U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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Scale-up Production of Graphene Monoxide for Next-Generation LIB Anodes| AMMTO

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Project Overview

- Scale eCOphite™ anode material , a novel product discovered by COnovate with better performance than graphite in lithium-ion batteries.

- This fits AMMTO roles with a focus on *applied* R&D of an innovative new anode material for LIB's working towards the broader DOE goal of U.S. energy storage manufacturing.

- **Barriers:** Scaling patented eCOphite materials from milligram lab bench to 10's kg scale using continuous methods for ton scale production while retaining battery performance.

- **Impact:** eCOphite material is a drop-in replacement for graphite anodes made from domestic bio-sourced feedstocks, delivering low-cost, low-carbon footprint solution with higher capacity and faster charging.

Project Outline

Innovation: Scale up of eCOphite material to multi-kilo scale

Project Lead: Trevor Dzwiniel, Argonne National Laboratory

Project Partners: Carol Hirschmugl, COnovate, Inc.

Timeline: 6/1/21 to 7/31/23, 90% complete

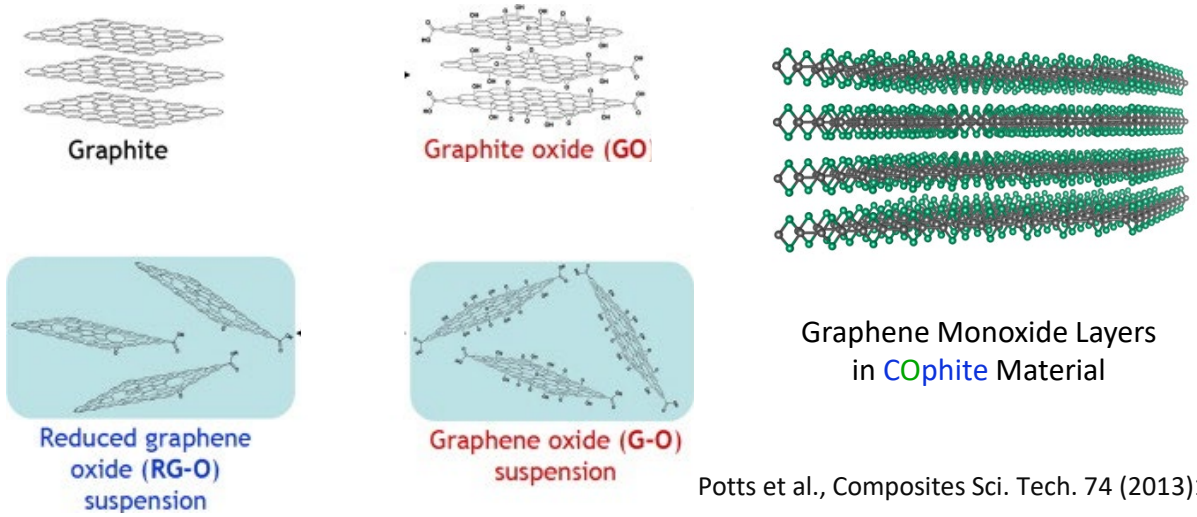
Budget: $600K total (ANL), 50% cost share (COnovate)

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$101K	$192K	$307K	$600K
Project Cost Share	$73K	$429K	$98K	$600K

End Project Goal: Successfully demonstrate eCOphite material production at pilot scale with 10 kg volume production and enabled enhanced LIB performance.

Background & Strategic Approach

Graphene Monoxide Versus Other Carbon-oxygen Structures



Graphene Monoxide Layers in COphite Material

Potts et al., Composites Sci. Tech. 74 (2013)166

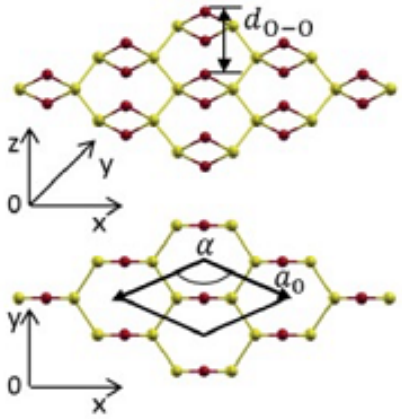
Graphene Monoxide is distinct from Graphite Oxide, Graphene Oxide and reduced Graphene Oxide.

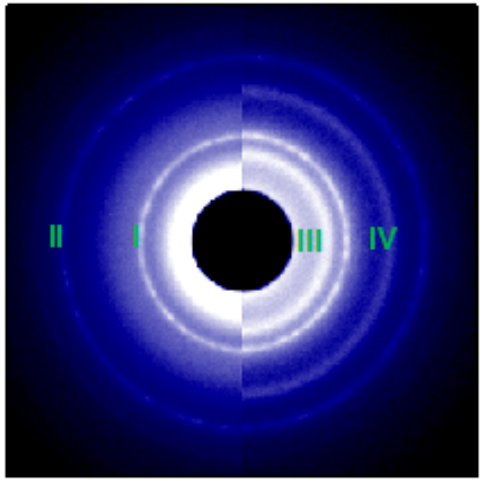
Graphene Monoxide discovered at nanograms and scaled to milligrams before 2020.

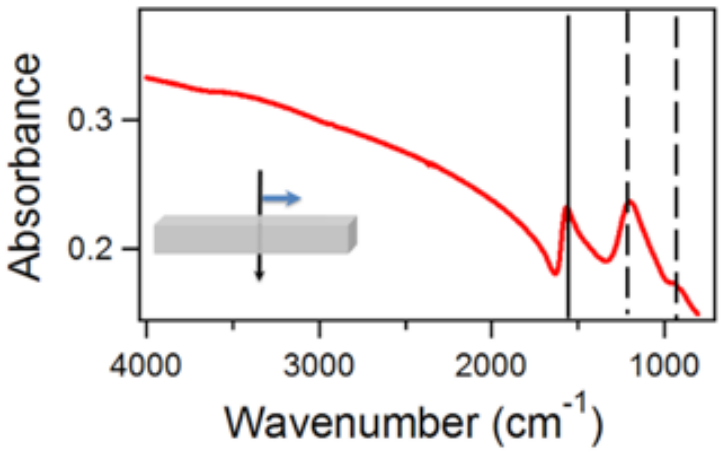
Graphene Monoxide confirmed with diffraction and spectroscopy.

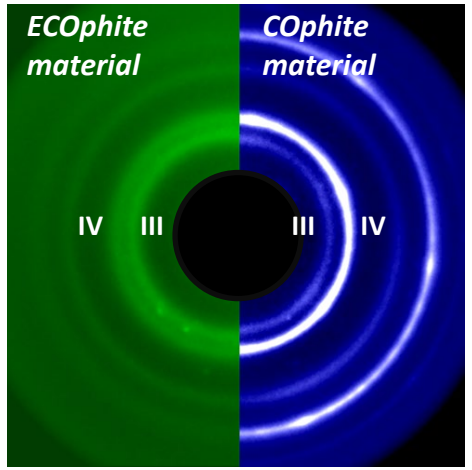
Mattson, E.C., et. Al., ACS Nano 5(12), 9710-9717 (2011). Hirschmugl, C., et. al. U.A. Pat Appln Nos. PCT/US21/13274 & USPTO17148010 (2021).

Evidence for Graphene Monoxide in COphite™ and eCOphite Materials



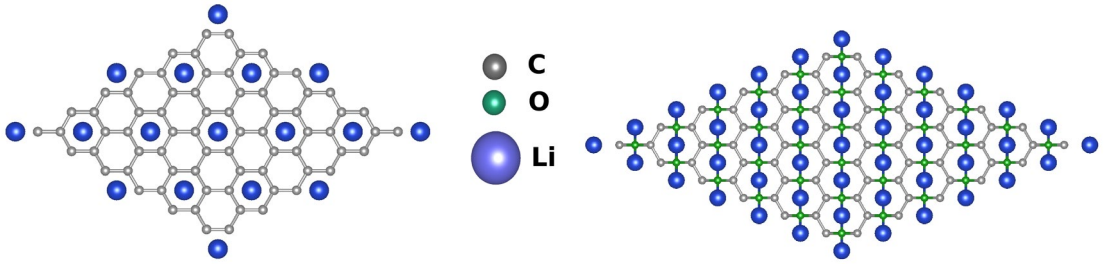






Background & Strategic Approach

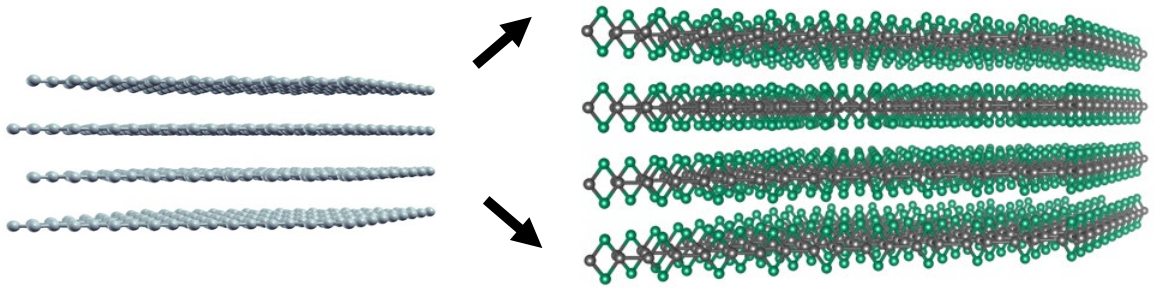
Lithiation of Graphite and Graphene Monoxide



Graphite:
372 mAh/g (LiC_6)

Graphene Monoxide:
957 mAh/g ($Li_2C_2O_2$)*

Layer Spacings of Graphite and Graphene Monoxide

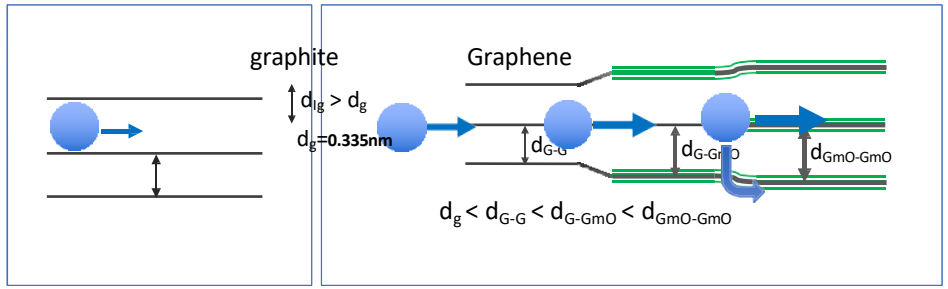


Graphene Layers
in Graphite

Graphene Monoxide Layers
in COphite Material

Oxygen Functional groups lead to higher lithium capacity than graphite.
Increased Interlayer spacing enables faster charging than graphite.

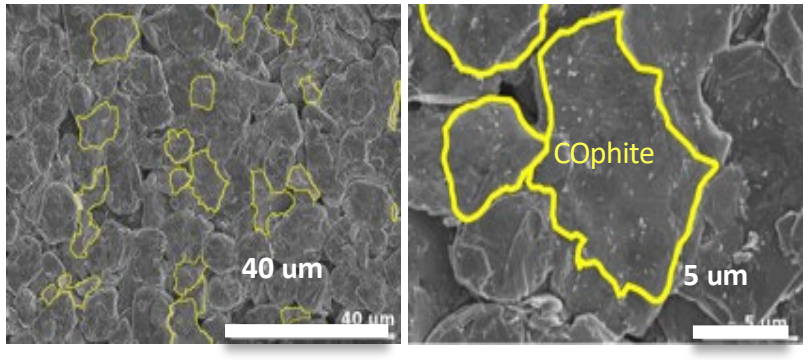
eCOphite and COphite Material Composites



*D Radevych, M Gajdardziska-Josifovska, C Hirschmugl, M Weinert, J. Phys. Chem. C 125(2021)11820, Patent No. 9,236,633/B2 (2016).

Background & Strategic Approach

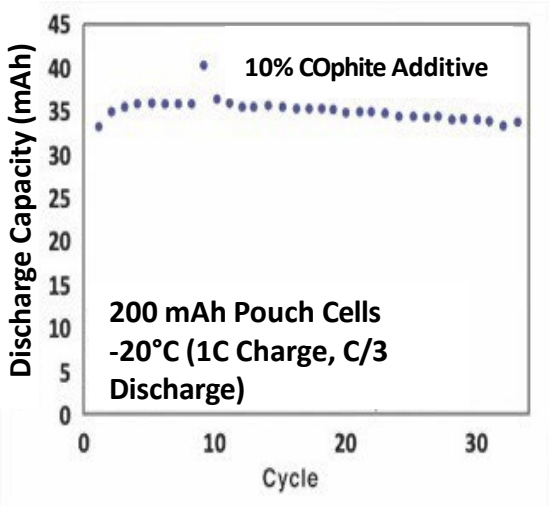
COphite Drop-in Additive in Electrodes

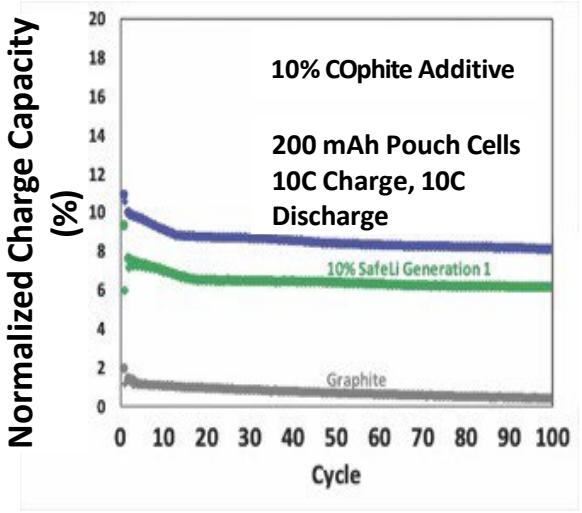


SEM images of 10% COphite material with 90% Graphite active anode material

- COphite material compatible with existing conventional anodes.
- COphite material drop-in additive.
- TRL: 4 (Demonstrated Minimum Viable Product).
- Anodes of 90% Graphite & 10% COphite Materials Demonstrated 2X Capacity, 6X Faster Charging.

Enhanced Lithium-Ion Battery Performance





Low Temperature Performance and Safety

Graphite w/Li deposition

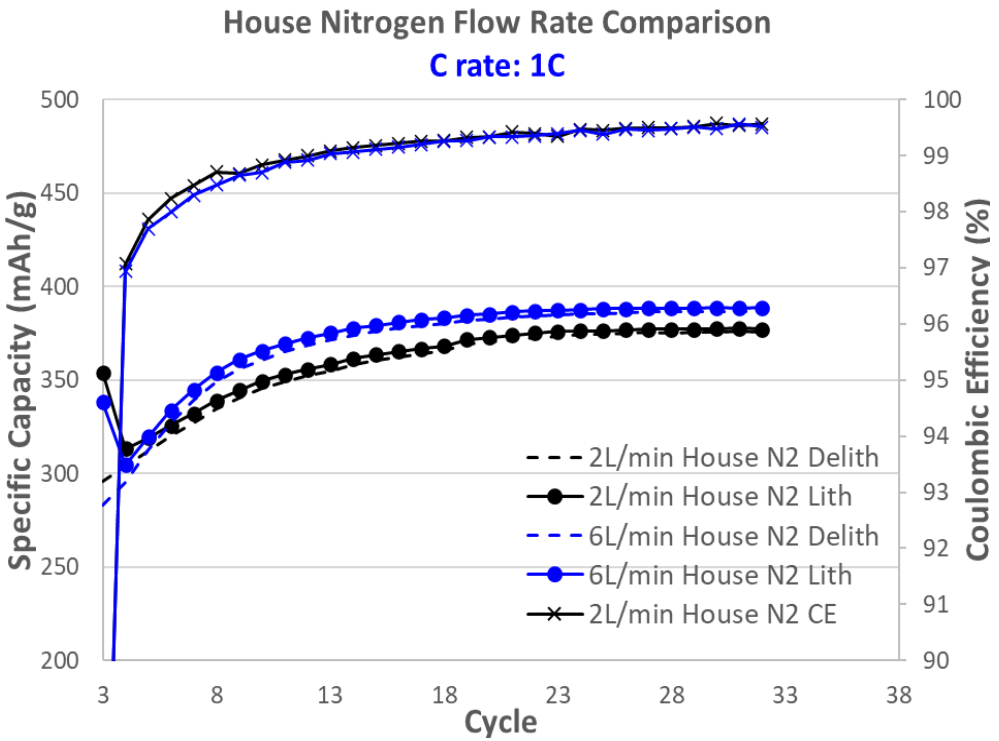
graphite + 10% COphite Material w/ minimal Li deposition

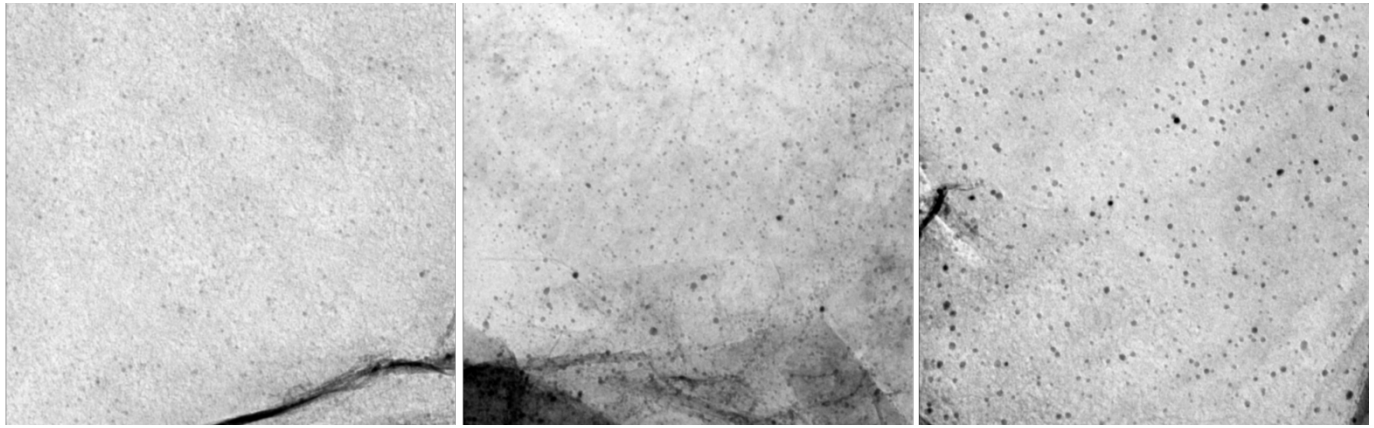
Separators after cycling 200 mAh pouch cells at 20°C (10 cycles) followed by 0°C (100 cycles)

Results and Achievements

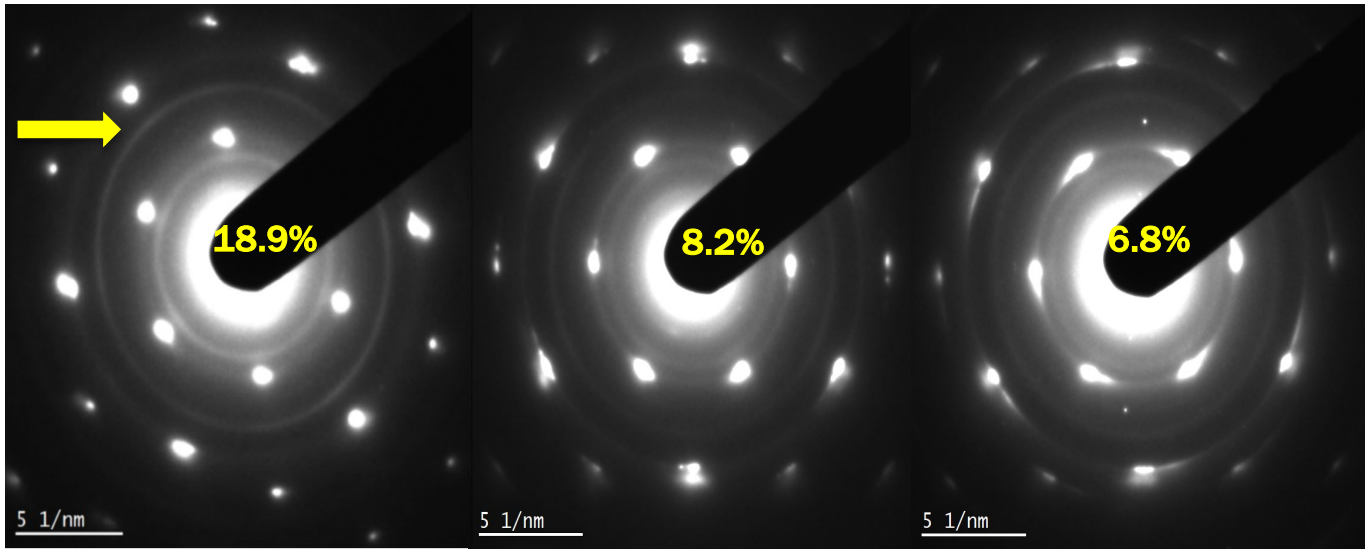
Initial research to assess calcination process variable effects on material.

- Run using 1” tube furnace.
- Flow rate and temperature predominant factors.





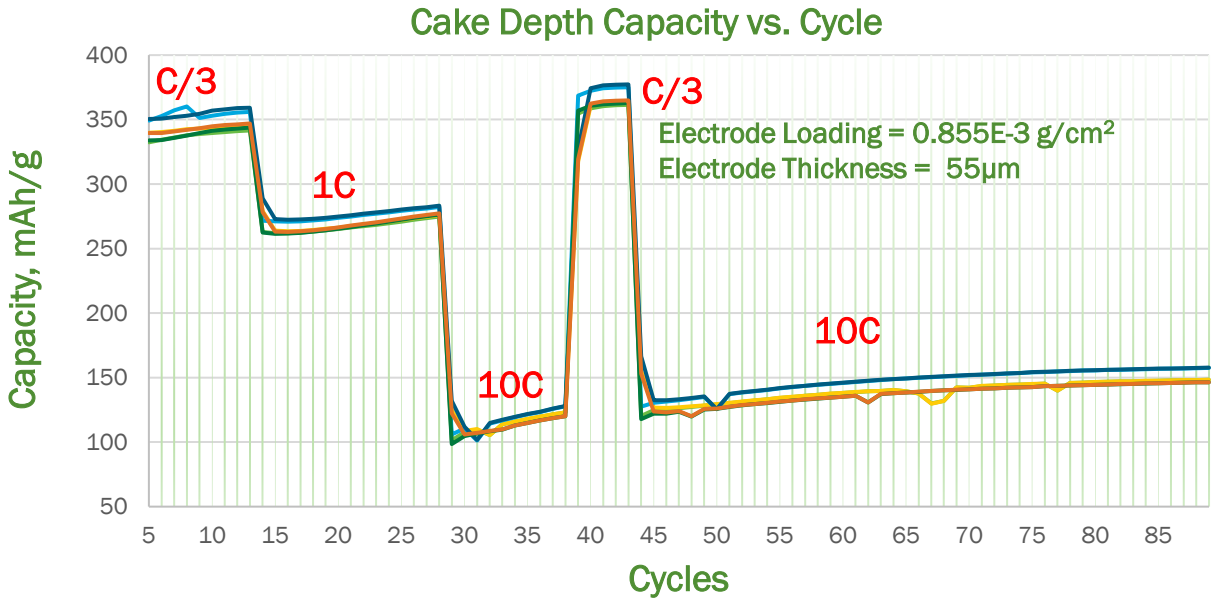
SEM image for flow rate of 6, 4, 2 L/min effect



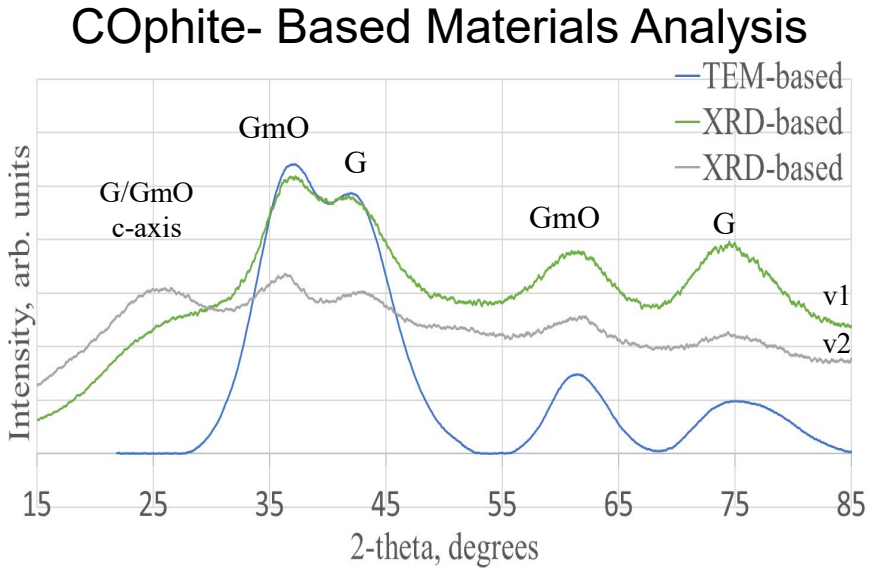
E-diffraction image showing COphite signature

Results and Achievements

- Scale-up to 3” and 6” tube furnace smooth.
  - Met mid-project goal of 100g scale.
  - No cake depth issues (XRD, cycling).
  - Tube furnace outperformed box furnace.
- Work on electrodes/ match industry std.



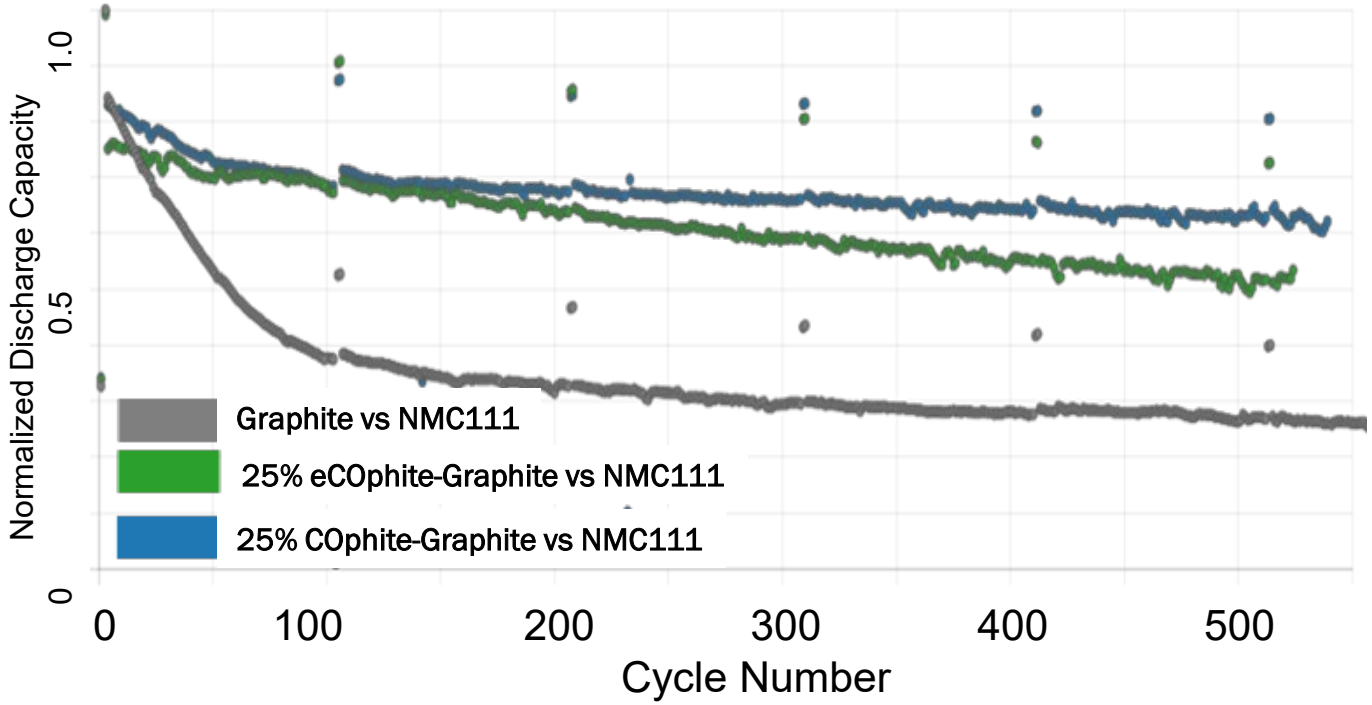
COphite blend vs Li half cell. Cycled at: 3 x C/20; 10 x C/3; 15 x 1C; 10 x 10C; 5 x C/3; 100 x 10C from 10mV-2V.



Results and Achievements

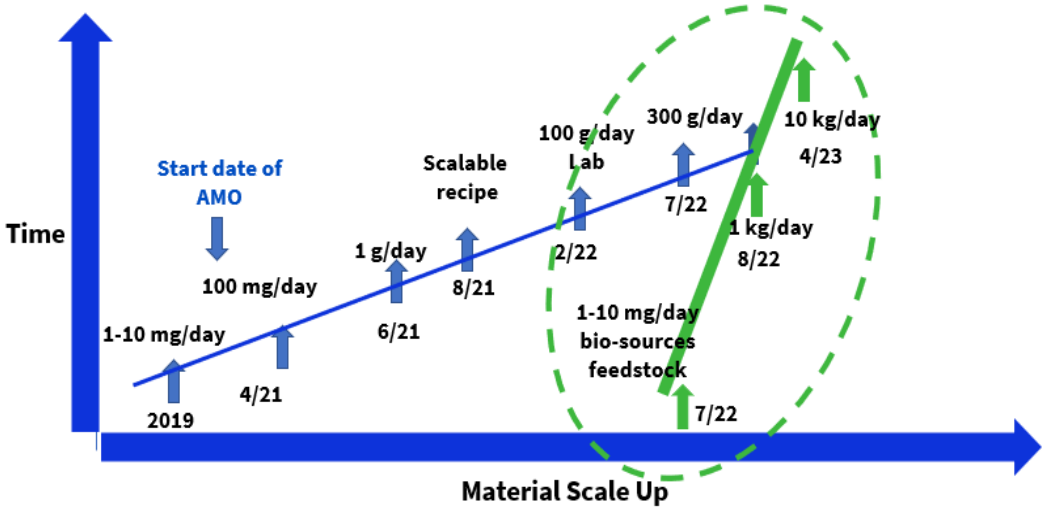
- Final scale goals realized with continuous processing.

Single Layer Full Cell Charge Rate Testing



Charge Rate testing: Graphite/ (e)-COphite material blend electrodes vs NMC111 2C charge, C/2 Discharge. 2.0V to 4.3V for (e)-COphite based cells, 3.0-4.3V for Graphite Cells @ 21°C.

GREAT PROGRESS ON DE-RISKING SCALE UP



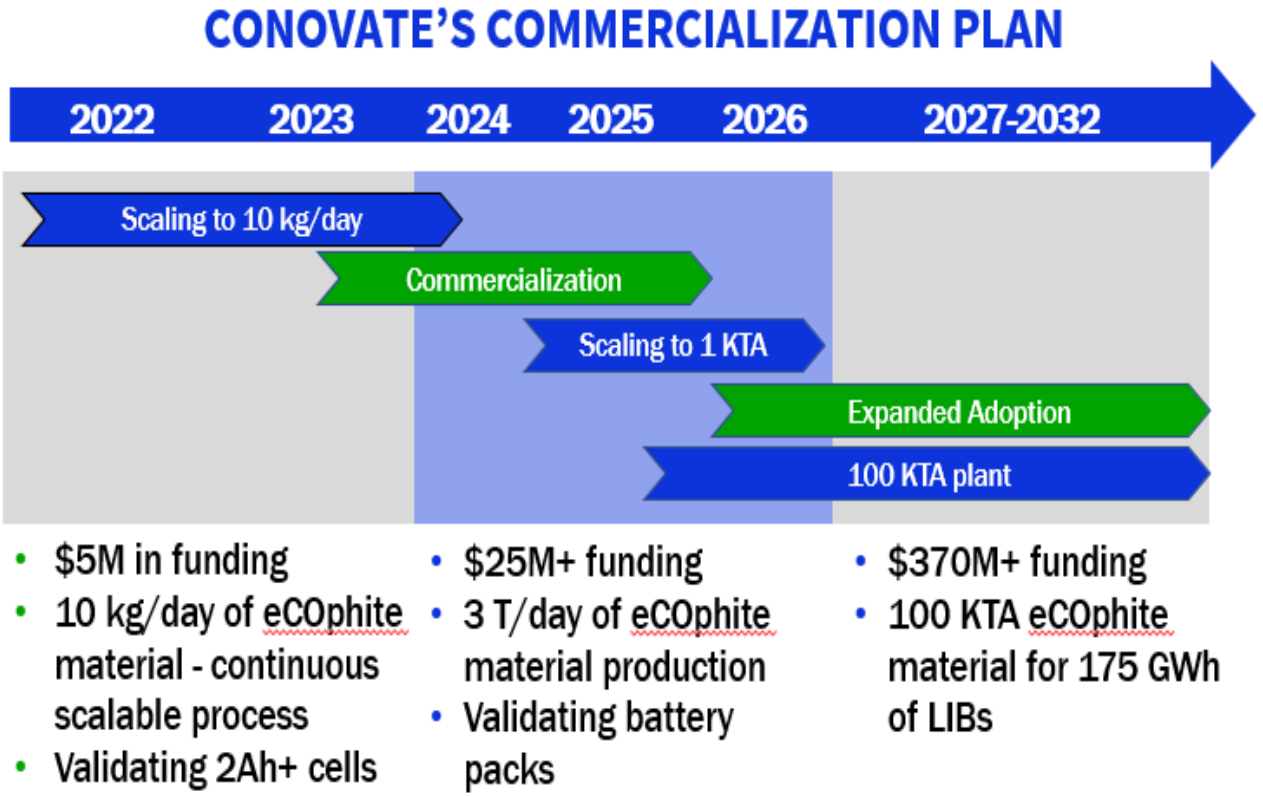
3rd party battery validation: Material Quality HIGH

Future Work, Technology Transfer, & Impact

Future Work:
10kg continuous processing at MERF and Harper and 2Ah batteries.

Technology Transfer:
COnovate's Commercialization Plan is outlined to the right.

Impact:
This project supported the scale-up of eCOphite material manufacturing from mgs to multi-kilos using proven scalable processes. The project transitioned to domestic feedstocks that can be leveraged into a new domestic manufacturing capability. This fits AMMTO roles with a focus on *applied* R&D of an innovative new anode material for LIB's working towards the broader DOE goal of U.S. energy storage manufacturing.



Questions?

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