Energy & Environmental Research Center (EERC)

Advanced Processing of Coal and Coal Waste to Produce Graphite for Fast–Charging Lithium–ion Battery Anode

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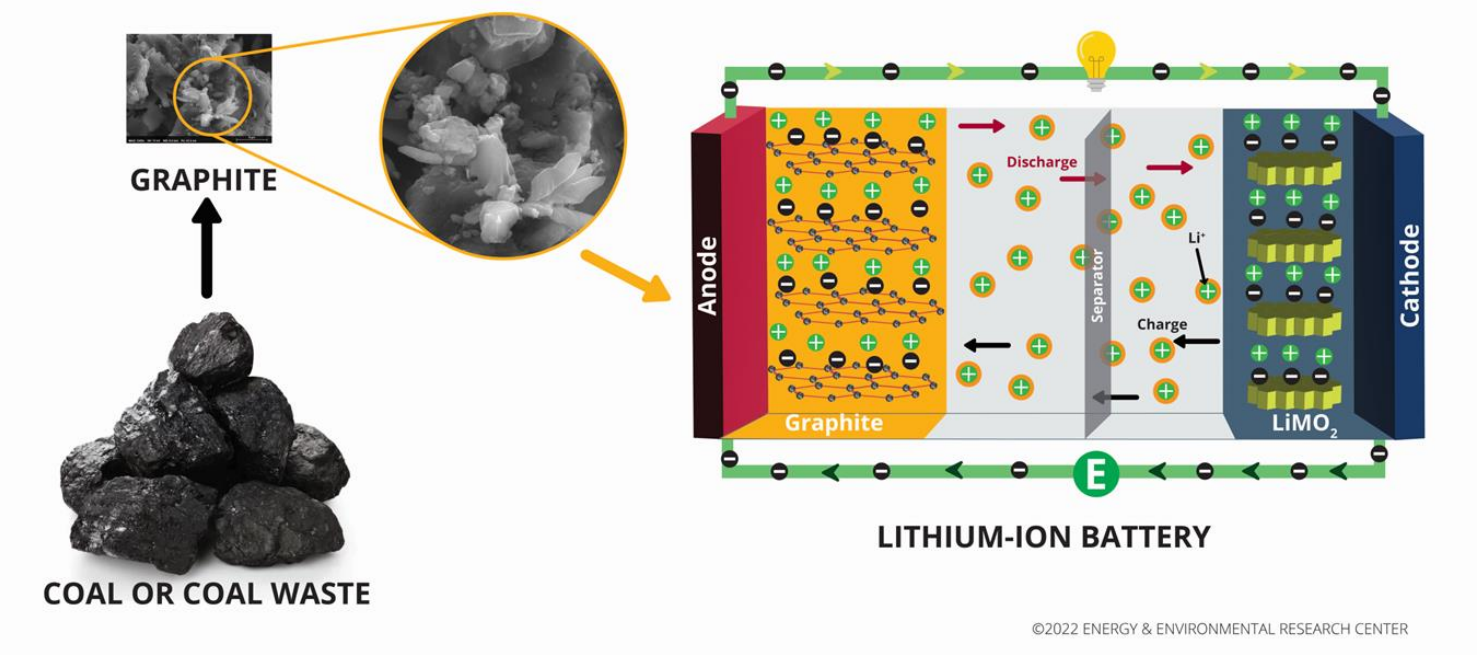
OUTLINE

- Project Overview
- Motivation
- Background
- Upgraded Coal-to-Products (UCP) Technology
- Project Technical Approach
- Progress and Current Status
- Technology Development Plans
- Summary and Conclusions

Project Overview: Objective and Duration

The overall objective is to validate an approach to make high-grade graphite from North Dakota lignite and lignite coal waste and to fabricate and test a fast-chargeable lithium-ion battery anode prototype made from the produced graphite.

Project Duration: 36 months, April 2022 to March 2025



Project Overview: Funding and Partners

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY $1,000,000

Lignite Energy Council $500,000

NORTH AMERICAN COAL® $45,000

EERC UNIVERSITY OF NORTH DAKOTA

UND UNIVERSITY OF NORTH DAKOTA Institute for Energy Studies

Total Funding = $1,545,000

Driving Force For The Study

New Coal Markets in Nonenergy Sectors – Revitalize Coal Communities

High-Value Products for Next-Generation Applications and Carbon-Free Energy Future

Big Market Opportunity

From

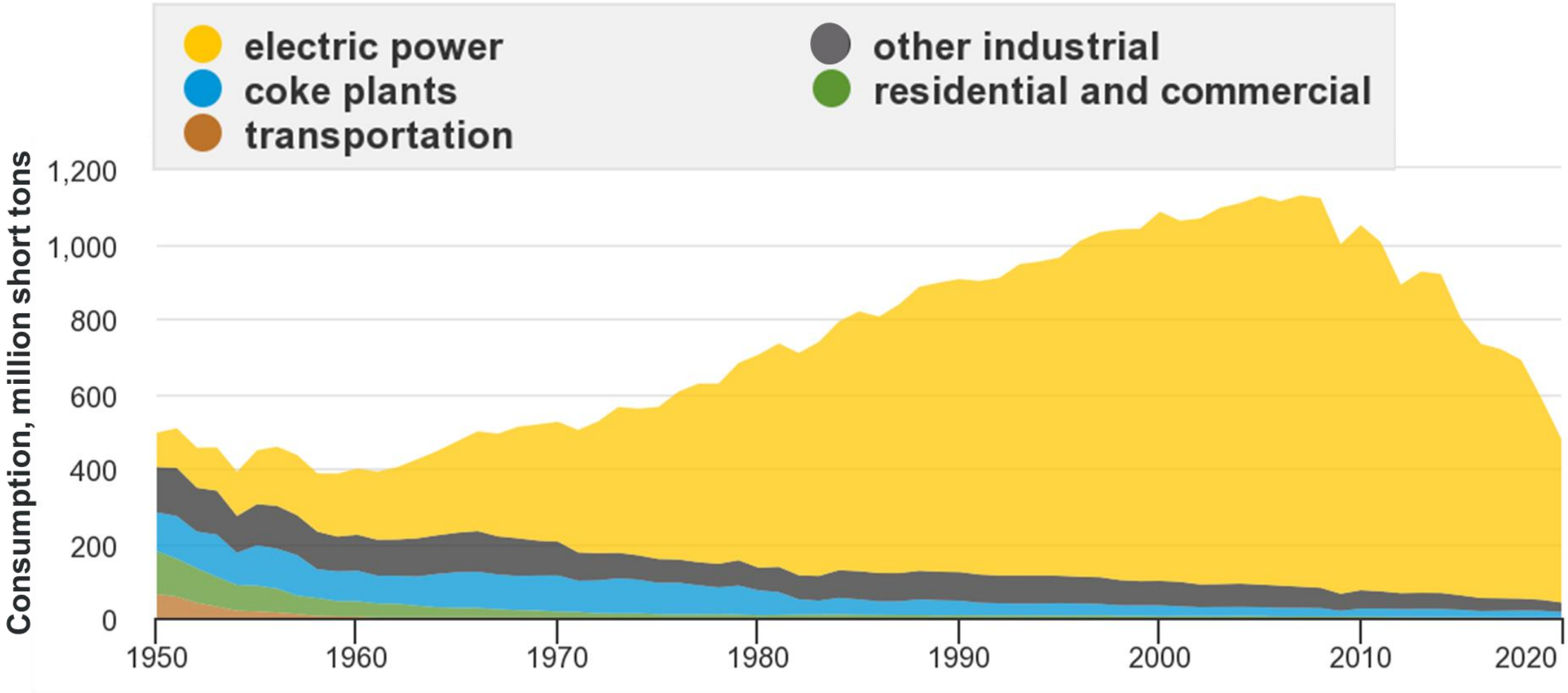
$14.3 billion (2019)

to

$21.6 billion (2027*)

*Allied Market Report, 2022

U.S. Coal Consumption By Major End Users 1950–2020



Source: https://www.eia.gov/energyexplained/coal/use-of-coal.php (accessed 9/7/2021).

The U.S. Coal Equation

Coal Equation For Decarbonized Energy Future

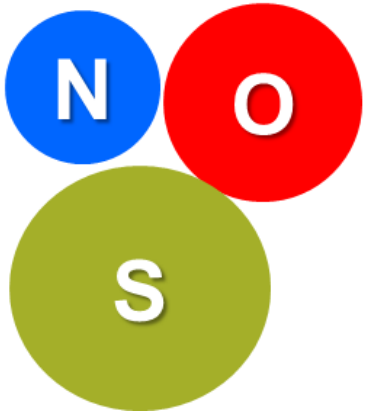
Keep everybody happy with a balanced coal equation.

Coal Challenges For High-Value Carbon Products

Ash impurities

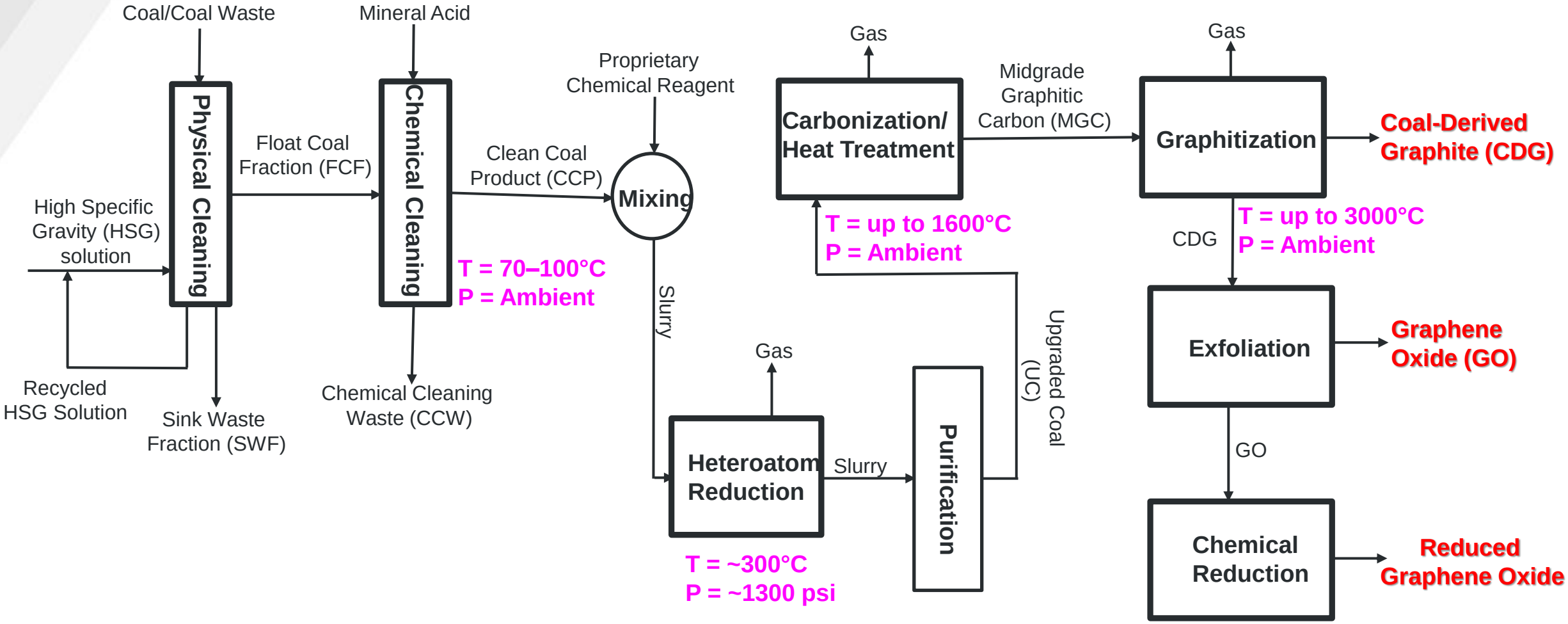
High VM (low rank coals)

Heteroatoms



Low FC (low rank coals)

Upgraded Coal-to-Products (UCP) Technology

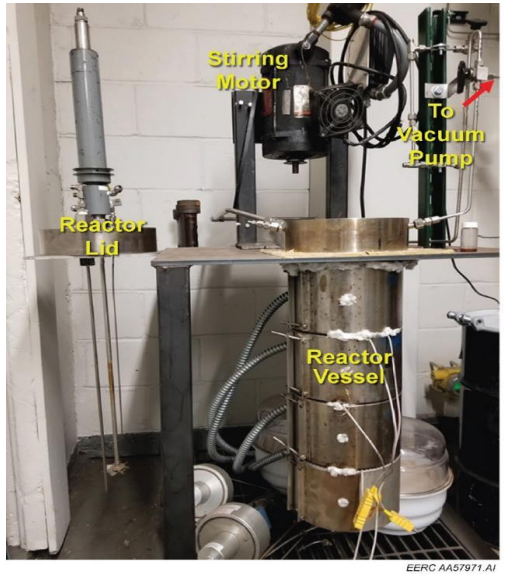


The UCP Technology is applicable to ALL coal ranks and their wastes

Scientific Principles of the UCP Technology

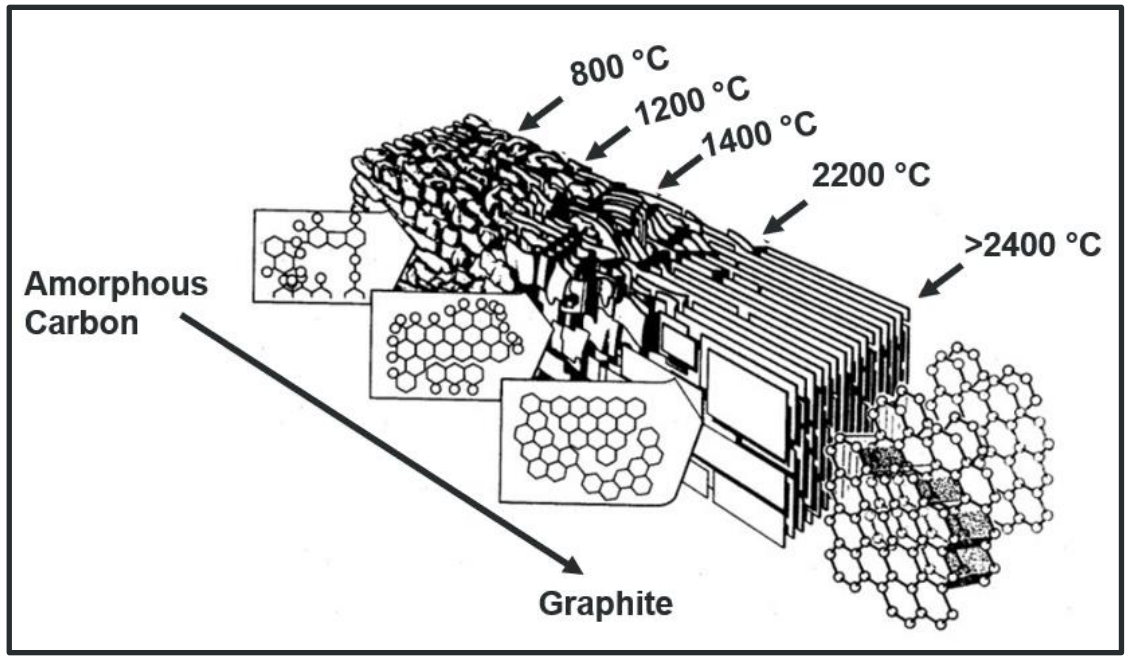
Simple Wet Chemistry Processes

- Physical Cleaning (Float–sink concept)
- Chemical Cleaning (with mineral acid, **No HF!**)
- Heteroatom Reduction Reaction (proprietary reagent)



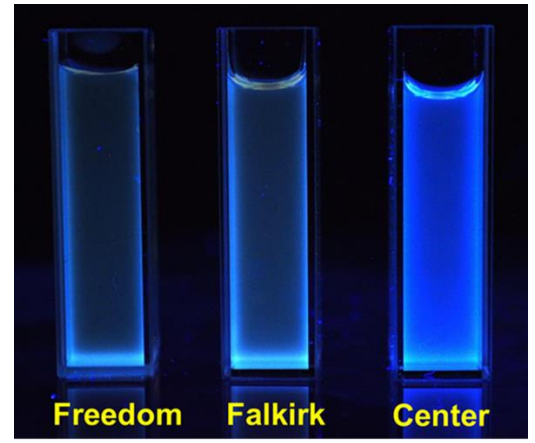
Controlled Heat Treatment

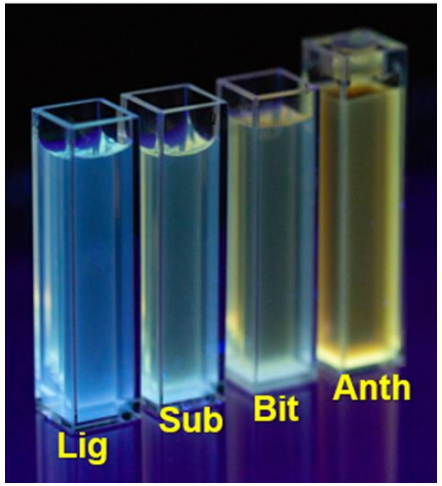
- Staged Carbonization (up to 1000 °C)
- Heat treatment (up to 1600°C)
- Graphitization (up to 3000°C)



Technology Development History

- **Summer 2019** – ND State Energy Research Center (SERC) seed funding for **~$200k**
  - GQDs made from lignite from 3 different mines
- **Summer 2020** – DOE award for **~$930k**
  - GQDs, GO, rGO, and graphite from lignite, subbituminous, bituminous, and anthracite
- **Spring 2022** – DOE award ~**$1.5m**
  - Lignite-derived graphite for LIB anode
- **Next Steps** – Scale-up & commercialization





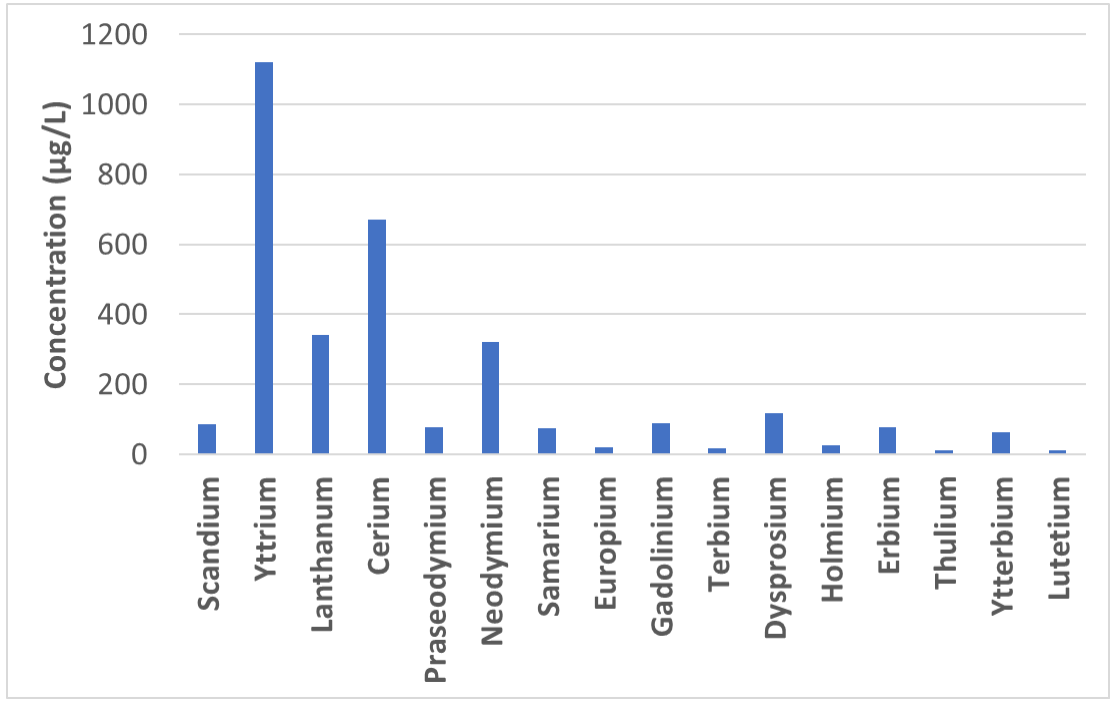
Technical/Economic Advantages and Challenges

Advantages

- **Environmentally Sustainable**
  - Processing under inert conditions
  - Significantly less gaseous emissions (CO_2,NO_x, SO_x)
  - Most toxic species recovered as aqueous wastes for easy handling
- Simple process
- Easily scalable
- Potentially economically feasible
- **Recovery of other critical minerals like REEs**
- **Byproducts from carbonization step**

Challenges

- Product filtration process (practical challenge)



Site Selection Criteria for Potential UCP Deployment

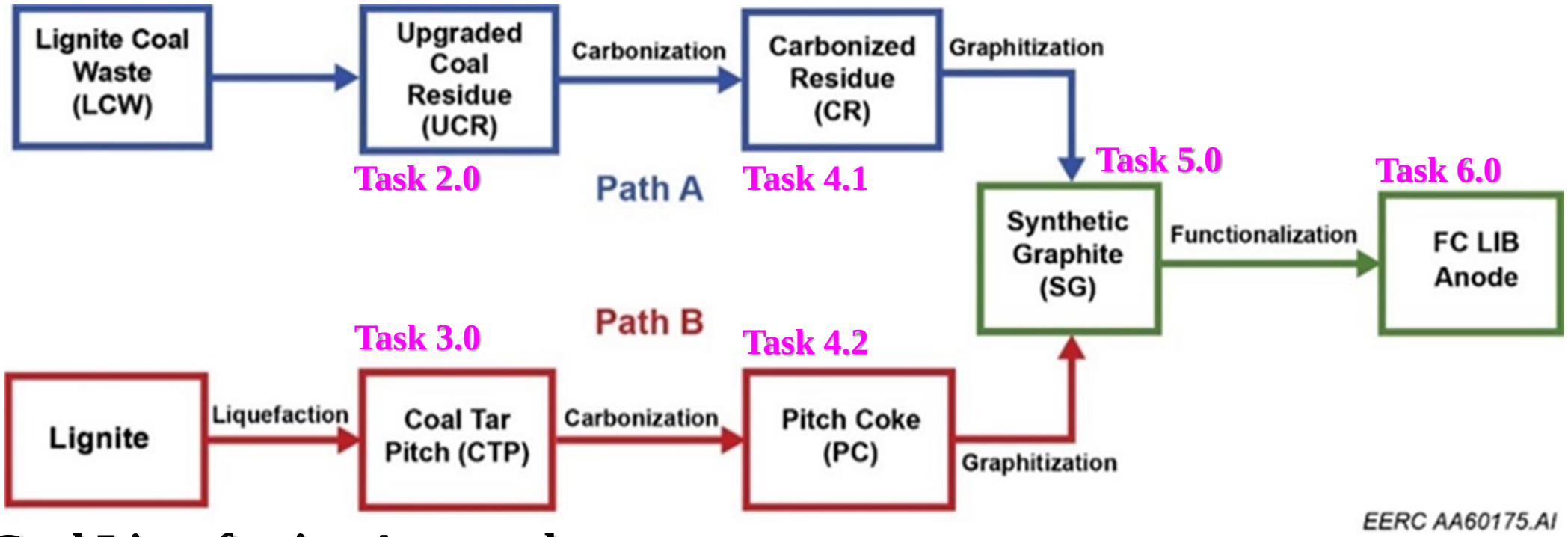
- Modular Deployment Units
- Co-location with coal mines
- Available water resources
- Potentially powered by wind and/or solar energy

Short ride

or conveyed to plant

Technical Approach

Upgraded Coal-to-Products (UCP) Process



Coal Liquefaction Approach

Task 6.0 – Economic Feasibility Analysis

Project Schedule and Success Criteria

Schedule of Milestones

- **M1** – Coal upgrading, Due 11/30/22
- **M2** – Coal-derived tar pitch (CTP), Due 11/30/22
- **M3** – Upgraded coal carbonization, Due 4/30/23
- **M4** – CTP carbonization, Due 4/30/23
- **M5** – Graphitization, Due 9/30/23
- **M6** – Graphite functionalization, Due 9/30/24
- **M7** – LIB anode testing, Due 12/31/24
- **M8** – Economic analysis, Due 1/31/25

Success Criteria

- **BP1 (18 months, 9/30/2023)**
  - 3 lb upgraded coal
  - 1.5 lb carbonized coal products
  - 0.5–1 lb coal-derived graphite
- **Go/no-go DP (9/30/23)**
  - 1 lb coal-derived graphite for LIB testing
- **BP2 (18 months, 12/31/2024)**
  - LIB performance data
  - Economic analysis report

Risk Identification and Mitigation Strategies

Risk Category	Impact Level	Mitigation Strategy
Financial risks - Equipment cost increases after award	low	Detailed initial quote estimates were built into the budget
Cost/Schedule - Budget overrun	low	Overall budget structured by task and subtask
Technical/Scope risks - Challenges getting high quality graphite and performance attributes	medium	Post-processing and functionalization are planned to mitigate risk if it occurs
Management & Planning - Overall planning & oversight risks	low	- EERC senior management oversight - Regular updates with DOE
ES&H Risks - Chemical/material exposure to personnel & environment	low	Follow established EERC safety procedures

Progress and Current Status of Project

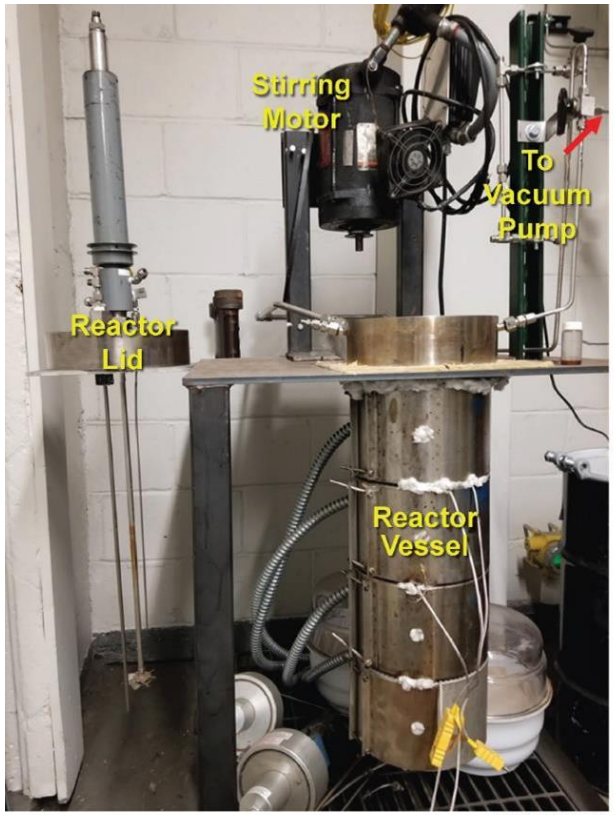
- The project has been ongoing for about 7 months and key accomplishments include:
  - Coal and coal waste upgrading (**M1**), Due 11/30/22, **30% complete**
  - Coal-derived Tar Pitch production (**M2**), Due 11/30/22, **25% complete**
  - Upgraded coal/coal wastes carbonization (**M3**), Due 4/30/23, **30% complete**
  - Coal-derived Tar Pitch carbonization (**M4**), Due 4/30/23, **5% complete**
  - Graphitization of coal-derived products (**M5**), Due 9/30/23, **5% complete**
- Preliminary results obtained so far are presented

Critical UCP Technology Equipment Needs – Graphitization

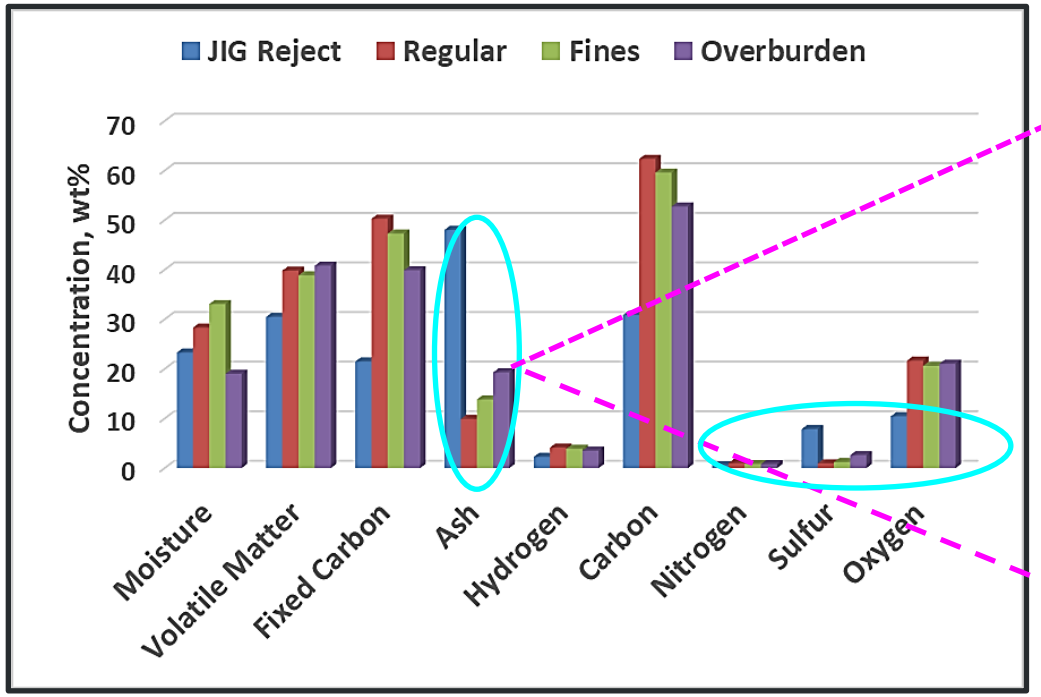
Critical Equipment Needs – HRR and Carbonization

Carbonization System

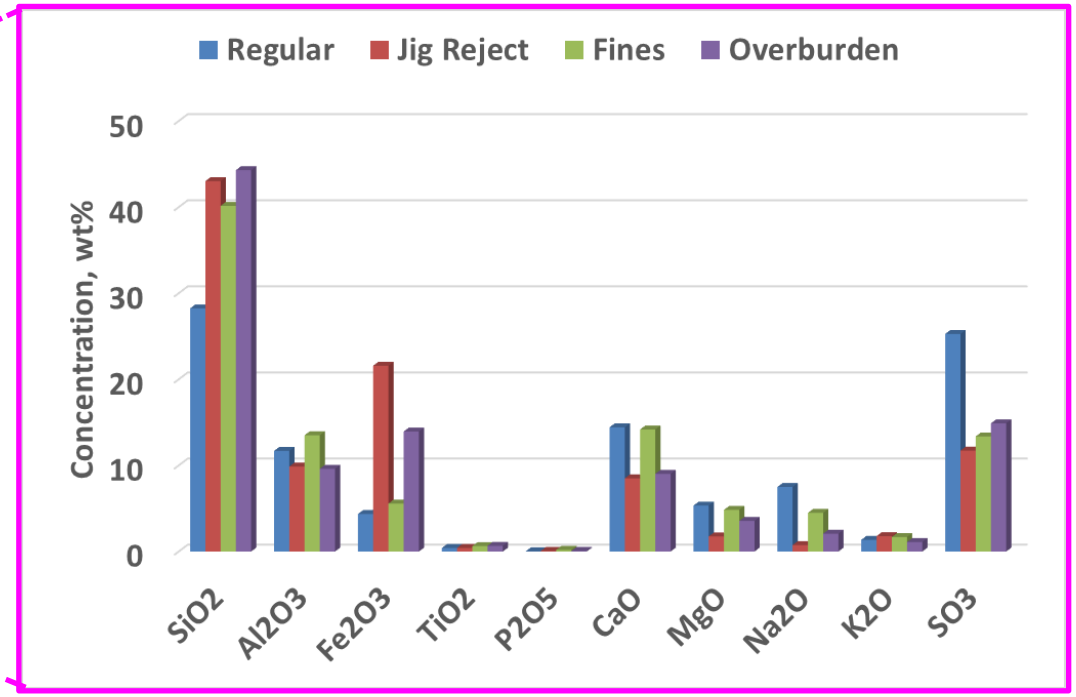
HRR Reactor



Analysis of Coal and Coal Wastes Feedstocks



Proximate & Ultimate Analysis

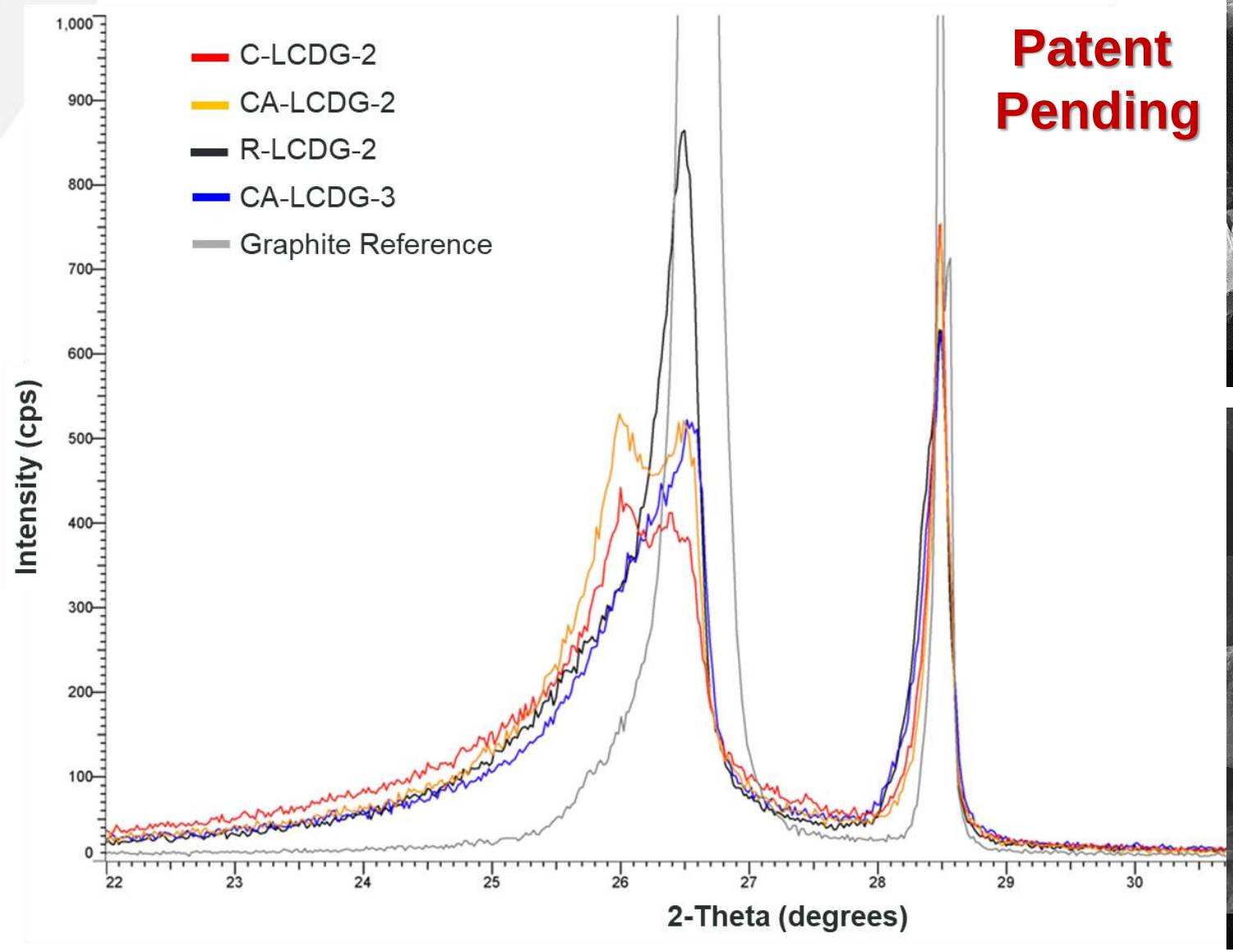


XRF Analysis

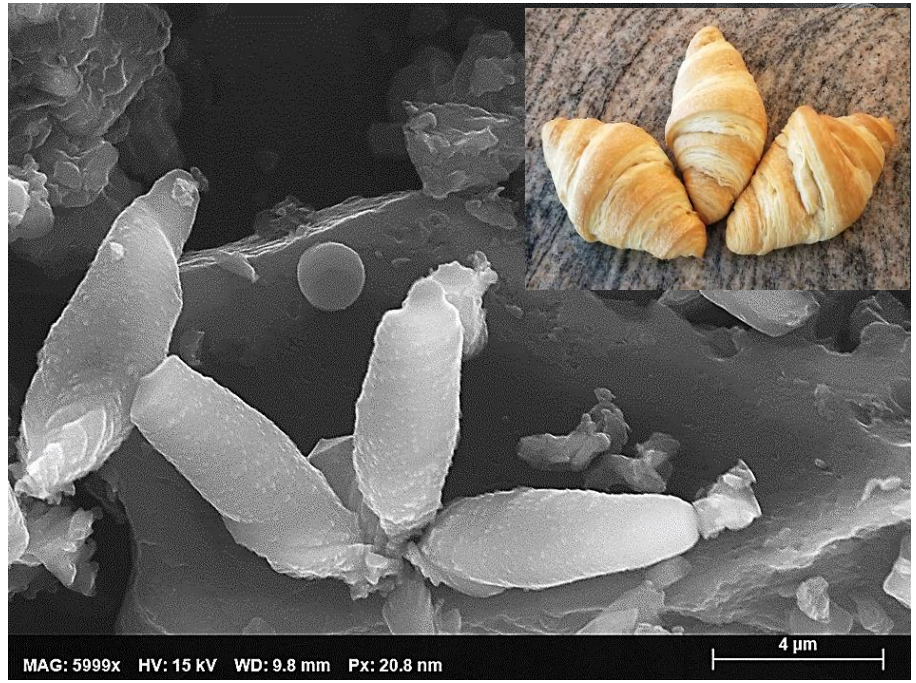
Preliminary Coal and Coal Wastes Ash Removal

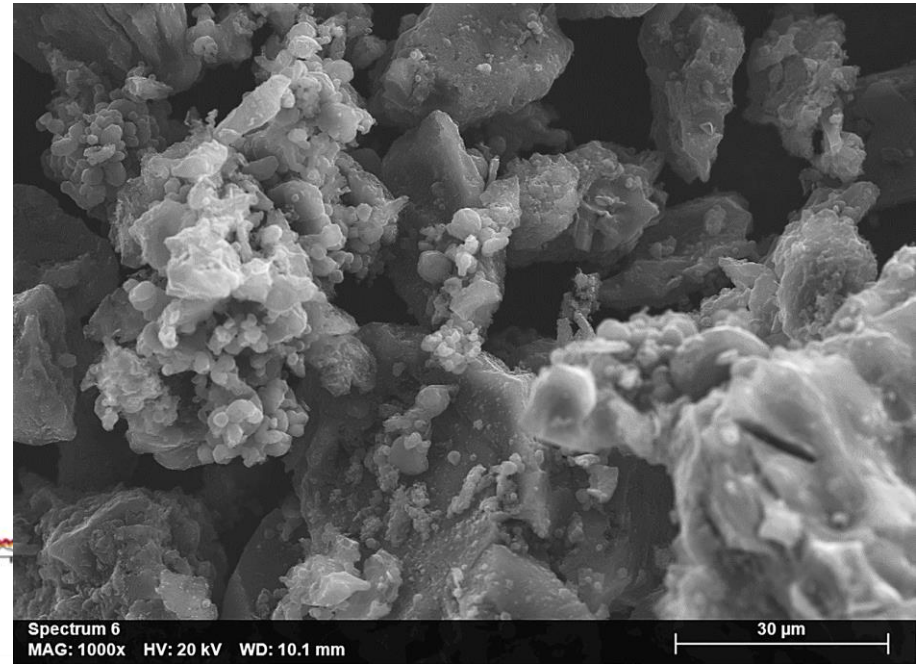
Coal Type	Raw Coal Ash (wt%)	Clean Coal Ash (wt%)	Ash Reduction (%)
Regular	9.90	5.63	43.1
Fines	13.85	7.54	45.6
Overburden	19.30	4.43	77.0
Jig Reject	48.03	23.58	50.9

“Croissant” Graphite



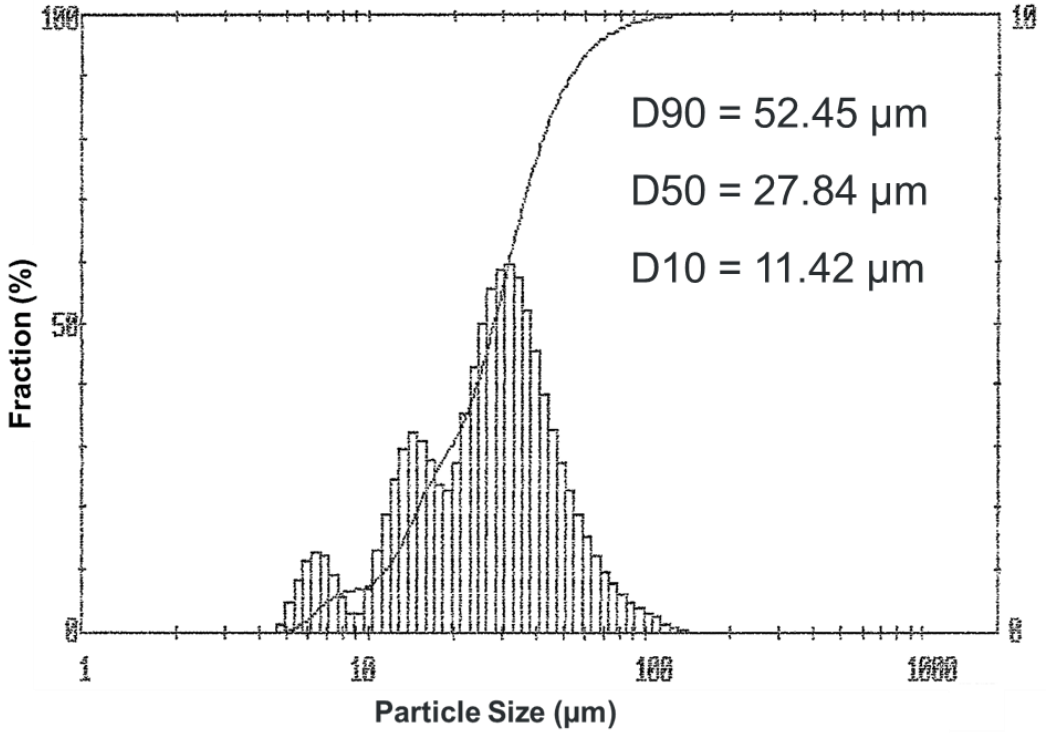
Patent Pending





Preliminary Lignite Coal-Derived Graphite (LCDG) Characteristics

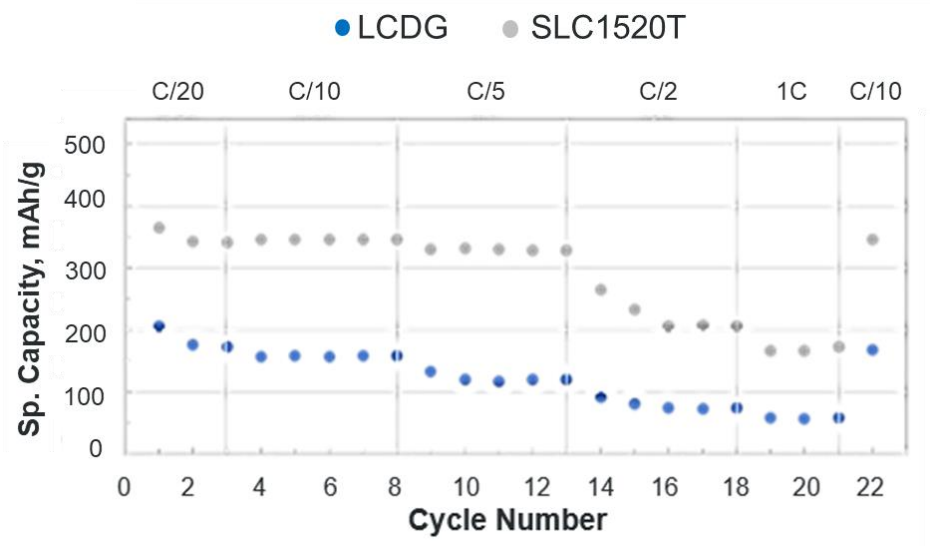
Property	LCDG	Commercial Graphite
Carbon Purity (%)	>99.95	≥ 99.95
Ash (wt%)	0.015	<0.2
Moisture (%)	0.008	<0.01

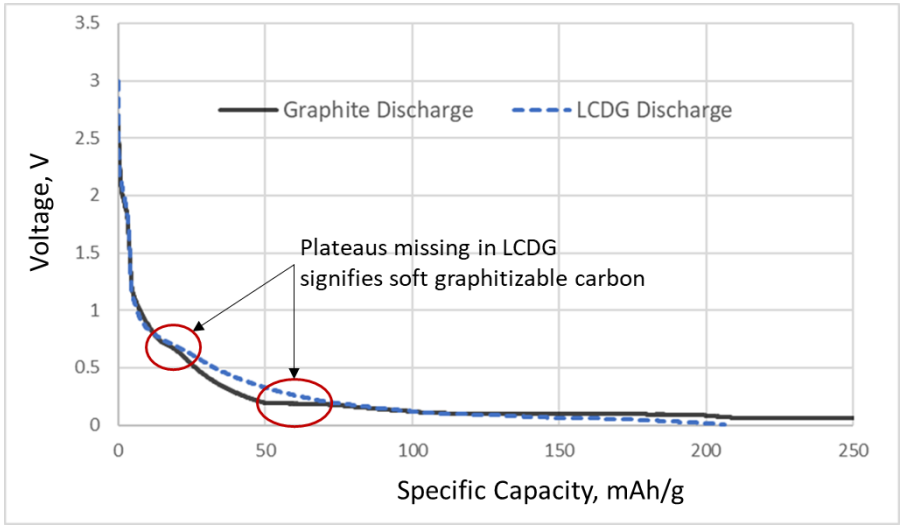


Potentially Hazardous Species

Property	As (ppm)	Cd (ppm)	Cr (ppm)	Fe (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Total (ppm)	Total (%)
LCDG	0.15	0.09	0.60	201	1.65	4.96	0.03	0.30	209	0.021

Preliminary Performance Data For LCDG in LIB Coin Cells



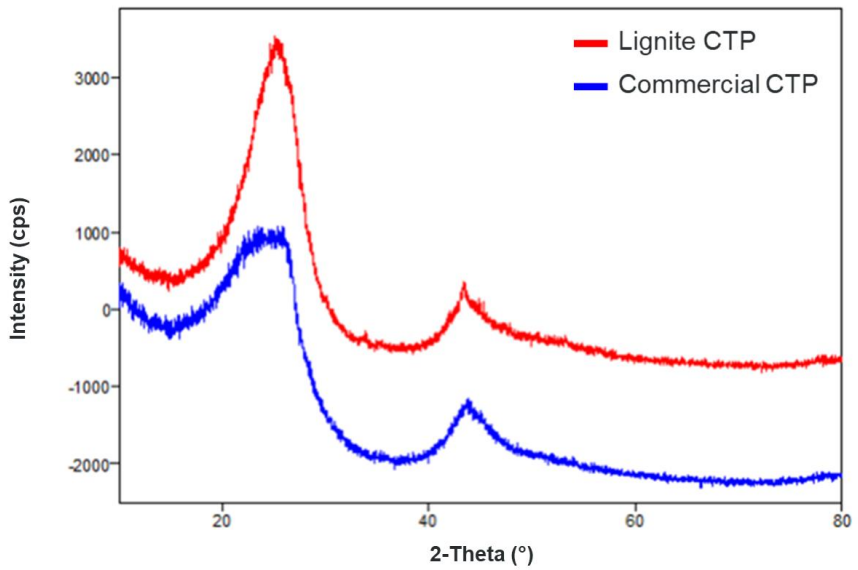


Electrochemical Performance of LCDG Compared to SLC150T

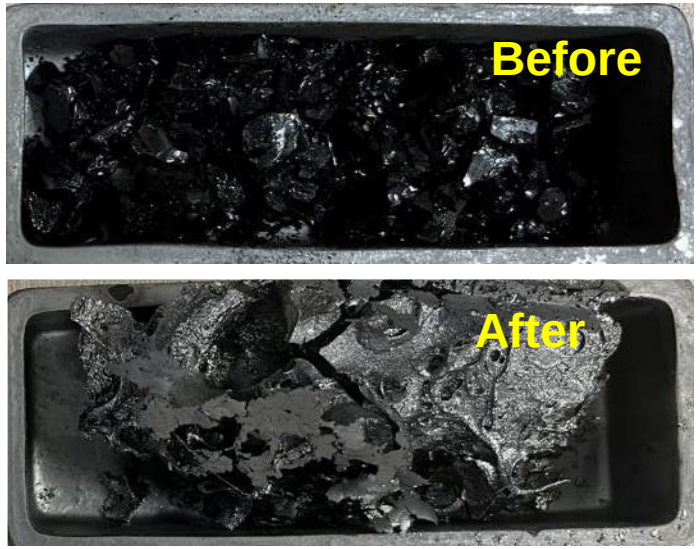
Material	First Cycle Specific Capacity, mAh/g	FCE, %	3rd Cycle Average Potential, V	21st Cycle Sp. Capacity at 1C, mAh/g	22nd Cycle Retention Capacity at C/10, %
Higher or Lower Is Better	Higher	Higher	Lower	Higher	Higher
SLC1520T	377.20	92.54	0.14	73.95	99.9
LCDG	205.63	85.55	0.15	49.95	105

Carbonized Lignite and Commercial CTP

Commercial CTP



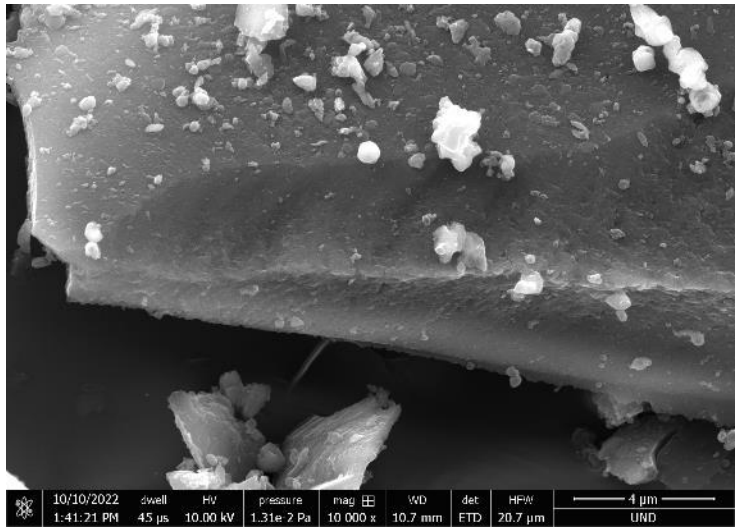
ND lignite CTP



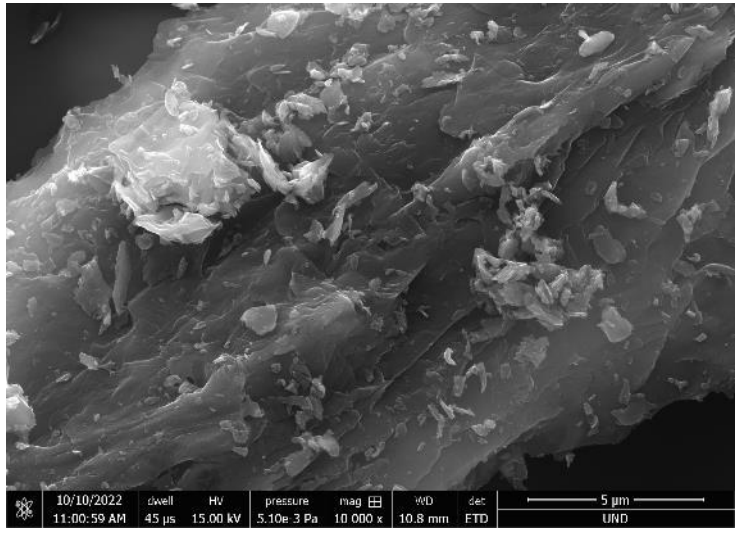
CTP Source	ND Lignite	Commercial
Softening Point (°C)	102	>95
Ash (wt%)	1.05	0.25
Coking Value (%)	28.1	33.1
Graphite Yield (%)	92.0	93.4

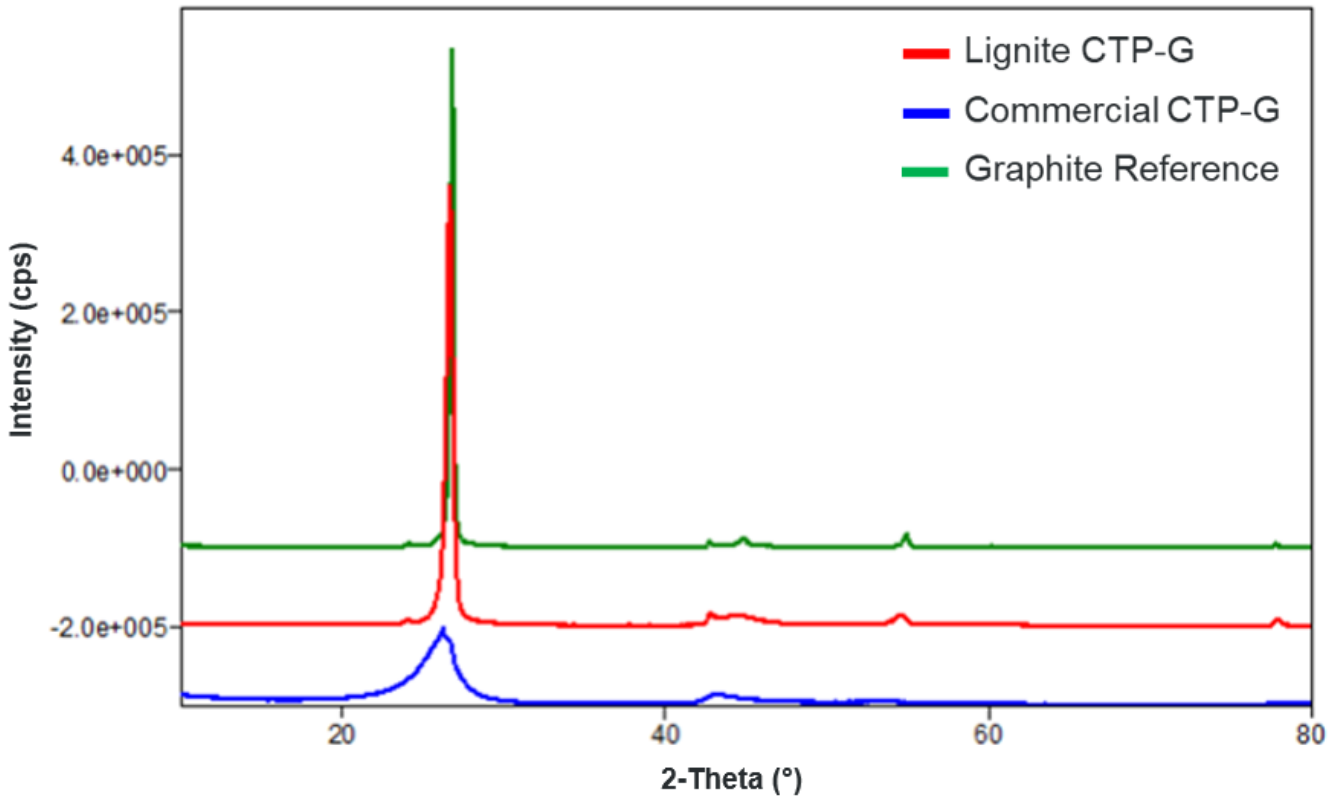
Graphitized Lignite and Commercial CTP

Commercial CTP-G



ND lignite CTP-G





Technology Development and Commercialization Plans

- **Current Plans**
  - Optimize graphitization conditions
  - Fine tune graphite properties via postprocessing
  - Full product characterization
  - Performance testing in LIB anode prototype
- **Next Steps**
  - Bench-Scale system for 5–10 lbs feedstock per batch
  - Scale-up process parameters optimization
  - Process control, Equipment, and Data Acquisition & Management
- **Scalability/Commercialization Potential**
  - Simple process, easily scalable, **upfront capital intensive**

Community Outreach and Workforce Development Efforts

Workforce Development

- 4 graduate students
- 3 undergraduate students

Community Outreach

- Seminars at area community colleges planned

Summary and Conclusions

- High-quality graphite can be made from coals of all ranks using the UCP process.
- Preprocessing conditions are key to achieve high quality, particularly croissant graphite.
- Additional process optimization and post-graphitization processing are ongoing to further improve graphite performance for LIB applications.
- **The UCP technology is an emerging environmentally sustainable process for efficient conversion of coal or coal wastes to high-value carbon products.**

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THANK YOU!

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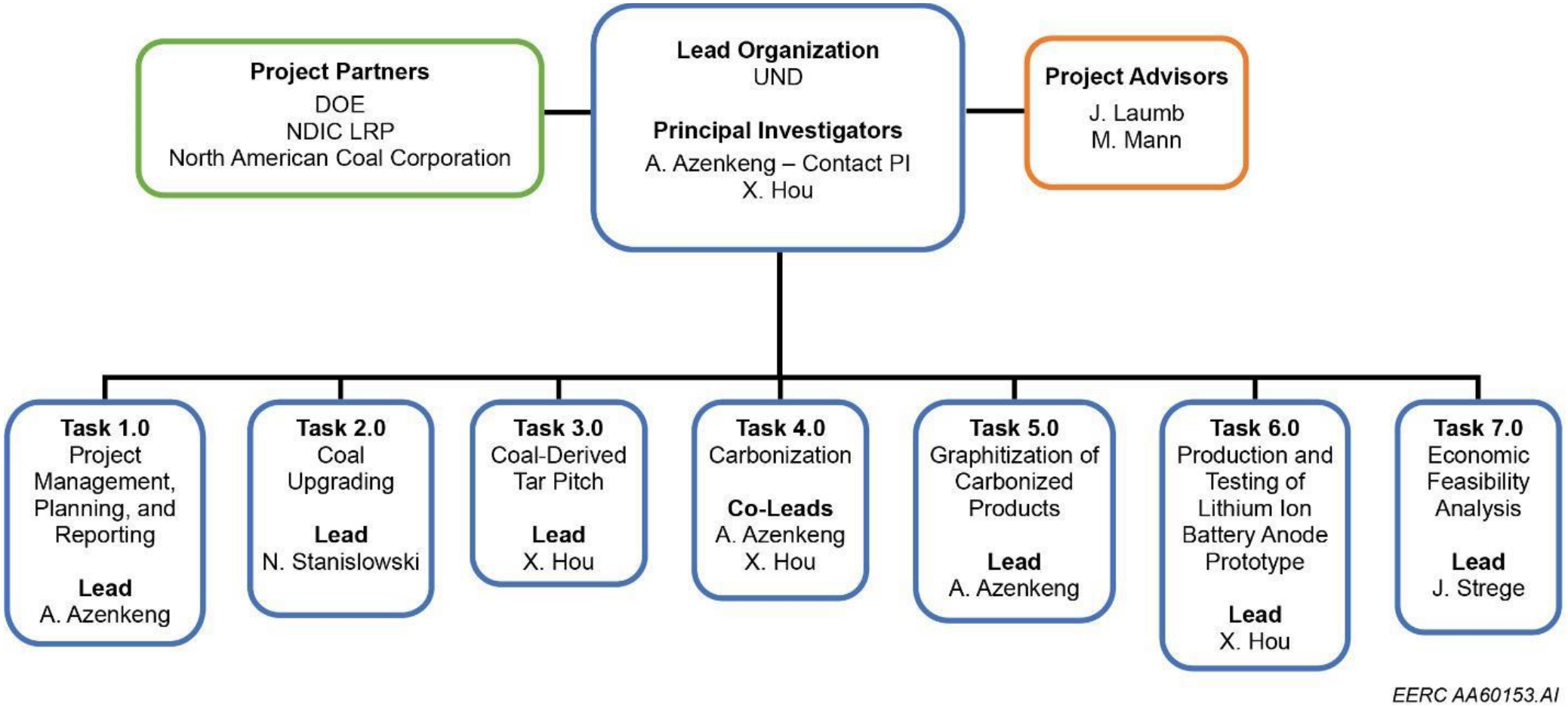
Organization Chart



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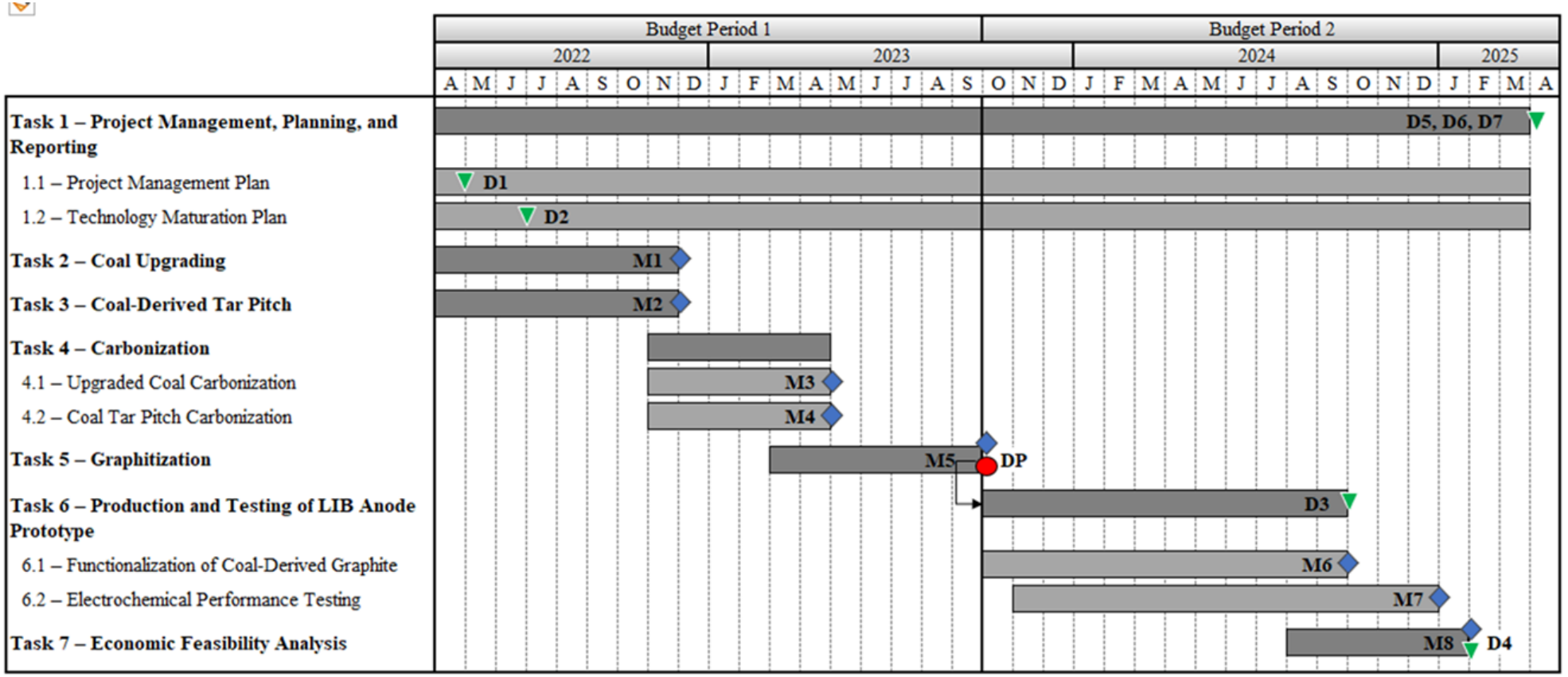
Gantt Chart



Key for Deliverables (D)	Key for Milestones (M)	
D1 – Updated Project Management Plan	M1 – Completion of Coal Upgrading	Summary Task
D2 – Technology Maturation Plan	M2 – Completion of Coal-Derived Tar Pitch	Activity Bar
D3 – LIB Anode Prototype	M3 – Completion of Upgraded Coal Carbonization	Deliverable (D)
D4 – Techno-Economic Analysis	M4 – Completion of Coal Tar Pitch Carbonization	Milestone (M)
D5 – Summary of Environmental Justice Considerations	M5 – Completion of Graphitization	Decision Point (DP)
D6 – Summary of Economic Revitalization and Job Creation Outcome	M6 – Completion of Functionalization of Coal-Derived	Critical Path
D7 – Final Report	M7 – Completion of Electrochemical Performance Testing	
	M8 – Completion of Economic Feasibility Analysis	

LH 05.03.2022