DOE Bioenergy Technologies Office (BETO) 
2019 Project Peer Review

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

Date: March 4-8, 2019
Technology Session Area Review

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

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Goal Statement

- Demonstrate production of high value products from waste streams, as given below, generated during conventional biochemical processing at a pilot scale level with 1 tpd throughput.
  - Aqueous waste stream (I) from alkaline pretreatment of corn stover
  - Solid waste residue (I), unhydrolyzed solids (UHS)
  - Aqueous waste stream (II) from hydrothermal processing
  - Biochar waste (II)

Outcomes: i) Four products from solid waste and aqueous waste, which include biocarbon, carbon nanofibers, lactic acid/PLA and phenols and ii) inclusion of revenues derived from these products into TEA and LCA demonstrating BETO’s 2022 cost target of $3/gge with >50% reduction in GHGs emission.
Tasks and Key Milestones

<table>
<thead>
<tr>
<th>TASK/KEY MILESTONE</th>
<th>FY 2018</th>
<th>FY 2019</th>
<th>FY 2020</th>
<th>FY 2021</th>
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<td>Task 1 Initial validation</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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NOTE: GREEN lines and text indicate Active Status; BLUE lines and text indicate Inactive Status

START DATE

3 Bioenergy Technology Office
# Project Budget Table

<table>
<thead>
<tr>
<th>Budget Periods</th>
<th>DOE Funding</th>
<th>Project Team Cost Shared Funding</th>
<th>Contingency</th>
<th>Project Spending to Date</th>
<th>Remaining Balance</th>
<th>Final Project Costs</th>
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*FFRDC $ / % BP-1 $1000 / 1% *FFRDC $ / % BP-2 $159,000 / 7%
Quad Chart Overview

Timeline
- Project start date: 07/01/2018
- Original project end date: 06/30/2021
- Percent complete: Still under validation

Barriers
- Barriers addressed
  - Ct-J: Identification and Evaluation of Potential Bioproducts,
  - Ct-K: Developing Methods for Bioproduct Production, and
  - ADO-A: Process Integration

Budget

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<tr>
<th></th>
<th>Total Costs Pre FY 17</th>
<th>FY 17 Costs</th>
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<th>Total Planned Funding (FY 19-Project End Date)</th>
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Partners
- Tyler Westover, Idaho National Laboratory (INL)
- Ram Gupta, Virginia Commonwealth University (VCU)
- Sandeep Kumar, Old Dominion University (ODU)
- Hao Fong, South Dakota School of Mines & Technology (SDSMT)
- Southwest Research Institute
## Project Overview

### Common problems
- Lignin/solid residue and acids land up in waste stream during biochemical processing
- Phenols and organics acids also found in waste stream of thermochemical processing
- Valuable carbon resource is wasted in solids and aqueous wastes
- Recovery and treatment of wastes do not contribute to offset the fuel costs

### Proposed solution
- If wastes are converted into high value products, it will offset the fuel cost
- *Novel* approach of integrated technologies for solid waste conversion into biocarbon and carbon nanofibers, and aqueous waste conversion into lactic acid and phenols
- Reduce solid waste, utilize aqueous phase carbon, generates products that will reduce fuel cost
This project provides-
Data/results for i) technology development for the conversion of solid waste (UHS) derived from corn stover into biocarbon and carbon nanofibers and enrichment of aqueous waste with lactic acid and phenols, ii) pilot scale testing at 1 tpd throughput, and iii) TEA and LCA

Application of products in other industries
Batteries, EMI shielding, heat management, conductors, capacitors, packaging, agriculture, transport, electronics, textiles etc

Market price of the products (2016)
- Biocarbon > $3/kg
- Carbon nanofibers ~ $1200/kg
- Polylactide (PLA) ~$4/kg
- Phenol ~ $1/kg
2 – Approach Technical: Summary

1. Develop integrated technology platform to effectively process wastes derived from corn stover processing into solid and liquid products
2. Characterize the products yield and quality
3. Perform TEA and LCA and estimate fuel costs in terms of $/gge

Bench scale
- Physical tests
- Characterization
- Mass/energy balance

Pilot scale
- 1 tpd throughput
- Characterization
- Mass/energy balance
- TEA and LCA

Diagram:
- Alkaline pretreatment
- Enzymatic hydrolysis
- Unhydrolyzed solids, UHS (I)
- Feedstock preprocessing
- Hydrothermal processing (N\textsubscript{2} or CO\textsubscript{2})
- Solid waste biochar (II)
- Aqueous waste stream (I)
- Aqueous waste stream (II)
- Wet oxidation
- Biocarbon (Product 1)
- Carbon fiber mat (Product 2)
- Phenols (Product 4)
- LA/PLA (Product 3)
2 – Approach (Technical)

**Challenges**
- Products yield and quality at a pilot scale
- Suitability of char produced at a pilot scale for biocarbon and carbon nanofibers
- Effectiveness of wet oxidation on liquid side co-products
- Transport of UHS and aqueous waste

**Key success factors**
- % agreement between lab and pilot scale trials
- In-depth estimation of revenue from the products

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![Flowchart](attachment:flowchart.png)

- **Feedstock Preparation** (INL, Pilot Scale) 1 TPD
- **Alkaline Pretreatment** Pilot (INL), Lab (ODU)
- **Enzymatic Hydrolysis** Pilot (INL), Lab (ODU)
- **Hydrothermal Liquefaction** Pilot (SDSMT)
- **Wet Oxidation** (SDSMT)
- **Biochar** (1) (VCU)
- **Biocarbon** (2) (SDSMT)
- **Nanofibers** (2) (SDSMT)
- **UHS**
- **Hydrothermal processing**
- **Phenols (4)** (SDSMT)
- **Lactic Acid/Polylactide (3)** (SDSMT)
- **Aqueous Waste (I)**
- **Aqueous Waste (II)**
Biocarbon (product-1)

Carbon nanofibers (product-2)

2 – Approach (Technical)

Lactic acid and phenols (products 3 & 4)

2 – Approach (Management)

- **Validation visits: plan and coordinate**
  - SDSMT&T, ODU and VCU

- **Task leadership: plan, prioritize, coordinate, review progress**
  - Bi-weekly team coordination meetings
  - Bi-weekly team coordination meetings with DOE personnel
  - Quarterly BETO review meeting

- **Create and follow approved management plans**
  - Milestones (quarterly) and deliverables
  - Performance metrics

- **Responsibilities**
  - Corn stover preprocessing and pilot scale alkaline pretreatment and enzymatic hydrolysis (1 batch): Tyler Westover
  - Alkaline pretreatment and enzymatic hydrolysis (lab scale): Sandeep Kumar
  - Hydrothermal liquefaction and wet oxidation (lab and pilot): Rajesh Shende
  - Conversion of char into biocarbon (lab): Ram Gupta, (pilot) Mark Feng
  - Conversion of char into carbon nanofibers (0.5-1 kg/day): Hao Fong
3 – Technical Accomplishments/progress/Results

New project
- Start date 07/01/2018
- Project is currently under verification phase
  (IE completed verification for ODU and VCU sites; Feb 19 – Feb 21, 2019 SDSMT site)

Progress
- SDSMT Site is being prepared for the visit
- Laboratory and analytical equipment are being tested
- Personnel are being trained to master processes
- Experimental work- INL has prepared and delivered 2 kg of pelletized corn stover. ODU is performing alkaline pretreatment and enzymatic hydrolysis. SDSMT is working on hydrothermal liquefaction of corn stover derived UHS to establish baseline values for different products.
4 – Relevance

Enabling biofuels by developing technologies for high value products from biochemical waste processing

- Directly supporting BETO’s Mission:
  - Developing cost effective technologies for bio-based products to economically leverage production of hydrocarbon fuels
  - Developing technologies for converting waste streams into high value products is in DOE/BETO programmatic interests
  - Proposed products will offset fuel cost meeting BETO’s 2022 cost target of $3/gge.

- Project metrics and targets are driven by TEA and LCA
4 – Relevance

Market potential of the products

- **Biocarbon** 22 kt/y of graphite will be required for the 0.5 million estimated batteries (70 kWh) by 2020.
- **Carbon nanofibers** $1 billion by 2021 at CAGR 24-25%
- **Lactic acid/PLA** Lactic acid 1961 kt and $3.82 billion by 2020 (CAGR 18.6%) and PLA $5.16 billion by 2020 (CAGR 20.9%)
- **Phenols** $19.78 billion by 2026 at CAGR 4.6%


5 – Future Work: Overview

Project will address following areas:

- Thorough bench scale experimentation for waste conversion and characterization of different liquid and solid products
- Pilot scale testing of waste conversion technologies for high value products with throughput of 1 tpd
- Desired char characteristics for further conversion into biocarbon and carbon nanofibers
  - highly dependent on hydrothermal processing conditions
  - bench scale trials are successful but pilot scale need to be verified
- Enrichment of lactic acid by wet oxidation
  - bench scale experiments are needed to validate wet oxidation with biochemical aqueous streams
- In-depth TEA and LCA, and estimation of fuel cost by taking into account revenue generated from the products
5 – Future Work: Overview

Process/product optimization
5 – Future Work: Timeline

- Project validation 3 months

- Next 18 months: Bench scale experiments with corn stover
  - alkaline pretreatment and enzymatic hydrolysis
  - hydrothermal liquefaction of UHS
  - wet oxidation of aqueous streams
  - preparation of biocarbon and carbon nanofibers
  - characterization of different products

- Next 15 months: Bench/pilot scale experiments with corn stover
  - pilot scale alkaline pretreatment and enzymatic hydrolysis
  - pilot scale hydrothermal liquefaction of UHS
  - >lab - <pilot scale wet oxidation of aqueous streams
  - pilot scale preparation of biocarbon
  - >lab - <pilot scale preparation of carbon nanofibers
  - pilot scale pump flow characteristics for UHS (15-20 wt% loading)
  - characterization of different products
Summary

Overview: This is a new project, which is currently under verification phase. Site verification for ODU and VCU sites have been completed. SDSMT site verification is planned from Feb 22 through Feb 24.

Approach: Technical approach includes development of integrated technology platform to effectively convert wastes derived from corn stover processing into solid and liquid products, characterization of the products, and TEA and LCA.

Technical Accomplishments/Progress/Results: INL has preprocessed corn stover with a hammer mill. ODU has performed alkaline pretreatment and enzymatic hydrolysis with this material on a lab scale. Hydrothermal liquefaction of corn stover derived UHS is being carried out at SDSM&T.

Relevance: Enabling biofuels by developing technologies for high value products from biochemical waste processing.

Future work: Project validation, followed by bench scale and pilot scale waste conversion technology development for high value products.
Additional Slides
Publications, Patents, Awards, and Commercialization

This project: None so far as this project is newly awarded

Previous related project (few examples):

Status of technology transfer (commercialization): None
Commercialization plan

- Technology transfer activities are planned with the commercial entities to explore marketability of the products derived from the waste streams. Initial correspondence has been established.

- With Entrepreneur In Residence (EIR) program at SDSMT (and similar activities at partnering institutions), a successful plan will be developed for large scale product development systems for the waste streams originated in integrated biorefineries.

- Partnership with NREL for future large scale trials.
Risks and Improvement Areas

Risks
1. Project is 3 years of focused effort on process/product optimization and pilot scale demonstration with 1 tpd throughput
2. Coordination among partnering institutions to ship the required materials for the next stage of processing
3. Technical risks such as product yields and characteristics of final products derived at the pilot scale

Mitigation Plan/Strategies
1. Need better planning and prompt communication to address the expectations
2. Focus on bench scale optimization in the initial phase and develop strategies from the beginning of the project for pilot scale testing
3. Simplify technology platform processing and product analysis