Development of Sustainable Biobased Products and Bioenergy in cooperation with the Midwest Consortium for Sustainable Biobased Products and Energy

DOE – Products Platform Stage Gate Review Meeting
August 9, 10, 2005

Michael Ladisch and Wally Tyner
Purdue University

On behalf of the Midwest Consortium

Acknowledgements

Gene Petersen, Anna Hanley — DOE Golden Field Office

Steve Kelly, Andy Aden — NREL

Todd Werpy — PNL

Melissa Klembara — DOE

Leslie Pezullo — BCS

Alex Toro, Rich Dreschel, Rollo Everett, Gary Welch — Aventine Renewable Energy

Rick Hendrickson, Randy Woodson, Lesley Oliver — Purdue University

Mohammed Moniruzzaman — Genencor

Phil Shane — Illinois Corn Marketing Board

This work supported by DOE Grant # DE-FG36-04GO14220

Presentation Outline

- Overall Project Goals and Objectives
- Organization of the Approach to meeting these Goals and Objectives (tasks and subtasks)
- Major objectives
  - Technical or economic target or objective
  - All risks associated with meeting these targets or objectives
  - Milestones established to measure progress and financial or performance metrics
  - Go No/Go decision points
  - Accomplishments to date
  - Future plans and partners
- Market and customers
- Competitive Advantage
- Strategic Fit
- Conclusions

Introduction

Midwest Consortium for
Sustainable Biobased Products and Energy

(initiated in 1999)

Michael Ladisch, Randy Woodson, Nathan Mosier, Wally Tyner — *Purdue University*
Hans Blaschek, Thaddeus Ezeji, *U. Illinois*
Bruce Dale, Balan Venkatesh *Michigan State University*
Mike Cotta, Bruce Dien, *USDA NCAUR*
Brent Shanks, *Iowa State University*
John Verkade, *Ames Laboratory*
Seth Snyder, Jim Frank *Argonne*

Project Goals

1. Integrate institutional capabilities of the Midwest Consortium to add value to Distillers Grains (DG)

2. Carry out research to process DG to
   - additional fermentable sugars, ethanol, bioproducts
   - obtain a protein enriched solid residue

3. Contribute directly to the DOE's multi-year plan as relates to the sugar platform and products
   - help to meet targets to establish biomass as a significant source of sustainable fuels in the US

Overall Project Goals & Objectives

1. Conduct research on the pretreatment fundamentals, enzyme catalysts, and microbial systems for converting both starch and cellulosic materials to ethanol at conditions consistent with the operation of a dry mill, including economic models;

2. Carry out fundamental studies on the structure and function of hydrolytic enzyme, biomimetic, and organic catalysts with respect to the structure and function of the cellulose and hemicellulose in corn fiber and corn stover that enhances their conversion to sugar; and where it makes sense;

3. Partner with regional ethanol producers and government agencies to achieve sustainable systems for renewable bioenergy and bioproducts by defining engineering fundamentals for utilizing lignocellulosics and fiber materials as feedstocks in dry mills.

2004 Fiber Production

	2004 Ethanol (Billion gallons)	2004 Fiber (million metric tons)
Dry Mills	2.55	7.30 distillers grains
Wet Mills	0.85	0.43 gluten meal 2.36 gluten feed

Renewable Fuels Association, 2005; http://www.ethanolrfa.org/outlook2005.pdf

Production of DDGS

Corn is cleaned, tempered, ground into appropriate size, cooked, hydrolyzed with amylolytic enzymes and fermented with yeasts.

Ethanol and carbon dioxide produced

Distiller's wet grains (DG) and solubles are the residues remaining after fermentation

Residues are blended and dried to produce distiller's dried grains (DDG) or DDG with solubles (DDGS)

2004 Ethanol Production Facilities

Renewable Fuels Association, 2005; http://www.ethanolrfa.org/outlook2005.pdf

Organization /Approach

Tasks (work started Oct, 2004)

1. **advanced pretreatments**
   to enhance the digestibility/reactivity of the fiber component (cellulose and hemicellulose) of DG,
2. **enzymatic hydrolysis of pretreated DG**
   to produce fermentable sugars, remove part or all of the cellulose and hemicellulose, increase feed value of residual solids,
3. **fermentation of hexose and pentose sugars**
   to ethanol and their transformation to other biobased products,
4. **analysis of composition**
   and advanced separation methods for ethanol and other products,
5. **life cycle analysis**
   to quantify key environmental features of corn based biorefineries and the crop production systems that support them
6. **comprehensive economic analysis**
   of the processes, technologies, and markets, incorporating uncertainty in key technological and market parameters.

Task 1. Pretreatment

1. **Pretreatment** of the distiller's grains or DDGS by
   AFEX (ammonia freeze explosion, Michigan State) or
   Aqueous pressure cooking at 160 C, 10 to 20 min, pH 4 to 7 (Purdue)

Target: Optimize pretreatments to maximize glucan and pentosan conversion, minimize enzyme usage and inhibitor formation, and maximize fermentation yield to ethanol and other bioproducts.

Identify optimal conditions while obtaining a net fermentable sugar cost of 5 cents/lb or less (including cost of hydrolysis)

Pretreatments carried out and pretreated DG supplied to other members of the Consortium for evaluation and research purposes.

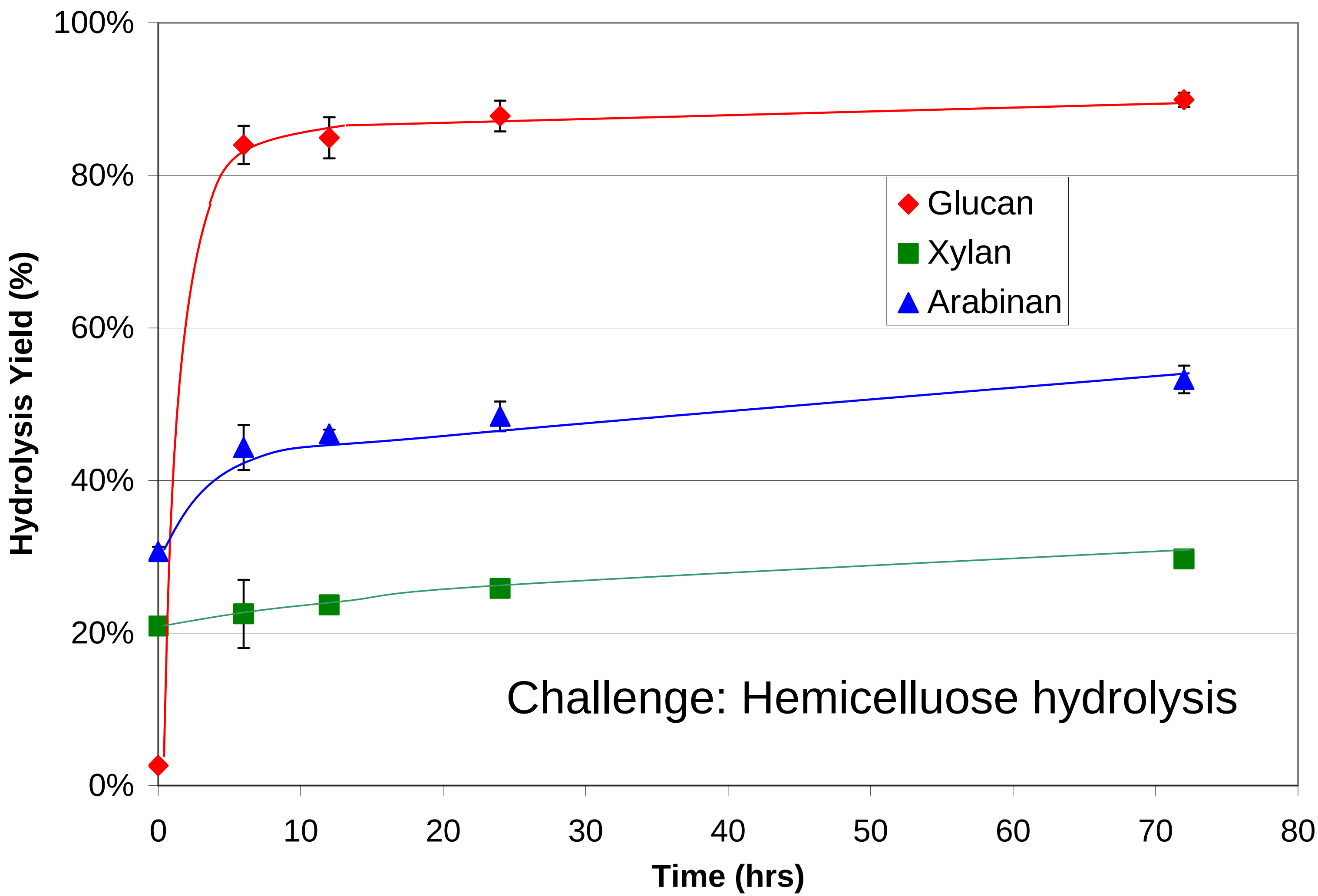
Task 2. Hydrolysis

Enzyme Digestibility of DG (%) Measured at U. Illinois

Time (h)	Untreated DG	AFEX treated DG	Hot Water treated DG
0	2.3	2.4	1.7
6	-	64.3 ± 1.1	78.3 ± 1.1
12	-	**75.6 ± 0.7**	**88.4 ± 1.1**
24	62.7 ± 0.5	89.6 ± 1.6	95.8 ± 1.0
48	-	97.8 ± 0.9	99.6 ± 0.8
72	71.5 ± 1.4	102.6 ± 2.7	99.1 ± 1.9
168	**76.2 ± 1.1**	-	-

Need to optimize with respect to hemicelluose hydrolysis, enzyme composition, sugar concentration

Task 2. Hydrolysis



Task 2. Hydrolysis

Enzyme preparations have xylanase activity

Enzyme Prep.	Filter paper (IU/ml)	CMC (IU/ml)	OSX (IU/ml)	WSX-HV (IU/ml)	WSX-LV (IU/ml)	WIX (IU/ml)	CFX (IU/ml)
Novozyme	8.50	481	123	118	224	48.9	55.9
Spezyme CP	58.2	4277	2622	3022	3898	3635	506
GC 220	49.0	5185	2782	3955	4480	2258	581

Xylans: **OSX**: oat spelt xylan; **WSX-HV**: wheat soluble xylan, high viscosity
WSX-LV: wheat soluble xylan, low viscosity; **WIX**: wheat insoluble xylan
CFX: corn fiber arabinoxylan

USDA NCAUR

Task 3. Fermentation

3. Fermentation. Targets for the fermentation:

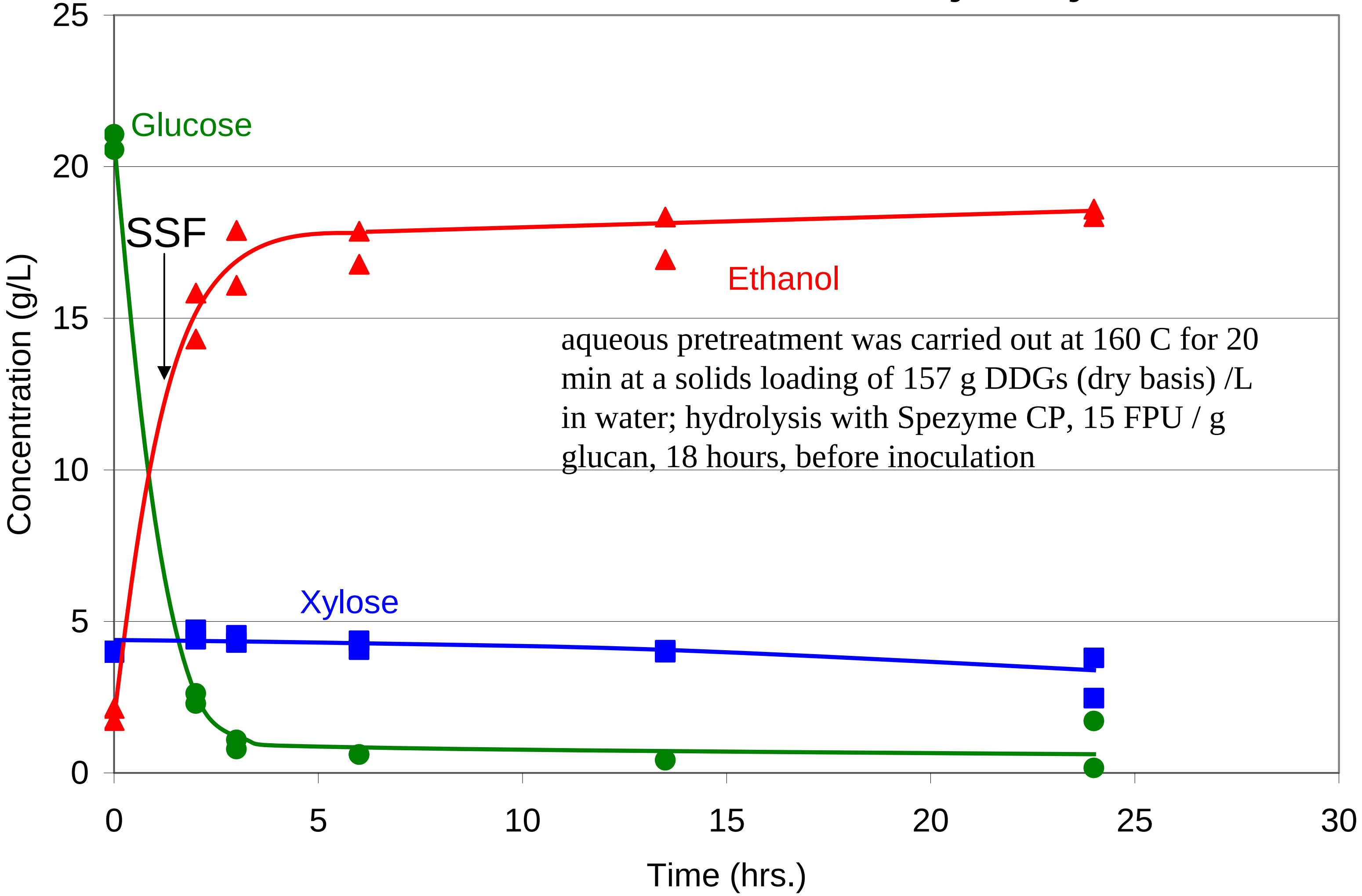
80% of theoretical to ethanol starting with fermentable sugar (hexose and pentose) concentrations of 100 g / L

minimize inhibition by sugar degradation products from pretreatment and/or hydrolysis (may require conditioning or separation of fermentable sugars).

attain net ethanol cost of $1 per incremental gallon.

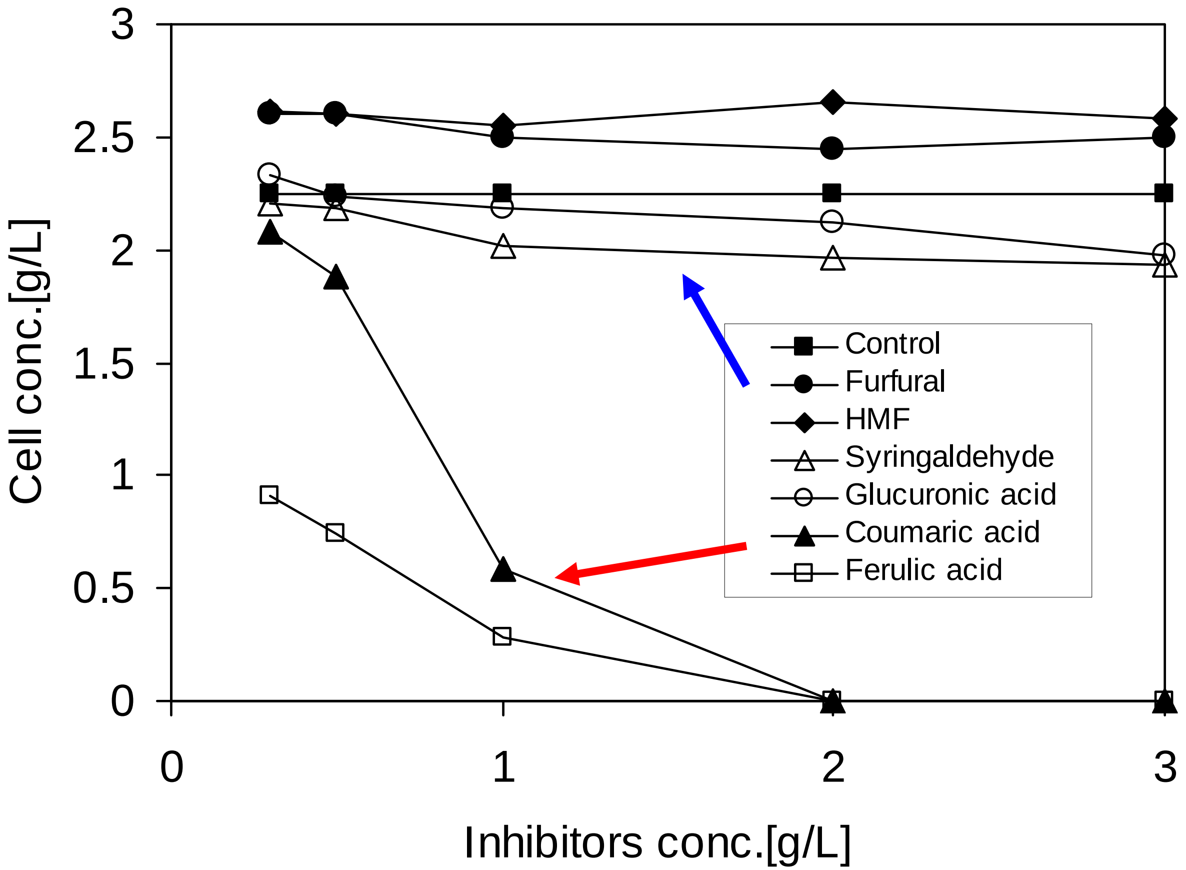
Task 3. Fermentation

S. cerevisiae strain 424A(LNH-ST))
Fermentation of Pretreated DG hydrolysate



Task 3. Fermentation

Clostridium beijerinckii Fermentation Time: 72 hours. Type of Medium: P2 medium (Qureshi and Blaschek, 1999), 35 C



U. Illinois

Task 4. Analysis of Composition

Analysis of composition:

uses the standard dilute acid hydrolysis analysis procedures developed by the National Renewable Energy Laboratory (LAP-002) to determine the carbohydrate composition of DG.

Glucan from starch was differentiated from glucan from cellulose by using a mixture of amylase and amyloglucosidase to hydrolyze the distillers' grains.

Other procedures also follow NREL LAPs for analysis of the various components of DG.

Work is continuing on pretreated, and pretreated and hydrolyzed solids

Task 4. Analysis of Composition

	Average (95% confidence intervals)
Ethanol Extractables (% dry matter)	10.7%
Glucan (total) (% dry matter)	20.9 ± 7.1%
Cellulose (% dry matter)	16.0 ± 6.6%
Starch (% dry matter)	5.2 ± 1.0%
Xylan (% dry matter)	8.2 ± 3.3%
Arabinan (% dry matter)	5.3 ± 0.7%
Protein (% dry matter)	26.4%
Total Dry Matter Mass Closure	92.7%

Work is continuing on pretreated, and pretreated and hydrolyzed solids

Task 5. Life Cycle Analysis

Life cycle analysis

Assess environmental impacts of new processes to allow for more rapid implementation of new technology.

will be carried out after the Consortium has prioritized candidate approaches for the pretreatment, hydrolysis, fermentation, and processing of DG.

Uses DAYCENT and Aspen software

Work still to be initiated by the end of 2005

Task 6. Economic Assessment

Process model of a dry mill corn to ethanol plant

economic analyses of ethanol production for gauging the impact of changes, rather than calculate a specific cost of a given plant design.

base case model at scale of between 30 million to 100 million gallon per year annual capacity is the first milestone. Completion by 2005.

Uncertainty analysis will be added, especially for calculating economic impact for utilizing DG

Excel based model. Guthrie scaling factor approach. Total plant cost estimated by fixed capital investment method. Variable costs from industry data

The Dry Mill Ethanol Model

Costs	Capital Cost Description	45 million gallon plant	Cost Est
Direct	Purchased Equipment		$12,357,302
2	Instillation		$5,807,932
3	Instrumentation		$4,448,629
4	Piping		$8,402,965
5	Electrical		$1,359,303
6	Buildings (service)		$2,224,314
7	Yard Improvements		$1,235,730
8	Service Facilities (instld)		$8,650,111
Total			$44,486,286
Indirect	Engineering & Supervision		$4,077,910
10	Construction Expense		$5,066,494
11	Legal Expense		$494,292
12	Contractors Fee		$2,718,606
13	Contingency		$5,437,213
Total			$17,794,515
Total	Fixed Capital Invmnt		$62,280,801
	Interest Start Up		$2,179,828
	Working Capital		$9,342,120
		TOTAL	$71,622,921

Task 6. Economic Assessment

Preliminary Results

BBI Ethanol Handbook (2004)			
	DM Model Estimates		BBI Estimates
Nameplate Gallons	Total Fixed Cost	$ / Gallon	$ / Gallon
100,000,000	105,595,847	1.05	-
85,000,000	90,821,904	1.07	1.05
65,000,000	75,025,149	1.15	1.15
50,000,000	64,374,259	1.29	1.25
40,000,000	57,811,381	1.45	1.35
30,000,000	51,623,465	1.72	1.45
20,000,000	45,709,606	2.29	1.65
15,000,000	42,791,058	2.85	1.75
10,000,000	39,821,154	3.98	1.95

Market and Customers

a. The market and customers for this research are anticipated to be principally the wet mill industry, with the majority of it being located in the Midwest.

a. Production costs that will be required to make the utilization of DG economically attractive are estimated to be on the order of $1 per gallon of incremental ethanol produced, although this needs to be confirmed using the economic model currently under development.

a. Market dynamics of expanding dry mill ethanol production and expanding generation of DG require processes that add value to the DG by utilizing the fiber components more completely, and add value to material (protein, oil, nutritional components, residual fiber) that remains, require adding value to DG

Competitive Advantage

a. The window of opportunity is between now and 2010; dry milling industry expected to undergo rapid expansion

   Drying of the DG to obtain DDGS, and the marketing of this material as animal feed is already filling the market.

b. Other competing technologies may be from processes being developed to fractionate valuable components in fiber derived from a wet mill

c. Issues that could dramatically change the market include a precipitous drop in ethanol demand from corn (grain), a precipitous drop in ethanol usage overall, or a major increase in the price of DDGS.

d. Prioritization of the investments for achieving improvements, to be used 5 years from now, requires that research on adding value to DDGS or DG be carried out now so that a knowledge base for new processes is available

The Midwest Consortium is not competing with industry, rather it is a discovery and engagement oriented consortium of public research organizations

Strategic Fit

a. Members of the Midwest Consortium have major experience in this area with LORRE having carried out work in bioprocessing for 25 years. Project is an excellent fit with capabilities of the Consortium.

b. The milestones that this project supports are ethanol production from mixed sugars, and C5/C6 conversion to chemical or materials products, as well as the sugars platform and the dry mill pathway.

   In the dry mill pathway, this project supports the milestones of biomass fractionation with sugar production and ethanol production form mixed sugars.

c. This research is at the detailed investigation stage (exploratory research).

d. Vision for demonstration phase 3 to 5 years from now: retrofit of a dry grind ethanol plant for converting DG to additional fermentable sugars while obtaining a very high value protein stream for animal feeding.

Milestone Fit

Milestone Hierarchy – Corn Dry Mill Improvements

Biomass Fractionation with Sugar Production

B Milestone
(M 2.2) Demonstrate and Validate economical residual starch conversion in a dry mill ($/lb fiber) by 2009.

Ethanol Production From Mixed Sugars

B Milestone
(M 2.3) Demonstrate and validate economical conversion of mixed sugars to ethanol in a dry mill. ($/gal EtOH) by 2009

Supporting C Milestones:
•*Same 1-3 as for B milestone (M 1.3)*

C5 or C6 or mixed C5/C6 Sugars conversion to Chemical and Material Products

B Milestone
(M 2.4) Demonstrate and validate economical conversion of mixed sugars to products in a dry mill. ($/lb product) by 2008

Supporting C Milestones:
•*Same 1-10 as for B milestone (M 1.4)*

B Milestone
(M 2.5) Demonstrate and validate economical new products from C6 sugars in a dry mill. ($/lbs product)

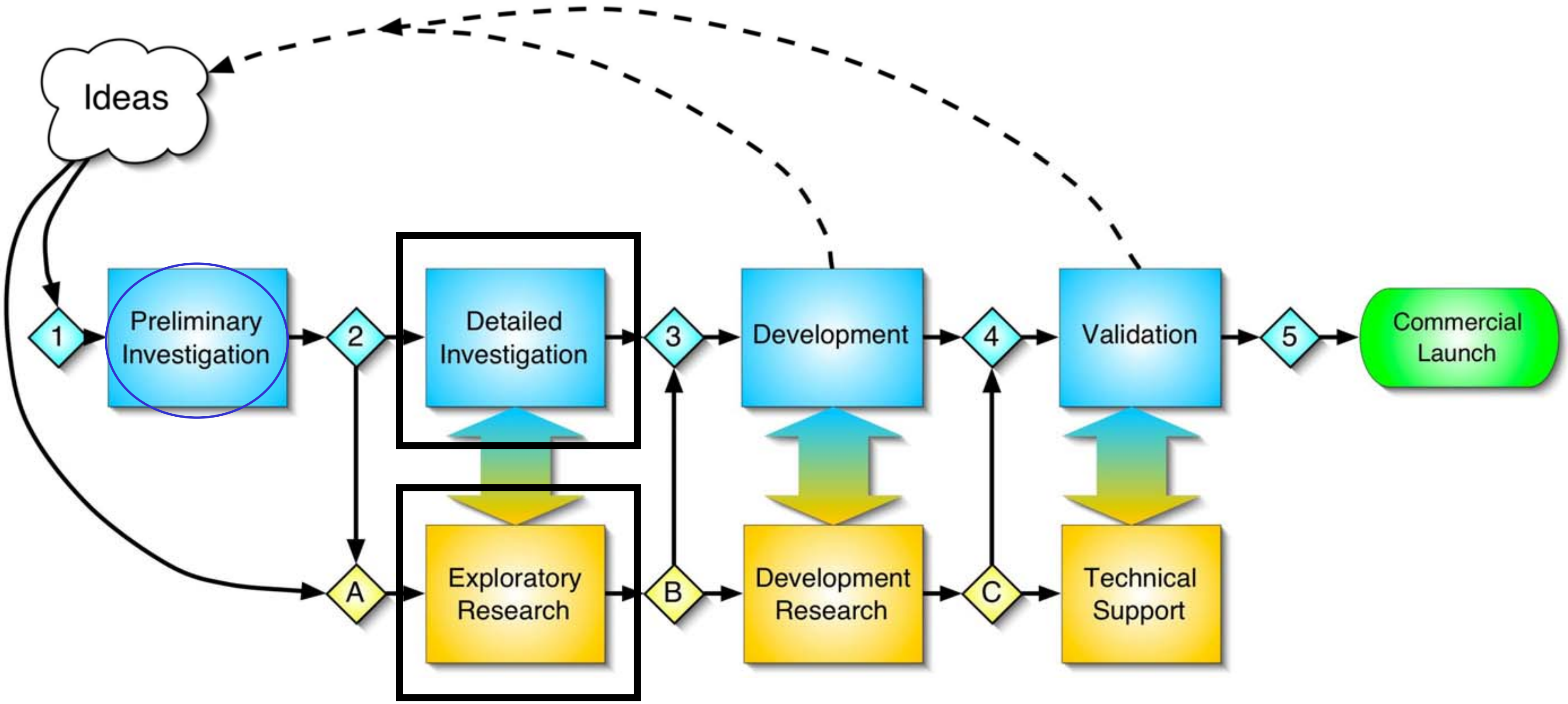
Supporting C Milestones:
•Develop new organisms capable of fermenting C6 sugars to products identified in the "Top Ten" analysis
•*Same as 1-9 of supporting C's for B milestone (M 1.5)*

Supporting C Milestones:

- Develop new organisms for fermenting C5 sugars to products in the "Top Ten" analysis
- Organism productivity rates of 1.5-2.5 g/Lhr
- Yield from sugars greater than 90%
- Final concentration from fermentation should be at least 100 g/l
- Organisms need to be robust with respect to impurities
- Develop new catalysts for converting sugars to products in the "Top Ten" analysis
- Catalysts must achieve selectivity of greater than 90%
- Catalyst lifetime of at least 1 year
- Catalyst fouling minimized
- New membrane technologies to recover products at low cost (at less than 15% of product value)

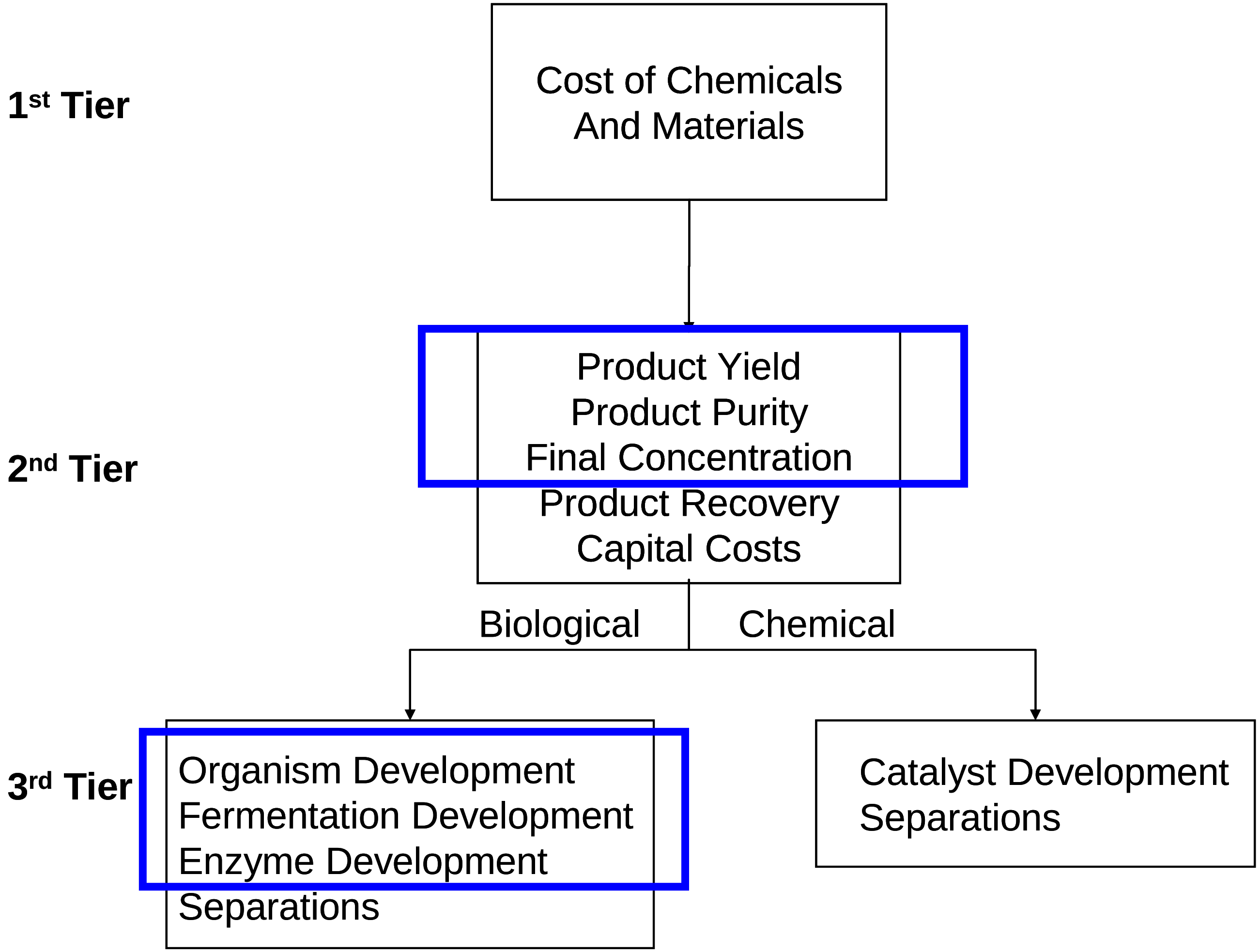
Stage Gate Fit

What Stage is the project in?



<Indicate (highlight, circle, etc.) what Stage your project is in>

Technical Barriers Addressed: Chemicals and Materials



Next Steps

Pretreatments
- loading (200 g/L)
  - flow properties (viscosity properties)
  - heat transfer characteristics

Enzyme hydrolysis and catalysis (particularly hemicelluose hydrolysis)

Fermentability of hexose and pentoses (ethanol concentration of 50 g/L)

Economic impact (and costs) of processes that add value to DG

Engagement of dry millers as test beds and first adaption of new technology

Fundamental microscopy, labeling, structure / function studies to be initiated
- develop fundamental understanding of how DG characteristics are modified via bioprocessing
- thermal processing characteristics

Conclusions / Summary

Distiller's Grains (DG) are a valuable resource

Cellulose conversion technology may add value to this dry mills

New enzymes are important for processing DG

Organisms that co-ferment pentoses and hexoses open up new horizons / processes / markets for co-product streams

Dry mills provide another path to cellulose conversion to liquid fuels and chemicals; economic analysis will identify impacts

Multi-disciplinary, multi-institutional Consortium team approach is effective in carrying out DG research

Supports DOE Sugars platform and dry mill pathway