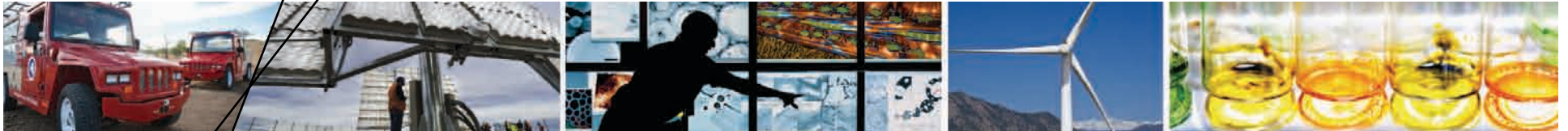




DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Biochemical Process Improvements & Synthetic Biology Validation Projects



March 24, 2015

Technology Area Review: Biochemical Platform

**Principal Investigators: James D. McMillan,
Nancy Farmer, and
Jeff Linger**

Organization: NREL

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

Goal Statement

- **Overall goal:** Improve sugar platform technologies to reduce production costs (2022 target = \$3/GGE in \$2011).
 - Help DOE monitor projects to maximize their likelihood of success and the accuracy of reported technical progress.
- **Approach:** Validate process performance and cost improvements achieved in each awarded project:
 - DE-FOA-0000337: Integrated Process Improvements for Biochemical Conversion of Biomass Sugars from Pretreatment to Substitutes for Petroleum-based Feedstocks, Products and Fuels.
 - DE-FOA-0000719: Innovative BioSynthetic Pathways to Advanced Biofuels
- **Benefits to United States:** Ensure technical rigor & alignment with BETO objectives; increase probability of projects' success. Reduce future commercialization risk and help efficiently leverage BETO funding towards program goals.

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

FINANCIAL ASSISTANCE FUNDING OPPORTUNITY ANNOUNCEMENT



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Golden Field Office

Innovative Biosynthetic Pathways to Advanced Biofuels
Funding Opportunity Announcement Number: DE-FOA-0000719
Announcement Type: Initial 001
CFDA Number: 81.087

Issue Date: 05/24/2012
Letter of Intent Due Date: 06/21/2012, 5:00 PM Eastern Time
Application Due Date: 07/10/2012, 5:00 PM Eastern Time

Applicants must submit a Letter of Intent by the due date to be eligible to submit a Full Application.

Quad Chart Overview (BC Validation)

Timeline

- **Start: FY12 (Oct. 2011)**
- **End: FY15 (Sept 2015) (projected)**
- **Percent complete: 75%**

Barriers

Barriers addressed

- Addresses all BC platform barriers except Bt-A Feedstock Variability, especially:
- Bt-D/E. Pretreatment Process and Costs
 - Bt-H/J. BC Process Cleanup & Integration
 - Bt-I/X. Catalyst Efficiency / BC/TC Interface

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date)
DOE Funded	\$411,626	\$349,000	\$141,000	\$215,000
Project Cost Share (Comp.)*	--	--	--	--

Partners

Awarded projects for validation:

- Genomatica
- Michigan Biotechnology Institute (MBI)
- Texas Eng. Expt'l Station (TEES)
- Virdia (formerly HCl Cleantech)
- Virent

Quad Chart (SynBio Validation *lite*)

Timeline

- Start: April 2013
- End: FY15 (Sept 2015 projected)
- Percent complete: ~75%

Barriers

Primary Barriers addressed:

- Bt-C Biomass Recalcitrance
- Bt-D Pretreatment Processing
- Bt-E Pretreatment Costs
- Bt-F Cellulase Enzyme Production Cost
- Bt-G Cellulase Enzyme Loading
- Bt-J Catalyst Development

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date)
DOE Funded	--	\$21,375	\$21,766	\$56,609
Project Cost Share (Comp.)*	--	--	--	--

Partners

Awarded projects for validation:

DOE/NREL Validated

- 1) Novozymes
- 2) Lygos
- 3) J. Craig Venter Institute (JCVI)

DOE/INL/ Validated

- 4) Pacific Northwest National Laboratory (PNNL)
- 5) Texas AgriLife Research

Validation Projects Overview

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

• BC Validation Awardees



• SynBio Validation Awardees



Approach (Technical)

Rigorous validation process followed based on approaches and learnings from Enzyme and Strain Validation projects.

- Validation Plan is structured similarly to past Enzyme and Strain Validation Plans.
- Employ larger validation teams because more eyes, ears and brains are better.
- Ensure consistency by reviewing validation process prior to and during site visits, and maintaining the same core validation team.
- Verify accuracy of key analytical methods by analyzing unknown standard samples (e.g., biomass, sugars and/or products).



Validation sites across the United States

Validation sites across the United States

Validation sites across the United States



Approach (Management)

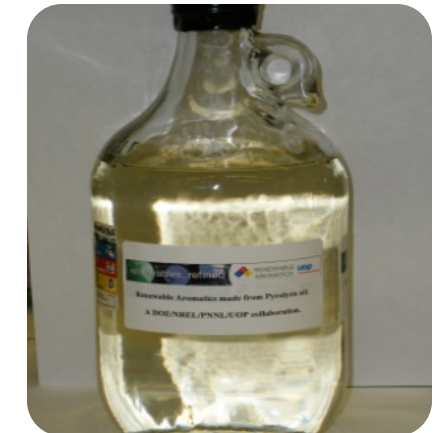
Success Factors: Ability to verify data integrity, benchmark process performance and cost, and future technical and cost improvements.

Challenges:

- 1) Disparate methods / approaches across diverse project portfolio;
- 2) Logistics for Topic 2 awards having ≥ 2 sites to visit per validation;
- 3) One project award insufficiently scoped to allow full validation

Project management occurs within the context of NREL's Biomass Program AOP, with quarterly and annual milestones.

The schedule for each validation is set by the cognizant DOE Project Officer. There are mid-award project Stage Gates/go/no-go decisions for each project being validated.



Project Validation Stages

- **Initial (Benchmark) Validation**

- 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**

- 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.*
- No intermediate validations for SynBio projects (2-year projects)

- **Final Validation**

- **Document final performance improvement and cost reduction accomplishments;** repeat benchmark. Were targets reached?

Validation Process Overview

Major Elements of Project Validation

- **Obtain/review project methodologies** in advance of site visit (and in 1:1 meetings during visit)
- **Supply “unknowns”** (feedstock/intermediate/product) to verify accuracy of key analytical methods
- **Visit site(s) to conduct initial, intermediate and final validations:**
 - 1) Directly observe validation experiments being performed
 - 2) Verify integrity of laboratory QA / QC procedures
 - 3) Review performance calculations and techno-economic modeling approach and data-based cost projections.
This information is summarized in the data tables.
- **Validate each project separately** using common methodology tailored to specific nature of project.
- **Document findings in validation reports** to DOE (including recommendations for improvements).



Technical Accomplishments Overview

- **Developed Validation Plans & completed initial validations for all 10 projects.**
 - Established performance benchmarks against which future improvements are assessed.
 - SynBio validation plan and initial validations completed FY13-FY14
- **Completed Intermediate Validations and mid-project stage gate reviews**
 - Only for BC Validation projects: Genomatica, MBI, TEES & Virent
 - Virdia elected to stop their project prior to intermediate validation
- **In Progress (FY15): Completing Final Validations** for all continuing projects
 - **Genomatica***, JCVI, Lygos, **MBI***, Novozymes, PNNL, TEES, Texas Agrilife and Virent.

**Final Validation site visits completed through February, 2015.*



Technical Progress - Genomatica

- **Topic 1 project:** Single unit operation
- **Project objective:** Develop engineered organism and optimized fermentation process to enable conversion of cellulosic sugars to the industrial chemical 1,4-butanediol (BDO).
- **Accomplishments:** Intermediate validation site visit conducted June 7-15, 2013, and Stage Gate review held July 25, 2013. Results showed Genomatica exceeded their project's titer and productivity targets. Phase II research addressing yield improvements and downstream processing.
- **Status:** Final validation site visit completed January 25-30, 2015; anticipate completing final report in March, 2015.



Genomatica



See Genomatica's presentation for technical details.

Technical Progress - MBI

- **Topic 1 project:** Single unit operation
- **Project objective:** Improve AFEX pretreatment process (“AFEX3”) to provide a stable intermediate of consistent quality at a cost and in a format compatible with long-term storage and ease of transport.
- **Accomplishments:** Intermediate validation site visit July 8-12, 2013. Results (and validation report) informed project Stage Gate (7/24/13). Future targets remain focused on scaling up AFEX3 and optimizing system throughput while maintaining performance.
- **Status:** Final validation site visit on Feb 9-13, 2015; final report due in March, 2015.



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See MBI's presentation for technical details.

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.
- **Accomplishments:** Intermediate validation site visits conducted November 24 – December 6, 2013 (NREL) and January 6-10, 2014 (Virent). Validation results informed project Stage Gate (2/12/14), which resulted in a modest reduction in future project scope.
- **Status: Final validation underway** (NREL portion); Virent portion will carry into Q3, 2015.



Image??



See Virent's presentation for technical details.

SynBio Validation Project Overview



Find **new sources of enzymes** which can be targeted to deliver more cost-effective solutions for deconstructing biomass into processable components



Develop **new technologies to produce enzymes** that more efficiently deconstruct biomass to make biofuel



Develop **efficient, inexpensive synthetic biology methods and tools** to convert biomass into common and specialty chemicals



Focused on the **production of fuel and chemical precursor molecules in *Aspergillus niger*** growing on lignocellulosic hydrolysates.



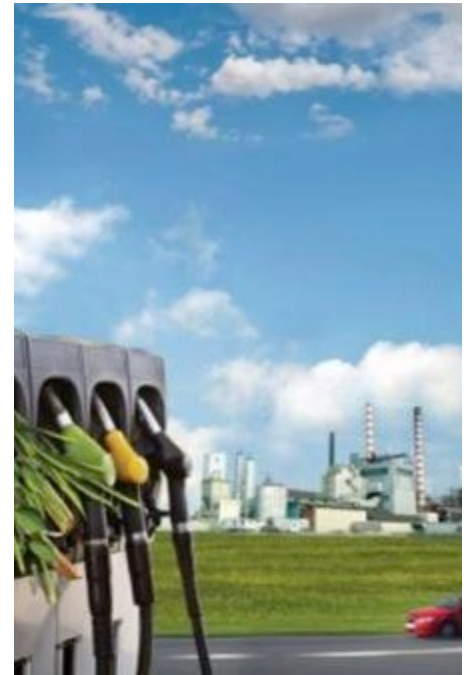
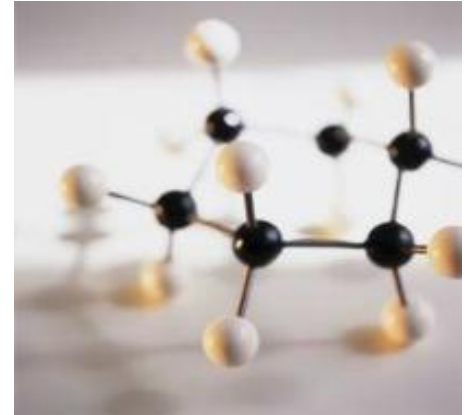
Focused on the **conversion of lignin to fungible fuels.**

Technical Accomplishments Overview

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e1Yd r	✓	g4	Ygg ea Eh
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Yer	✓	g4	Ygg ea Eh
	✓	g4	Ygg ea Eh
Fr ga	✓	g4	Ygg ea Eh

Relevance

- **The Validation projects contribute to meeting MYPP strategic and performance goals** to convert biomass sugars (and other carbohydrate and lignin derivatives) to hydrocarbon fuels, as described in recent reports:
 - *Davis, R. et al. (2013). Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of Sugars to Hydrocarbons. NREL/TP-5100-60223.*
 - *Biddy and Jones. (2013). Catalytic Upgrading of Sugars to Hydrocarbons Technology Pathway. NREL/TP-5100-58055.*
- **Project validations support 2017 and 2022 goals** to develop and demonstrate advanced biomass “sugar platform” technologies to produce hydrocarbon fuels at a production cost \leq \$3/GGE.
- **Validation activities provide multiple benefits:**
 - 1) support validated projects’ Stage Gate reviews;
 - 2) are a key QA/QC R&D element for TRL levels 3 \rightarrow 9;
 - 3) help ensure DOE BETO’s funds are well invested and effectively aligned to advance programmatic goals.
- **Market / commercialization barriers** are addressed by the project technology developers rather than these tasks.



Future Work (FY15)

For each active project:

BC Validation: Genomatica, MBI and Virent

SynBio Validation: Novozymes, Lygos, JCVI, PNNL and Texas Agrilife

- **Review quarterly reports** (as requested)
- **Complete final project validations** and associated final validation reports. (FY15)

Prepare end of year summary deliverable report documenting final accomplishments (process improvements and related cost reductions), cross cutting issues and lessons learned. (FY15)



Summary

- **Overview/Approach:** Validation process successfully being implemented for all of the awarded projects, leveraging lessons learned from previous BC platform strain and enzyme improvement project validations. For BC Validation, comprises initial, intermediate and final validation site visits and documentary reports. SynBio is a “Validation Lite”, with all work at bench-scale and involving only initial and final validations.
- **BC Validation Results:** Initial project validations completed Sept '11–Dec '12, intermediate validations July '13–Jan '14, and final validations underway for FY15 completion.
 - Topic 1/single unit operation: Genomatica, MBI and TEES
 - Topic 2/integrated process: Virent and Virdia
 - Initial validations established the performance against which future improvements are assessed; intermediate validations informed Stage Gate reviews
- **SynBio Validation Results:** Initial project validations completed Sept '11–Dec '12, intermediate validations July '13–Jan '14, and final validations underway for FY15 completion.
- **Relevance:** Facilitate higher quality outcomes for awarded projects.
- **Future Work:** Final validations (already underway), on track for completion in FY15).

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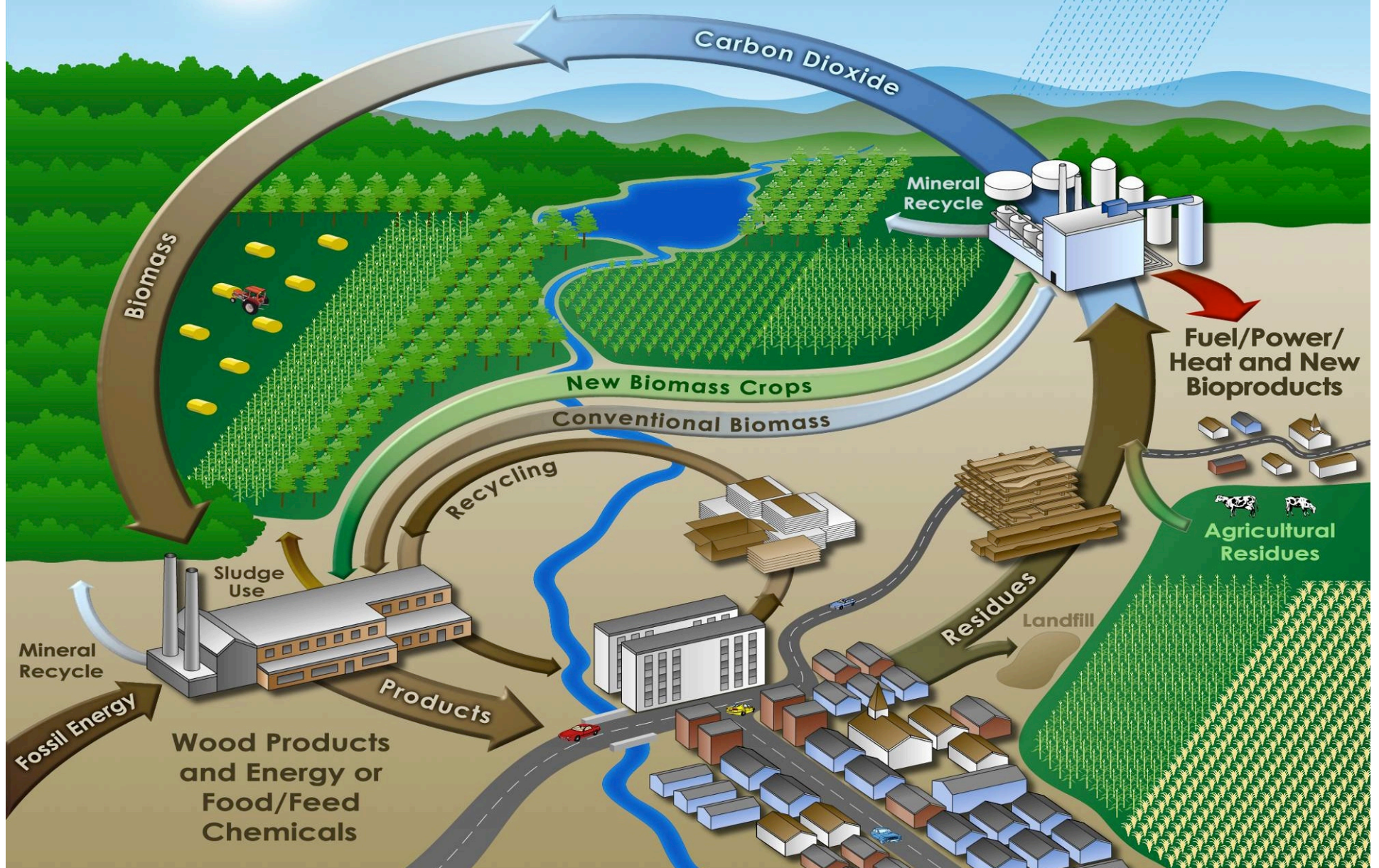
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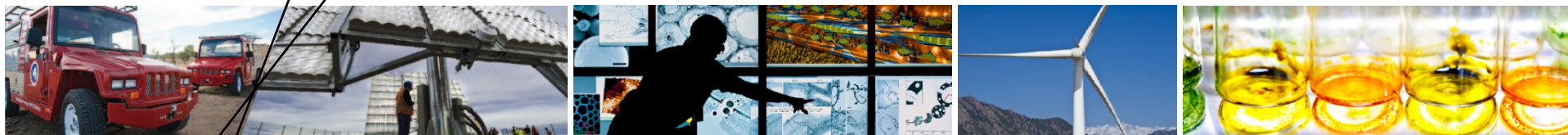
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Questions?





Additional Slides
(only presented if asked to)?

Technical Progress – TEES & Viridia

TEES: Topic 1 w/ partners Texas A&M and Terrabon

- **Project objective:** Develop a novel pretreatment process for cellulosic biomass feedstocks using a combination of chemical and mechanical processing.
- **Accomplishment:** Intermediate validation site visit on August 19-23, 2013. Results (and validation report) informed project Stage Gate (10/02/13).
- **Status:** Project halted by DOE after its intermediate Stage Gate review.



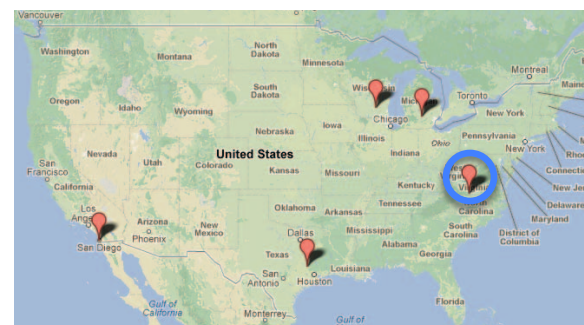
TEES



TEES presented at 2013 Peer Review.

Viridia: Topic 2 w/ partner LS9

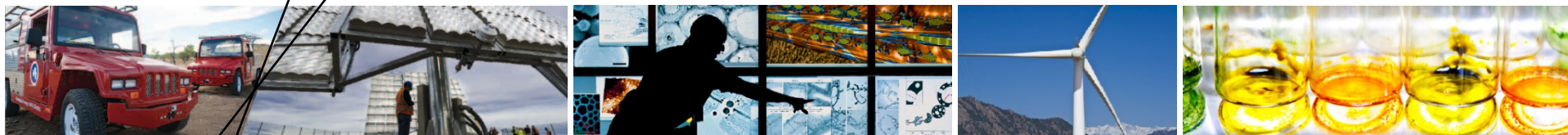
- **Project objective:** Develop improved process based on concentrated HCl acid hydrolysis followed by microbial conversion to convert woody feedstocks to sugars and then to diesel products
- **Status:** Between initial and intermediate validations, Viridia elected to discontinue their project, thus project halted prior to intermediate validation and mid-project Stage Gate review.



Viridia



Viridia presented at 2013 Peer Review.



Additional Slides
(for reviewers, not for presentation)?

Responses to Previous Reviewers' Comments

- **Not applicable.** The BC Process Improvements Validation task was previously reviewed in 2013 (see p274-275 of 2013 Peer Review Report). Reviewer comments were uniformly constructive and supportive and as such do not warrant a response. Some comments are perhaps more relevant to DOE, e.g.,
 - 1) Questioning the importance of the validation process to the progress of the projects being validated;
 - 2) Asking if rather than a validation type process, this should be a consulting service to the projects; and
 - 3) Wondering how such a validation-oriented project fits or is scored within the merit review.

Publications and Presentations

- **None.** All projects are proprietary.
- **Most of the awardees have given some public presentations and publications related to these projects or the technologies underlying them (e.g., see presentations made at 2013 Peer Review), however no project specific data has been released to the public.**
- **Commercialization is being pursued by (some of) the companies / institutions receiving DOE cost share funding awards for the projects being validated, i.e., commercialization is not part of either of these validation tasks.**