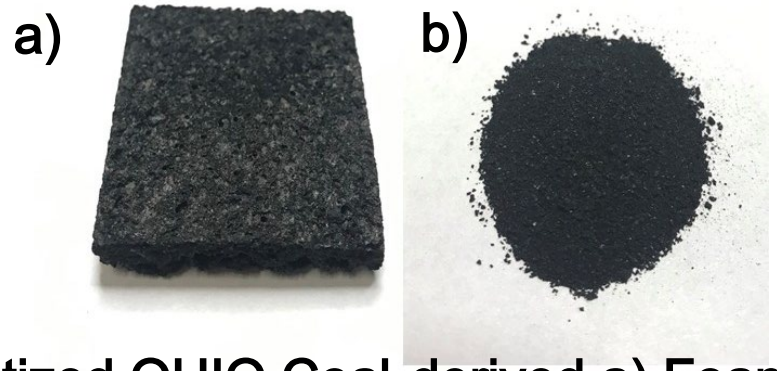
Technology Advantages

- Conversion of coal wastes into graphitizable carbon foams to establish a U.S. supply chain
- Utilizing nation's coal resources as energy storage materials for LiBs
- Diversifying and securing U.S. battery/energy storage supply chains
- Lower graphite prices than currently realized
- Converting rural mining brownfields into energy storage material manufacturing hubs with prevailing wage jobs



Preliminary Estimated Graphite Selling Prices vs. 20-year Internal Rate of Return.



Graphitized OHIO Coal-derived a) Foam (4 in by 3 in) and b) Pulverized Powder

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Project Objectives

Overall: Develop coal-derived graphite materials for transportation and grid-scale energy storage applications. Coal waste(s) will be given preference as the process feedstock with caking coals from reclaimed mining wastes, currently operating mines, coal tar pitches, and combinations thereof.

Budget Period 1

- Characterize coal-derived waste feedstocks
- Manufacture coal-derived graphite and quantify relevant properties
- Construct and validate coin cells using coal-derived graphite as the negative electrode
- Develop initial porous electrode models for half and full coin cells
- Conduct initial modeling of aging and degradation mechanisms
- Develop initial microstructure models

Project Objectives

Overall: Develop coal-derived graphite materials for transportation and grid-scale energy storage applications. Coal-waste(s) will be given preference as the process feedstock with caking coals from reclaimed mining wastes, currently operating mines, coal tar pitches, and combinations thereof.

Budget Period 2

- Synthesize 1 kg batch of coal-derived graphite
- Conduct analysis of large format (pouch) cells using coal-derived graphite as the negative electrode
- Complete computational modeling
- Develop preliminary techno-economic analysis

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Project Scope

Project Milestones

Description	Planned Completion Date	Actual Completion Date
Construct first coin cells with coal-derived graphite	November 14, 2022	Initiated this week
Complete development of porous half-cell model	February 14, 2023	
Quantification of coal-derived graphite properties	May 14, 2023	
Coin cell performance data for model verification	May 14, 2023	
Synthesize 1 kg batch of coal-derived graphite	February 14, 2024	
Preliminary techno-economic analysis	July 14, 2024	

Project Scope: Risks and Mitigation Strategies

Risk	Mitigation Strategy
Feedstock Availability	Test a host of feedstock and a mixture thereof to increase supply chain security to meet future domestic graphite demands.
Graphite Purity	Analyze a range of coal-derived materials for impurities and utilize this information to select feedstock or mixtures thereof capable of achieving battery graphite purity specifications.
Market Acceptance	Create market acceptance LiB coin and pouch cell tests will be conducted to demonstrate acceptable performance with coal-derived graphite. Additional potential market segments will also be identified.
Process Economics	Minimize coal-derived graphite manufacturing costs using multi-variable techno-economic studies including but not limited to feedstock pricing, project financing, product sales price, location, and production capacity.

Project Scope

Project Success Criteria

- Produce a coal-derived graphite material using continuous manufacturing methodologies
- Produce coal-derived graphite meeting battery-grade graphite specifications
- Demonstrate coal-derived graphite-containing pouch battery with 80% capacity of commercial materials (~300mAh/$g_{graphite}$)
- Estimated coal-derived graphite 20-year 40% IRR sales price of $\leqslant \$8,000/tonne$

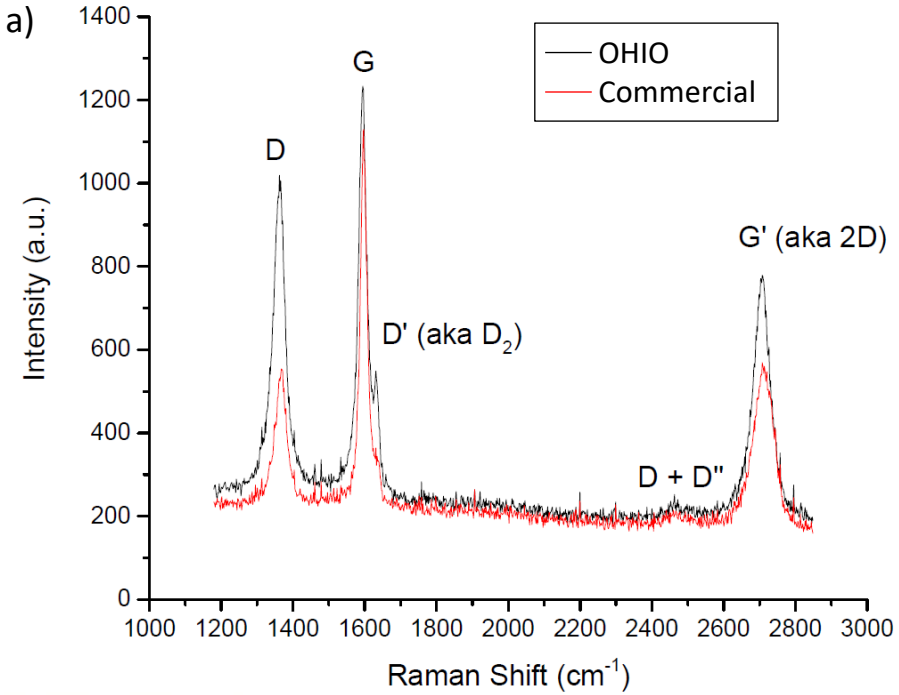
Graphite Synthesis

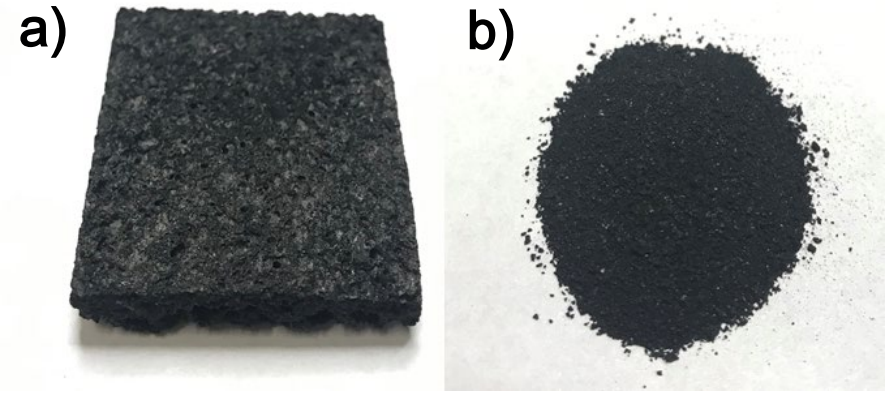
Coal-derived graphite synthesis procedures

- Bench-scale batch and semi-continuous methods
- Graphitization: 2200-3000 ℃

Feedstocks

- Bituminous coal, bituminous waste coal, coal-derived pitches





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LiB Battery Testing

Arbin Battery Cycler

- 16 channels
- Multiple current ranges
- Cables to extend battery testing into the environmental chambers (testing down to -40 °C)

MBraun Labstar Pro Glovebox

- Ar atmosphere
- Used for storage of lithium and other materials
- Final assembly point for coin cells

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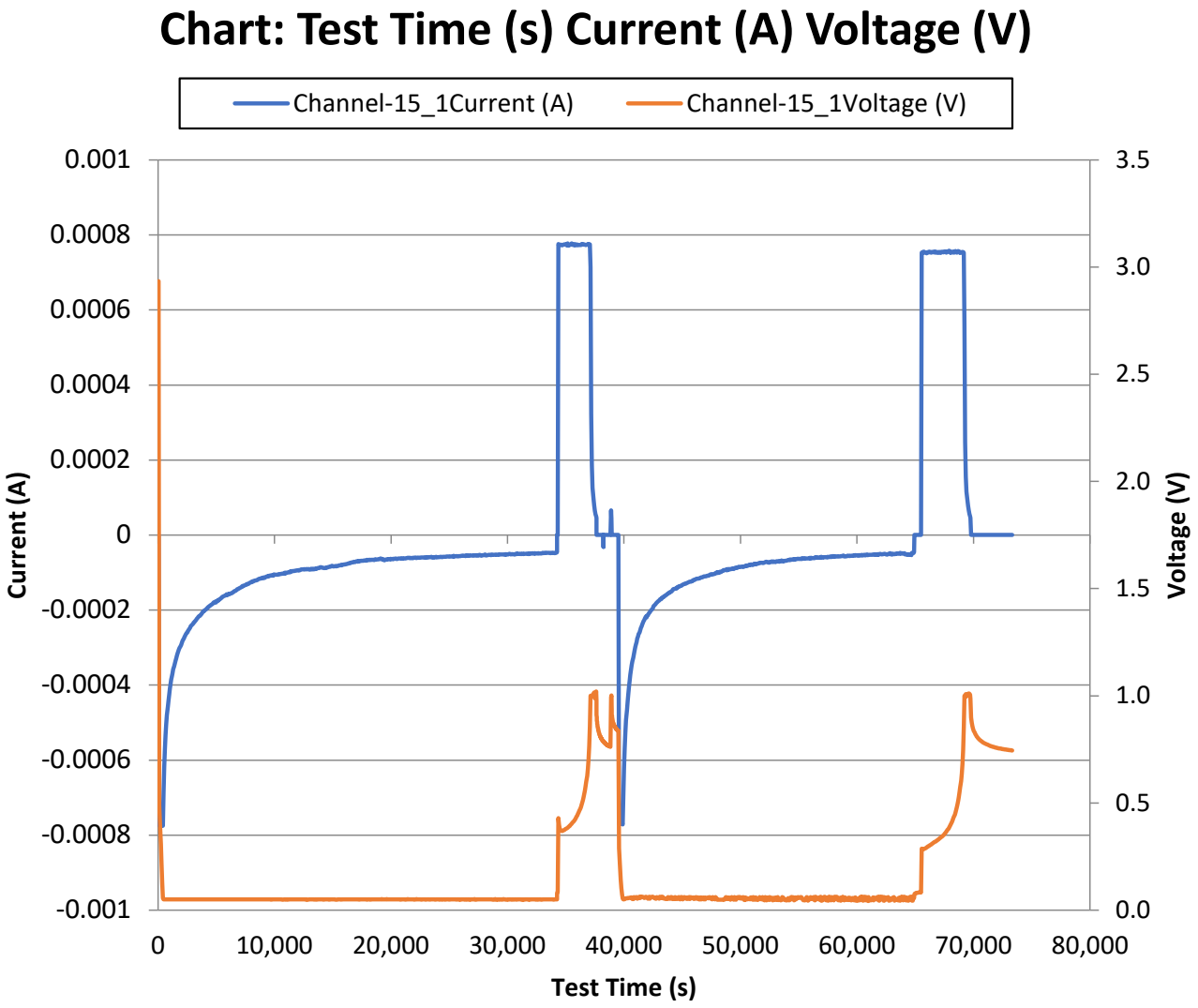
LiB Battery Testing

Coin Cell Testing

- Rapid materials screening
- Project focus is on negative electrode materials
  - Use commercial NMC or Li electrodes, electrolyte, and separator
  - Negative electrode
    - Commercial electrode (graphite coated on Cu by commercial vendor)
    - In-house electrode using commercial materials (purchase battery-grade graphite, conductive additive, binders); mix electrode slurry; coat onto battery-grade Cu foil
    - Benchmark to compare coal-derived graphite electrodes
- Battery formation
  - Typical C/3 charge/discharge cycles
  - Form SEI layer
- C/50 cycling
  - Overvoltage

LiB Formation Cycle



- Half-Cell (Li and in-house commercial graphite slurry electrodes)
- ~5 mg/cm^2 mass loading, 40% porosity
- C/3 charge/discharge cycles for cell formation
- Benchmark for coal-based graphite electrodes

Ongoing Efforts

- Coal-based graphite electrodes
  - 10% coal-based graphite:90% commercial graphite
  - 50% coal-based graphite:50% commercial graphite
  - 90% coal-based graphite:10% commercial graphite
  - 100% coal-based graphite

Future Development & Summary

Graphite Synthesis

- Synthesize several graphite materials from coals and commercial coal-derived pitches

LiB Testing

- Complete baseline characterization testing with commercial graphite material
- Conduct separate testing with graphite made from pitch and coal
- Evaluate mixtures of commercial and coal-derived graphite materials

Acknowledgements

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Questions

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