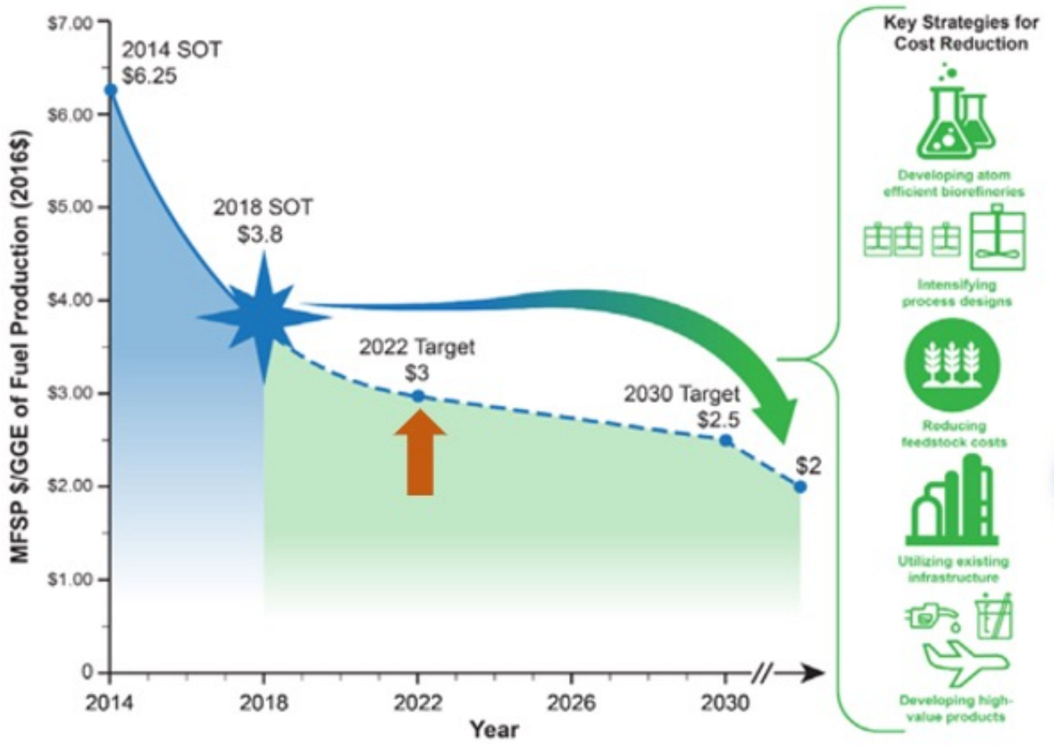
DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Pilot-Scale Biochemical and Hydrothermal Integrated Biorefinery (IBR) for Cost-Effective Production of Fuels and Value-Added Products

Date: April 3-7, 2023
Technology Area Session: Systems Development and Integration

Principal Investigator: Rajesh Shende
Organization: South Dakota of School of Mines & Technology

Project Overview



https://www.energy.gov/sites/prod/files/2020/07/f76/beto-integrated-strategies-to-enable-low-cost-biofuels-july-2020.pdf ; Ruan et al., *Integrated Processing Technologies for Food and Agricultural By-Products*, Academic Press (2019); *2016 Billion-Ton Report, USDOE.*

Relevance to BETO's Programmatic Goals

Development of conversion technologies for high value products from the waste solid residue derived during biochemical processing to generate revenue

Corn stover → Pre-processed corn stover → **Sugars** (Not the focus)

Pre-processed corn stover → Unhydrolyzed Solid → **HTL** → Aqueous waste / Biochar / Heavy bio-oil (HBO)

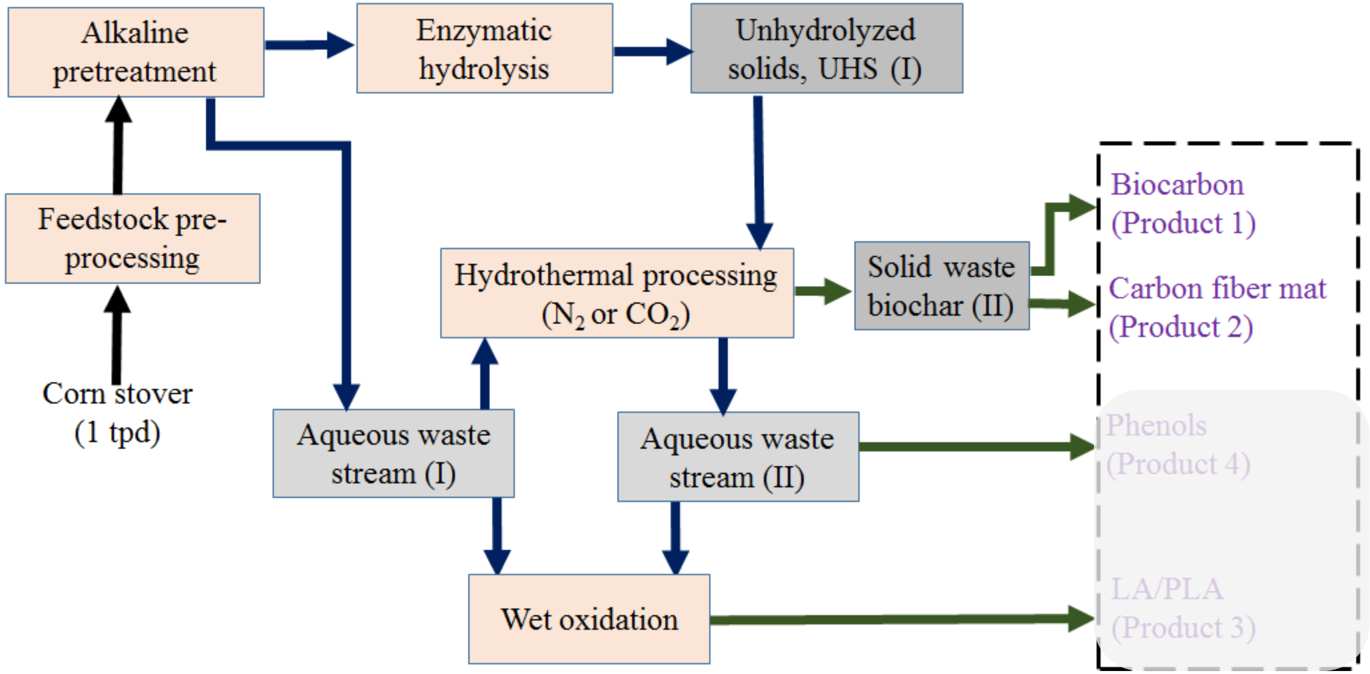
Biochar →

1. Biocarbon
2. Carbon nanofibers

Achieve quality – SSA, porosity, and specific capacitance for market

1 - Approach

Technical



BETO Focus Area: Enabling biofuels by developing technologies for high value products from biochemical waste processing

Enhanced to address 2021 peer-review

Biocarbon (Product-1)

Carbon nanofibers (Product-2)

Lab scale
- Optimization
- Mass/energy balance
- Product yield and quality

Pilot scale
- 1 tpd throughput
- Mass/energy balances
- Products yield and quality

TEA/LCA
- Product cost estimates
- Processing costs
- System boundary variations

Tungal et al., *Applied Energy* (2014); Nan et al., *Materials Letters* (2017); Kumar et al., *Biomass Conversion and Biorefinery* (2016); Thakkar et al., *Fuel Processing Tech.* (2021); Shell et al., *Bioresource Tech. Reports* (2021).

Project Management

Project Structure- Partners, Lab and Pilot Scale Processing

OLD DOMINION UNIVERSITY

Sandeep Kumar
Alkaline Pretreatment &
Enzymatic Hydrolysis
Lab process optimization

Corn stover

UHS

SOUTH DAKOTA MINES

Rajesh Shende
Hydrothermal Liquefaction
Lab and pilot scale (0.4 tpd)

Corn stover

Corn stover

Idaho National Laboratory

John Aston
Preprocessing of corn stover
Alkaline pretreatment
Enzymatic hydrolysis*
Pilot scale (1 tpd)

* NREL subcontract

Lab

Pilot

Biochar

Hao Fong
Electrospinning for carbon nanofibers
Lab, pre-pilot scale (0.5-1 kg/day)

Biochar

VCU

Ram Gupta
Graphitization for biocarbon
Lab process optimization

SOUTH DAKOTA MINES

Graphitization for biocarbon
Pilot scale (150 kg/day)

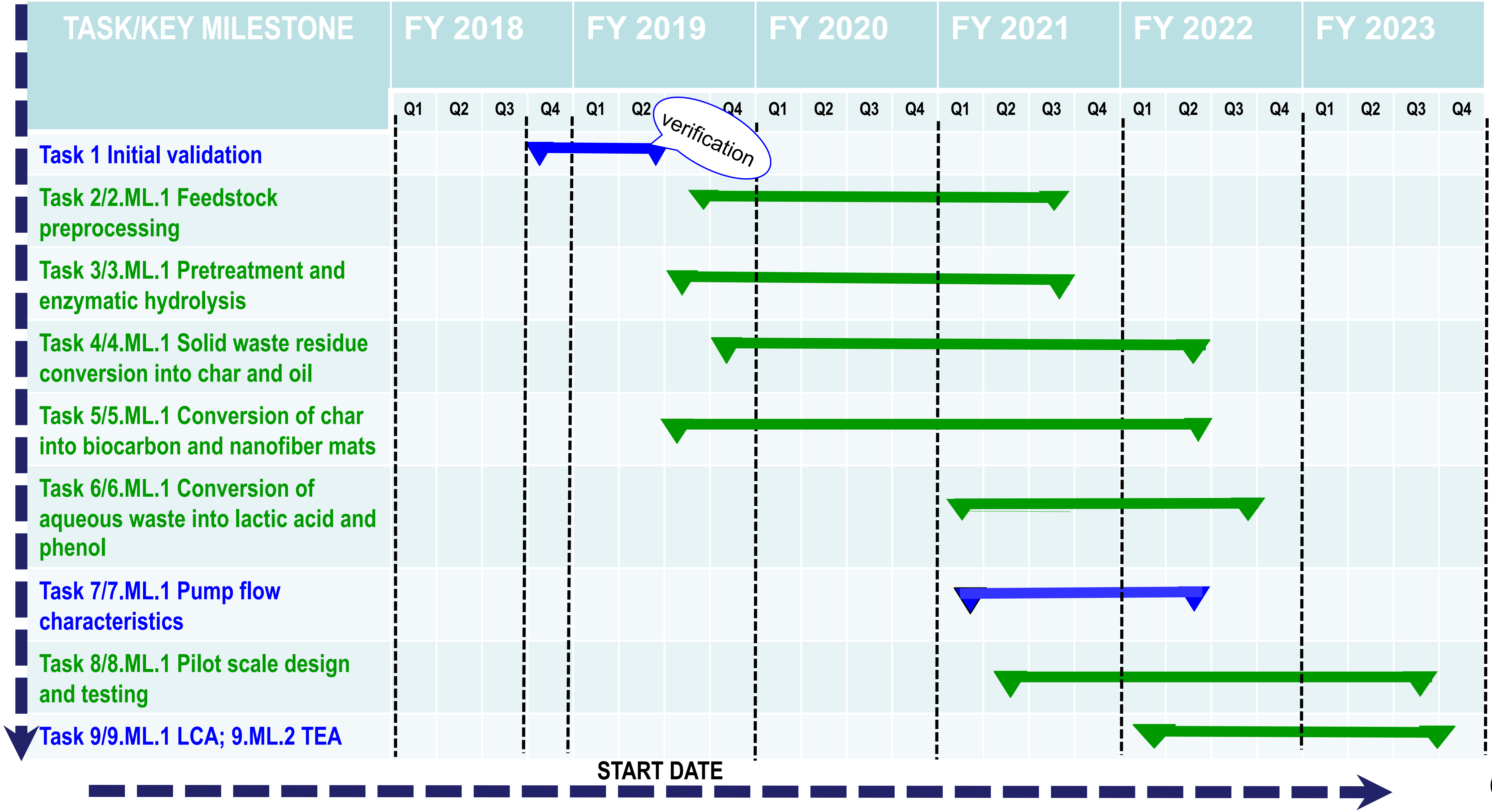
Industry partners: NEI Corporation, CA
Nanopareil LLC, SD, Polykyala LLC, TX

Goal Statement

- Demonstrate production of selected high value products from unhydrolyzed solid (UHS) waste generated during conventional biochemical processing of corn stover at a pilot scale level with 1 tpd throughput.

- **Outcomes**:
  - High value products – 1) graphitic carbon (referred as biocarbon) and 2) carbon nanofibers
  - Quality of the carbon products in terms of specific surface area, porosity, and specific capacitance
  - Potential revenues and the GHG emission.

Project Timeline



NOTE: GREEN lines and text indicate Active Status; BLUE lines and text indicate Inactive Status

Potential Challenges, Key Success Factors

Potential Challenges

- ❖Yield and quality of selected high-value products at a pilot scale level (technical)
- ❖HTL pilot plant design and fabrication (technical)
- ❖Integrate processing at different locations (scheduling, transport of UHS and processed material) (Management)

Key success factors

- ❖ Quality assessment of high –value products; biocarbon and carbon nanofibers
- ❖ Evaluation and testing of the products by our industry partners
- ❖ Estimation of revenue from the high-value products and the GHG emission

2 - Progress and Outcomes

Preprocessing: Biomass Feedstock National User Facility

The BFNUF comprises:

- A full-scale, fully integrated Process Development Unit (PDU) with modular design with a capacity of 2 ton/hr for herbaceous biomass and 5 dry ton/hr for woody biomass.
- Single-stage or two-stage hammer mill grinding, knife milling, various separations screens and classifiers, in-line characterizations
- Various mechanical conveyors with Feedstock metering bin
- Pelleting (Bench, 1 ton/hr and 5 ton/hr)

Preprocessed corn stover and supplied to partners

The values determined for $Sieve_{10}$, $Sieve_{50}$, and $Sieve_{90}$ are within the target values ($Sieve_{10}$ > 0.1 mm and $Sieve_{90}$ < 3 mm) the project.

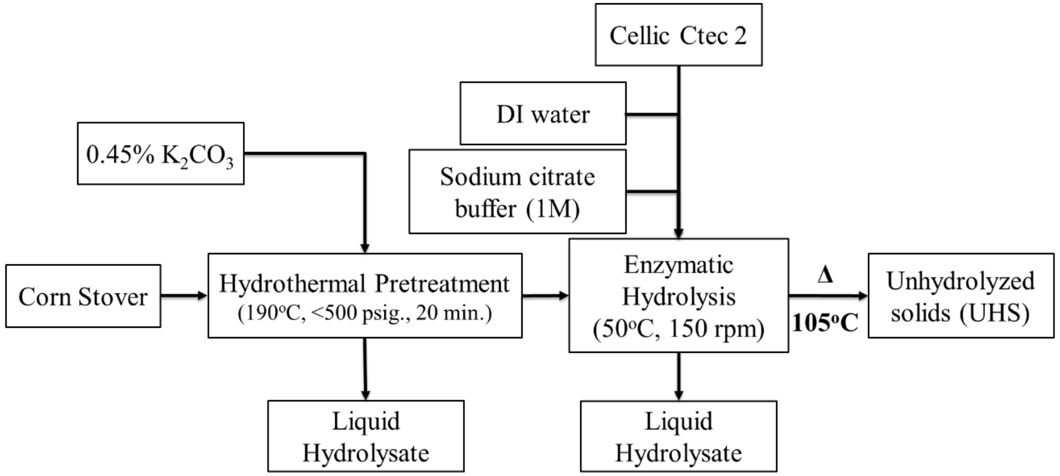
Low Ash (6.75 w.%)

High Ash (13.03 w.%)

Idaho National Laboratory

Pretreatment and Enzymatic Hydrolysis

INL chemical preprocessing system (CPS)



Optimized alkaline pretreatment process of corn stover

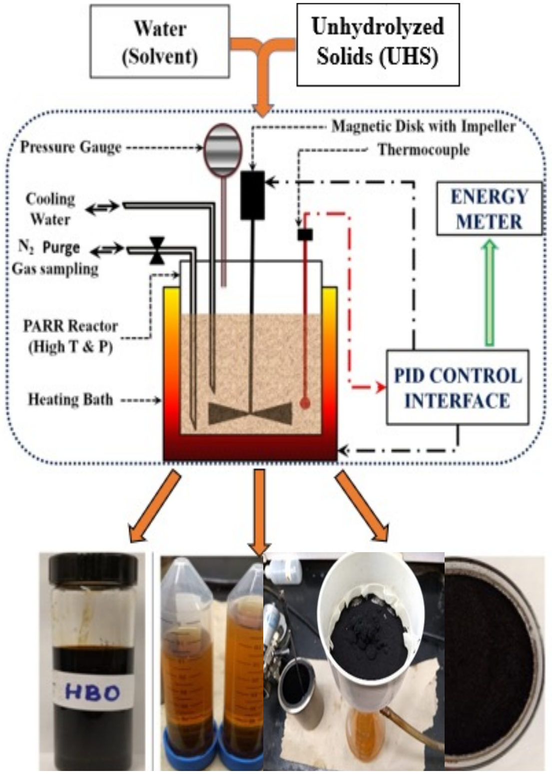
Operating parameters of the chemical preprocessing system and the corresponding maximum operational pressure achieved.

Material	Flow rate (kg/min)	Moisture Content (wt%)	Hopper Screw Speed (RPM)	Plug Screw Speed (RPM)	Maximum Operational Pressure (psig)
Corn stover knife milled to pass ½ - inch screen	1	30	10	18	180
Corn stover crumbled to pass a 4-mm screen	1	50	10	18	120
Corn stover knife milled to pass ½ - inch screen	1	30	10	24	160
Corn stover crumbled to pass a 4-mm screen	1	50	10	24	145
Corn stover knife milled to pass ½ - inch screen	1	30	10	18	180
Corn stover crumbled to pass a 4-mm screen	1	50	10	18	140
Corn stover knife milled to pass ½ - inch screen	1	30	10	24	135
Corn stover crumbled to pass a 4-mm screen	1	50	10	24	105

INL Chemical Preprocessing System (CPS)

- Unique pretreatment/preprocessing system
- Ambient ≤ T ≤ ~200 ºC, Ambient ≤ P ≤ ~ 200 psig
- Wide pH (0.5 – 13.5), numerous approved solvents
- Continuous up to 1 dry ton/day
- Batch reactors (3×10-L, non-agitated)
- Currently being configured to achieve 3.ML.1

Hydrothermal Liquefaction of UHS



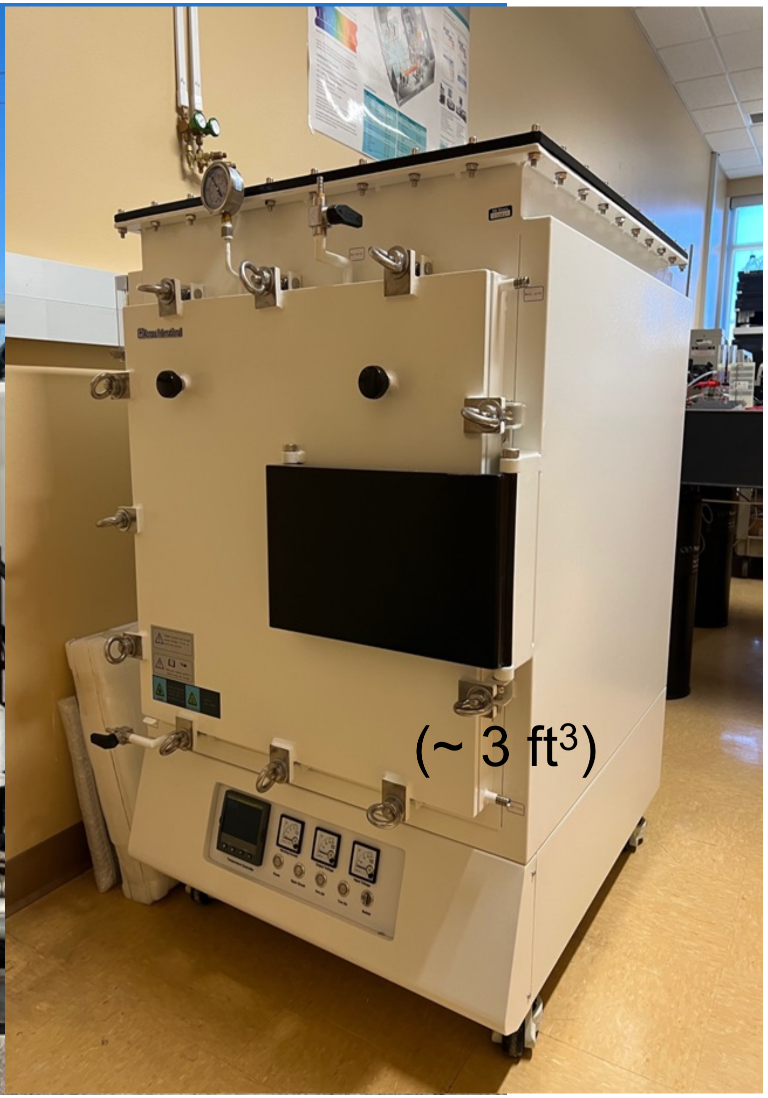
Bio-oil Aq. Stream Hydrochar

Advantages - Direct wet processing (avoid drying costs), diverse biomass substrates, high value products, bio-oil with high HHV, energy recovery, better char characteristics

Processing	Char		HBO		Phen[redacted]ic (GCM[redacted] area[redacted] wt%
	wt%	HHV (MJ/kg)	wt%	HHV (MJ/kg)	
Non-catalytic	36%	18	28%	30	18[redacted]7%
Catalytic	43%	17	23%	31	15[redacted]4%

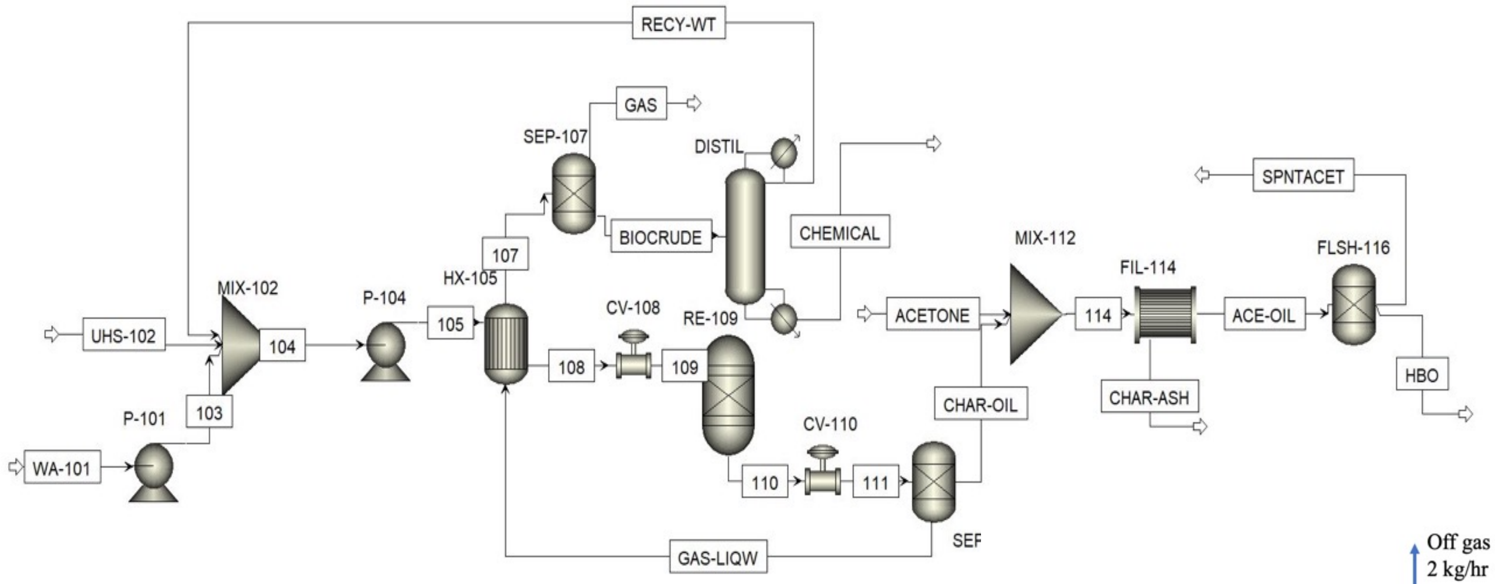
Hydrothermal Liquefaction of UHS Pilot Scale

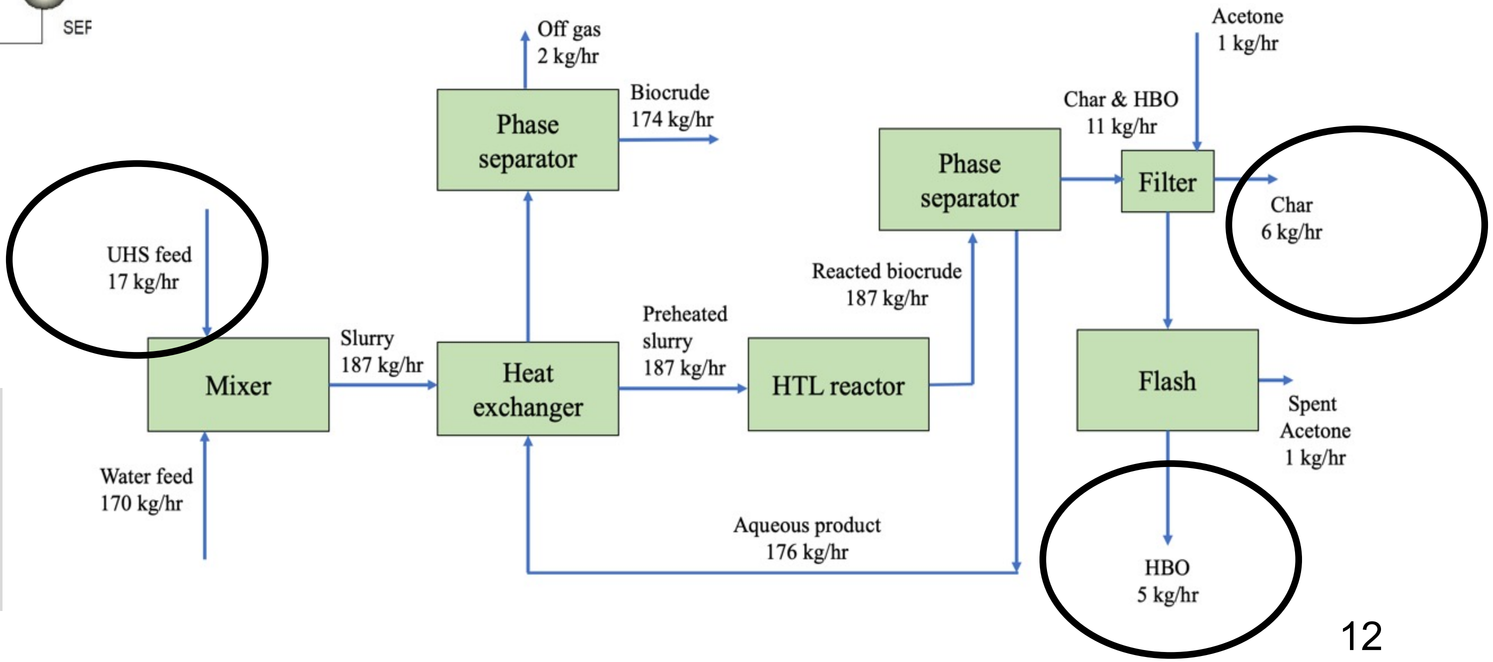
8 ft x 16 ft
skid mounted
~15000 lbs
Height ~11 ft
(3 ft for the
motor)



Designed and fabricated pilot scale HTL SS316 – 300 ^oC, 2200 psi rated (SDSMT)

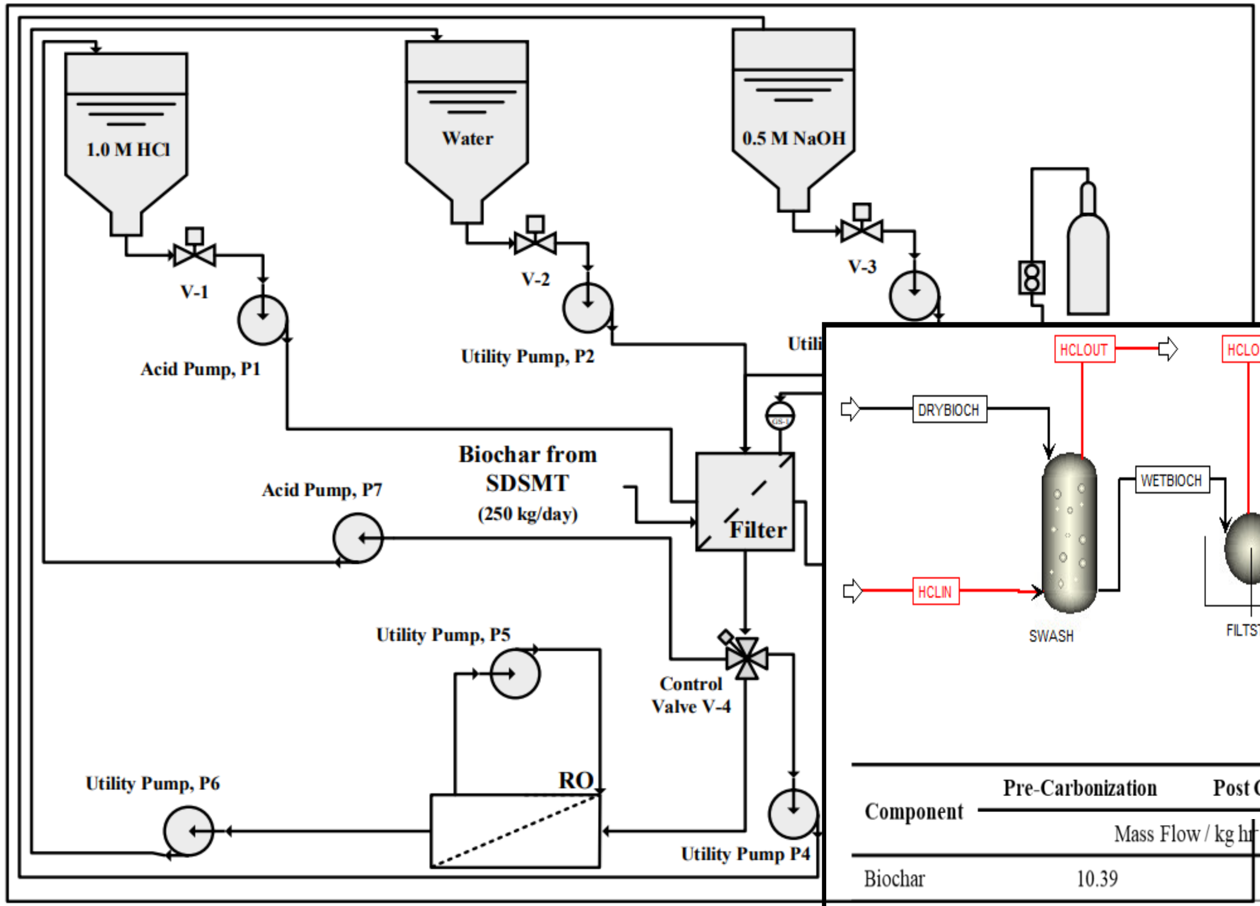
HTL Modelling ASPEN PLUS

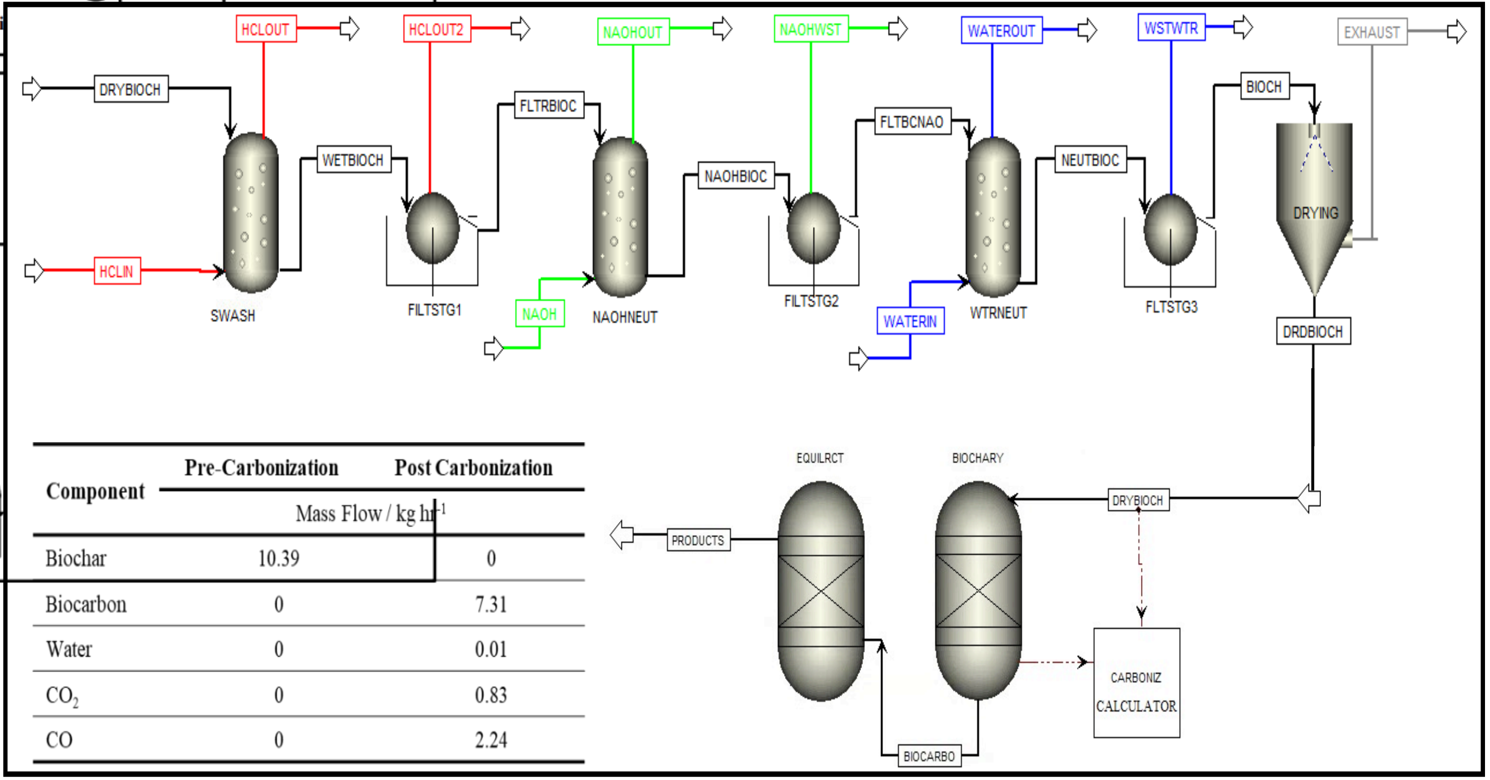




Raw material: UHS
HBO: 35 MJ/kg (based on GCMS)
Hydrochar: Carbon 100% basis

Hydrochar to Biocarbon – ASPEN Plus Modeling





Component	Pre-Carbonization	Post Carbonization
	Mass Flow / kg hr^{-1}	
Biochar	10.39	0
Biocarbon	0	7.31
Water	0	0.01
CO_2	0	0.83
CO	0	2.24

Hydrochar to Biocarbon – ASPEN Plus Modeling

At 10 ton/hour Capacity

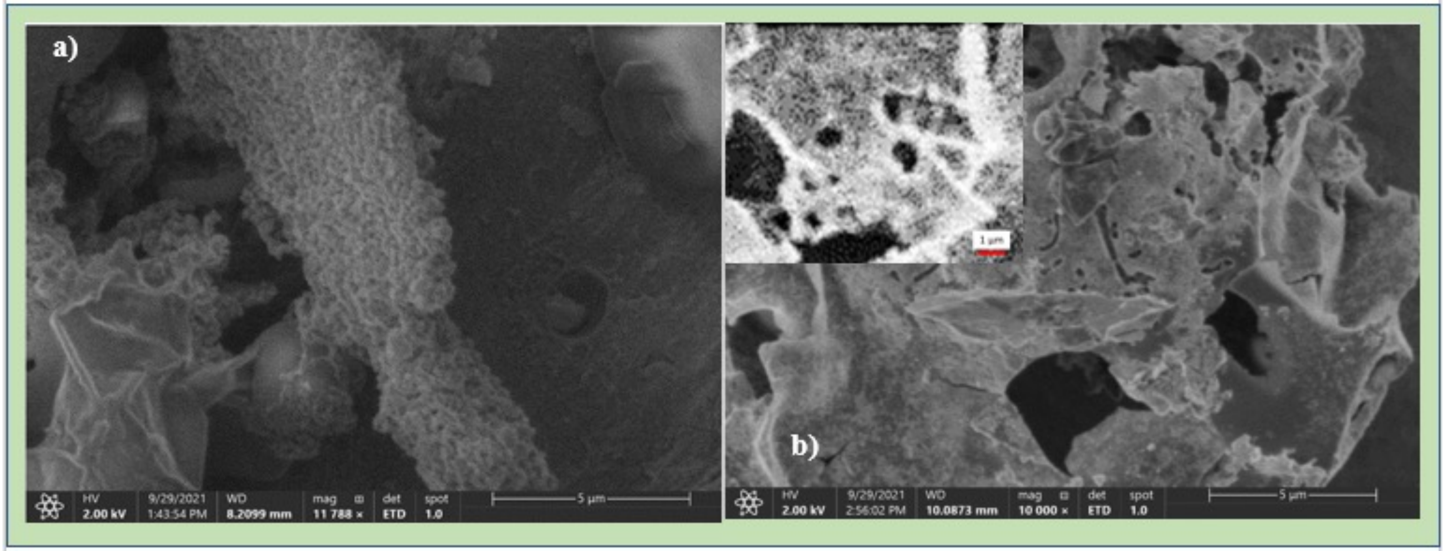
Pilot Scale Equipment	**Capacity**	**Material of Construction**	**Cost per unit**	**Company**
HCl Tank	200 gal	Plastic	$2,321	Tamco
Water Tank	500 gal	Plastic	$1,263	Ace Roto-Mold / Den-Hartog
NaOH Tank	100 gal	Plastic	$483	Tamco
Filtration Unit	85 kg	Hastelloy	$80,000	Nano-Mag
Box Furnace	4.2 cu ft	Multiple	$35,297	Grieve
Reverse Osmosis (pump incl.)	7,000 gal day^{-1}	Multiple	$7,190	Crystal Quest
Acid Pump X 2	50 GPM	Metal	$6,910	Magnatex Pumps
Utility Pump X 4	40.5 ft head	Metal	$208	Little Giant
Total			**$140,582**	

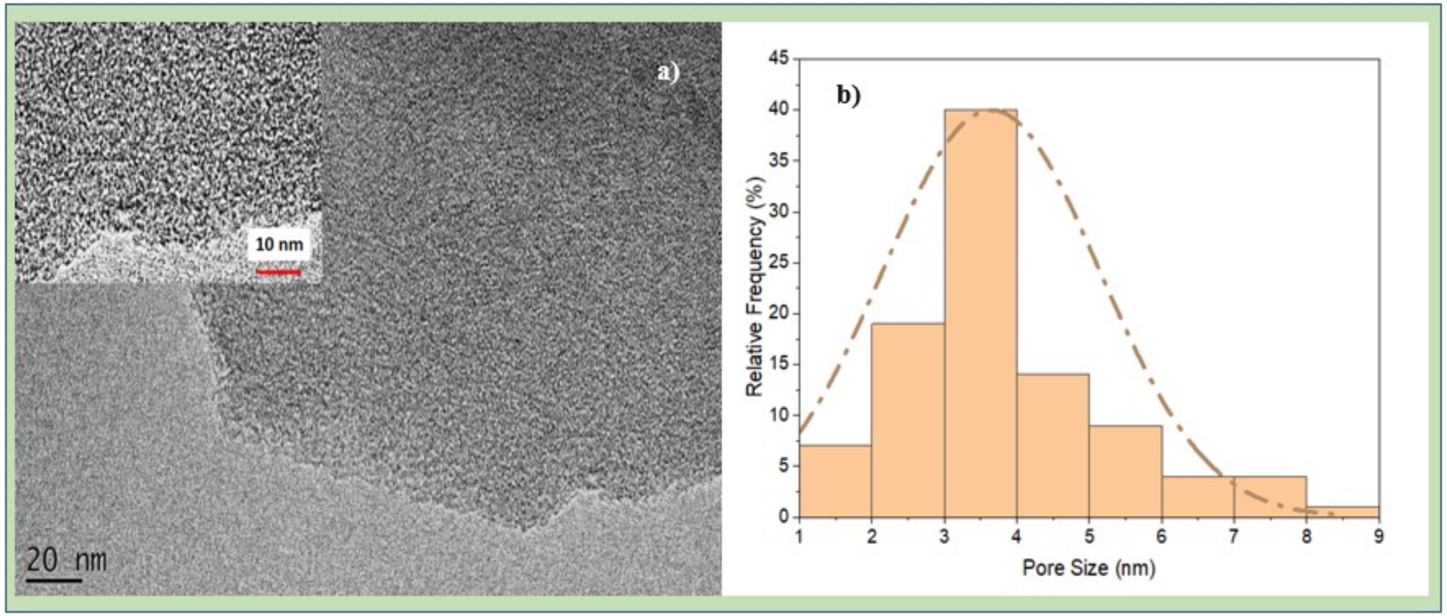
Description	**Manual Calculations**
Equipment Costs	$140,600
Installation Costs	$370,000
Total Capital Costs	$524,000
Utility Costs (yearly)	$28,100
Operating Costs (yearly)	$249,000
Yearly Return (Est.)	$330,000
Time to Payoff	7 yrs.

Graphitized carbon can be sold at $6-$20/kg
Total char feedstock = 87,600 kg
Biocarbon = 56,940 kg (C: avg. 85%)

Graphitized Carbon Characteristics

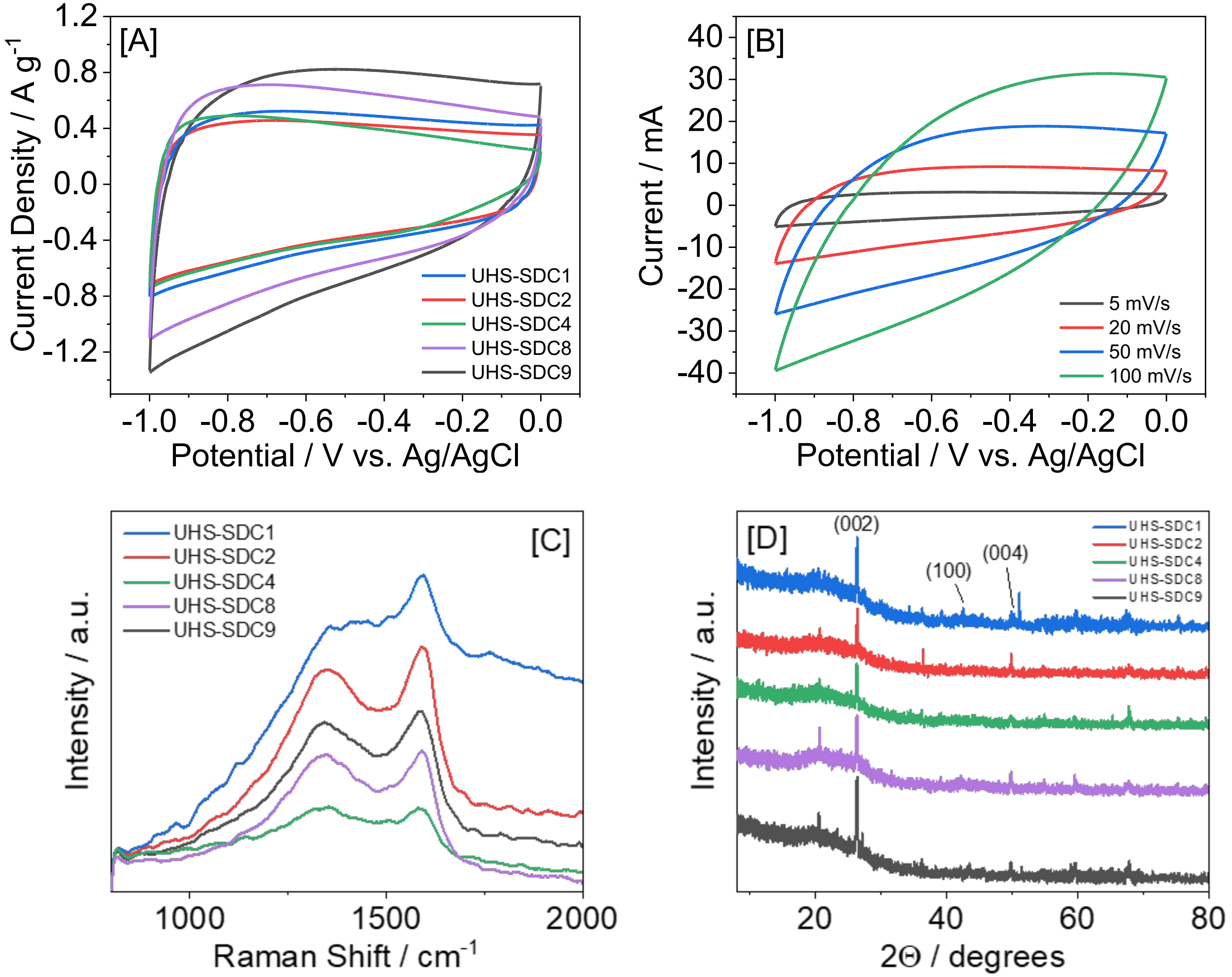
Quality – unique features
Raman microcrystalline size: 4 nm
Specific surface area: >2000 m^2/g
Avg. pore size: 2.2 nm
Pore volume: > 1.0 cm^3/g

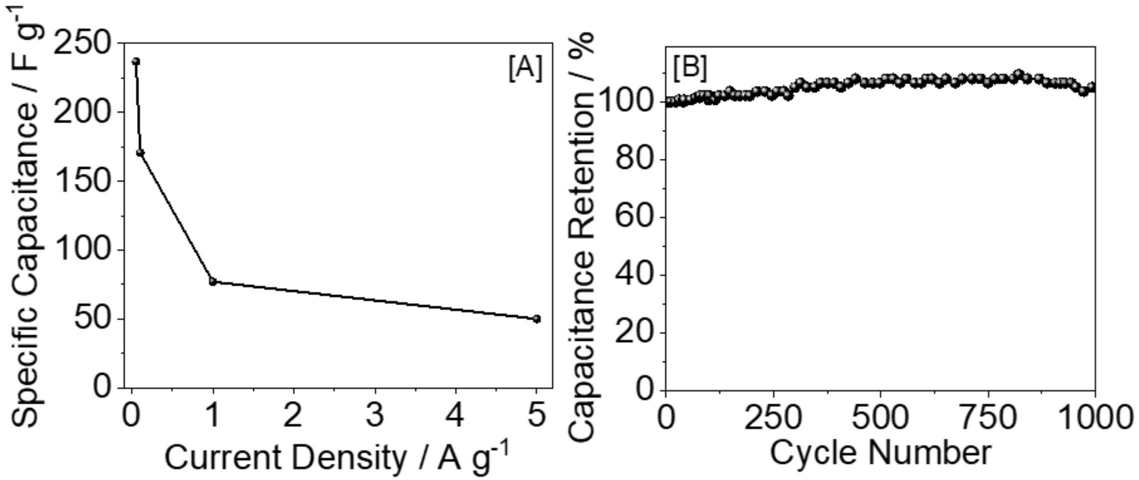




Amar et al., *Renewable Energy*, (2021)
Shell et al, I&EC (2021)
Amar et al., *Int. Journal of Energy Research* (2020)
Choudhary et al., *Advanced Materials* (2017)
Khang Huynh, MS Thesis (2022)
Bharath Maddipudi, PhD current (2023)
Huynh Khang, PhD current (2023)

Graphitization of biochar to biocarbon





Optimal processing conditions for graphitization

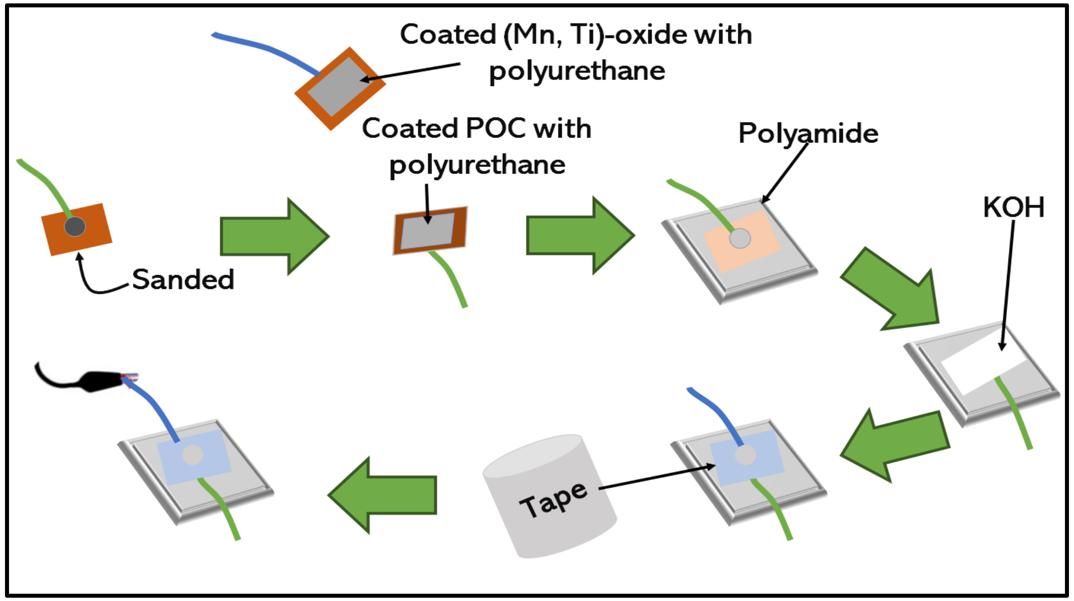
- Temperature: 850 °C
- Ramp rate: 5 °C min^{-1}
- Duration: 3 h
- Atmosphere: Argon (ultra high purity)

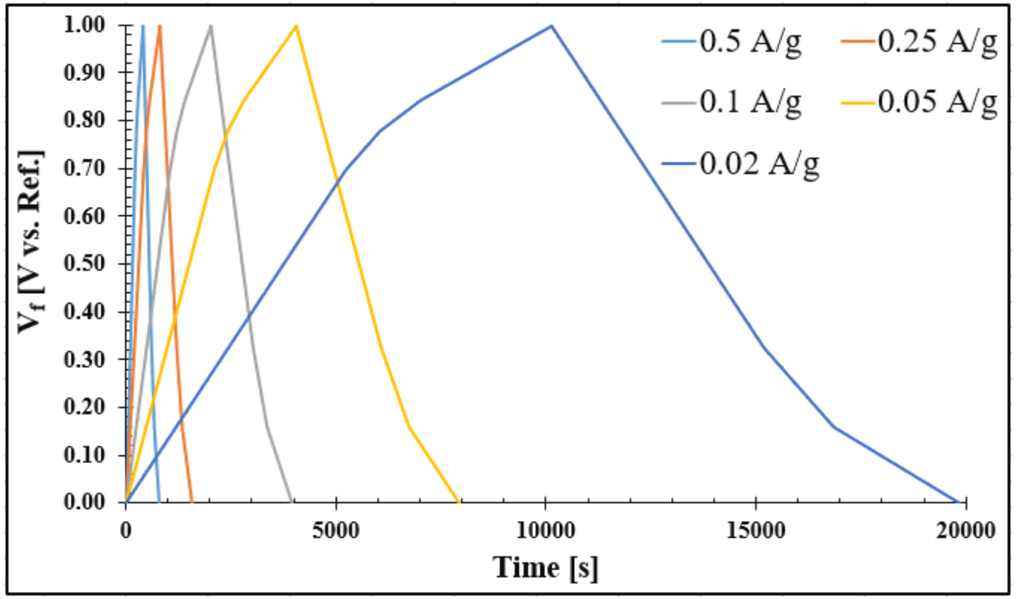
At optimal processing conditions, non-catalytic HTL of UHS derived biochar was processed to battery grade biocarbon and yielded a specific capacitance value of **242 F/g**.

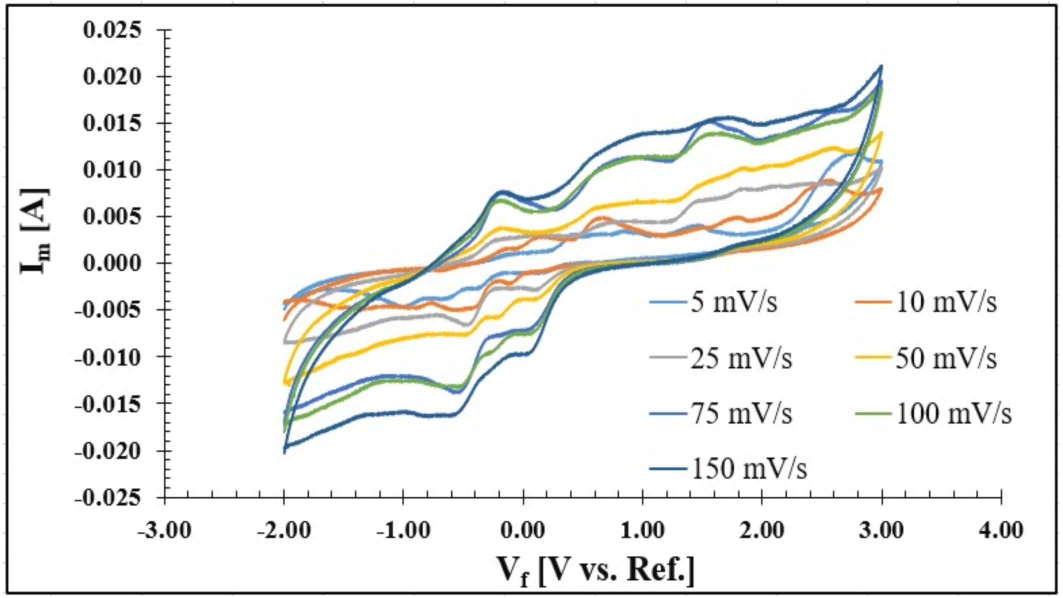
Electrochemical performance compares most closely with corn stover derived biocarbon (246 F g^{-1}) Jin et al. (2014).

Shell et al., *Bioresource Tech. Reports* (2021); Jin et al., *J of Analytical and Applied Pyrolysis* (2014); I&EC (2021)

Asymmetric Supercapacitors







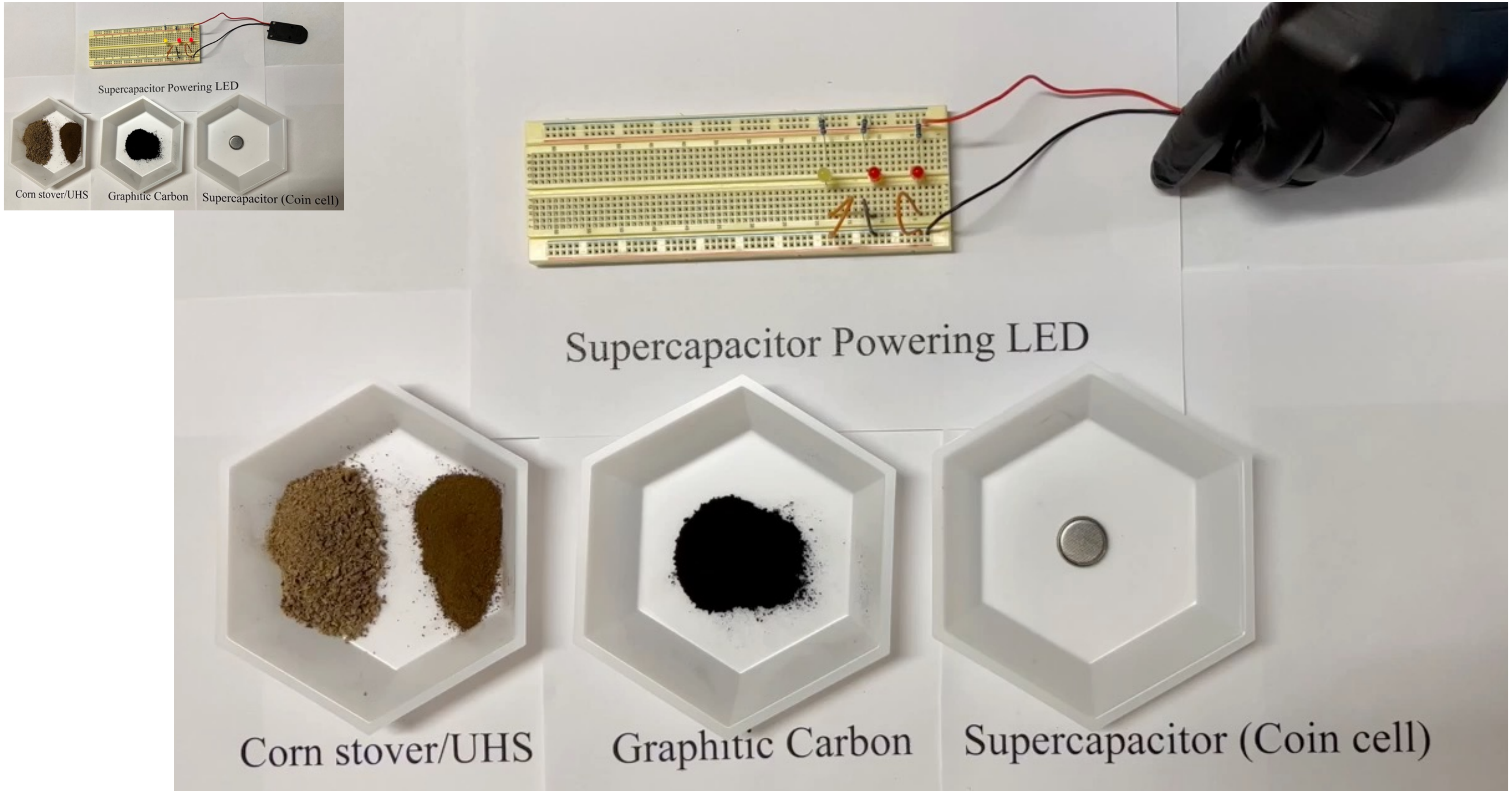
Specific capacitance: 310 F/g

Energy density: 43 Wh/kg

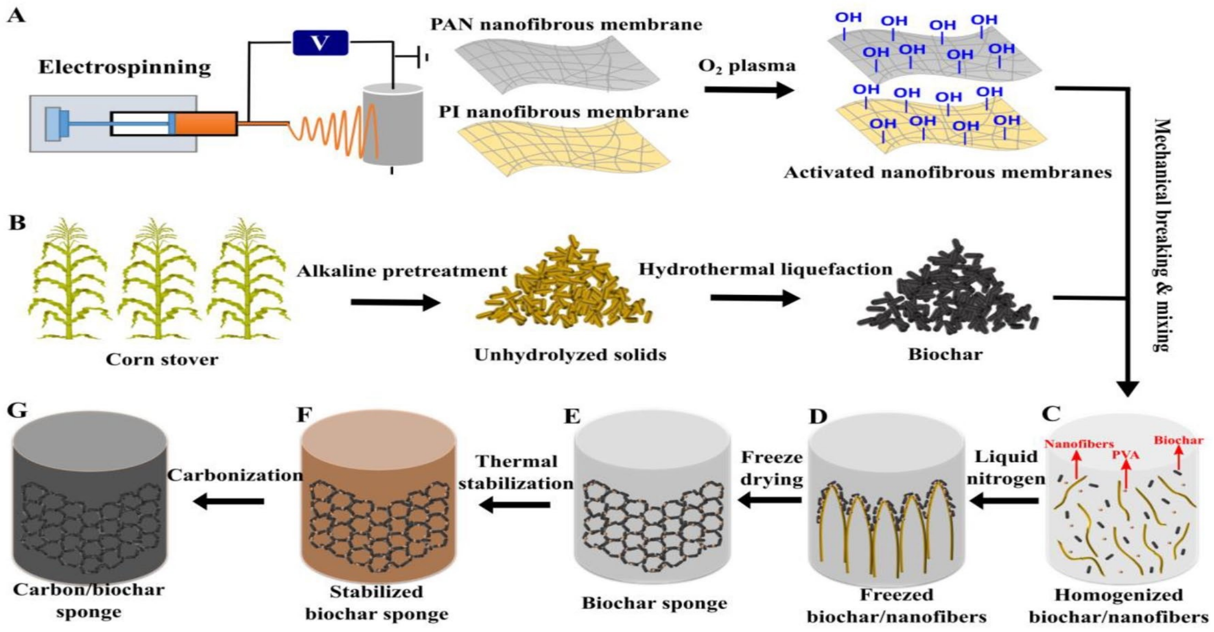
Power density: 1.99 kW/kg

Cyclic stability: >95% after 100 cycles

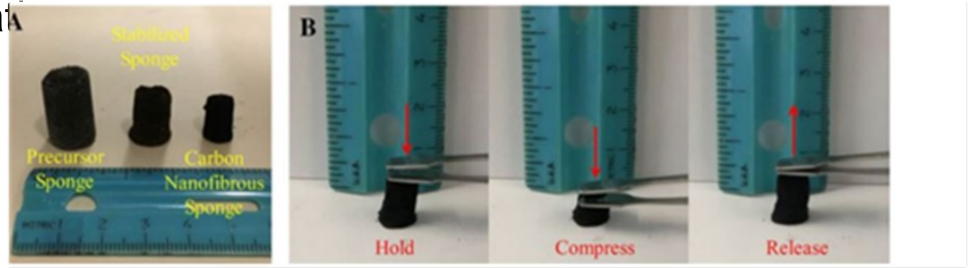
Carbon from Cornstover/UHS for Energy Storage

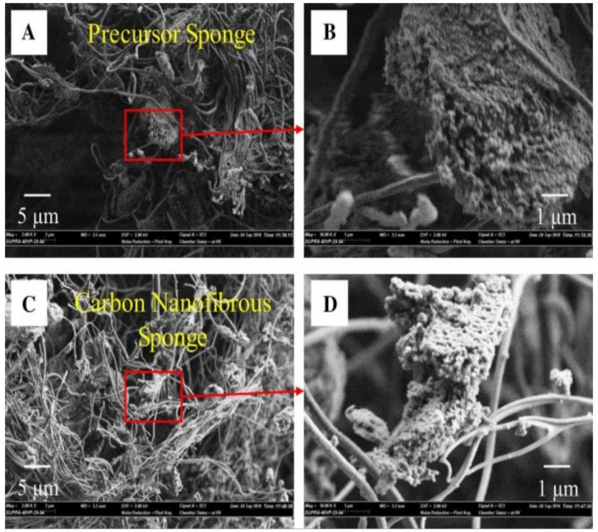


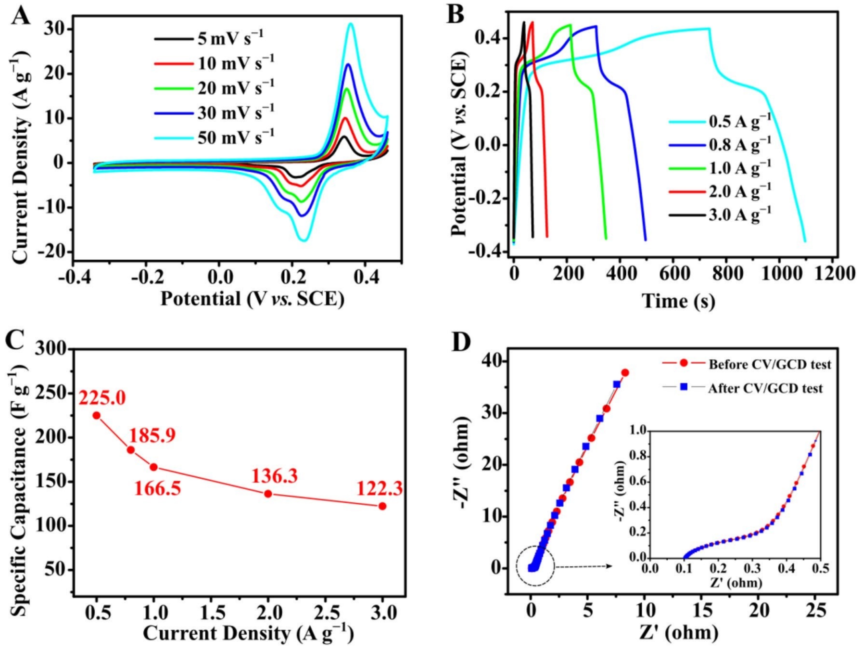
Process for Carbon Nanofibrous Sponge



A. electrospun PAN and PI nanofibrous membranes, **B.** Hydrothermally generated biochar particles, as well as the five steps in the fabrication of carbon nanofibrous sponge, **C.** Homogenization, **D.** Fast freezing, **E.** Freeze drying, **F.** Thermal stabilization, **G.** Carbonizat

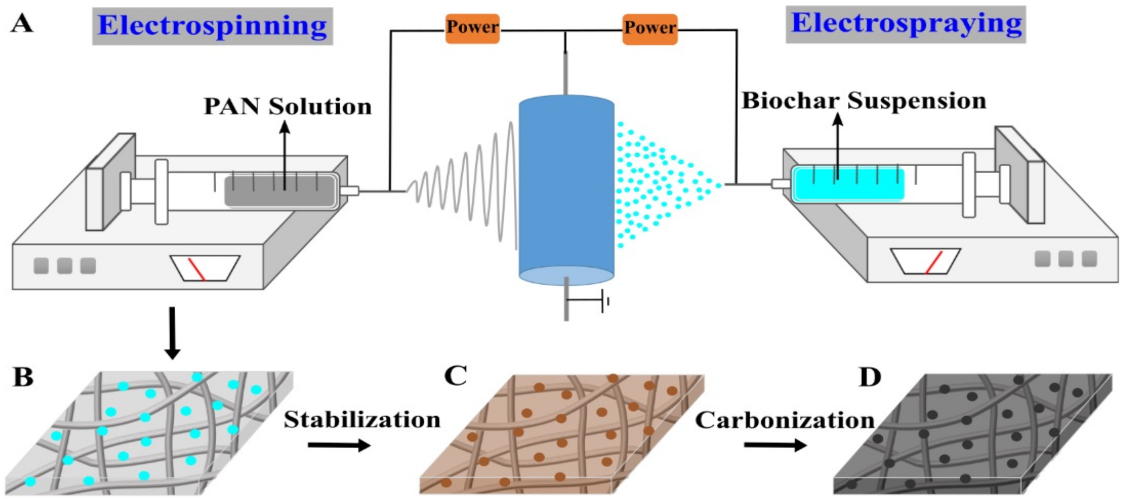


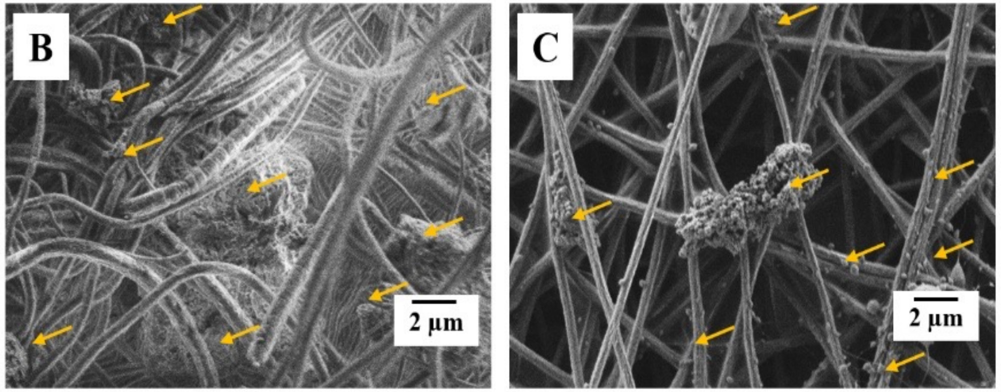




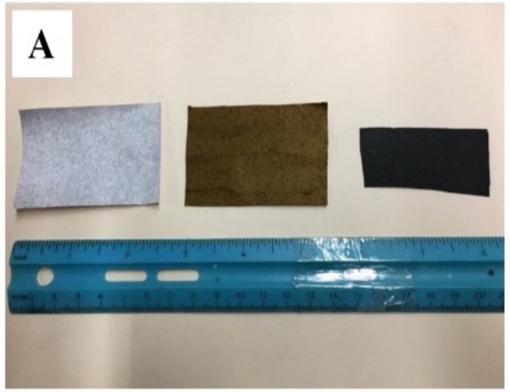
Tao et al., *Advanced Fiber Materials* (2020)

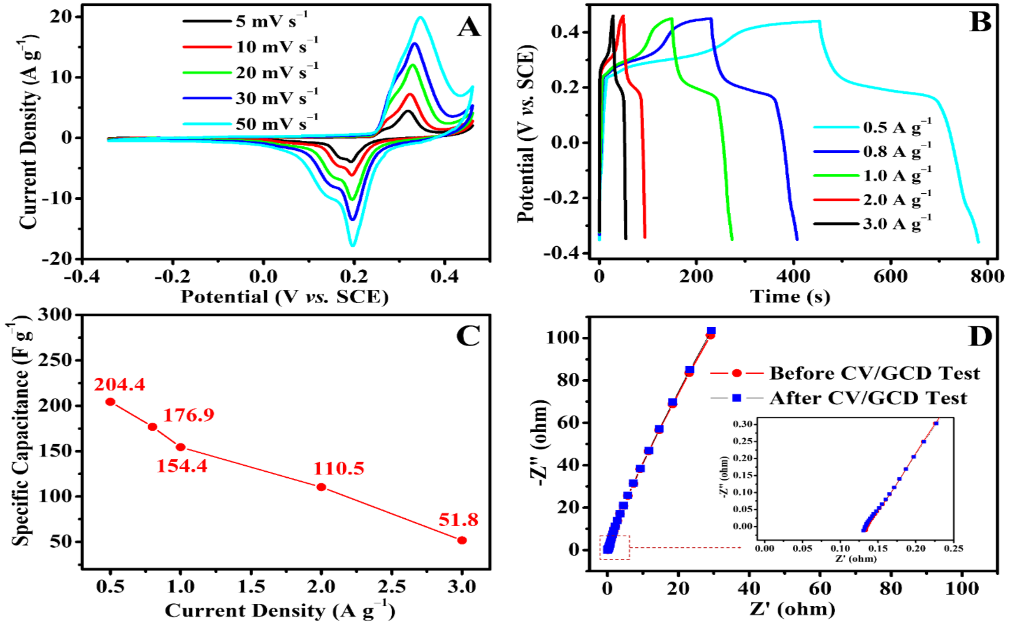
Preparation of Carbon Nanofibrous Felt





A. Simultaneous electrospinning and electrospraying, **B.** PAN/biochar precursor membrane, **C.** Stabilized membrane, **D.** Carbon nanofibrous felt.





Li et al., *Polymers*, 2021

3 – Impact (DOE/BETO)

- ❖ Directly impacting BETO’s Mission of developing cost-effective technologies for high-value products from waste streams

- ❖ Integrated technologies developed here will generate additional revenue stream from the value-added products and help meeting BETO’s 2022 target of $3/gge.

- ❖ Expected positive impact on the GHG emission, reduction by > 50%.

- ❖ Impacting readily available market with increasing demand for the high value products (in 2028) – biocarbon/ Graphitic carbon ($25.7 billion) carbon nanofibers ($1.7 billion), phenol ($27.2 billion), lactic acid ($2.43 billion)

3 – Impact (Partnerships and SD)

- Positively impacted collaboration among 3 universities, INL, and SwRI with future collaborations with NREL, PNNL and industries.

- Technology transfer to industries/commercialization- NEI corporation, Nanopareil LLC, Polykyala LLC and EIR at SDSMT ((https://www.sdsmt.edu/Research/Economic-Development/Entrepreneur-In-Residence-Program/)

- Publications: 13, presentations – 21 and invention disclosure – 1

- Positively impacting South Dakota with bioprocessing pilot scale facilities initiative.

3 – Impact (Outreach and Education)

- IBR related educational workshop activities are being planned for the local high school and Native American students (Summer 2023) (https://www.sdsmt.edu/learn/).

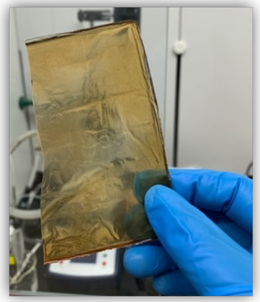
- Training undergraduate students at SD Mines (CBE 467) to develop process engineering design for integrated bioprocessing. Learning outcomes from the current research activities will be included in the elective courses (CBE485/CBE485L Renewable and Sustainable Energy lecture/lab courses).

- Positively impacting GRA and salary support to the graduate students, post-docs, and research associates at collaborating institutions.

- COVID-19 pandemic situation affected project schedule. Extension was requested to complete the remaining pilot scale trials.

Summary

Products:



Biocarbon Carbon nanofibers Polylactide

Total char feedstock = 87,600 kg
Biocarbon = 56,940 kg (C: avg. 85%)
Biocarbon can be sold at $6-$20/kg

Product for commercialization: A start-up company is interested in commercializing the **Biocarbon** for battery and supercapacitors

Hydrochar and lactic acid yields: 40 wt.% and 22 wt.%

Quality: Biocarbon (specific surface area ~2900 m^2/g), specific capacitance 225 - 310 F g^{-1} carbon nanofiber felt (up to 40 wt% hydrochar) and sponge (50% wt% hydrochar)

Response to FY-2021 Peer-Review Comments

Comment 1: Is this waste or a specialized solid product? Four products downselected to two?
Response: The focus of the proposed work is to utilize the waste streams generated from the biochemical technology platform and convert it into high-value products. It is expected that the revenue stream generated from these high-value products will reduce the fuel cost to meet the objective of $3/GGE. Originally, we proposed to derive four products—product 1, biocarbon; product 2, carbon nanofibers; product 3, phenol; and product 4, lactic acid—from the UHS recovered from the biochemical platform. Among these, products 1 and 2 are solid products, whereas products 3 and 4 are liquid side products. Product 1, biocarbon, which is also used for battery carbon electrodes, has outperformed in terms of specific capacitance (>300 F/g) and cyclic stability over 10,000 charging/discharging cycles. This type of carbon is currently being sold in the market at approximately $20,000/ton.

Weakness: This project is badly in need of industry advisors. The goals are not realistic,
Response: Currently, my team is working with commercial entities such as NEI Corporation, Nanopareil LLC, Polykala LLC, and Lonza Group AG. In addition, we have contacted the Office of Economic Development at the SDSMT to share technology concepts at the Entrepreneur in Residence program. This program offers entrepreneurship activities, business formation and networking, market trend analysis, team building, IP, etc. Many CEOs will be on the South Dakota School of Mines and Technology campus, and it is the PI's intent to meet these chief executive officers and present the technology concept, products, and their quality, and to seek guidance on the commercialization strategy. Our industry advisors will help us set up the commercial goals, market assessment, investments, and profit estimation. There was a business competition, our group won the best CEO competition award for the carbon product.

Quad Chart Overview

Timeline
- *Project start date: 07/01/2018*
- *Project end date: 01/14/2024 (tentative)*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$343,394*	$1,926,160
Project Cost Share *		$231,835

TRL at Project Start: 3
TRL at Project End: 5

*Only fill out if applicable.

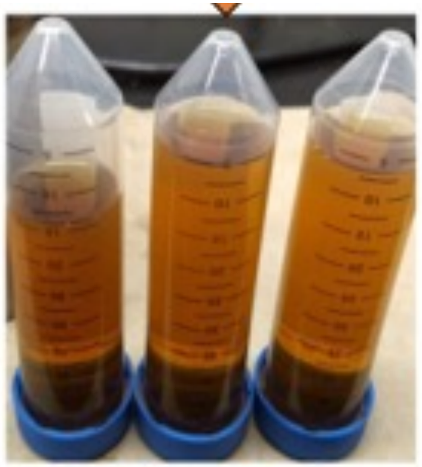
Project Goal
❖ Demonstrate production of high value products from solid waste generated during conventional biochemical processing at a pilot scale level with 1 tpd throughput.

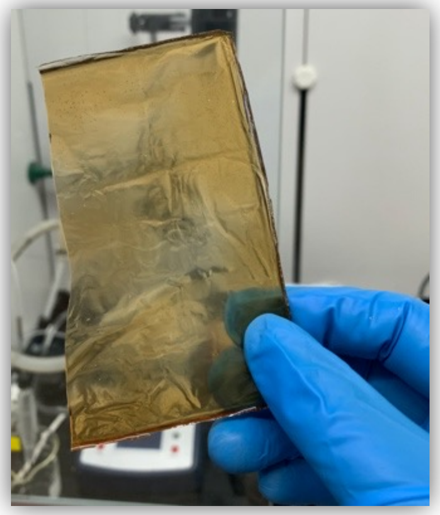
End of Project Milestone
~80%

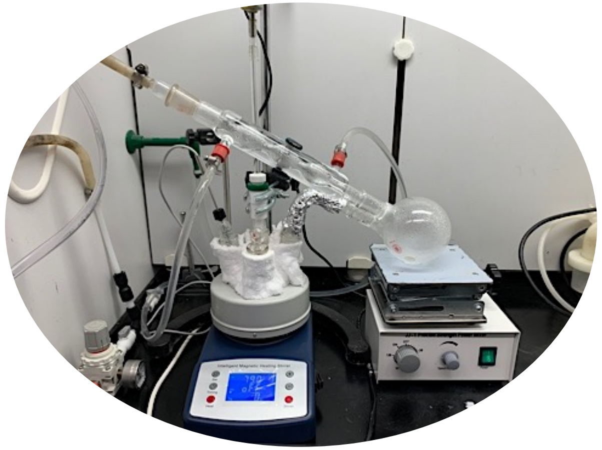
Funding Mechanism
FOA_DE-FOA-0001689_Optimization

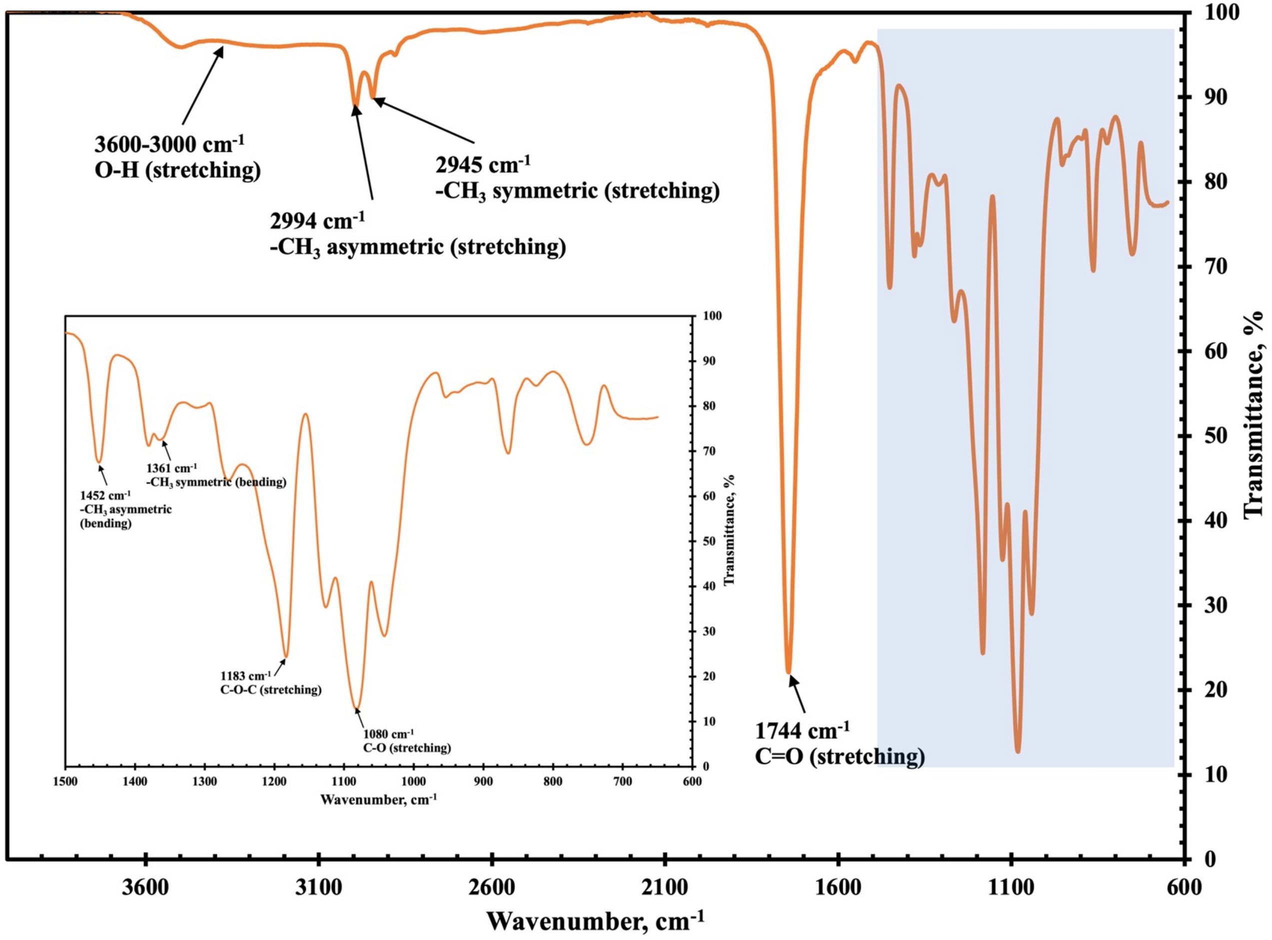
Project Partners*
- Virginia Commonwealth University
- Old Dominion University
- Idaho National Lab

Lactic Acid to PLA









Preprocessing: Biomass Feedstock National User Facility

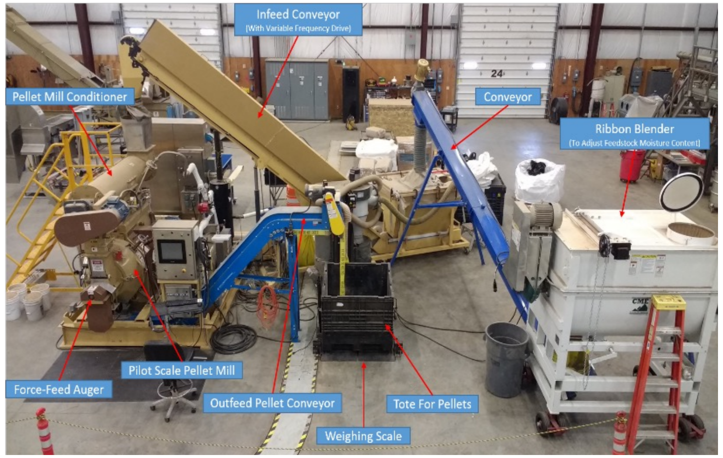


Table 3. Breakdown of modeled, estimated cost per ton of each unit operation for various preprocessing pathways using combined mechanical and chemical preprocessing [1,2,3].

Feedstock Pathways	Corn Stover Bale Preprocessing
Rotary Dryer (optional)	$12.50
Conveyor	$0.70
Mechanical Separation (optional sieving)	$1.00
Air Classifier (optional)	$2.81
Chemical Pretreatment and Drying	$29.15
Size Reduction	$17.21
Pelletization	$7.68

References

1. Hartley, D.S., Thompson, D.N., Cai, H. 2020. Woody Feedstocks 2019 State of Technology Report. Idaho National Laboratory. Idaho Falls, ID INL/EXT-20-57181. OSTI ID: 1607741
2. Hu, H., Westover, T.L., Cherry, R. et al. Process Simulation and Cost Analysis for Removing Inorganics from Wood Chips Using Combined Mechanical and Chemical Preprocessing. *Bioenergy Research* 10, 237–247 (2017).
3. Jaya Shankar Tumuluru, Kara G Cafferty, Kevin L Kenney. 2014. Techno-economic Analysis of Conventional, High Moisture Pelletization and Briquetting Process. ASABE Annual meeting, Paper #141911360, Montreal, Quebec Canada July 13 – July 16, 2014.

Publications

1. Shell, Katelyn; Amar, Vinod; Bobb, Julian; Hernandez, Sergio; Shende, Rajesh; Gupta, Ram 2021. **Graphitized Biocarbon Derived from Hydrothermally Liquefied Low-Ash Corn Stover**. *Ind. Eng. Chem. Res. 2022, 61, 392−402*
2. Amar, V.S., Houck, J.D., Maddipudi, B., Penrod, T.A., Shell, K.M., Thakkar, A., Shende, A.R., Hernandez, S., Kumar, S., Gupta, R.B. and Shende, R.V., 2021. **Hydrothermal liquefaction (HTL) processing of unhydrolyzed solids (UHS) for hydrochar and its use for asymmetric supercapacitors with mixed (Mn, Ti)-Perovskite oxides**. *Renewable Energy*, *173*, pp.329-341.
3. Shell, K.M., Rodene, D.D., Amar, V., Thakkar, A., Maddipudi, B., Kumar, S., Shende, R. and Gupta, R.B., 2021. **Supercapacitor performance of corn stover-derived biocarbon produced from the solid co-products of a hydrothermal liquefaction process**. *Bioresource Technology Reports*, *13*, p.100625.
4. Li, X., Xu, T., Liang, Z., Amar, V.S., Huang, R., Maddipudi, B.K., Shende, R.V. and Fong, H., 2021. **Simultaneous Electrospinning and Electrospraying for the Preparation of a Precursor Membrane Containing Hydrothermally Generated Biochar Particles to Produce the Value-Added Product of Carbon Nanofibrous Felt**. *Polymers*, *13*(5), p.676.
5. Thakkar, A., Shell, K.M., Bertosin, M., Rodene, D.D., Amar, V., Bertucco, A., Gupta, R.B., Shende, R. and Kumar, S., 2021. **Production of levulinic acid and biocarbon electrode material from corn stover through an integrated biorefinery process**. *Fuel Processing Technology*, *213*, p.106644.
6. K. Shell, B. Maddipudi, V. Amar, A. Thakkar, R.V. Shende, S. Kumar, and R.B. Gupta **Production of Supercapacitor Carbon Electrodes from Corn-stover via a Facile Thermal Activation**. *TechConnect briefs (2021)*
7. Amar, V.S., Houck, J.D. and Shende, R.V., 2020. **Catalytic HTL-derived biochar and sol-gel synthesized (Mn, Ti) -oxides for asymmetric supercapacitors**. *International Journal of Energy Research*, *44*(15), pp.12546-12558.
8. Amar, V., Houck, J., Maddipudi, B. and Shende, R., 2020. **NiFe2O4/ZrO2 Core-Shell Nanoparticles for Hydrogen Generation from Thermochemical Water-Splitting Process**. *J Catal Chem Eng Adv*, *7*(1), p.105.
9. Jaswal, R., Shende, A., Nan, W., Amar, V. and Shende, R., 2019. **Hydrothermal liquefaction and photocatalytic reforming of pinewood (pinus ponderosa)-derived acid hydrolysis residue for hydrogen and bio-oil production.** *Energy & Fuels*, *33*(7), pp.6454-6462.
10. Amar V.S., Shende A., and Shende R.V., 2019. **BTMO catalyzed hydrothermal liquefaction of lignocellulosic biomass**. *TechConnect Briefs*, pp.195-198.
11. V.S. Amar, J.D. Houck, and R.V. Shende, **"Sol-gel synthesis of mesoporous MnTi- oxides for Supercapacitors,"** *Supercapacitors: TechConnect Briefs (2019).*

Publications

12. Khang T. Huynh, Vinod S. Amar, Bharathkiran Maddipudi, Anuradha R. Shende, Rajesh V. Shende **KOH Activated Hydrothermal Liquefaction (HTL) Derived Hydrochar from Corn Stover as Electrode Material for Asymmetric Supercapacitor** (Under revision).

13. Huynh, K., Maddipudi, B., Amar, V., Houck, J., & Shende, R. **HTL Derived Biochar for Supercapacitor Electrodes**. In TechConnect World Innovation Conference, TechConnect Briefs, pp. 184-187, 2021

14. Huynh, K., Maddipudi, B., Amar, V., Bauer, G., Shende, A., & Shende, R. **Asymmetric supercapacitor fabricated with ferrite/CHTL-derived hydrochar electrodes**. In TechConnect World Innovation Conference, TechConnect Briefs, pp. 130-133, 2022.

15. Valorization of corn stover derived unhydrolyzed solids to value added products via non-catalytic hydrothermal liquefaction at non-catalytic optimized processing conditions, Chemical Engineering Journal, February 2023 (under preparation).

16. Optimization of catalytic hydrothermal liquefaction of lignin rich unhydrolyzed solids and extraction of value-added products. Bioresource Technology, February 2023 (under preparation).

Awards

1. Secured 1st place in SD Mines CEO Business plan competition with proposed plan in turning corn stover into a valuable form of biocarbon.
   Ref: https://www.sdsmt.edu/News/2022-CEO-Business-Competition/#.Y_Miuy-B1qs

Presentations

1. Bharathkiran Maddipudi, Khang Huynh, Vinod Amar, Anuradha Shende, Grant Bauer, Rajesh Shende, **Hydrothermal co-liquefaction of crop residue and plastic waste for sustainable production of oil and hydrochar**, TechConnect World Innovation Conference, June 13-15, 2022, Washington, DC, USA.
2. Vinod Amar, Bharathkiran Maddipudi, Grant Bauer, and Rajesh V. Shende, **Core-shell and immobilized ferrite nanoparticles for CO2 free sustainable hydrogen production via thermochemical water-splitting process**, TechConnect World Innovation Conference, June 13-15, 2022, Washington, DC, USA.
3. Khang Huynh, Bharathkiran Maddipudi, Vinod Amar, Anuradha Shende, Rajesh Shende, **Asymmetric supercapacitors fabricated with ferrite/CHTL-derived hydrochar electrodes**, TechConnect World Innovation Conference, June 13-15, 2022, Washington, DC, USA.
4. Khang Huynh, Bharath Maddipudi, Anuradha Shende, Rajesh Shende**, Effect of surfactant on HTL derived hydrochar physicochemical characteristics** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
5. Khang Huynh, Bharath Maddipudi, Anuradha Shende, Rajesh Shende **Glycerol as a co-solvent for hydrothermal liquefaction of corn stover** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
6. Khang Huynh, Bharath Maddipudi, Anuradha Shende, Rajesh Shende **Sol-gel synthesis of doped (Mn, Ti)-oxides for asymmetric supercapacitors** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
7. Bharathkiran Maddipudi, Khang Huynh, Vinod Amar, Anuradha Shende, and Rajesh Shende **Catalytic hydrothermal liquefaction of lignocellulosic biomass for fuels and value-added products.** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
8. Bharathkiran Maddipudi, Khang Huynh, Paiton Mueller, Rajesh Shende. **Surfactant assisted hydrothermal liquefaction of corn stover.** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
9. Bharathkiran Maddipudi, Khang Huynh, Vinod Amar, Katelyn Shell, Anuj Thakkar, Anuradha Shende, Sergio Hernandez, John Aston, Sandeep Kumar, Ram Gupta, Rajesh Shende **TEA/LCA of integrated biochemical and hydrothermal processing of corn stover for fuels and high value products** 2022 AIChE Annual Meeting, Nov 13-18, 2022.
10. Bharathkiran Maddipudi, Vinod S. Amar, Khang Huynh, Anuj Thakkar, Katelyn Shell, Runzhou Huang, Sergio Hernandez, Sandeep Kumar, Ram Gupta, Hao Fong, Anuradha Shende, and Rajesh Shende, **Integrated Biochemical and Hydrothermal Processing of Corn Stover for Fuels and High Value Products**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.
11. Max Lampert, Bharathkiran Maddipudi, Vinod S. Amar, Anuradha Shende, and Rajesh Shende, **Evaluation of Ultrasonic Pretreatment on Catalytic Hydrothermal Liquefaction of Woody Biomass**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.

Presentations

13. Vinod S. Amar, Bharath Maddipudi, Anuradha Shende, and Rajesh Shende, **Thermally Induced Two-step Chemical Looping Process for Hydrogen, Syngas, and Ammonia Production**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.
14. Khang Huynh, Bharathkiran Maddipudi, Vinod S. Amar, Anuradha Shende, and Rajesh Shende, **Fabrication and Testing of Asymmetric Supercapacitors Fabricated with (Mn, Ti)-Oxides and CHTL Derived Hydrochar/Graphene**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.
15. Khang Huynh, Bharathkiran Maddipudi, Vinod S. Amar, Anuradha Shende, and Rajesh Shende, **Adsorption Kinetics Studies of Catalytic HTL Derived Biochar**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.
16. Katelyn Shell, Vinod Amar, Sergio Hernandez, Rajesh Shende and Ram Gupta, **Electrochemical Studies on Graphitized Biocarbon Derived from Hydrothermally Liquefied Low Ash Content Corn Stover**, AIChE Annual Meeting, Nov 7 – Nov 11, 2021, Boston, MA.
17. K. Shell, V. Amar, B. Maddipudi, A. Thakkar, R. Shende, S. Kumar, and R.B. Gupta, **Production of Supercapacitor Carbon Electrodes from Corn-stover via Facile Thermal Activation**, TechConnect World Innovation Conference and Expo, Oct 18 – Oct 20, 2021, National Harbor, MD.
18. B. Maddipudi, V. Amar, H. Dosch, A. Shende, and R. Shende, **Fabrication of a rapid Response On-chip Biosensor**, TechConnect World Innovation Conference and Expo, Oct 18 – Oct 20, 2021, National Harbor, MD.
19. J.D. Houck, V.S. Amar, and R.V. Shende, **Nanocomposites of Mesoporous (Mn, Ti)-Oxides and Graphene Nanoplatelets for Charge Storage**, TechConnect World Innovation Conference and Expo, Oct 18 – Oct 20, 2021, National Harbor, MD.
20. V. Amar, K. Huynh, B. Maddipudi, K. Shell, J. Houck, A. Thakkar, R.B. Gupta, S. Kumar, S. Hernandez, A. Shende and R.V. Shende, **HTL Derived Biochar for Supercapacitor Electrodes**, TechConnect World Innovation Conference and Expo, Oct 18 – Oct 20, 2021, National Harbor, MD.
21. Abu Md Numan-Al-Mobin, Bharath Maddipudi, Vinod S. Amar, Rajesh V. Shende and Hao Fong, **Effect of Biochar Loading on Carbon Nanofibrous Sponge Produced from Biochar and Electrospun Polymer Nanofiber**, TechConnect World Innovation, Washington DC, Jun 13-15, 2022.