2015 DOE Bioenergy Technologies Office(BETO) IBR Project Peer Review

Recovery Act: Pilot Integrated Cellulosic Biorefinery Operations to Fuel Ethanol

Award Number: DE-EE0002875

March 23, 2015

Demonstration and Market Transformation Program

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ICM, Inc.

ICM 20 Year ANNIVERSARY

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Project Goal Statement

- Leverage its existing pilot plant
- Operate the pilot cellulosic integrated biorefinery using a biochemical platform with pretreatment and enzymatic hydrolysis technology coupled with a robust C5/C6 co-fermenting organism to refine cellulosic biomass into fuel ethanol and co-products
- Create an economically efficient model for future biorefineries
- Reduce Greenhouse Gases (GHG) by >60% when compared to petroleum based products
- Displace imported oil used to make commercial fibers, solvents and fuel additives

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Project Relevance and Outcomes

- Demonstrate Fully Integrated Operations Converting 10 Dry TPD of 3 Cellulosic Feedstocks to Ethanol and Co-Products
- 1 X 1,000 hour performance run complete (dry frac fiber)
- 1 X 500 hour performance run complete (wet frac fiber)
- 1 X 1,000 hour performance run started March 12 (switchgrass)
- 1 X 1,000 hour performance run June/July (energy sorghum)
- Full Techno-Economic Model
- Roll Proven Technology to Commercial Marketplace

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Quad Chart Overview

Timeline

- Project start: January 28, 2010
- Project end: August 31, 2015
- Percent complete: 90%

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	15,446,942	2,429,304	4,531,733	2,592,021
Project Cost Share (Comp.)	3,861,735	607,326	1,132,933	666,142 + 3,506,646 contingency

Barriers

- Pretreatment/hydrolysis achieves 80% conversion to sugars
- Solid/Liquid separation achieves <1% suspended solids, sugar & NH3 recovery, microbial control
- Ethanol over 80g/L with >90% yields
- Additional barriers?
  - Feedstock Handling

Partners

- Partner: Novozymes 5%
- Other interactions/collaborations:
  - Growers 1%, Ceres 0%, AGCO 0%, Stinger 0%
  - LifeLine Foods 0%
  - Southern Research <1%
- Non-technical project management partners: None

1 - Project Overview

- Project Location – **ICM, Inc., St. Joseph MO**
- Company headquarters – **ICM, Inc., Colwich, KS**
- High Level overview of:
  - Feedstock handling
    - **Dry Frac Corn Fiber, Wet Frac Corn Fiber, Switchgrass/Energy Sorghum Bales, Forage Equipment**
  - Conversion technology
    - **Pretreatment, Enzymatic Hydrolysis, Co-Fermentation of C5/C6 sugars**
  - Product purification
    - **Conventional Ethanol Distillation**
- Scale of the project under development with DOE assistance
  - **10 Dry Tons Feedstock per Day**
    - **Captive Corn Fiber, Energy Sorghum, Switchgrass**
  - **260,000 Gallons Ethanol per Year (commercial capacity)**

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2 – Approach (Technical)

- **Key unit operations/process steps you identified for improvement**
  - Feedstock materials handling
  - Pretreatment
  - Solid/Liquid Separations

- **Identify the specific technical barrier(s) this project addresses**
  - Design pretreatment to give consistent product with high sugar yield
  - Overcome feedstock differences
  - **Is it still a hurdle or has it been overcome?**
  - Pretreatment works consistently well with corn fiber
  - Energy sorghum/switchgrass are greater challenge
  - Feedstock handling/slurry pumping significant challenges
  - Feedstock processing differences normalized

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2 – Approach (Management)

> **Success Factors:**
  - Identify Key Technical Solutions – Biological and Mechanical
  - Develop Valid Techno-Economic Simulation Model
  - First Adopter Identification
  - National Policy

> **Challenges:**
  - People

> **Team Based Approach:**
  - WBS Structure
  - Multidisciplinary
  - Regular Team Planning and Review Meetings

2 - Technical Accomplishments/Progress/Results

- **Completed & Obtained NEPA Approval - 2010**
- **Completed Construction – August 2011**
  - 10 TPD Feedstock Capacity
  - 260,000 GPY Ethanol Capacity
- **Completed Qualification Run – April 2012**
- **Operations - Ongoing**
  - Completed 2 X integrated performance runs – corn fiber
    - November 2012, June 2013
  - Solved Materials Handling Challenges
  - 2 Integrated performance runs planned in 2015
    - Switchgrass and Energy Sorghum

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2 - Technical Accomplishments/Progress/Results

- **Feedstocks**
- Corn fiber
  - Process Co-Product/Waste
- Energy sorghum
  - Annual crop
- Switchgrass
  - Perennial crop

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Integrated 10-TPD Gen 1.5 Pilot Plant

•FST Feedstock

ICM BIOFUELS™

Full-Scale Operational Since March 2013

•Pretreatment

• Hydrolysis /
•Fermentation

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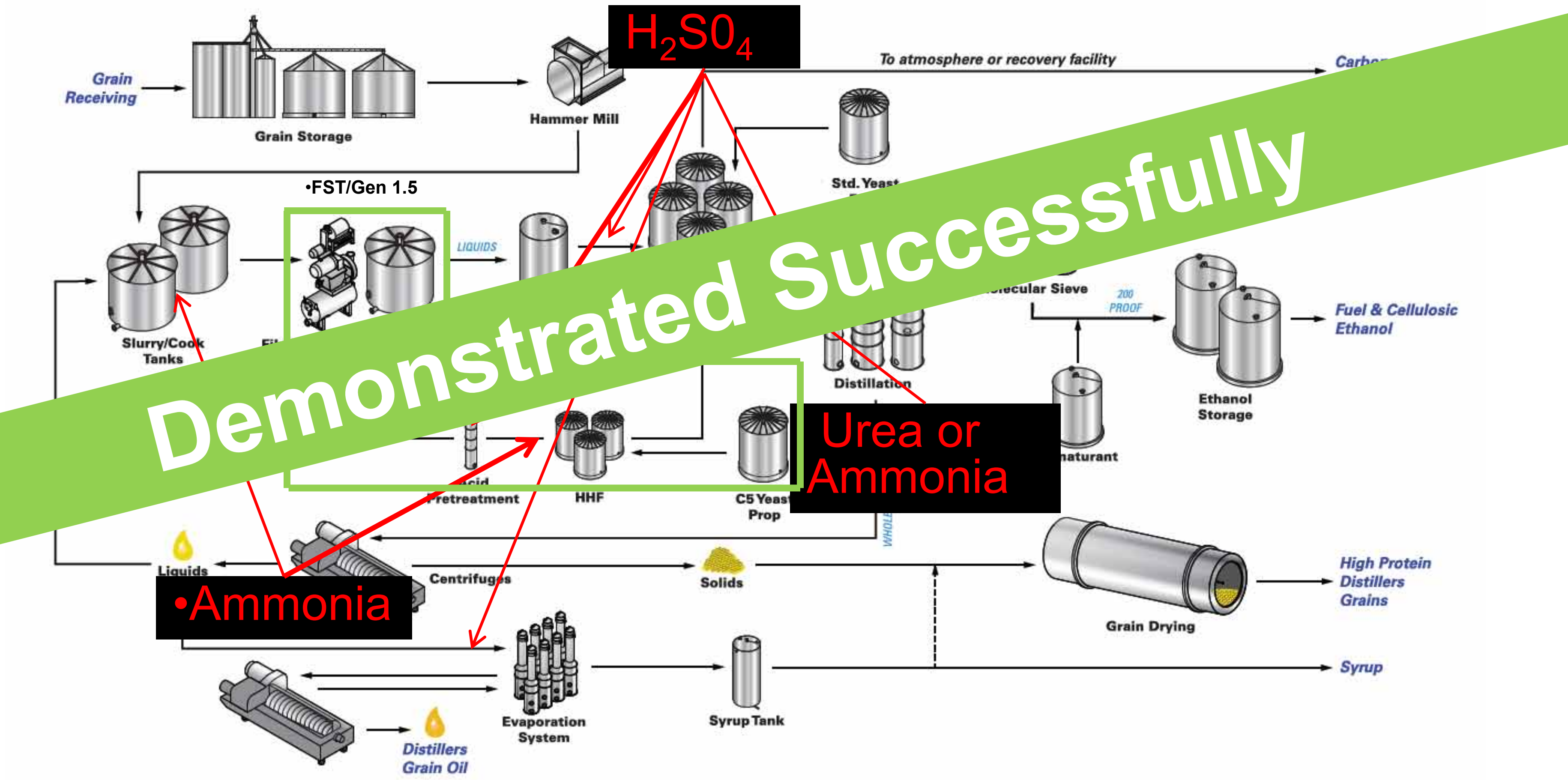
Gen 1.5 Ethanol with FST™



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batch number	type	fermentation type	Finish time (h)	% yield increase	glycerol reduction
average	SHF-CM (n=8)	C6 (cell + starch)	56	6.8%	21.8%
average	HHF-CM (N=16)	C5/C6	56	9.3%	31.6%
average	CM control (n=8)	C6 (starch only)	58		

- 1700-hours of pretreatment run time
- 32 X 10,000 gallon starch/cellulose integrated pilot fermenters
- 26 X 35,000 gallon hydrolyzate tanks
- 6 X 535,000 gallon full-scale test fermenters
- 6 X 535,000 gallon full-scale control fermenters

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Generation 1.5: Integrated Corn Fiber Production Potential

- **Additional 1.3-1.5 billion gallons (5.7 billion liters) of cellulosic ethanol annually**
  - Existing grain ethanol plants
- **Advantages over Co-Located/Greenfield Design Models**
  - Reduced capital requirements ($2-3 USD /installed gallon)
  - Reduced chemical inputs
- **Flexible rollout (fermentation/regulatory)**
- **3.1+ Gallons (11.4 liters) per bushel yield**
  - Increase in Protein/Fat Value Feed
  - Increased Oil Recovery 50-70%
  - Co-Products Diversification
- **Increased ethanol yield/bushel of 7-10%**
- **Patent Pending Process**

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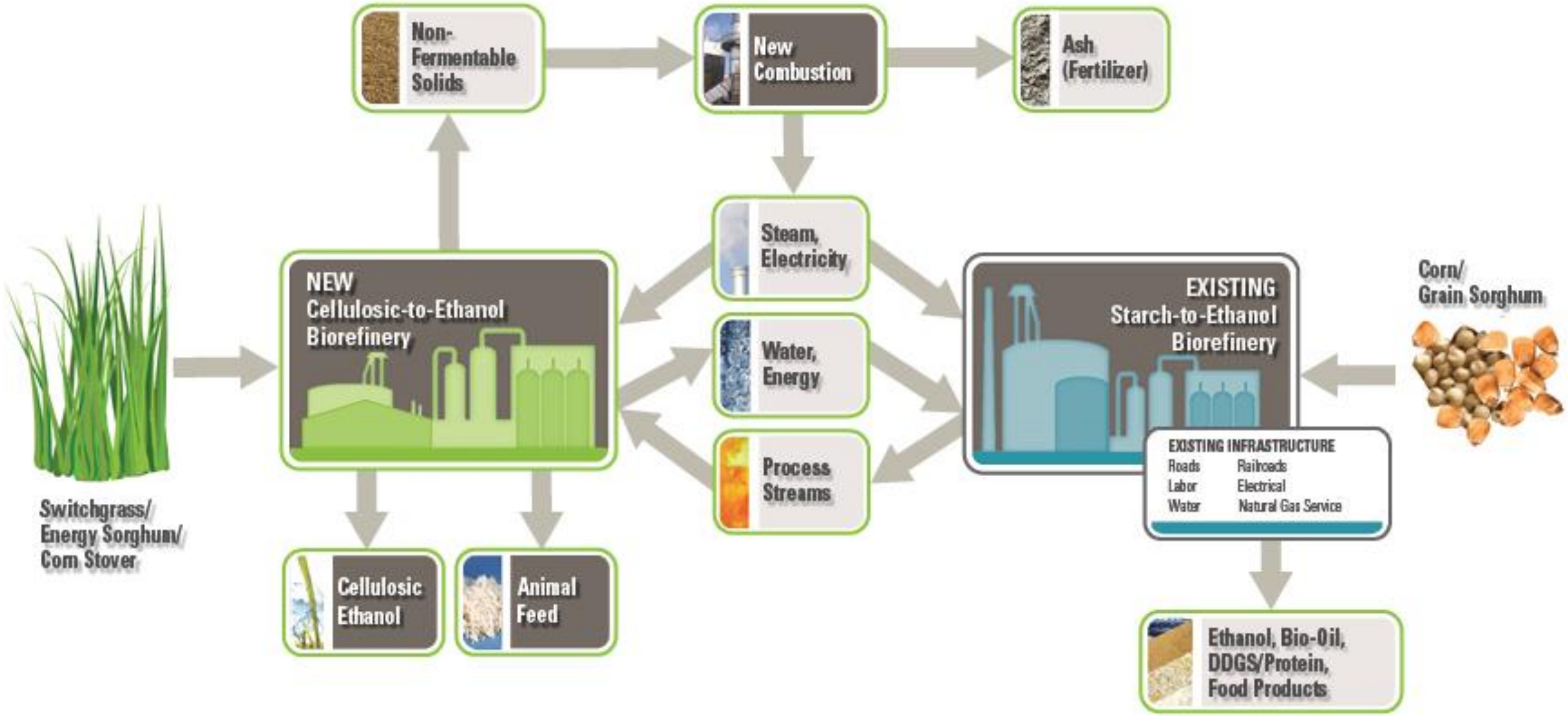
Generation 2.0 Co-Located Cellulosic Integrated with Generation 1.0 Grain Ethanol Plant



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3 - Technical Accomplishments/ Progress/Results

- **Solid/Liquid Separations**
  - **Identify Improved Options**
    - DE Filter Aid
    - DE Dust
    - DE Dilution of Energy Content
  - **Filter Press Addition**
    - 45% Solids
    - 98+% Sugar Recovery
    - No Filter Aid
    - No Energy Dilution

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3 - Technical Accomplishments/ Progress/Results

Clarified Sugars

- Pretreatment
- Hydrolysis
- Remove unconverted solids
- Clarified sugars

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3 - Technical Accomplishments/Progress/Results

Fouling

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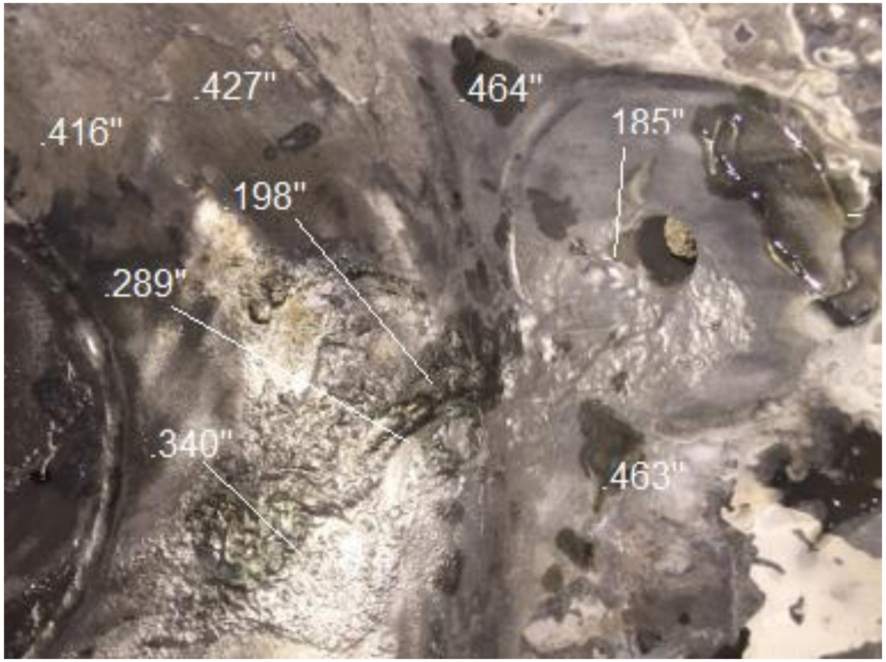
3 - Technical Accomplishments/ Progress/Results

- **Feedstock Handling**
  - Pneumatic Conveying
  - Inert Materials Removal
  - Washing
  - Slurry Pumping

3 - Technical Accomplishments/ Progress/Results

- Pretreatment Reactor Corrosion



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Improvements Against Initial Benchmarks

> **Product cost**

- 15.3% reduction

> **Product Yield (Gallons Fuel/dry tonne of feedstock)**

- 86% glucan conversion – new 98% glucan conversion (14% increase)
- 79.2 gallons/tonne (300 liters/tonne) –
  new 88.7 gallons/tonne (338 liters/tonne) (12% increase)

> **Energy demand (Kwhr/tonne feedstock, kWh/gallon fuel)**

- 2 kWh /gallon
- 158 kWh /tonne

> **Infrastructure Cost of any co-located plant significantly reduced**

> **Environmental sustainability**

- Generate methane from wastewater treatment, Generate heat from residual solids, Share water with co-located plant, Share heat with co-located plant

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4 - Relevance

> **Describe how the project will support planned commercial deployment and/or replicability**
>
> - Gen 1.5, Gen 2.0 Co-Located, Gen 2.0 Greenfield
> - First Commercial Sale of Cellulosic Gen 1.5 by end of 2015
> - First Commercial Sale of Cellulosic Gen 2.0 by end of 2016

4 - Relevance

- **Project will contribute to sustainability and lower life cycle emissions**
  - Carbon content of ethanol from IBR project 41.69 g CO_2e/MJ
  - Percent reduction (gasoline baseline) >60%
  - Net project Lifecycle GHG emissions 158,168 tCO_2e/yr
  - Project GHG Emissions Reduction 180,692 tCO2e/yr
  - Volume offsets to reach 20% LC reduction from gasoline – 0 tCO2e/yr
  - Cost offsets to reach 20% LC reduction from gasoline - $0/yr
  - Cost offset all project emissions (100% carbon neutral) $126,534/yr
  - Net decrease primary energy consumption
  - 3,082,592 MMBtu/yr
  - 75.7% reduction in primary energy compared to gasoline
  - Reduction in oil consumption 531,481 bbl/yr

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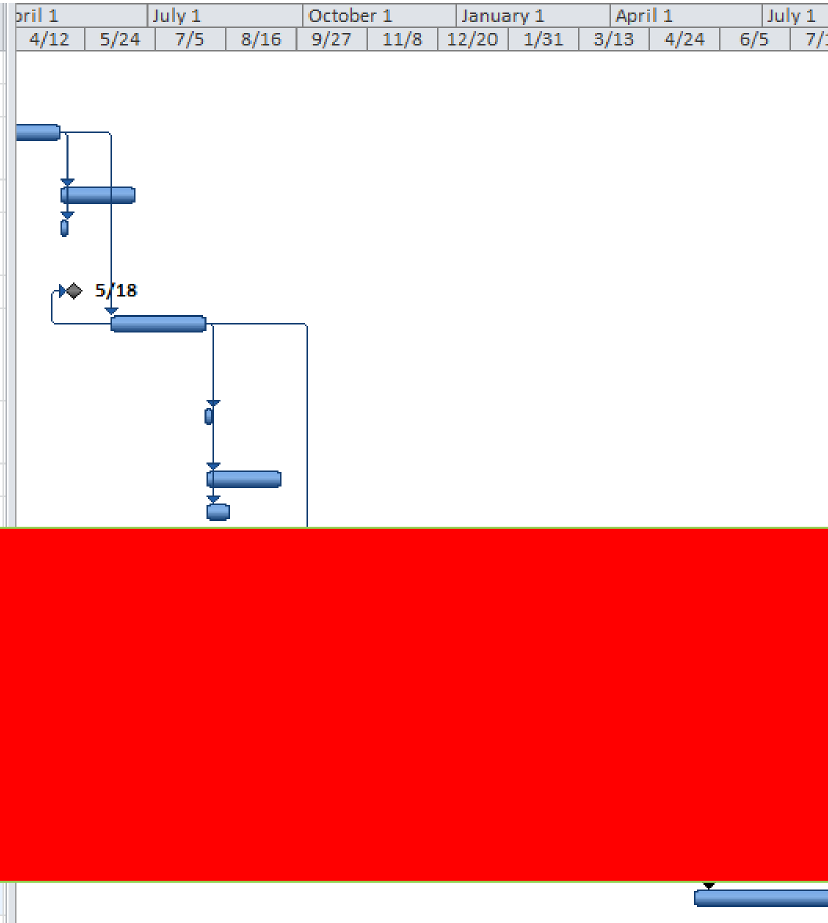
Future Work

	WBS		Task Name	Duration	Start	Finish
19	2.3.1.5.7		Data Analysis Break 4	0 edays	Thu 2/12/15	Thu 2/12/15
7	2.3.2.16		Yeast Production for Integrated Run	0 edays	Sun 2/1/15	Sun 2/1/15
10	2.3.2.16		SG Integrated Run 1,000 Hr Run	57 edays	Fri 3/13/15	Sat 5/9/15
11	11		1000 hour run lab work	45 edays	Sat 5/9/15	Tue 6/23/15
12	2.3.2.17		Gassification Testing of Non-Fermentables	5 edays	Sat 5/9/15	Thu 5/14/15
18	2.3.1.5		Yeast Production for Integrated Runs	0 edays	Mon 5/18/15	Mon 5/18/15
20	2.3.1.7		ES Fermentation, Beer Separation , Aerobic Fermentation, Yeast Seperation 1,000 Hr Run	57 edays	Mon 6/8/15	Tue 8/4/15
22	2.3.1.8		Gassification Testing of Non-Fermentables	5 edays	Mon 8/3/15	Sat 8/8/15
21	21		1000 hour run lab work	45 edays	Tue 8/4/15	Fri 9/18/15
23	2.3.1.7		Data Analysis Break 5 and Lab	14 edays	Tue 8/4/15	Tue 8/18/15
[redacted]						
34	2.3.5.8		Project closeout	60 days	Fri 5/20/16	Fri 8/12/16



Summary

> **Overview**

This IBR has shown commercial scale conversions and value for captive cellulosic fiber in grain ethanol plants. Key materials handling/processing and pretreatment challenges for energy crop processing have been addressed. One performance run is in progress and another is scheduled for June/July.

> **Approach**

This IBR leverages ICM's prior extensive ethanol industry experience, pre-award lab and pilot data, and a pre-existing grain-based pilot facility expected to provide a high probability of successful technology demonstration.

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Summary

> **Technical Accomplishments**

All permitting, construction, water testing, qualification testing, and 1,700+ hours in 2 integrated campaigns have been successfully completed. Conversions of feedstock to C5/C6 sugars and subsequent fermentation to ethanol have improved upon initial projections. Technical barriers identified/addressed.

> **Progress and Results**

Two integrated performance runs totaling 1700+ hours showed that the integrated fiber design (Gen 1.5) works at both pilot and full commercial scales, with up to a 10% ethanol yield increase per bushel by converting the cellulosic fiber in corn. The potential production, if all existing grain ethanol plants adopt this technology, is about 1.3 – 1.4 BGY of cellulosic ethanol at a CAPEX of $2-3 per installed gallon.

Summary

> **Relevance**

Project is confirming the commercial viability of ICM's integrated fiber (Gen 1.5) and co-located (Gen 2.0) designs for cellulose conversion to ethanol and co-products. First commercial designs have been completed for both with first commercial operations expected in 2016 and 2018. CAPEX for Gen 1.5 estimated at $2-3/installed gallon.

> **Future work**

During the remainder of the contract (2015), ICM plans to complete 2 X 1,000 hour campaigns using switchgrass (in progress) and energy sorghum as feedstocks using ICM's co-located design. ICM further expects the CAPEX of this design to be about $6-8 per installed gallon.

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Additional Slides

Responses to Previous Reviewers' Comments

- Management Shortcomings (p1)
  - ICM has instituted a formal Management of Change process that has improved communications and safety of operations where specific modifications are made within the process.
- Underestimated commissioning & shakedown (p2)
  - Yes, commissioning and shakedown did take longer than expected. I don't think we are alone on this issue. You don't know what you don't know.

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Responses to Previous Reviewers' Comments (2)

- Have not shown ASTM standards on ethanol (p2)
  - ICM has conducted initial tests on a single sample. All areas were within specifications with the exception of pH which was slightly low.
- Have not de-risked switchgrass and energy sorghum feedstock processing (6)
  - Start up of each feedstock has taken longer than expected. For example, it was not possible to foresee the challenges going from lab scale to a 10 TPD scale, particularly in the area of side reactions in pretreatment and physical movement of feedstock, both pneumatically and hydraulically.

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Responses to Previous Reviewers' Comments(3)

- Project business risk (p5) - Policy
  - ICM considers US national policy the biggest barrier to cellulosic technology commercialization at this point. Current policy is inconsistent, conflicting, and counterproductive as currently implemented. It functionally prohibits market growth for ethanol and places D6 and D3 RINS in competition with each other instead of being additive to each other. As a direct result, it discourages future investment in Gen 2.0 commercial operations in the US. Thus, this leads ICM to believe that current Gen 2.0 opportunities are outside the US. We do believe Gen 1.5 opportunities are very promising.

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Patents, Awards, Publications, and Presentations

- *List all patents, awards, publications, and presentations, that have resulted from work on this project. Use as many pages as necessary; use at least 12 point font.*

Patents

- **None**

Awards

- **None**

Publications

- **None**

Presentations

- *See Next Pages*

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral presentation. These Additional Slides will be included in the copy of your presentation that will be made available to the Reviewers.

Presentations

- **SIMB Fuels and Chemicals Symposium – May 2013**
  - *Pretreatment Scale Up For Co-located Systems*
  - Comparison of Wet and Dry Fractionation on Generation 1.5™ Ethanol Technology
  - *Fermentation Processes in the ICM Generation 1.5™ Integrated Cellulosic Ethanol*
- **Fuel Ethanol Workshop – June 2013**
  - *Pilot and Commercial Demonstration of Generation 1.5 Cellulosic Ethanol Production*
  - *ICM Generation 1.5 Cellulose to Ethanol*
- **Advanced Biofuels Leadership Conference 2013**
  - *Generation 1.5 Ethanol: Ready for Commercialization, But is There a Market?*
- **BBI International Biofuels Conference – March 2014**
  - *Commercialization of ICM's Generation 1.5 Technology*
- **Advanced Biofuels Leadership Conference – April 2014**
  - *Commercialization of ICM's Generation 1.5 Technology*
- **SIMB Fuels and Chemicals Symposium – April 2014**
  - *Commercialization of ICM's Generation 1.5 Technology*
- **Fuel Ethanol Workshop – June 2014**
  - *ICM's Line of Sight to Cellulosic Ethanol*

Presentations – 2

- **Advanced Bioeconomy Leadership Conference NEXT – November 2014**
  - *Benefits and Challenges of Liquid Fuel and Chemical Production from Renewable Feedstocks*
- **Advanced Biofuel Leadership Conference – March 2015**
  - *Perspectives on the Road to Cellulosic Ethanol*
- **SIMB Fuels and Chemicals Symposium – April 2015**
  - *Pretreatment of Switchgrass Scale Up: Lessons Learned*
  - *ICM's Line of Sight to Cellulosic Ethanol*
- **Fuel Ethanol Workshop – June 2015**
  - *Benefits and Challenges of Liquid Fuel and Chemical Production from Renewable Feedstocks*
  - *Line of Sight to Cellulosic Ethanol*
  - *Pretreatment Scale Up of Lignocellulosic Feedstock: Lessons Learned*

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