NC STATE UNIVERSITY

tcbiomass

Catalytic Graphitization of Biomass for Green Battery Anodes

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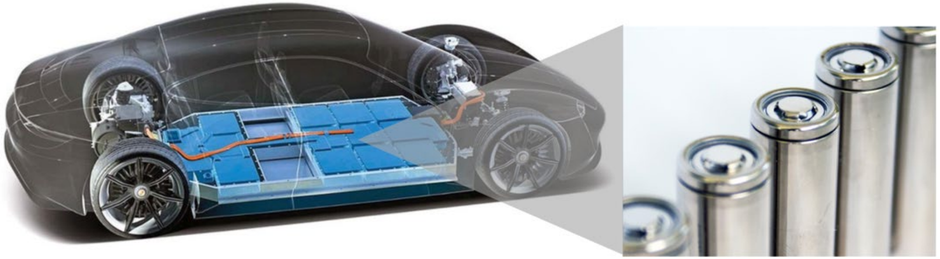
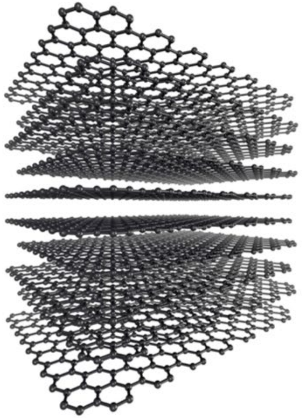
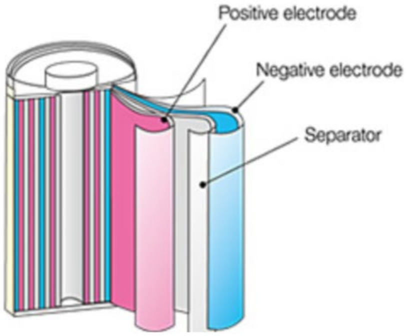
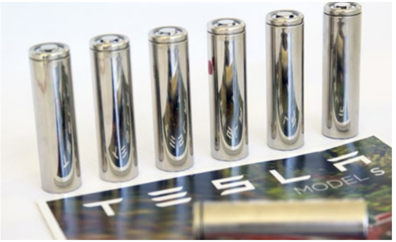




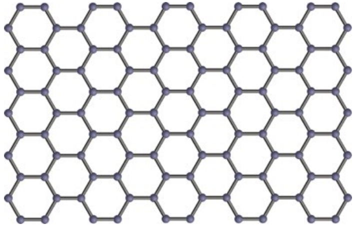


Motivation: Graphite Applications

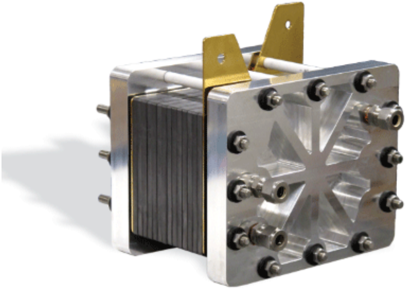


Li-Ion Cells

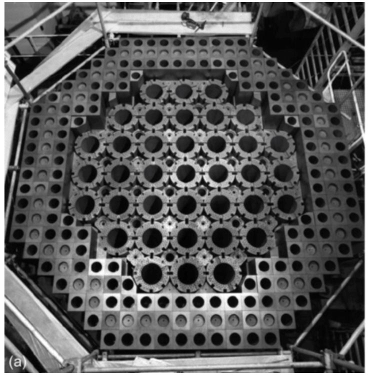
Supercapacitors



Graphene Precursor



Fuel Cells



Nuclear Reactors

Refractories

EAF Electrodes

Structural Materials

Motivation: Graphite Market

All Applications

- ~$17.5B in 2020
- ~25% CAGR through 2030
- "Strategic & critical mineral"
- 100% of US supply imported in 2018
- Only 2 graphite mines operating in North America

Li-Ion Application

- ~25% of graphite market (2018)
- > 90% of anode graphite produced in China
- 115 Li-ion megafactories in the pipeline
- ~70% of anode material will be synthetic graphite in 2030

Motivation: Graphite Applications

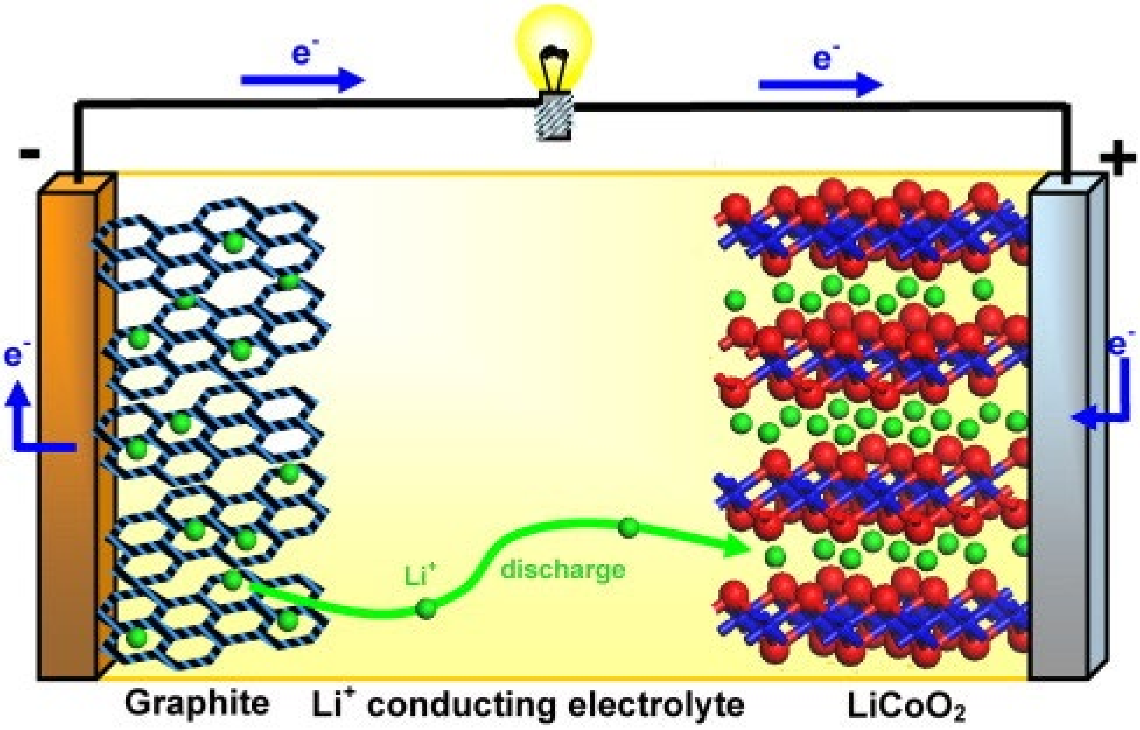
*"Our cells should be called Nickel-**Graphite**, because the cathode is nickel and the anode is **graphite** with silicon oxide…[there's] a little bit of lithium in there, but it's like the salt on the salad"*

Elon Musk, 2016

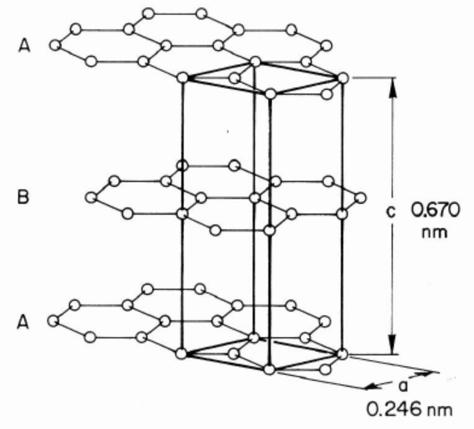
Graphite: 10 - 20% of Li-ion cell costs

Graphite in Electric Vehicles

X 8,250

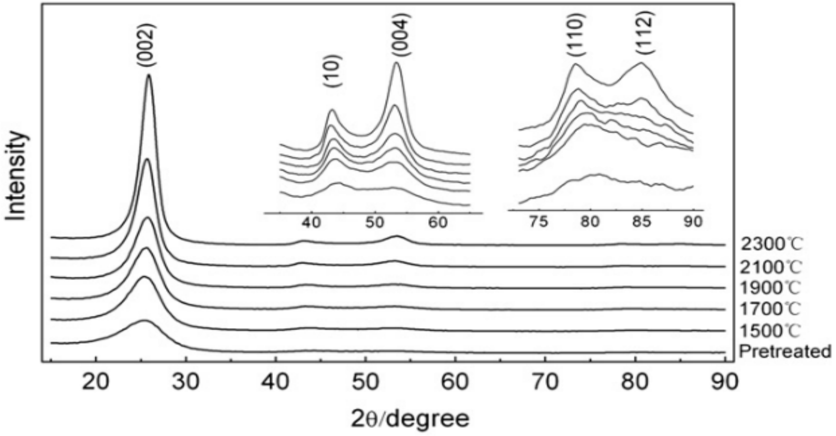


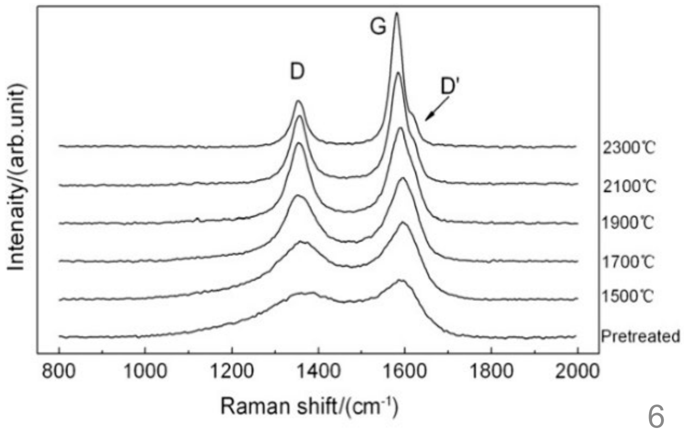
Graphite Properties



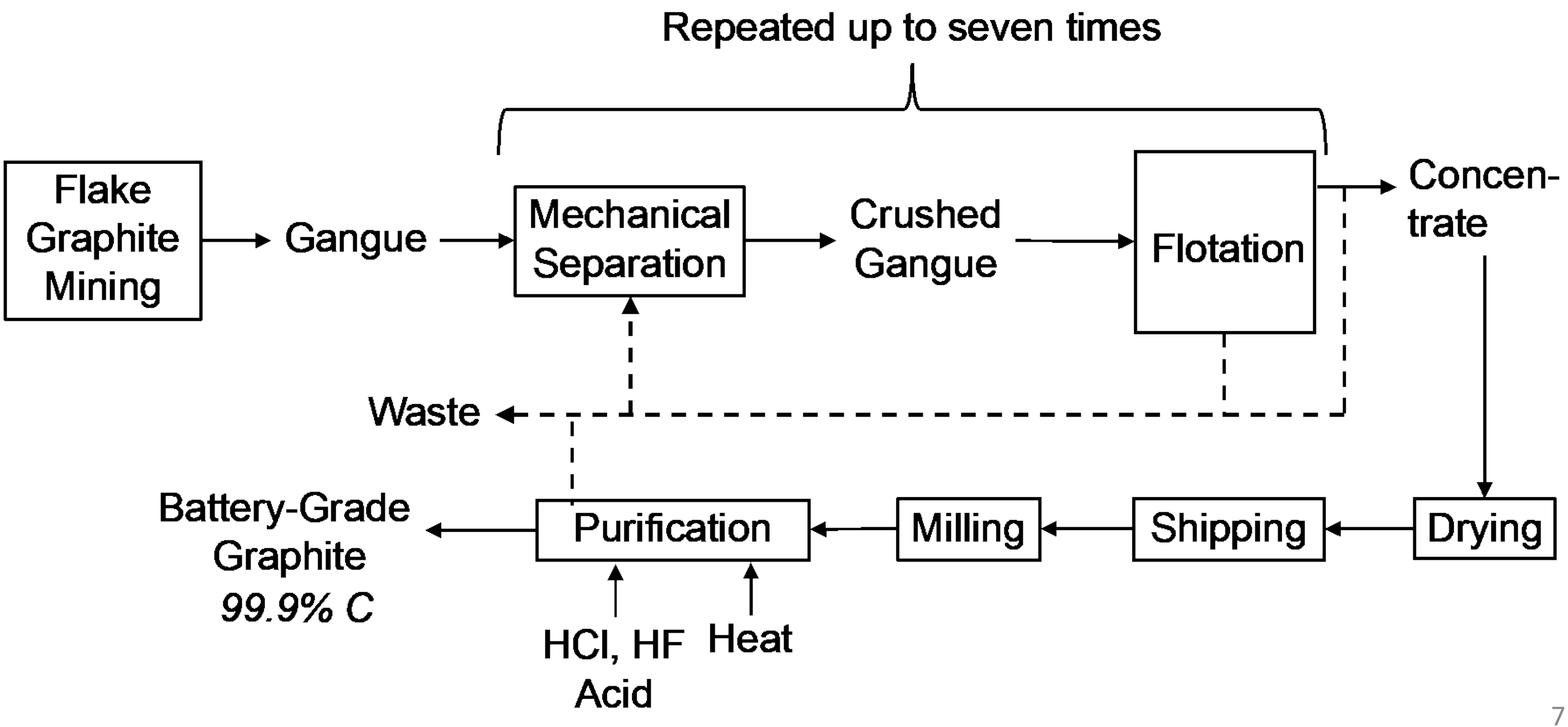
$$B(2\theta) = \frac{K\lambda}{Lcos(\theta)}$$

$$\alpha = \frac{I(G)}{I(D) + I(G)}$$

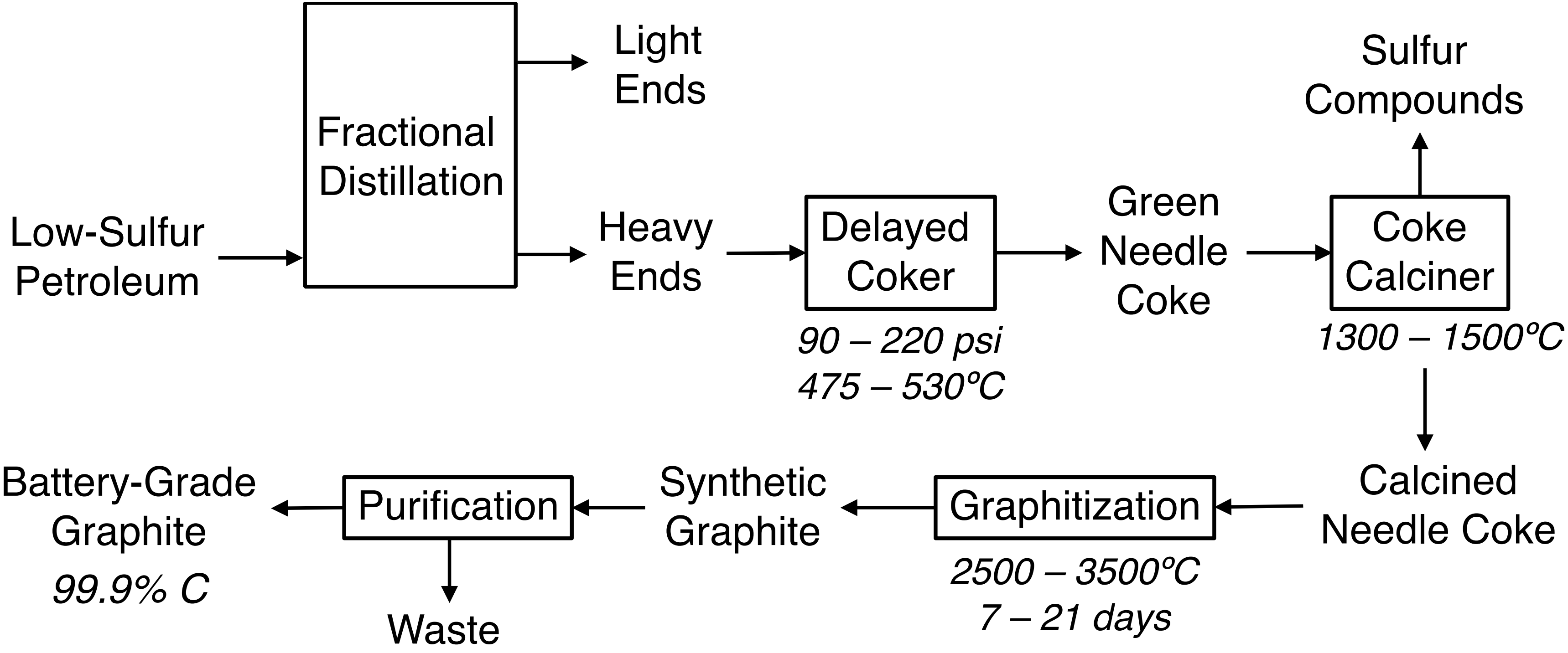




Standard Approach: Mineral Graphite Production



Standard Approach: Synthetic Graphite Production



Biomass-Derived Graphite: A New Form of "Bioenergy"?

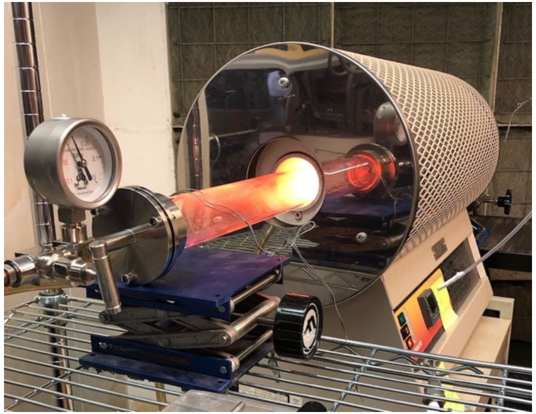
- Historically, biomass has been viewed as a non-graphitizing carbon precursor
- However, recent literature shows high quality graphite produced via *catalytic* graphitization

Catalytic Graphitization of Biomass to Graphite

Biomass
(non-graphitizing)

Iron Shavings

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



~1200ºC
~1 - 3h
No HF

Hydrochloric Acid Reflux

Graphite

Hydrogen

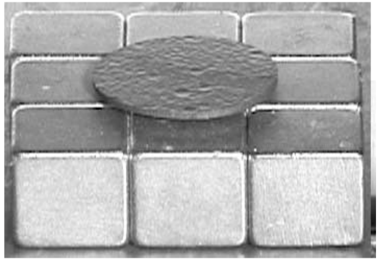
Iron Chloride

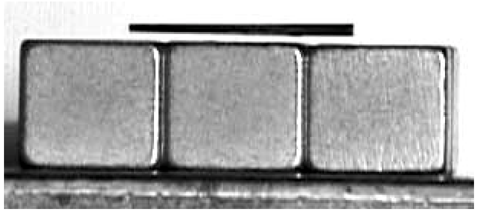
Alternative Methods for Iron Removal

- Selective oxidation of base-grown graphite

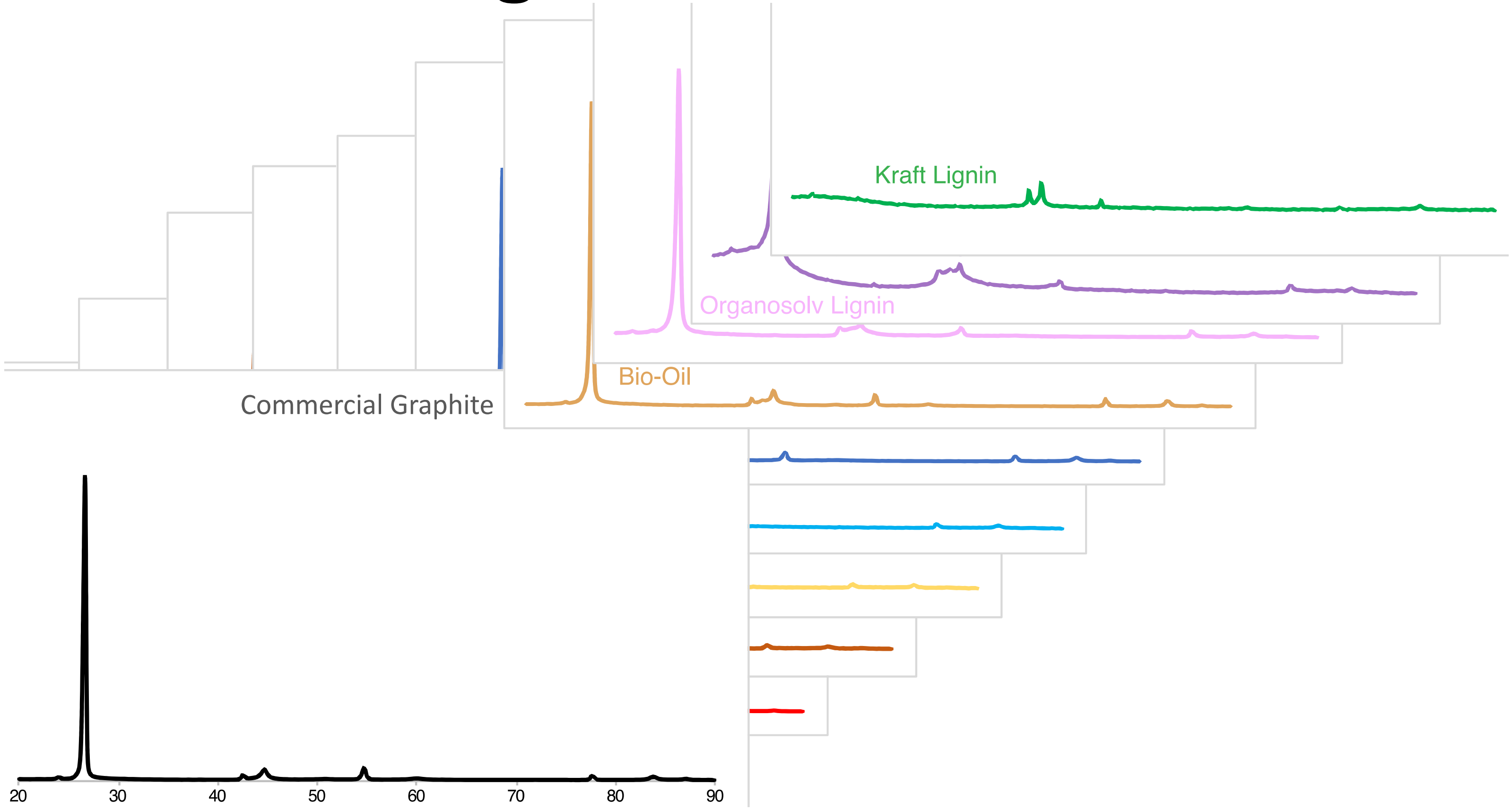
$$Fe\text{-}C + O_2 \rightarrow Fe_2O_3 + C$$

- Density separation via mechanical grinding & fluidization
- Sintered metal plates
- Diamagnetic effect of graphite
- Integration into steel refining

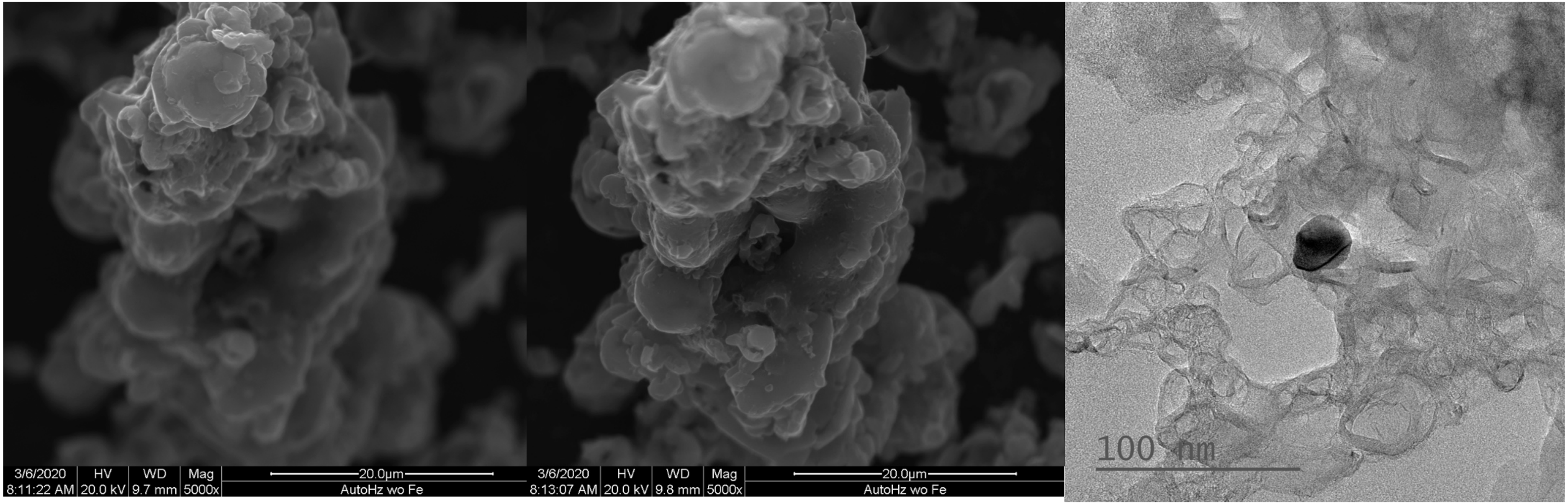




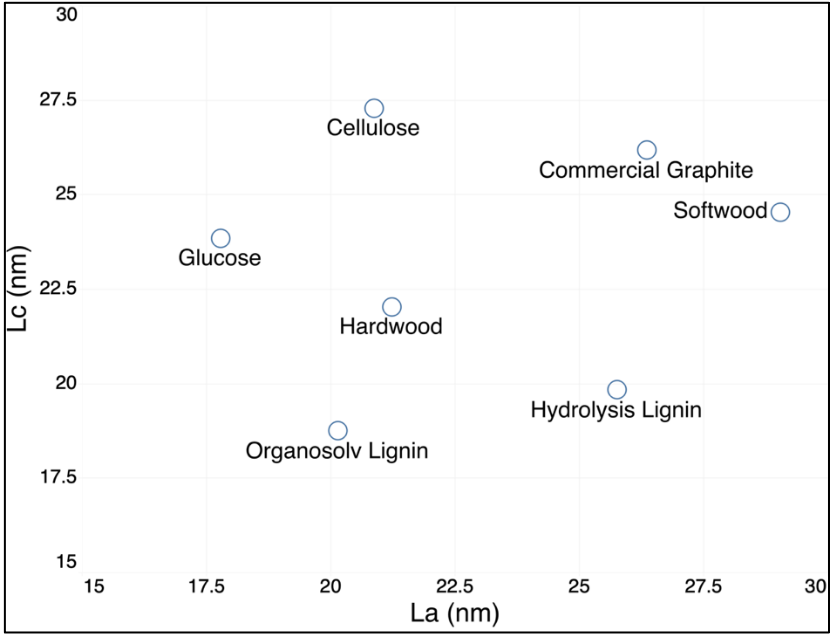
Screening Biomass Feedstocks

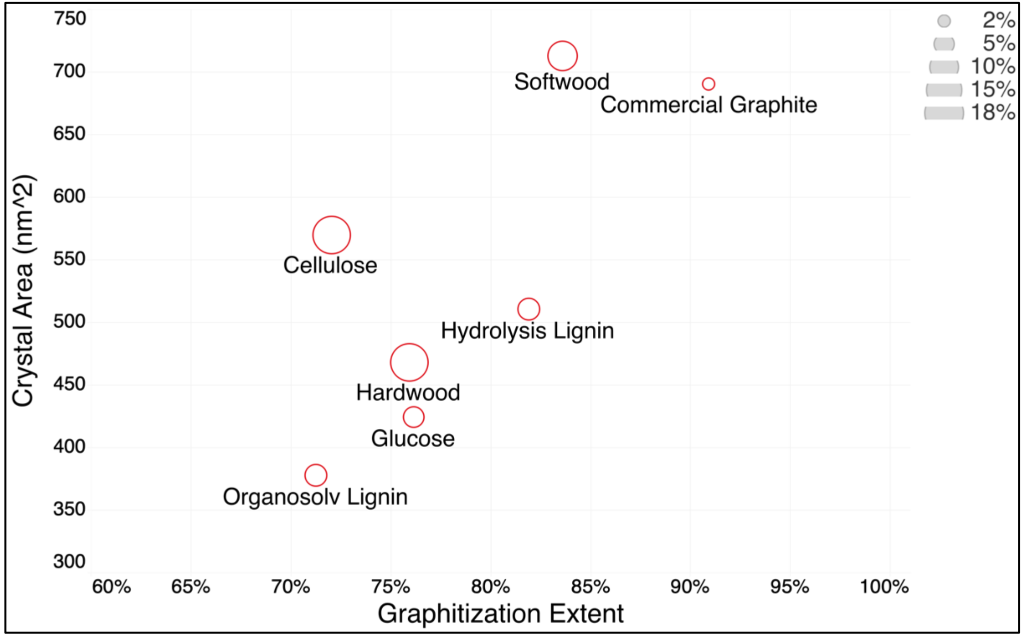


Biographite Morphology

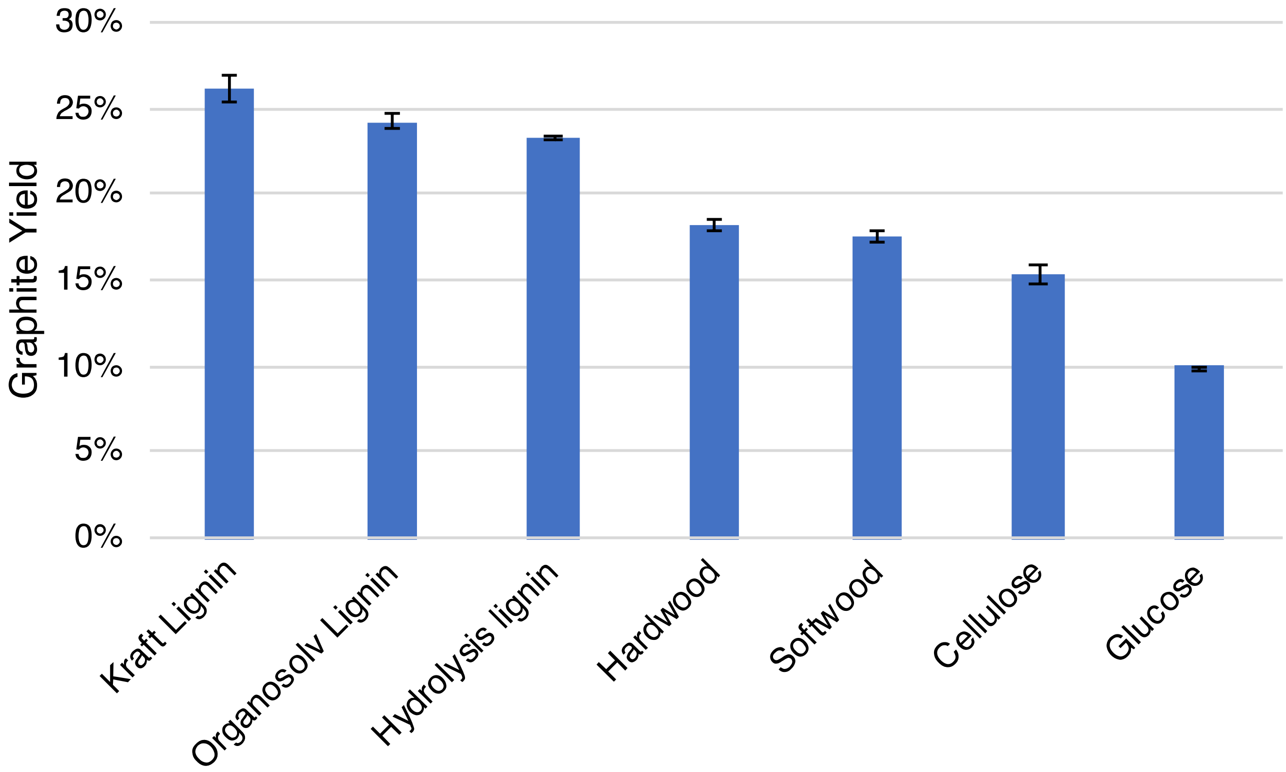


Biographite Quality



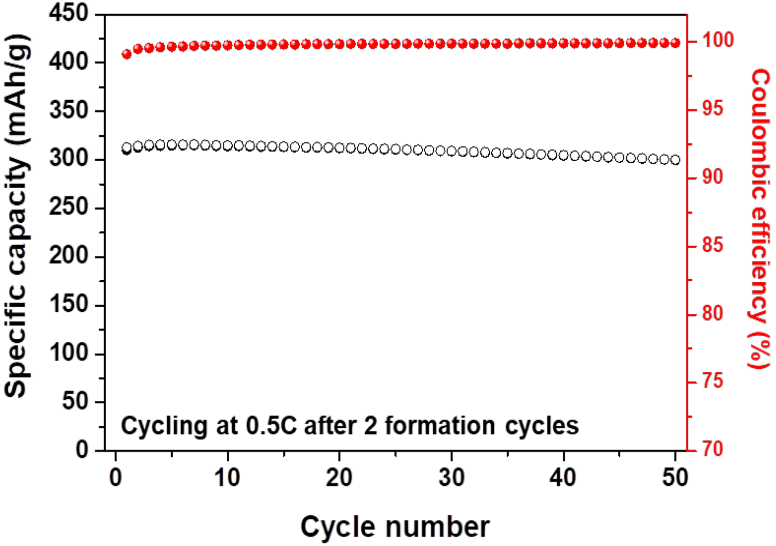


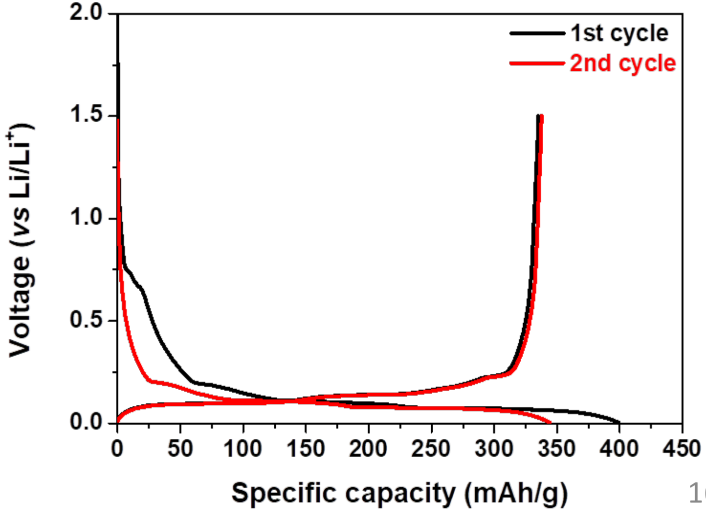
Biographite Yields



Electrochemical Performance

- ~325 mAh/g capacity
- Capacity retention of 89% over 100 cycles
- > 99% Coulombic efficiency





Conclusions & Future Directions

- Transition metals catalyze graphitization of disordered biochar at relatively low temperatures
- Softwood and cellulose perform better than other solid biomass feedstocks
- Catalyst separation is a major challenge. Low ash feedstocks preferred, such as bio-oil.
- Non-catalytic pathways now seem possible for particular feedstocks
- Further improvements in battery cycle life required

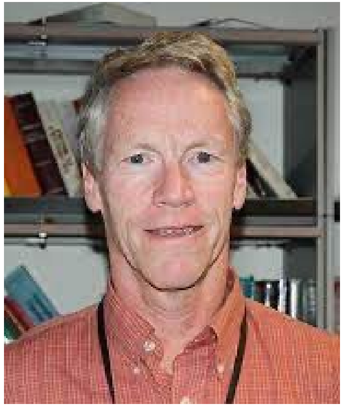
Ongoing Projects

1. Screening Biomass Feedstocks for Catalytic Graphitization

2. Optimizing the Graphitization of Paper Waste

3. Catalytic Graphitization of Heavy Biocrude

Sunkyu Park, PhD
Professor, NCSU



Mark Nimlos, PhD
Group Research Manager, NREL

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A simple method for producing bio-based anode materials for lithium-ion batteries†

William J. Sagues, [a,b,c] Junghoon Yang,[d] Nicholas Monroe,[a] Sang-Don Han, [d] Todd Vinzant,[c] Matthew Yung,[c] Hasan Jameel,[a] Mark Nimlos [c] and Sunkyu Park *[a]

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Research Article

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Graphitization Behavior of Loblolly Pine Wood Investigated by *in Situ* High Temperature X-ray Diffraction

Seunghyun Yoo,[†] Ching-Chang Chung,[‡] Stephen S. Kelley,[†] and Sunkyu Park*[,†]

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Structural Characterization of Loblolly Pine Derived Biochar by X-ray Diffraction and Electron Energy Loss Spectroscopy

Seunghyun Yoo, Stephen S. Kelley, David C. Tilotta, and Sunkyu Park*

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Are lignin-derived carbon fibers graphitic enough?

William J. Sagues,[a] Ankush Jain, [b] Dylan Brown,[a] Salonika Aggarwal,[a] Antonio Suarez,[a] Matthew Kollman, [a] Seonghyun Park[a] and Dimitris S. Argyropoulos *[a,c]

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- Dr. Junghoon Yang, NREL
- Dr. Matthew Yung, NREL
- Todd Vinzant, NREL