2013 DOE Bioenergy Technologies Office(BETO) IBR Project Peer Review

Recovery Act: Pilot Integrated Cellulosic Biorefinery Operations to Fuel Ethanol

Award Number: DE-EE0002875

May 20, 2013

Integrated Biorefinery Program Review Panel

Douglas B. Rivers, Ph.D.
ICM, Inc.

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Project Description

- Project Location – **ICM, Inc., St. Joseph MO**
- Company headquarters – **ICM, Inc., Colwich, KS**
- High Level overview of:
  - Feedstock handling
    - **Dry 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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Quad Chart Overview

Timeline

- Project start date
  - BP-1: **January 28, 2010**
  - BP-2: **August 31, 2010**
  - BP-3: **April 1, 2012**
- Project end date
  - Mechanical Turnover – **July 2011**
  - Start-up – **August 2011**
  - Commissioning – **February 2012**
  - Operations – **April 2012**
  - Completion – **December 2014**
- Percent complete – **54%**

Budget

- Total project funding
  - DOE share - **$25,000,000**
  - Contractor share - **$6,710,210**
- Funding received by Fiscal Year
  - FY 2010 - **$ 860,469.03**
  - FY 2011 - **$10,362,734.10**
  - FY 2012 - **$ 4,223,739.00**
  - FY 3013 - **$ 2,429,304.27**
- ARRA Funding - **$25,000,000**

Project Development

What is the status of the project?

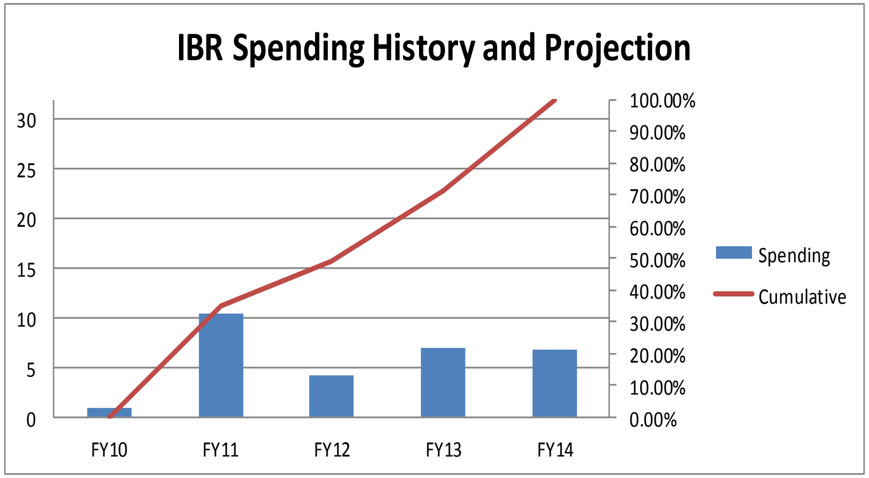
- Are you on track with cost and schedule? Yes
- Has the project scope changed? No
- Identify when the project is complete. **December 31, 2014**

Project Participants

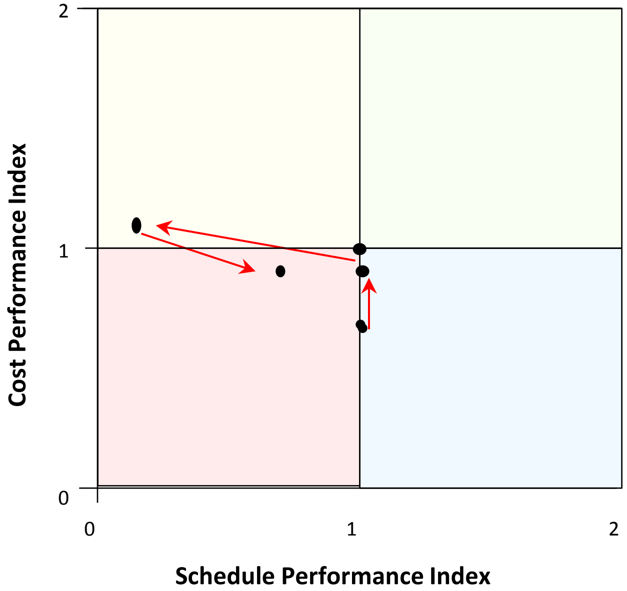
- Interactions/ collaborations
  - **Novozymes, LifeLine Foods, AGCO, Ceres, Stinger, Growers**
- Intellectual property licenses - **Yes**
- Project management – **ICM**
- Construction management - **ICM**
- Start-up and commissioning - **ICM**
- Operations - **ICM**

Cost and Schedule Performance

- **Spend Plan**



- **Earned Value**
  (Bull's-Eye Diagram)



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Project Overview

> 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 that gives a 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 is currently in optimization stage, switchgrass is in future**
- **Feedstock differences are being optimized as each is demonstrated**

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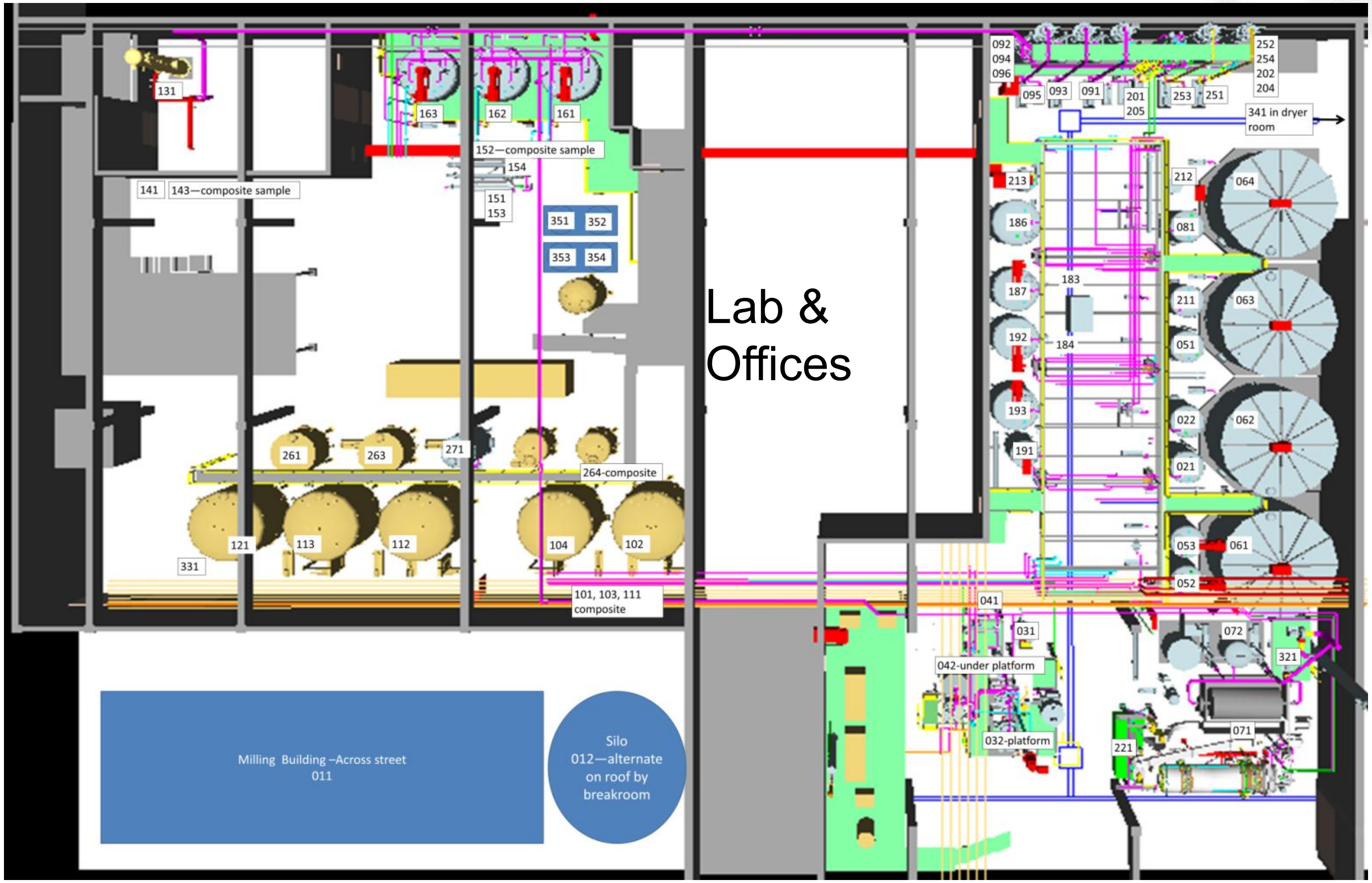
St. Joseph Generation 2 Pilot Plant: Layout and Process Flow



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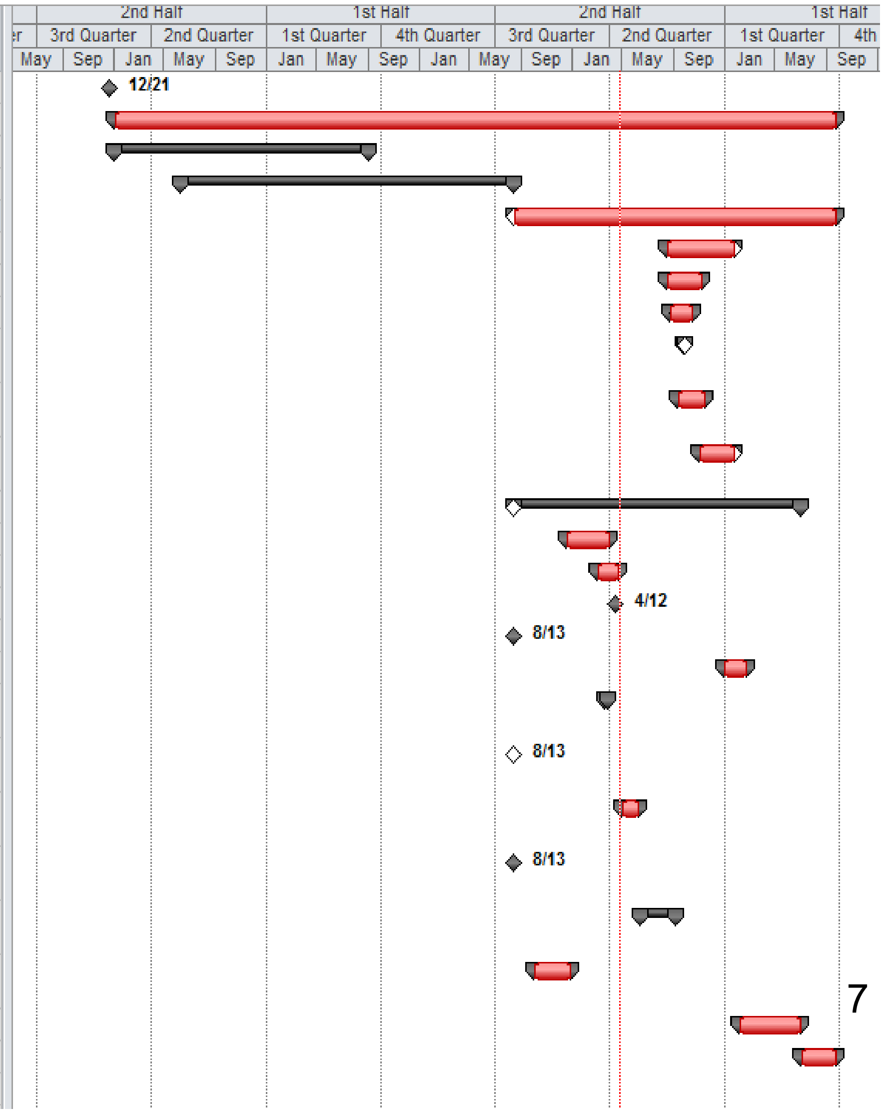
Baseline Gantt Chart

	WBS (DOE)	Task Name	Start	Finish	Duration
1	1	Grant Award	Mon 12/21/09	Mon 12/21/09	0 days
3	2	ICM DOE FOA-0000096	Fri 1/1/10	Tue 9/23/14	1219 days
4	2.1	Funding Period 1	Fri 1/1/10	Thu 9/1/11	430.55 days
129	2.2	Funding Period 2	Tue 6/8/10	Mon 8/13/12	556 days
698	2.3	Funding Period 3	Mon 8/13/12	Tue 9/23/14	551 days
699	2.3.1	Switchgrass pilot efforts	Wed 8/14/13	Fri 1/24/14	118 days
700	2.3.1.1	Test alternative Switchgrass milling	Wed 8/14/13	Tue 11/5/13	60 days
724	2.3.1.2	Dilute acid switchgrass pretreatment	Fri 8/23/13	Wed 10/16/13	39 days
733	2.3.1.4	Switchgrass 1st stage mixing and hydrolysis (Deleted)	Wed 9/25/13	Thu 9/26/13	1 day
741	2.3.1.5	Switchgrass S/L separation and concentration	Tue 9/10/13	Wed 11/13/13	47 days
751	2.3.1.7	SG Fermentation, Beer Separation, Aerobic Fermentaiton, and Yeast Separation	Thu 10/31/13	Fri 1/24/14	62 days
761	2.3.2	Corn Fiber and Energy Sorghum pilot efforts	Mon 8/13/12	Mon 6/30/14	490 days
762	2.3.2.1	Energy Sorghum milling tests	Mon 12/17/12	Fri 3/29/13	75 days
771	2.3.2.2	Dilute acid energy sorghum	Sun 3/3/13	Fri 4/19/13	35 days
780	2.3.2.3	Energy sorghum pretreatment defined	Fri 4/12/13	Fri 4/12/13	0 days
781	2.3.2.4	Dilute acid Captive fiber (Moved to FP-2)	Mon 8/13/12	Mon 8/13/12	0 days
790	2.3.2.6	Autohydrolysis captive fiber	Sat 12/28/13	Thu 2/20/14	39 days
799	2.3.2.10	Energy Sorghum 1st stage mixingand hydrolysis (Deleted)	Thu 3/21/13	Wed 3/27/13	5 days
807	2.3.2.11	Corn fiber 1st stage mixingand hydrolysis (Deleted)	Mon 8/13/12	Mon 8/13/12	0 days
816	2.3.2.12	Energy Sorghum S/L separation and hydrolyzate concentration	Wed 5/1/13	Fri 6/7/13	27 days
826	2.3.2.14	Captive fiber S/L separation and hydrolyzate concentration (DELETED)	Mon 8/13/12	Mon 8/13/12	0 days
834	2.3.2.16	ES Fermentation, Beer Separation, Aerobic Fermentaiton, and Yeast Separation	Thu 6/13/13	Fri 9/6/13	62 days
843	2.3.2.19	CF Fermentation, Beer Separation, Aerobic Fermentaiton, and Yeast Separation	Mon 10/1/12	Thu 12/27/12	64 days
855	2.3.2.22	Additional campaigns information gathered	Sat 2/1/14	Mon 6/30/14	106 days
860	2.3.5	Project Close-out	Tue 7/1/14	Tue 9/23/14	61 days



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Current Gantt Chart

	WBS		Task Name	Duration	Start	Finish
1	2.3.2.1		Alternative Energy Sorghum Milling	125 edays	Mon 12/17/12	Sun 4/21/13
2	2		ICM wet Frac full scale run	40 edays	Mon 4/22/13	Sat 6/1/13
3	2.3.2.1		Alternative Energy Sorghum Milling contd.	30 edays	Mon 6/3/13	Wed 7/3/13
4	2.3.2.2		Dilute Acid Energy Sorghum Pretreatment	18 edays	Thu 7/4/13	Mon 7/22/13
5	2.3.2.12		Energy Sorghum S/L Separation	30 edays	Thu 8/29/13	Sat 9/28/13
6	2.3.2.16		Yeast Production for Integrated Run	14 edays	Mon 9/2/13	Mon 9/16/13
7	2.3.2.16		Co-Located Fermentation Testing Round 2	21 edays	Mon 9/16/13	Mon 10/7/13
8	2.3.2.16		Data Analysis Break 2	14 edays	Sat 9/28/13	Sat 10/12/13
9	2.3.2.16		Energy Sorghum Integrated Run 1,000 Hr Run	57 edays	Sat 10/12/13	Sun 12/8/13
10	2.3.2.17		Gassification Testing of Non-Fermentables	5 edays	Sun 12/8/13	Fri 12/13/13
11	2.3.1		Switchgrass Milling Tests	15 edays	Sun 12/8/13	Mon 12/23/13
12	2.3.1.2		Dilute Acid Switchgrass	18 edays	Mon 12/23/13	Fri 1/10/14
13	2.3.1.3		Data Analysis Break 3	5 edays	Fri 1/10/14	Wed 1/15/14
14	2.3.1.5		Switchgrass S/L Seperation & Hydrolyzate Concentration	30 edays	Wed 1/15/14	Fri 2/14/14
15	2.3.1.5		Yeast Production for Integrated Runs	14 edays	Thu 2/6/14	Thu 2/20/14
16	2.3.1.5.		Data Analysis Break 4	14 edays	Fri 2/14/14	Fri 2/28/14
17	2.3.1.7		SG Fermentation, Beer Separation , Aerobic Fe	57 edays	Thu 2/27/14	Fri 4/25/14
18	2.3.1.8		Gassification Testing of Non-Fermentables	5 edays	Thu 4/24/14	Tue 4/29/14
19	2.3.1.7		Data Analysis Break 5 and Lab Catch-Up 2-3 weeks	14 edays	Fri 4/25/14	Fri 5/9/14
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21	2.3.2.19		Data Analysis Break 6 and Lab Catch-Up 2-3 weeks	14 edays	Wed 8/14/13	Wed 8/28/13
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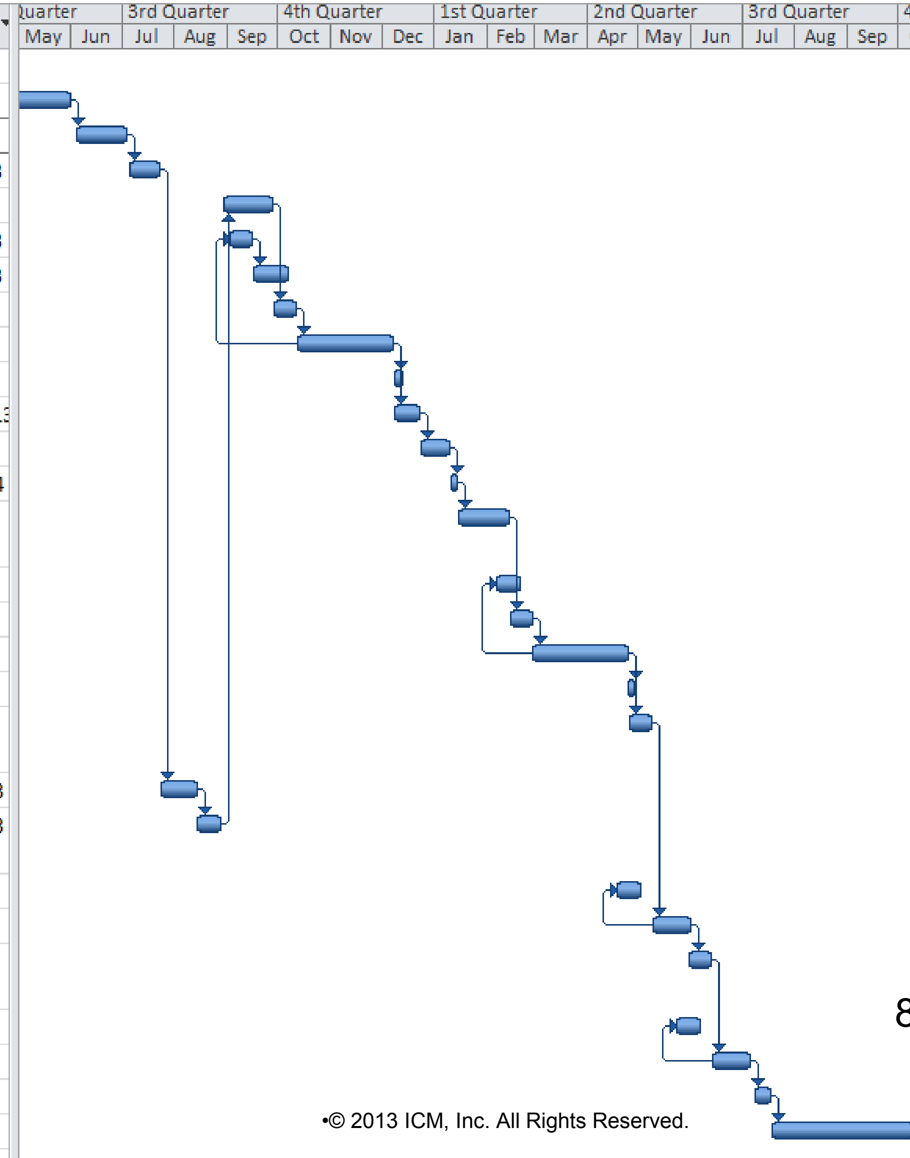
24	2.3.2.16		Data Analysis Break 7 and Lab Catch-Up 2-3 weeks	14 edays	Fri 5/30/14	Fri 6/13/14
25	2.3.2.16		Yeast Production for Integrated Runs	14 edays	Fri 5/23/14	Fri 6/6/14
26	2.3.1.7		Campaign 3 SG 500 HR Run	23 edays	Fri 6/13/14	Sun 7/6/14
27	27		Gasification Run	10 edays	Mon 7/7/14	Thu 7/17/14
28	28		Project closeout	60 days	Fri 7/18/14	Thu 10/9/14



1 – Project Management

- WBS Based Planning
- Team Based Approach
  - Technical
    - Multidisciplinary
  - Business
- Regular Team Planning and Review Meetings

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1 – Project Management (2)

> Systematic Approach – Workflow Process

- Protocol Preparation/Approval
- Training
- Execution
  - Pilot
  - Lab
  - Data Analysis
  - Reporting
  - Lessons Learned
  - Continuous Improvement
- Fixed Targets/Decision Points
  - Technical
  - Economic

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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
  - Completed 1,150 hour integrated run – corn fiber
    - November 2012
  - Future integrated runs planned in 2013 and 2014

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2 - Technical Accomplishments/ Progress/Results

- Construction
  - Procured All Required Equipment
  - Installed Equipment per Design Plan
  - Expanded Scope of State of Missouri Air Permit
  - Completed Water Testing

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2 - Technical Accomplishments/ Progress/Results

- Qualification Testing
  - Established All Unit Operations
  - Completed Preliminary Testing
  - 60- Day Co-Located Design Run
    - Ran All Unit Operations – Not All Continuously
  - Identified Opportunities for Improvement
    - Pretreatment
    - Yeast Propagation
    - Solid/Liquid Separations

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2 - Technical Accomplishments/ Progress/Results

- Yeast Propagation
  - Aseptic Operations
  - Timing
  - Continuous Sterilization Capacity

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2 - Technical Accomplishments/ Progress/Results

- Solid/Liquid Separations
  - DE Dust Control
  - Pond Depth/Drum Coating
  - Knife Setting
  - DE Cost
- Drying
  - Feed Rates/Settings
  - Steam Tube Coating

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2 - Technical Accomplishments/ Progress/Results

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

2 - Technical Accomplishments/ Progress/Results

- Integrated Fiber 1,000 Hour Run
  - Total Continuous Run Time – 1,150 Hours
  - Shut Down Predetermined – Day Before Thanksgiving
- Identified Regular CIP Pretreatment
- Replicated Prior Lab Data
- Pilot Scale – 15,000 gallon Fermentors
- Commercial Scale – 585,000 gallon Fermentors
- 7% Increased Yield – C6 Only
- 10% Increased Yield – C5 + C6
- Modified DDGS - Sold All 5 Batches at Full Market Price

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2 - Technical Accomplishments/ Progress/Results

- Pretreatment
  - Feedstock Feed/Slurry
  - Acid/Base Control
  - Fouling
  - Flash Control



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Fouling

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Fouling

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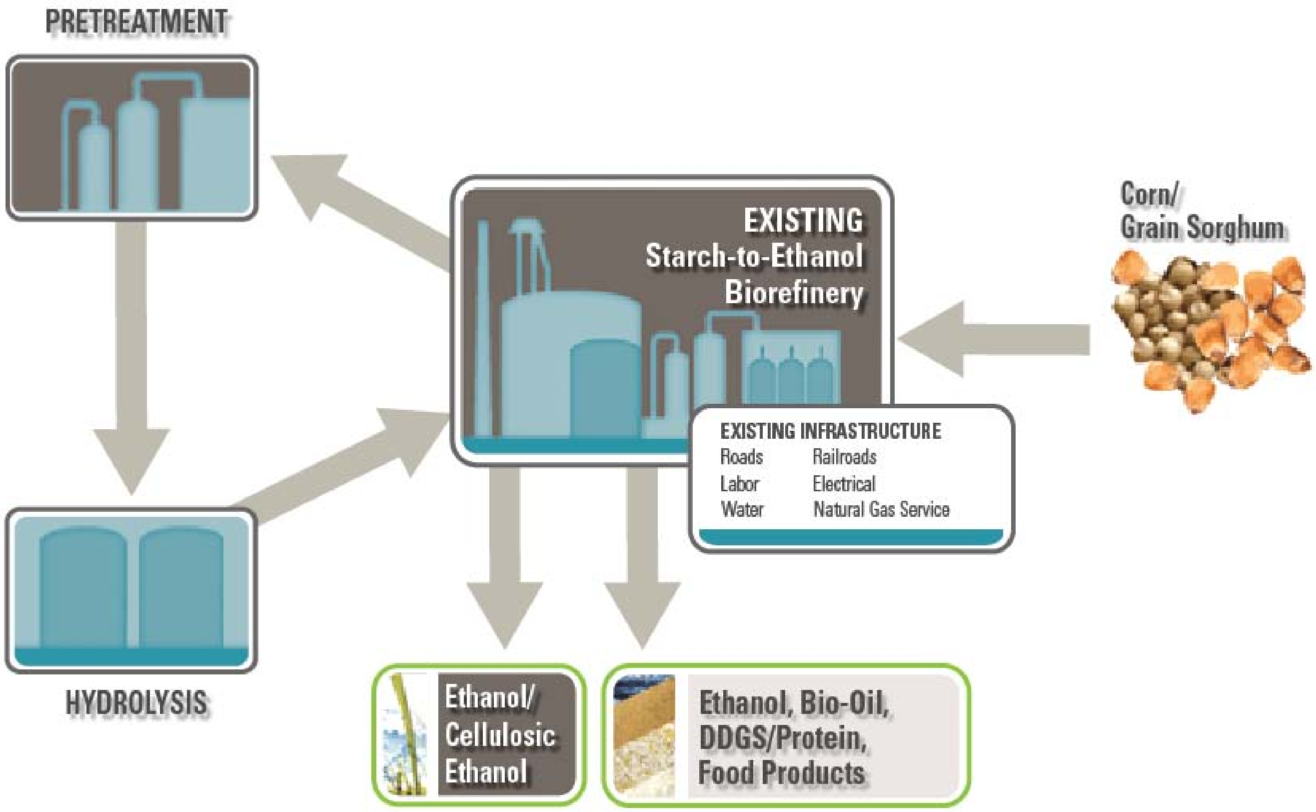
Generation 1.5: Integrated Cellulose at Existing Grain Facilities



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1000 Hour Integrated Run Overview

- 24 X 10,000 gallon starch/cellulose integrated pilot fermenters
- 18 X 35,000 gallon hydrolyzate tanks
- 5 X 535,000 gallon full-scale test fermenters
- 5 X 535,000 gallon full-scale control fermenters
- 1200-hours of pretreatment run time

batch number	fermentation type	Finish time (h)	ethanol concentration (% w/v)	% yield increase
501	C6 (cell + starch)	54	12.6%	6.5%
502	C5/C6	54	13.2%	11.6%
503	C5/C6	54	13.1%	11.2%
504	C6 (starch only)	54	11.8%	
505	C6 (cell + starch)	54	12.7%	7.3%
506	C5/C6	54	12.8%	8.8%
507	C5/C6	54	12.8%	8.7%
508	C6 (starch only)	54	11.8%	
509	C6 (cell + starch)	60	12.5%	7.4%
510	C5/C6	60	12.8%	10.4%
511	C5/C6	60	12.6%	8.8%
512	C6 (starch only)	60	11.6%	
513	C6 (cell + starch)	60	12.2%	8.5%
514	C5/C6	60	12.5%	11.1%
515	C5/C6	60	12.5%	11.1%
516	C6 (starch only)	60	11.3%	
517	C6 (cell + starch)	60	11.2%	6.2%
518	C5/C6	60	11.5%	8.3%
519	C5/C6	60	11.4%	8.2%
520	C6 (starch only)	60	10.6%	
521	C6 (cell + starch)	60	11.7%	6.5%
522	C5/C6	60	12.0%	9.6%
523	C5/C6	60	12.0%	9.1%
524	C6 (starch only)	60	11.0%	
average	**C6 (cell + starch)**	**58**	**12.1%**	**7.1%**
average	**C5/C6**	**58**	**12.4%**	**9.7%**
average	**C6 (starch only)**	**58**	**11.3%**	

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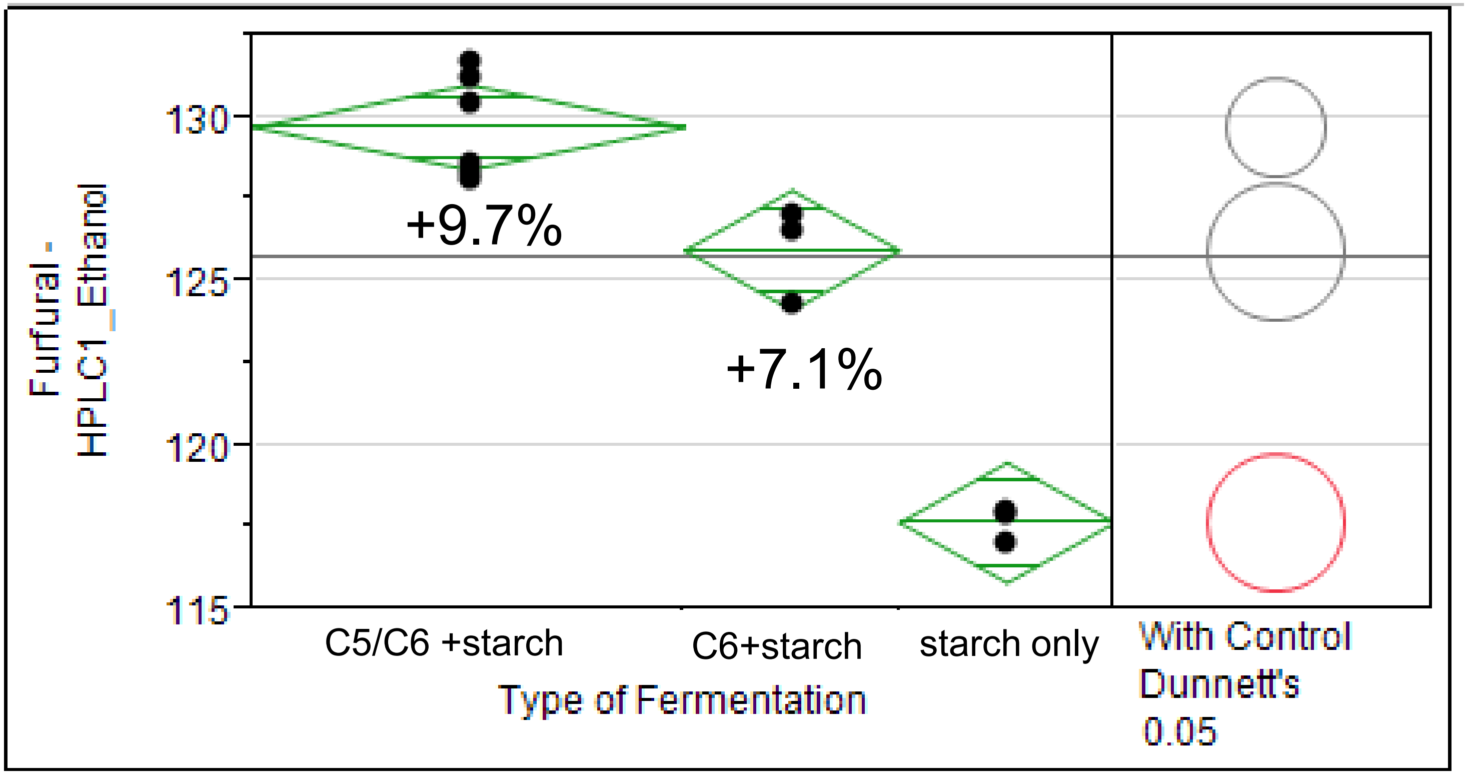
Increased Yields vs Control



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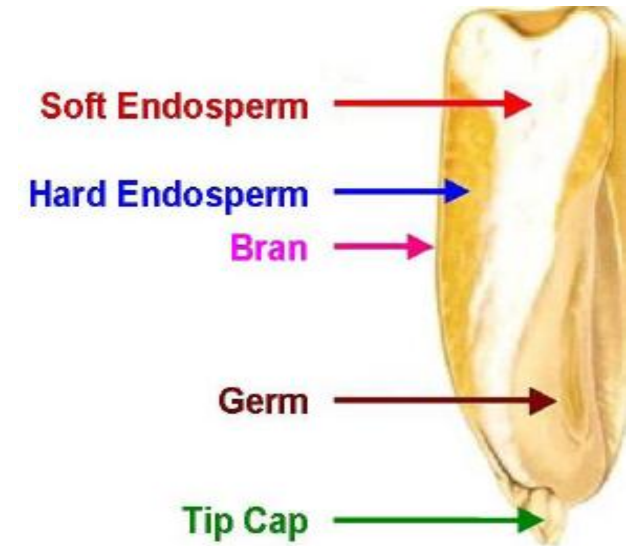
•Generation 1.5: Integrated Corn Fiber Production Potential

- **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)**
- **3.0+ Gallons** (11.4 liters) **per bushel yield**
  - Increase in Protein/Fat Value Feed
  - Increased Oil Recovery
  - Co-Products Diversification
- **Increased ethanol yield/bushel of 7-10%**
- **Patent Pending Process**



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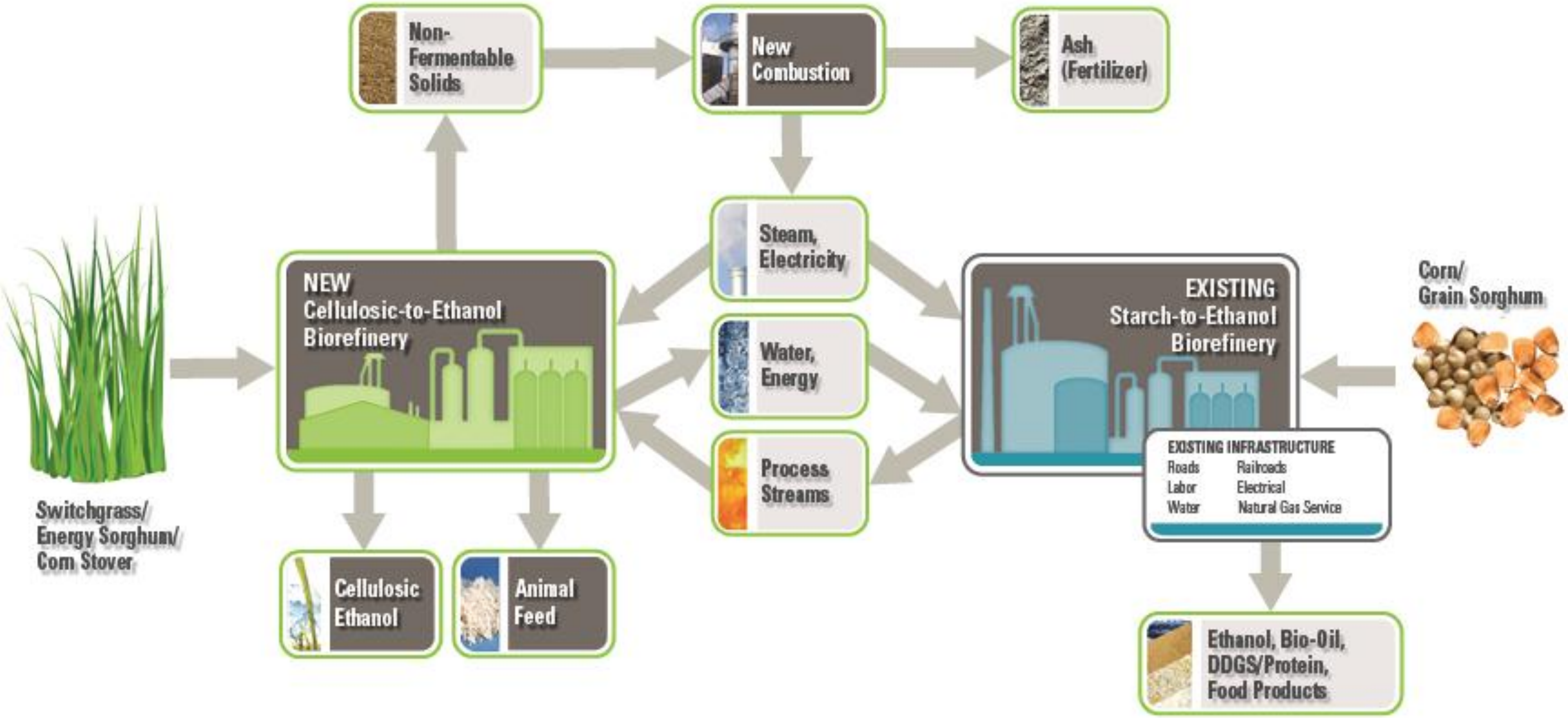
Generation 2.0 Co-Located Cellulosic Integrated with Generation 1.0 Grain Ethanol Plant



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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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Clarified Sugar Production

- Pretreatment
- Hydrolysis
- Remove unconverted solids
- Clarified sugars

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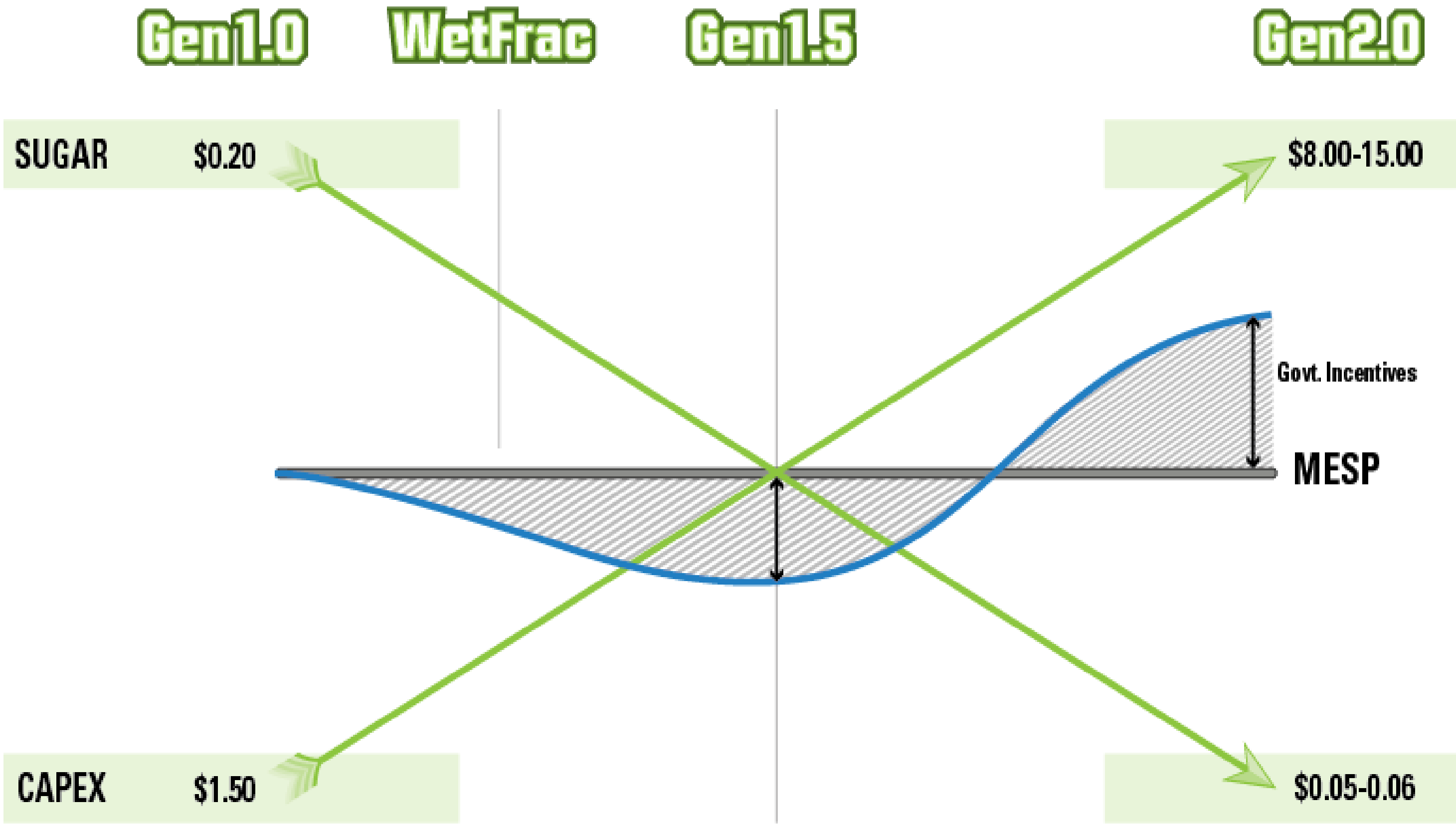
Ethanol Generations: Economic Parity



Projections based on pilot testing and/or early adopter installation.

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3 - 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 2013
  - First Commercial Sale of Cellulosic Gen 2.0 by end of 2014

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3 - 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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4 - Critical Success Factors

- Critical Success Factors
  - Yield of Ethanol
  - Yield and Quality of Co-Products
  - Required quantities of processing aids (enzymes, chemicals, filter aid, etc.)
  - Mechanical Reliability (high uptime)
- Top Challenges
  - Feedstock handling
  - Optimization of pretreatment with multiple, variable feedstocks
  - Optimization of yeast propagation/recycle strategy

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4 - Critical Success Factors

- **Risks that were successfully mitigated**
  - Feedstock availability
  - Feedstock handling
  - Pretreatment process control
  - Yeast Propagation

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Future Work

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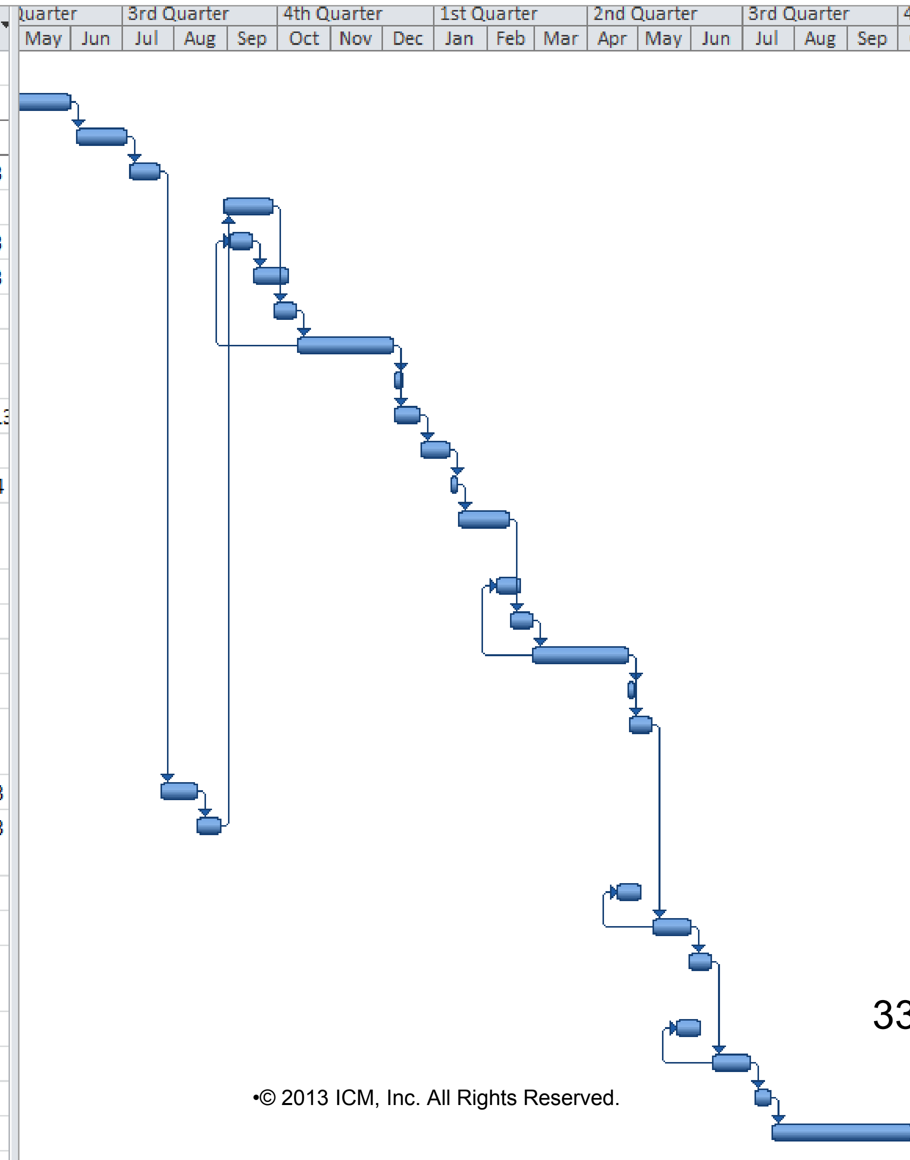

Summary

> **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 2013 and 2015.

> **Approach**

This IBR leverages off if 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 an initial 1,000+ hour integrated campaign have been successfully completed. Conversions of feedstock to C5/C6 sugars and subsequent fermentation to ethanol have improved upon initial projections.

> **Benefits and Expected Outcomes**

The initial integrated run has proven that the integrated fiber design (Gen 1.5) works at both pilot and commercial scales, thus allowing up to a 10% ethanol yield increase per bushel by converting the cellulosic fiber in corn. The potential if all existing grain ethanol plants adopt this technology is the production of about 1.3 – 1.4 BGY of cellulosic ethanol at a CAPEX of $2-3 per installed gallon.

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Summary

> Future work

During the remainder of the contract (2013-2014), ICM plans to complete additional 1,000 hour campaigns using switchgrass and energy sorghum as feedstocks using a co-located design. ICM further expects the CAPEX of this design to be about $6-8 per installed gallon.

> Success factors and challenges

Consistent ability to handle a bulky, low density feedstock from receipt at the plant through pretreatment operations.

Ultimately, the lack of market demand for new ethanol production capacity resulting from the lack of market implementation of E15 and higher blends, is critical.

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Additional Slides

(Not a template slide – for information purposes only)

- *The following slides are to be included in your submission for Peer Evaluation purposes, but <u>will **not** be part of your Oral presentation</u> –*
- *You may refer to them during the Q&A period if they are helpful to you in explaining certain points.*

Responses to Previous Reviewers' Comments

- *For on-going projects that were reviewed in 2011, please provide 2-4 significant comments, questions, recommendations, and/or criticisms received from the reviewers*
- *Provide information on how these were addressed by the project team since the last review*

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.

Responses to Previous Reviewers' Comments

- **The Project is behind schedule**
  - As shown in the Gantt Charts, we are on schedule to complete the project before the end of 2014.
- **The Project does not address business, market, and regulatory issues that impact commercial viability**
  - The concept of Generation 1.5 ethanol from corn fiber has reduced capex to about $2-3/installed gallon of capacity.
  - The market is a concern. Until E15 and higher blends of ethanol are made available to the consumer across the marketplace, there is no need to add additional ethanol capacity.
  - The GMO yeast that we have been using is currently in the review process for approval at FDA/CVM. We have identified a second GMO yeast provider with equally good results and it is also entering the process.

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Responses to Previous Reviewers' Comments (2)

- ***Manufacturing cost is higher than the program goal, and critical success factors are likely to add cost, thus commercial success will be a challenge***
  - *Generation 1.5 has a capex of only $2-3/installed gallon of capacity.*
  - *Generation 1.5 is expected to be able to sell at a reduced MESP (see MESP chart above) to achieve breakeven as a result of clear cost competitive advantages as confirmed in a 1,150 hour fully integrated campaign using commercial scale fermentors.*
  - *Generation 1.5 FEL-1 has confirmed pilot results thus far.*
  - *Similar positive impacts are expected to be confirmed in upcoming Generation 2.0 fully integrated pilot campaigns.*

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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

- 2013
- **SIMB Fuels and Chemicals Symposium**
  - Pretreatment Scale Up
  - Pilot and Commercial Demonstration of Cellulosic Ethanol Production
- **Advanced Biofuels Leadership Conference**
  - Generation 1.5 Ethanol: Ready for Commercialization, But is There a Market?

Presentations (2)

> **2012**

- **BBI Biofuels Conference**
  - Pathways to Clarified Sugars for Production of Fuels and Chemicals
- **Advanced Biofuels Conference**
  - Accelerating the Transition from G1 to G2 Ethanol
- **American Coalition for Ethanol**
  - ICM Pathway from Generation 1 Ethanol to Generation 2 Ethanol
- **Fuel Ethanol Workshop**
  - Co-Location of Cellulose and Corn Processes

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Presentations (3)

> **2011**
  - **Fuel Ethanol Workshop**
    - ICM Perspectives on the Conversion of Cellulose to Ethanol

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