2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

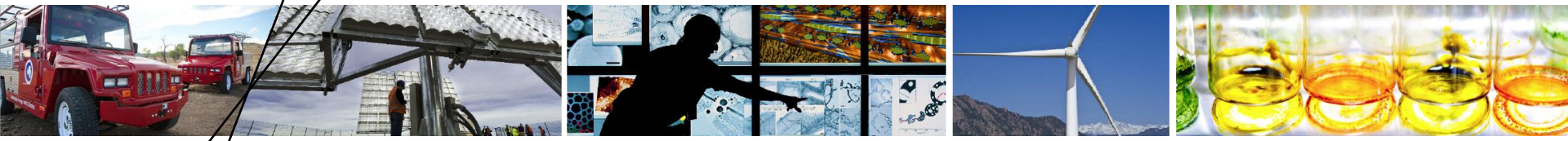
BC Process Improvements Validation Task (2.3.1.7)

Date: May 21, 2013
Technology Area Review: Biochemical Conversion

Principal Investigators: James D. (Jim) McMillan
and Nancy Dowe
Organization: NREL

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

BC Process Improvements Validation Task (2.3.1.7)



James D. (Jim) McMillan

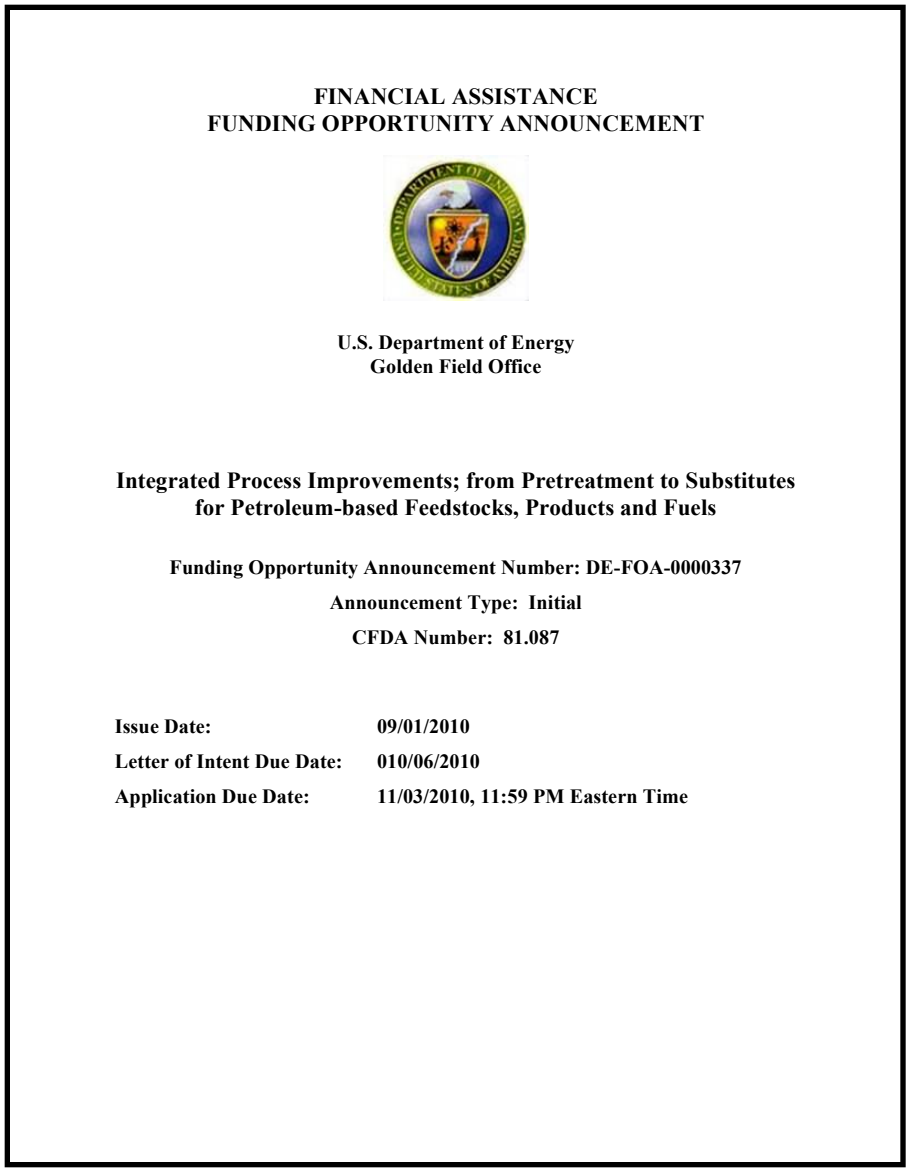
2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Alexandria, VA

May 21, 2013

Overall Goal

- Improve biomass sugar platform fuels and chemicals technologies
- Validate biochemical process performance and cost improvements achieved in projects cost-shared by DOE under FOA # DE-FOA-0000337, "Integrated Process Improvements for Biochemical Conversion of Biomass Sugars: from Pretreatment to Substitutes for Petroleum-based Feedstocks, Products and Fuels"
- Support DOE BETO's 2022 program objective to achieve an overall production cost of $3/GGE ($2011)
- For each project, NREL validation team personnel observe on-site validation experiments and review economic calculations to verify reported performance levels



FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

U.S. Department of Energy
Golden Field Office

Integrated Process Improvements; from Pretreatment to Substitutes for Petroleum-based Feedstocks, Products and Fuels

Funding Opportunity Announcement Number: DE-FOA-0000337

Announcement Type: Initial

CFDA Number: 81.087

Issue Date:	**09/01/2010**
Letter of Intent Due Date:	**010/06/2010**
Application Due Date:	**11/03/2010, 11:59 PM Eastern Time**

Quad Chart Overview

Timeline

- Start: FY12 (Oct. 2011); work initiated Sept. 2011 (other funds)
- Project end date: Sept. 2015 (estimated)
- Percent complete: 33%

Barriers

Addresses all biochemical platform barriers except Bt-B Feedstock Variability, especially:

- Bt-E. Pretreatment Costs
- Bt-K. BC Process Integration
- Bt-L. BC/TC Interface

Budget

Funding for FY11: $0K DOE
Funding for FY12: $850K DOE
Funding for FY13: $0K DOE
Funding for FY14: $250K DOE (req.)
The project is funded at an average level of $350-450K per year.

Partners

Awarded projects being validated:

- Genomatica
- Michigan Biotechnol. Inst. (MBI)
- Texas Eng. Exp't Station (TEES)
- Virdia
- Virent

Project Overview

- **Assist DOE with developing FOA; write validation plan (for award negotiation) (FY11)**
- **Conduct on site validations for each project**
  - Initial (benchmark) **(FY12-FY13)**
  - Intermediate **(FY13-FY14)**
  - Final **(FY14-FY15)**
- **Participate in each project's mid-award Stage Gate review (after intermediate validation) (FY13-FY14)**
- **Report accomplishments and cross cutting issues/lessons learned in quarterly and annual reports (FY12-FY15)**
- **Review projects' quarterly reports (as requested)**

genomatica
sustainable chemicals

mbi
De-Risking and Scale-Up of Bio-Based Technologies

TEES
TEXAS ENGINEERING EXPERIMENT STATION

virdia

VIRENT

Project Validation Types

- **Initial Validation (within 2-3 months of project initiation)**
  - Verify integrity of performance measurement methods and establish benchmark performance.
  - Confirm reasonableness of techno-economic modeling approach and establish benchmark cost.

    ➔ *Future progress is measured against these initial benchmarks*
- **Intermediate (or Pre-Stage Gate) Validation (20-24 months)**
  - Compare improved performance and cost achievements against previously established benchmark; repeat benchmark.
  - Validation results inform Project's mid-award Stage Gate Review; *outcome is a Go/No Go decision on phase 2 funding*.
- **Final Validation (36 months)**
  - Document final performance improvement and cost reduction accomplishments; repeat benchmark. Were targets reached?

Validation Data Tables

Standard Tables Summarizing Results and Future Goals

- Adapted to fit each project's specific process technology
- Use tables to document validated process performance

Benchmark and Target Performance Tables:

- **Table A1**: Feedstock, Pretreatment and Hydrolysis / Sacc Technology Performance Summary
- **Table A1.a**: Enzyme Performance and Cost Contribution
- **Table A2**: Fermentation Technologies for Advanced Biofuels
- **Table A3**: Combined Bioprocessing Technologies (not applied)
- **Table A4**: Sugar Catalysis Technology Performance Summary

Benchmark and Target Technical and Economics Table

- **Table B**: Process Details and Cost Estimate

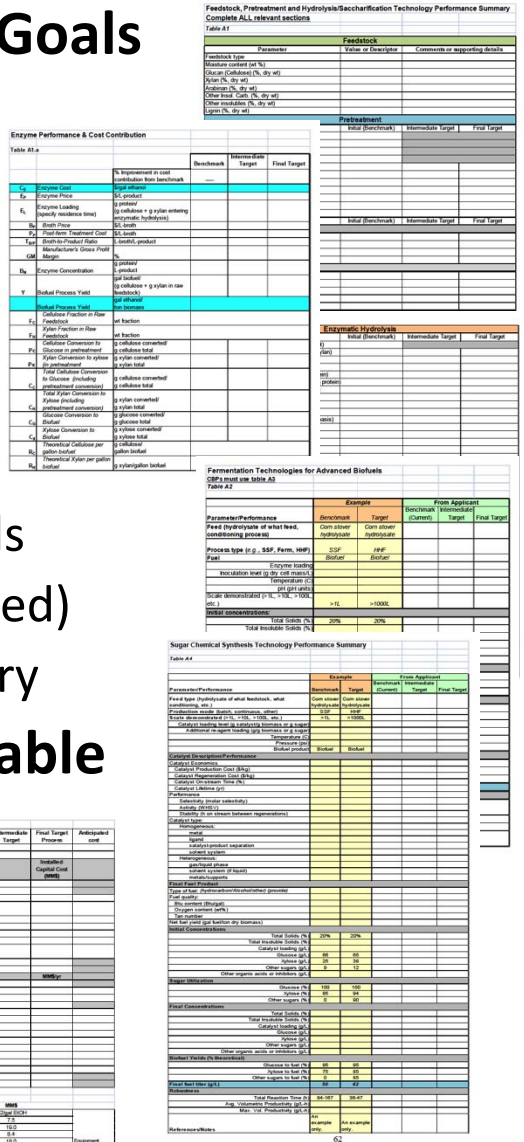


Table A1: Saccharification Performance - 1

Table A1: Feedstock, Pretreatment and Hydrolysis/Saccharification Technology Performance Summary
(excerpted and modified)

Feedstock			
Parameter	**Value or Descriptor**	**Comments or supporting details**	
Feedstock type			
Moisture content (wt %)			
Glucan (Cellulose) (%, dry wt)			
Xylan (%, dry wt)			
Lignin (%, dry wt)			
Other (%, dry wt) (specify)			
Pretreatment			
	Initial (Benchmark)	Intermediate Target	Final Target
Pretreatment type and mode			
Operatng conditions (T, P, t, etc.)			
Biomass feed rate (kg, kg/h, dry basis)			
Insoluble solids level (wt %)			
Catalyst type and loading (wt %)			
Pretreatment Output			
	Initial (Benchmark)	Intermediate Target	Final Target
Total solids (%)			
Insoluble solids (%)			
Liquid density (g/mL)			
pH (pH units)			
Solids Composition			
Glucan (Cellulose) (%, dry wt)			
Xylan (%, dry wt)			
Lignin (%, dry wt)			
Other insolubles (%, dry wt) (specify)			
Liquid Composition			
Glucose (g/L)			
Xylose (g/L)			
Gluco- and xylo-oligomers (g/L)			
Other solubles (g/L) (specify)			
Sugar Recovery Yields			
Glucose from glucan (% of theoretical)			
Xylose from xylan (% of theoretical)			

Table A1: Saccharification Performance - 2

Table A1: Feedstock, Pretreatment and Hydrolysis/Saccharification Technology Performance Summary (cont'd)

(excerpted and modified)

Enzymatic Hydrolysis			
	Initial (Benchmark)	Intermediate Target	Final Target
Enzyme used (manufacturer, product name, lot)			
Mode, feed rate and operating conditions			
Enzyme loading (mg protein/(g cellulose + g xylan)			
Reaction insoluble solids level (wt %)			
Residence Time (min)			
Enzymatic Hydrolysis Output			
Total solids (%)			
Insoluble solids (%)			
Liquid density (g/mL)			
pH (pH units)			
Solids Composition			
Glucan (Cellulose) (%, dry wt)			
Xylan (%, dry wt)			
Lignin (%, dry wt)			
Other insolubles (%, dry wt) (specify)			
Liquid Composition			
Glucose (g/L)			
Xylose (g/L)			
Gluco- and xylo-oligomers (g/L)			
Other solubles (g/L) (specify)			
Sugar Recovery Yields			
Glucose from glucan (% of theoretical)			
Xylose from xylan (% of theoretical)			
Complete Saccharification (Combined Pretreatment + Enzymatic Hydrolysis)			
Total Sugar Recovery Yields			
	Initial (Benchmark)	Intermediate Target	Final Target
Glucose from glucan (% of theoretical)			
Xylose from xylan (% of theoretical)			

Table B: Techno-Economic Performance

Table B. Process Details and Cost Estimates *(excerpted and modified)*

	Description	Current Process (Benchmark)	Intermediate Target Process (20-24 months)	Final Target Process (36 months)
Feedstock Type				
Feed Rate (dry ton/day)				
Fuel Yield (gallons/dry ton)				
Line 1: Annual Fuel Production (MM gallons)				
Equipment Costs (2007$)	**Description**	**Installed Capital (MM$)**	**Installed Capital (MM$)**	**Installed Capital (MM$)**
Feedstock Handling				
Pre-processing or Pretreatment				
Neutralization/Conditioning				
Chemical or Enzymatic Saccharification				
Biological or Catalytic Sugar Upgrading				
Product & Solids Residue Recovery				
Wastewater Treatment, Storage, Utilities				
Line 2: Total Installed Capital				
Total Installed Capital per Annual Gallon (line 2 divided by line 1)				
Operating Costs (2007$)	**Description**	**MM$/yr**	**MM$/yr**	**MM$/yr**
Feedstock				
Chemicals and Nutrients				
Biocatalysts or Catalysts (incl. licensing fees)				
Other Raw Materials				
Waste Disposal				
Steam				
Electricity				
Labor and Maintenance				
Line 3: Total Operating Costs				
Line 4: Co-product Credits				
Line 5: Net Operating Costs (line 3 minus line 4)				
Net Fuel Production Costs ($/gal) (line 5 divided by line 1)				

Approach

Adapt learnings from Enzyme and Strain Validations to design and implement a rigorous process

- Validation Plan analogous to previous Enzyme and Strain Validation Plans.
- Use larger validation teams because "more eyes/ears/brains are better."
- Ensure consistency by reviewing validation process prior to and during site visits, and maintaining the same core validation team.
- Analyze "unknown" samples (e.g., biomass, sugars and/or products) to verify the accuracy of key analytical methods.

For each project, observe, assess and audit performance validation experiments and review associated economic calculations

- Initial, Intermediate and Final Validations

***Note**:*

- *Each project is unique and applies specific (and proprietary) methods to quantify performance and cost improvements.*
- *All work performed under strict non-disclosure and confidentially agreements.*

Validation Process Overview

Major Elements

- Obtain and review methodologies in advance of site visits (and in 1:1 meetings during visits)
- Supply samples (“unknowns”) to confirm integrity of key analytical methods
- Visit site to conduct initial, intermediate (pre-stage gate) or final validation:
  1) Directly observe validation experiments being performed
  2) Assess laboratory QA / QC procedures
  3) Review performance calculations and techno-economic modeling approach and data-based cost projections.
- Each project validated separately using common methodology tailored to specific nature of project
- Document findings in validation reports to DOE (includes recommendations for method improvements, where applicable).

Technical Accomplishments Overview

- Developed Validation Plan (FY11)
  - Required for award negotiations
- Completed initial validations (and associated validation reports) on all 5 projects (Sept ’11–Dec ’12)
  - Established benchmark or starting point performance against which future improvements will be assessed
- Summarized results of all initial validations in a confidential report to DOE (Q1, FY13)
- Intermediate validations and mid-project stage gate reviews will commence starting in June ’13.

Technical Progress - Genomatica

- Topic 1 project: Single unit operation
- Project objective: Develop an engineered organism and optimized fermentation process to enable the conversion of cellulosic sugars to the valuable industrial chemical, 1,4-butanediol (BDO).
- Initial validation site visit conducted Sept. 25-30, 2011.
- Initial validation used to establish project conversion performance and cost benchmarks associated with metabolic conversion of biomass sugars to 1,4 BDO.

San Diego, CA

genomatica
sustainable chemicals

Technical Progress - MBI

- Topic 1 project: Single unit operation
- Partner: INL
- Project objective: Improve AFEX pretreatment process to provide a stable intermediate of consistent quality at a cost and in a format compatible with long-term storage and ease of transfer using multiple modes of transportation.
- Initial validation site visit conducted October 10-14, 2011.
- Initial validation resulted in revised initial benchmark and future targets focused on scaling up reactor design while maintaining performance.

Lansing, MI

mbi® De-Risking and Scale-Up of Bio-Based Technologies

Technical Progress - TEES

- Topic 1 project: Single unit operation
- Partner: Texas A&M
- Project objective: Develop a novel pretreatment process for cellulosic biomass feedstocks using a combination of chemical and mechanical processing.
- Successful initial validation site visit conducted May 14-18, 2012 (2nd visit).
- Initial validation resulted in developing revised test methods and establishing revised benchmark performance and cost values as well as revised future performance and cost targets.

College Station, TX

TEXAS ENGINEERING EXPERIMENT STATION

Technical Progress - Virdia

- Topic 2 project: Multiple unit operations
- Partner: LS9
- Project objective: Develop improved integrated process based on HCl concentrated acid hydrolysis followed by microbial conversion to convert biomass feedstocks including wood waste into sugars and then into diesel products
- Initial validation site visits conducted July 29-August 2, 2012 (Virdia) and June 26-29, 2012 (LS9)
- Initial validation resulted in revised benchmark sugar and fuel product yields and concentrations.

Danville, VA

virdia

Technical Progress - Virent

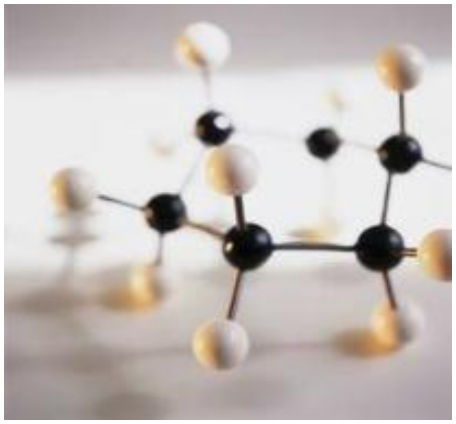
- Topic 2 project: Multiple unit operations
- Partners: INL and NREL
- Project objective: Develop a fully integrated process to convert cellulosic feedstocks to a mix of hydrocarbons ideally suited for blending into jet fuel.
- Successful initial validation site visits conducted February 6-22, 2012 (NREL) and March 5-9, 2012 (Virent)
- Initial validation resulted in changes to estimated fuel production costs and fuel products ratios, shifting from jet fuel to gasoline as the primary product.

Madison, WI

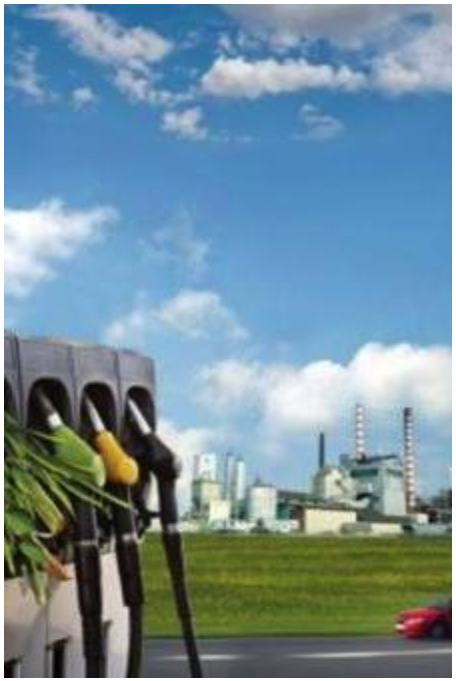
VIRENT

Relevance

- This task contributes to meeting **MYPP** strategic and performance goals and **CTAB Roadmap** (draft) objectives to produce and upgrade biomass sugars (and other carbohydrate and lignin derivatives) to hydrocarbon fuels, chemicals and oxygenate blends, as outlined in recent tech. memos:
  - *Davis et al. Biological Conversion of Sugars to Hydrocarbons Technology Pathway. NREL/TP-5100-58054. March 2013.*
  - *Biddy and Jones. Catalytic Upgrading of Sugars to Hydrocarbons Technology Pathway. NREL/TP-5100-58055. March 2013.*



- Validation of performance and cost improvements supports 2017 and out-year goals to develop and demonstrate advanced "sugar platform" technologies to produce hydrocarbon fuels from biomass at a production cost ≤ $3/GGE.



- Validation activities: 1) support Stage Gate reviews; 2) are a key R&D element for TRL levels 3 → 9; and 3) help ensure DOE's funds are well invested and align with and advance programmatic goals.

Success Factors and Challenges

- **Success Factors**
  - Ability to verify accuracy of requisite analytical methods
  - Ability to validate benchmark and improved unit operation or process performance and cost attributes

- **Challenges**

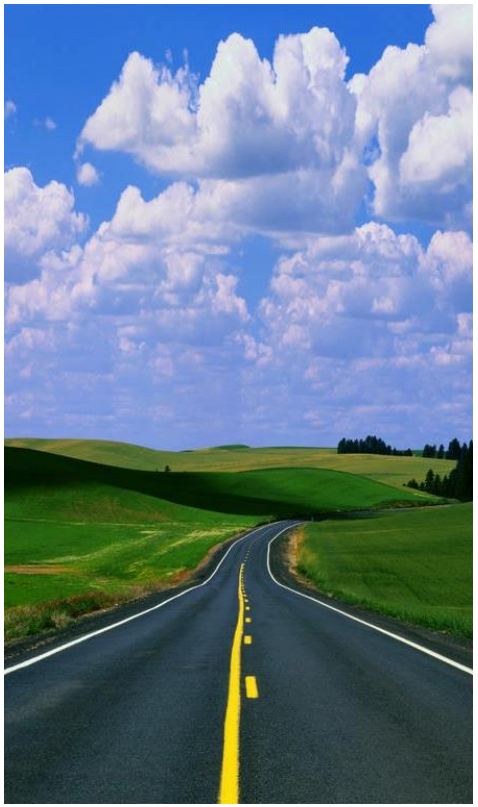
- Lack of common methods and approaches across diverse project portfolio: each project is unique and requires a customized validation
- Logistics: Topic 2 awards have required visits to ≥ 2 sites
- One project has key process steps outside funded scope of award

➢ **Market / commercialization barriers are addressed by the technology developers (not by this task)**

Future Work

For each project:

- Complete intermediate progress validation and participate in subsequent Stage Gate reviews (as scheduled) (FY13-FY14)
- Validate final process improvement and cost reduction achievements (FY14-FY15)



Prepare end of year summary deliverable reports documenting task accomplishments, cross cutting issues and lessons learned (annually)

As requested, review project quarterly reports and otherwise support DOE project monitoring

Summary

- **Validation process** adapted from previous BC platform strain and enzyme improvement project validations. Comprises initial, intermediate and final validation site visits and documentary reports.
- **Initial project validations completed Sept ’11–Dec ’12**
  - Topic 1 (single unit operation): Genomatica, MBI and TEES
  - Topic 2 (complete process): Virent and Virdia
  - Established benchmark or starting point performance against which future improvements will be assessed.
- **Intermediate (Pre-Stage Gate) validations scheduled to commence June 2013.** Stage Gate reviews including validation results to date will be held within 30-60 days of each project’s intermediate validation.

Acknowledgments

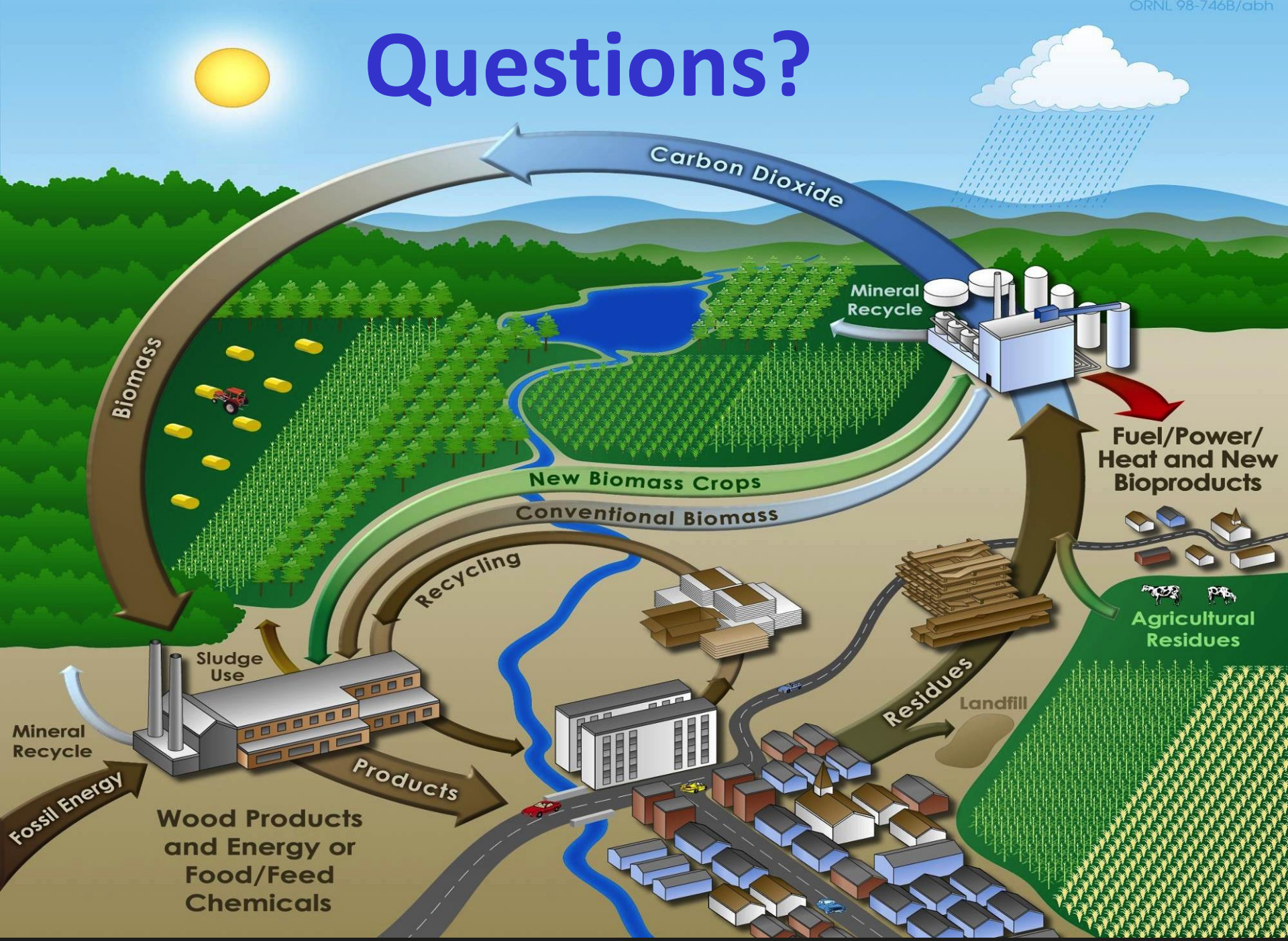
Funding: DOE EERE Bioenergy Technologies Office

DOE Project Officers: Bryna Berendzen and Leslie Pezzullo

CNJV DOE Support: Christine English, Jessica Phillips and Gina Lynch

NREL Validation Team: Ryan Davis, Nancy Dowe, Ed Jennings, Andrew Lowell, Steve Phillips, Joe Shekiro and Michael Talmadge

Questions?


ORNL 98-746B/abh
Carbon Dioxide
Biomass
Mineral Recycle
Fuel/Power/ Heat and New Bioproducts
New Biomass Crops
Conventional Biomass
Recycling
Agricultural Residues
Sludge Use
Residues
Landfill
Mineral Recycle
Products
Fossil Energy
Wood Products and Energy or Food/Feed Chemicals

Additional Slides

Responses to Previous Reviewers ‘Comments

- **Not applicable. This project hasn’t been previously reviewed (although the Enzyme and Strain Validation tasks that proceeded it have but are no longer active).**

Publications and Presentations

- None. All projects are proprietary.
- Most of the awardees have given some public presentations related to these projects, but specific project data has not been released to the public.
- Commercialization is being pursued by the companies / institutions receiving DOE cost share funding awards for the projects being validated, i.e., commercialization is not part of the validation task.