2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

US-India Consortium For Development of Sustainable Advanced Lignocellulosic Biofuels Systems

Date: May 22, 2013
Technology Area Review: Biochemical Conversion

Dr. Pratap Pullammanappallil, University of Florida

Dr. Shibu Jose, University of Missouri

Dr. Janaki Alavalapati, Virginia Tech

Goal Statement

The project goals:

- Sustainable switchgrass feedstock development using marginal lands.
- Biochemical conversion of switchgrass hydrolysate to butanol via butyric acid.
- Demonstrate production of biofuels at pre-commercialization scale.
- Demonstrate recovery and utilization of products from biofuel production residues.
- Life cycle, economic and supply chain analysis of feedstocks and biofuel.

Project also address the second generation biofuel R&D priority area of the US – India Joint Clean Energy Research and Development Center.

Quad Chart Overview

Timeline

- Project Start Date- September 19, 2012
- Project End Date - September 18, 2017
- Percent Complete- 7%

Budget

- Funding for FY11 - None
- Funding for FY12(1,179,151 / 1,363,375)
- Funding for FY13 (1,397,702/1,193,088)
- Years the project has been funded - One/$1,179,151

Barriers

- Barriers addressed
- Ft-B Sustainable Production: Existing data on the productivity and environmental effects of biomass feedstock production systems and residue collection are not adequate to support lifecycle analysis of biofuels
- Bt-J Catalyst Development: There is a need for biological or chemical catalysts that can convert the sugar mixture and inhibitors in the hydrolysate broth derived from biomass pretreatment and hydrolysis for the production of advanced biofuels, bioproducts, and fuel intermediates. Improvement in the robustness of catalysts, e.g. bacterial, fungal, algal, or chemical, and their ability to perform in hydrolysate broths can lead to significantly lower capital costs.
- Bt-K Biological Process Integration: Process integration remains a key technical barrier hindering development and deployment of biochemical conversion technologies.

Partners

- University of Florida, University of Missouri, Virginia Tech, Montclair State University, Texas A&M, Show Me Energy LLC, Green Technologies LLC and institutions and industry in India

Project Overview

Overall Goal

- To address second generation biofuel R&D priority area of the US-India Joint Clean Energy Research and Development Center

Technical Goals of the US team

- To develop and demonstrate commercially scalable ligno-cellulosic biofuels through:

  ✓ Sustained feedstock cultivation and supply

  ✓ Engineered biocatalyst and novel processes for biofuel production

  ✓ Environmentally and economically sustainable practices

1.1 - Approach

FEEDSTOCK DEVELOPMENT

University of Missouri, University of Florida, Show Me Energy LLC

By employing field-scale flood and drought tolerance labs and multi-location field trials

1. Improve feedstocks using genomics-assisted breeding and identify locally adapted cultivars, and their optimization for large-scale production

    - Improve Biomass and Sugar Yield
    - Improve Drought and Flood Tolerance

2. Develop production logistics and identify soil and environmental criteria to ensure a commercially successful advanced feedstock production system

    - Examine N-use efficiency – using ^{15}N labeled fertilizer under different soil/site conditions
    - Examine legume vs. fertilizer for N input in Switchgrass for specific soil/site
    - Surface N and P runoff and leaching from production systems

1.2 - Approach
BIOREFINERY TECHNOLOGIES

University of Florida, University of Missouri, Show Me Energy, Green Technologies

1. Development of a biocatalyst for production of butanol (via butyric acid) from switch grass
   - Construction of a microbial biocatalyst for production of butyric acid as sole fermentation product at high titer and yield
   - Hydrolysis and saccharification of switchgrass and
   - Fermentation of switchgrass hydrolysate to butyric acid using the engineered biocatalyst.
   - Compare the efficiencies of butyric acid fermentation to that of butanol fermentation by naturally occurring *Clostridium* isolates.

2. Development of novel co-products from the stillage of biofuel fermentation process and stillage utilization
   - Anaerobic digestibility of stillage
   - Pre-commercial scale system for recovery of plant nutrients from stillage.
   - Studies on land application of these residuals.
   - Development of lignin based nanocomposites.

1.3 - Approach

Sustainability, Marketing and Policy Analyses

Virginia Tech, Montclair State Univ, Texas A&M Univ, Show Me Energy, Green Technologies

Developing standards and protocols

- Aggregated index approach (literature review, stakeholder inputs and survey of expert survey, assess feasibility of standards & protocols)

Energy, emissions, and economic analyses

- Life cycle analyses for different production-conversion-distribution pathways (SimaPro software and Ecoinvent database)
- Other environmental impacts (e.g., land productivity) through lit. review.
- Feasibility analyses (techno-economic and capital budgeting model)
- Region wide socioeconomic and distributional impact analyses (Input Output Analysis, Social Accounting Matrix and CGE approach)

Supply chain management analyses

- Biomass supply chain otimization model, Firm level case study and assess drivers and barriers through survey of supply chain actors.

2 - Technical Accomplishments/ Progress/Results

- Three University of Missouri research farms as well as ten private farms have been identified where field trials will be located. Seeds and other planting materials (e.g. plugs) for switchgrass have been ordered. The flood and drought tolerance labs have been prepared in anticipation of planting in late April early May.

- Cloned all the genes necessary for the butyrate pathway from *Clostridium acetobutylicum*. A plasmid that carries these genes has been constructed for expression in *E. coli*.

- Testing and evaluation of individual units in the Stan Mayfield Biorefinery Pilot Plant have been completed. Test runs at a smaller scale have shown that 70 – 80 gallons of ethanol can be produced from a dry ton of sugarcane bagasse.

- Development of pilot plant for recovery of residuals from cellulosic biorefinery underway.

- Lignin was successfully extracted from cellulosic bioethanol process residues with high purity (greater than 94%) and high molecular weight (3934.95±0.9%). This lignin was used to modify the clay saponite to form lignin-clay hybrid.

- Initiated work on certification protocols and standards.

- Systematic analyses of peer reviewed and non-peer reviewed literature on indicators developed for sustainable feedstock management, energy balances, greenhouse gas emission reductions, and existing codes and guidelines for biomass harvesting and collection, transport and conversion is currently underway.

3 - Relevance

- Feedstock development
- Biochemical Conversion
- Process Integration
- Sustainability Analysis
- Joint R&D for deployment of second generation biofuel clean energy technologies in US and India

4 - Critical Success Factors

- Drought and flood tolerant switchgrass biomass yields of at least 10 tons/acre.

- Development and testing of biocatalyst that can produce high titer (~100 g/L) of butyric acid within three to four years, allowing sufficient time within project period to demonstrate utilization of this biocatalyst in a pre-commercialization scale system.

- Successful operation of a pre-commercialization scale biofuel production facility.

- Establishing benefits of land application of nutrients recovered from biofuel production residues in comparison to inorganic fertilizers.

- Estimates of feedstock availability, possible butanol production process configurations and mass and energy balances to complete life cycle and supply chain management analysis by end of project.

- Successful completion of the project is expected to result in benefits to both US and India by delivering a commercial working model for feedstock production and supply, biochemical conversion approaches and other biorefinery technologies that have been validated on pre-commercial scale systems, and overall economics and sustainability of biofuel production and supply systems.

5. Future Work

ID	Task Level	Task Name	Start	Finish	Q4 12 Oct Nov Dec
1	A	FEEDSTOCK DEVELOPMENT AND SUPPLY	9/18/2012	9/15/2017	
2	A.1	Improve Feedstock	9/18/2012	9/15/2017	
3	A.1.1	Screening for abiotic stress	9/18/2012	9/17/2014	Completed
4	A.1.2	Seed multiplication	9/18/2013	9/17/2014	Completed
5	A.1.3	Transcriptomic and microscopic studies	3/18/2014	3/17/2017	Started
6	A.2	Develop production logistics	3/18/2014	9/15/2017	
7	A.2.1	Multi-location field trials	3/18/2014	7/17/2017	Started
8	A.2.2	Feedstock matching	3/18/2014	7/17/2017	Started
9	A.2.3	Predicting yields	1/1/2015	10/28/2016	
10	B.	BIOREFINERY TECHNOLOGIES	9/18/2012	9/15/2017	
11	B.1	Biocatalyst development	9/18/2012	7/17/2017	
12	B.1.1	Construction of microbial catalyst	9/18/2012	7/17/2017	
13	B.1.2	Biomass saccharification studies	9/18/2013	7/17/2017	

7	A.2.1	Multi-location field trials	3/18/2014	7/17/2017	
8	A.2.2	Feedstock matching	3/18/2014	7/17/2017	
9	A.2.3	Predicting yields	1/1/2015	10/28/2016	
10	B.	BIOREFINERY TECHNOLOGIES	9/18/2012	9/15/2017	
11	B.1	Biocatalyst development	9/18/2012	7/17/2017	
12	B.1.1	Construction of microbial catalyst	9/18/2012	7/17/2017	Ongoing
13	B.1.2	Biomass saccharification studies	9/18/2013	7/17/2017	Ongoing
14	B.2	Stillage utilization and coproducts	9/18/2012	7/17/2017	
15	B.2.1	Pilot plant for recovery of struvite – construction and operation	9/18/2012	7/17/2017	Ongoing
16	B.2.2	Studies on application cellulosic (ethanol) biorefinery residuals	9/18/2012	7/17/2017	Started
17	B.2.3	Develop lignin based nanocomposites	9/18/2012	7/17/2017	Ongoing
18	C	SUSTAINABILITY STUDIES	9/18/2012	9/15/2017	
19	C.1	Develop standards and certification protocols	9/18/2012	7/17/2017	
20	C.1.1	Analyze existing protocols	9/18/2012	9/17/2014	
21	C.1.2	Develop protocols for new products	9/18/2013	9/15/2017	
22	C.2	Energy, emissions and economic analysis	3/18/2013	7/17/2017	
23	C.2.1	Determine energy ratios and emissions	3/18/2013	7/17/2017	
24	C.2.2	Economic feasibility studies	6/18/2013	7/17/2017	

14	B.2	Stillage utilization and coproducts	9/18/2012	7/17/2017	
15	B.2.1	Pilot plant for recovery of struvite – construction and operation	9/18/2012	7/17/2017	
16	B.2.2	Studies on application cellulosic (ethanol) biorefinery residuals	9/18/2012	7/17/2017	
17	B.2.3	Develop lignin based nanocomposites	9/18/2012	7/17/2017	
18	C	SUSTAINABILITY STUDIES	9/18/2012	9/15/2017	
19	C.1	Develop standards and certification protocols	9/18/2012	7/17/2017	
20	C.1.1	Analyze existing protocols	9/18/2012	9/17/2014	Completed
21	C.1.2	Develop protocols for new products	9/18/2013	9/15/2017	Started
22	C.2	Energy, emissions and economic analysis	3/18/2013	7/17/2017	
23	C.2.1	Determine energy ratios and emissions	3/18/2013	7/17/2017	Started
24	C.2.2	Economic feasibility studies	6/18/2013	7/17/2017	Started
25	C.3	Supply chain management	9/18/2012	7/17/2017	
26	C.3.1	Analyze existing supply chain	9/18/2012	7/17/2014	Ongoing
27	C.3.2	Identify drivers and barriers	9/18/2013	7/17/2017	Started

Summary

- The project addresses all aspects of biofuel production and supply – feedstock, conversion and sustainability.
- Switch grass and biomass sorghum grown on marginal land – flood and drought prone in Midwest.
- Novel approach to butanol production via butyric acid intermediate.
- Concomitantly develop standards and certification protocols, conduct life cycle and supply chain analysis for butanol and cellulosic ethanol.
- Implementation of feedstock development and biorefinery technologies at pre-commercial scale.
- Active participation of commercialization partners in US and India.