# What are the Possibilities for the Bioeconomy?

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February 12, 2008

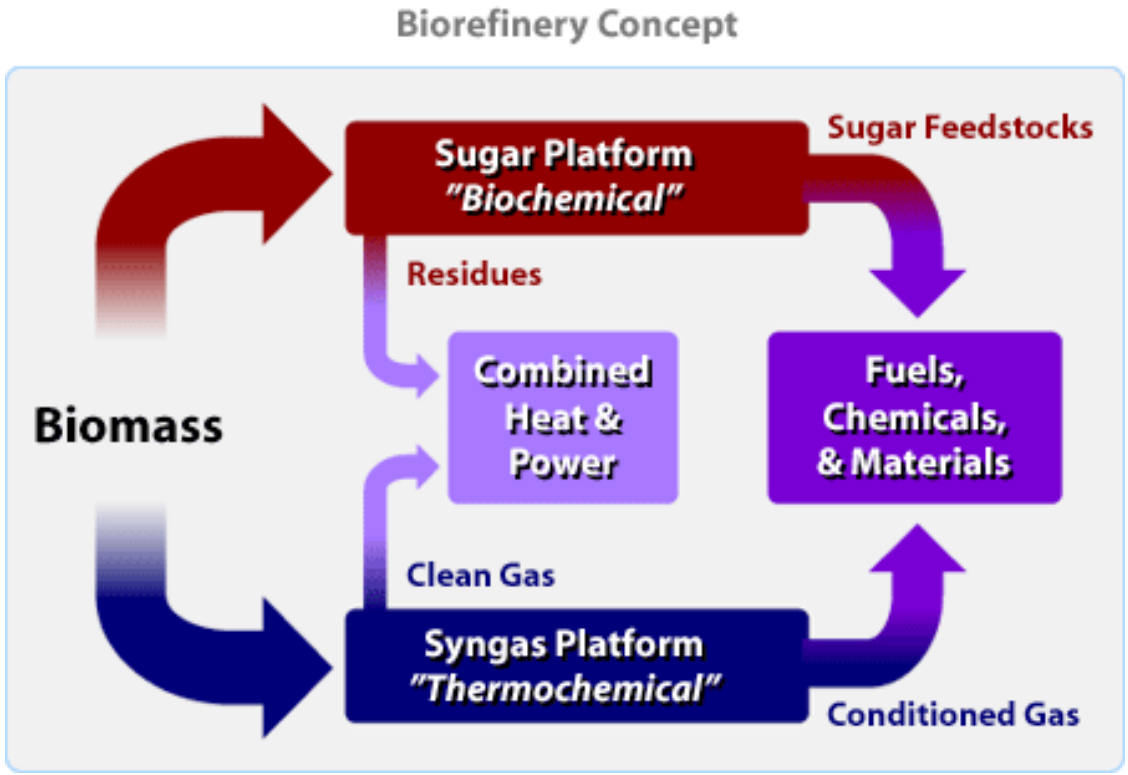
# Outline

- The Current Bioenergy Platforms
- The New Biology and Biomass Conversion
- Translational Research
- Biorefinery of the Future: The Possibilities

# What is a Biorefinery?

- A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum.

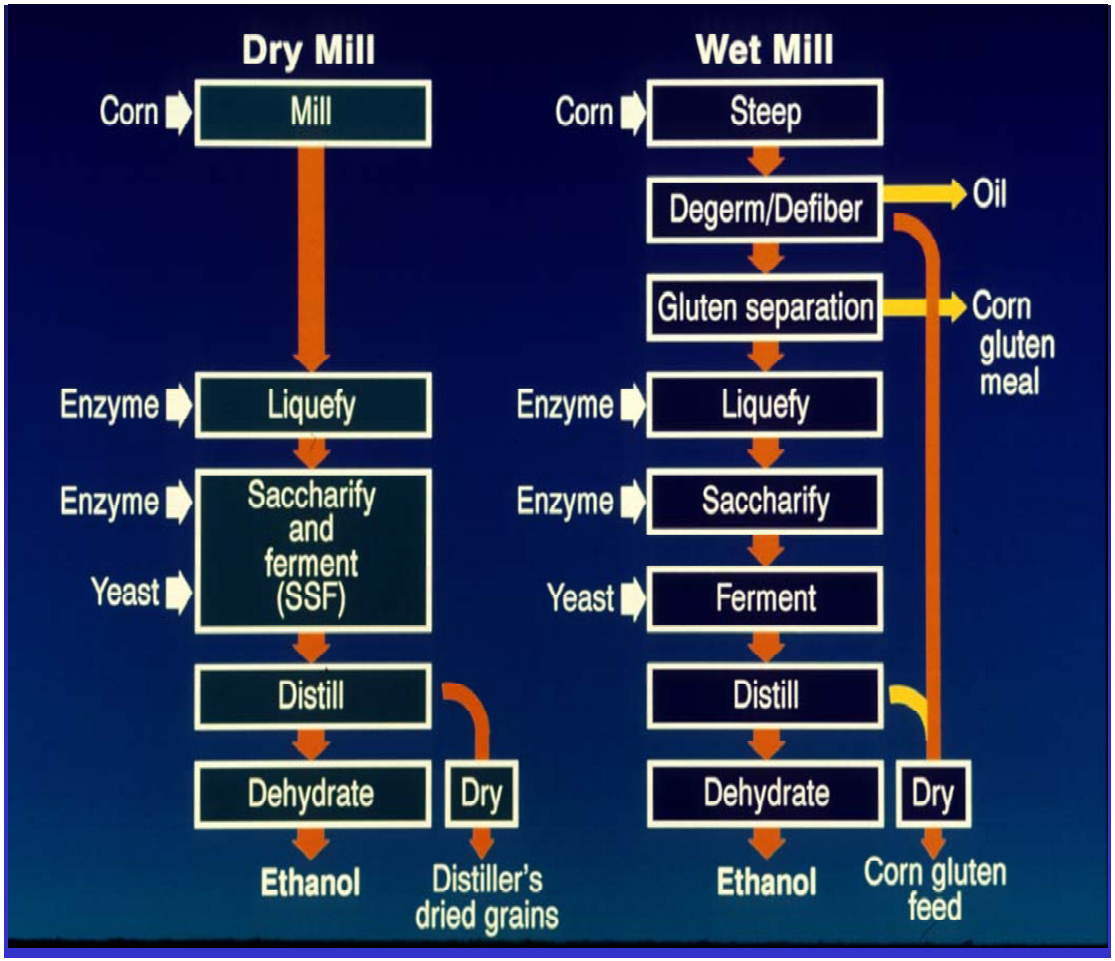
# Conceptual Biorefinery: NREL




The "sugar platform" is based on biochemical conversion processes and focuses on the fermentation of sugars extracted from biomass feedstocks.

The "syngas platform" is based on thermochemical conversion processes and focuses on the gasification of biomass feedstocks and co-products from conversion processes.

# Examples of Today's Biorefineries




Products:
Ethanol
Corn Syrup
Corn Gluten Meal
Corn Oil
$CO_2$

Co-Products:
DDGS
Fiber
Steep Water
Corn Gluten Feed

# Where are we today?

Mature technologies:

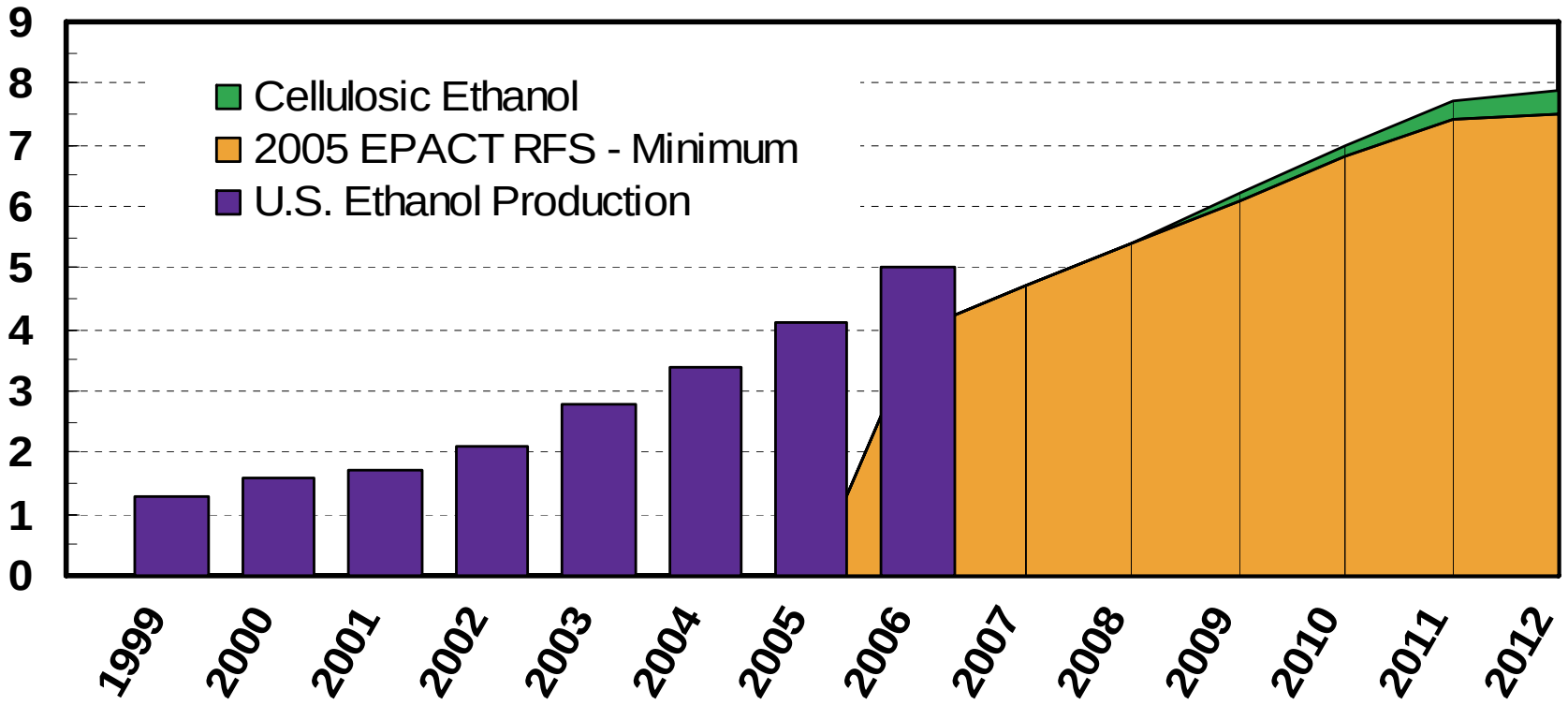
- Ethanol from corn starch
- Ethanol from sugar cane

# Ethanol Production from Corn

Actual and Projected U.S. Ethanol Production 1999-2012

Billion Gallons of Production

Source: December 2005 *Ethanol Today* Magazine

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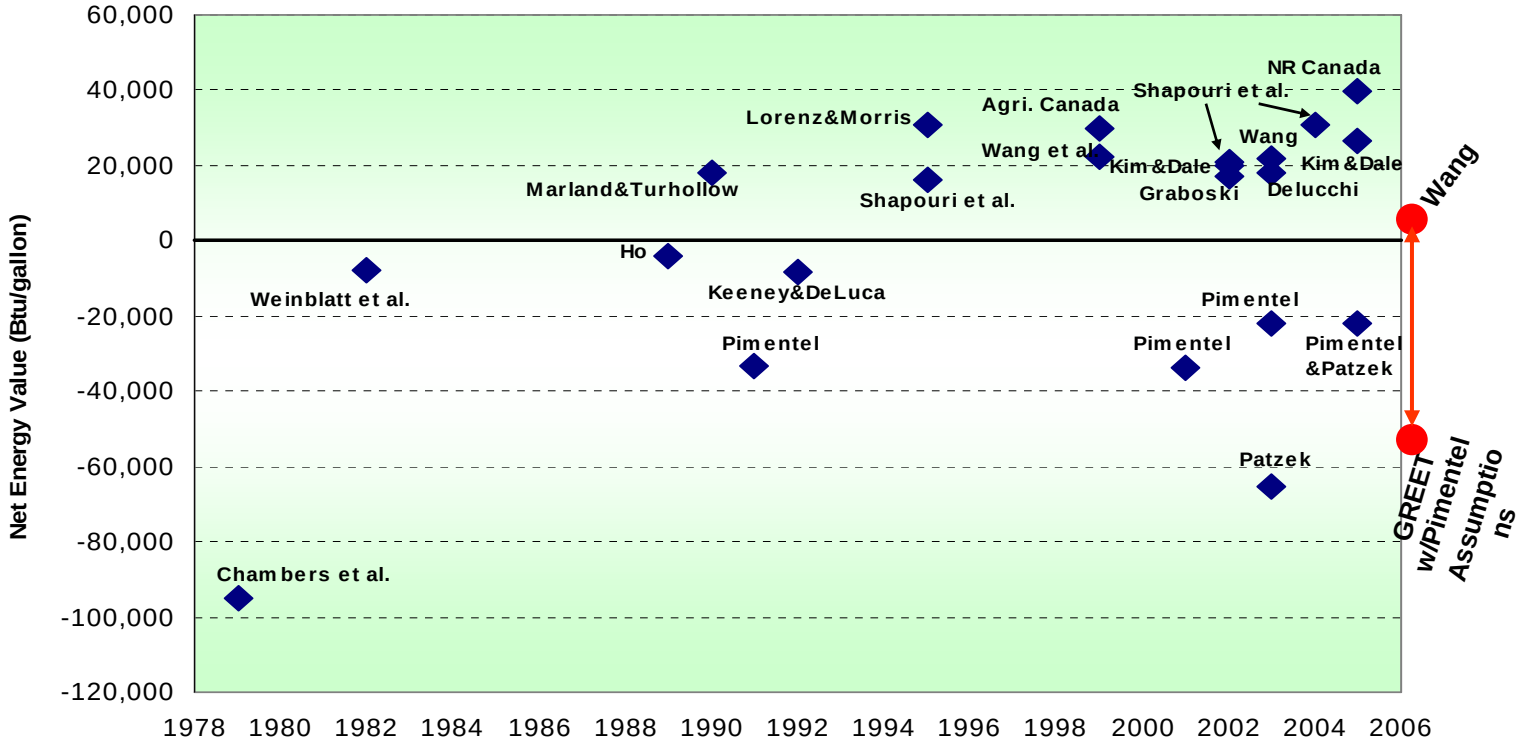
Source: Stanley R. Bull, NREL

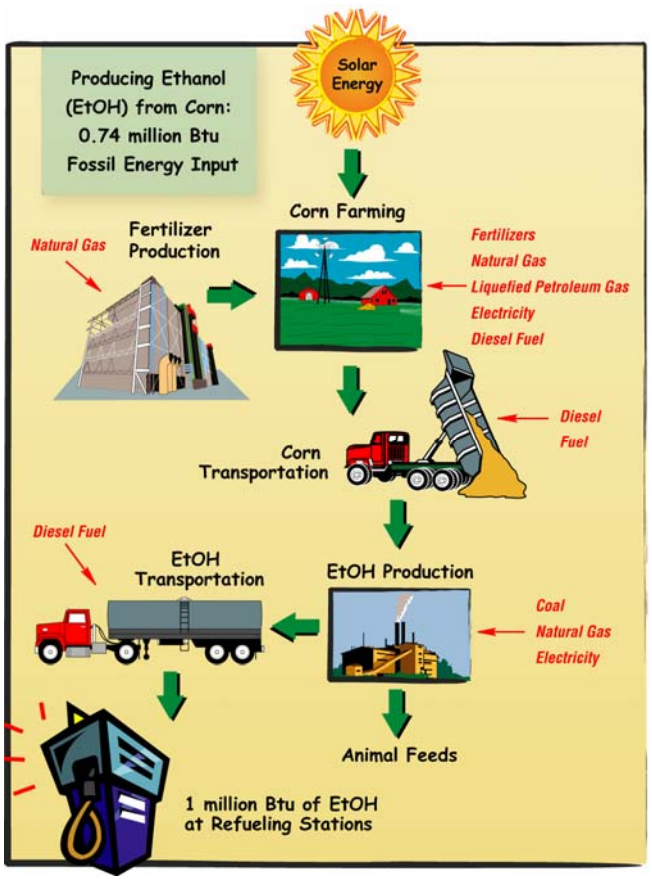
# Most of the recent corn EtOH studies show a positive net energy balance

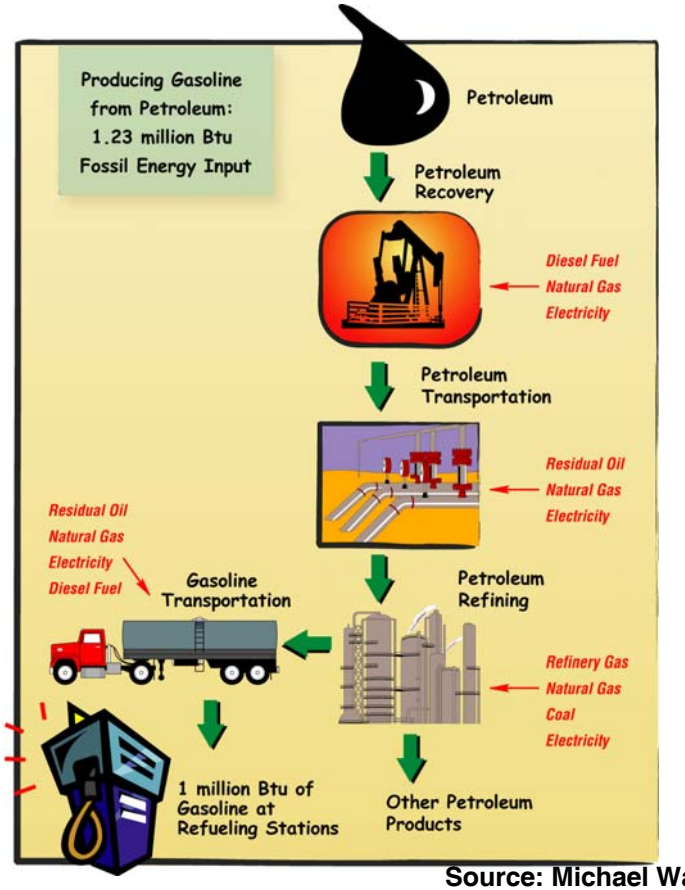



Energy balance here is defined as Btu content for a gallon of ethanol minus fossil energy used to produce a gallon of ethanol

**Source: Michael Wang, Argonne**

# Comparative results between Ethanol and Gasoline




Source: Michael Wang, Argonne

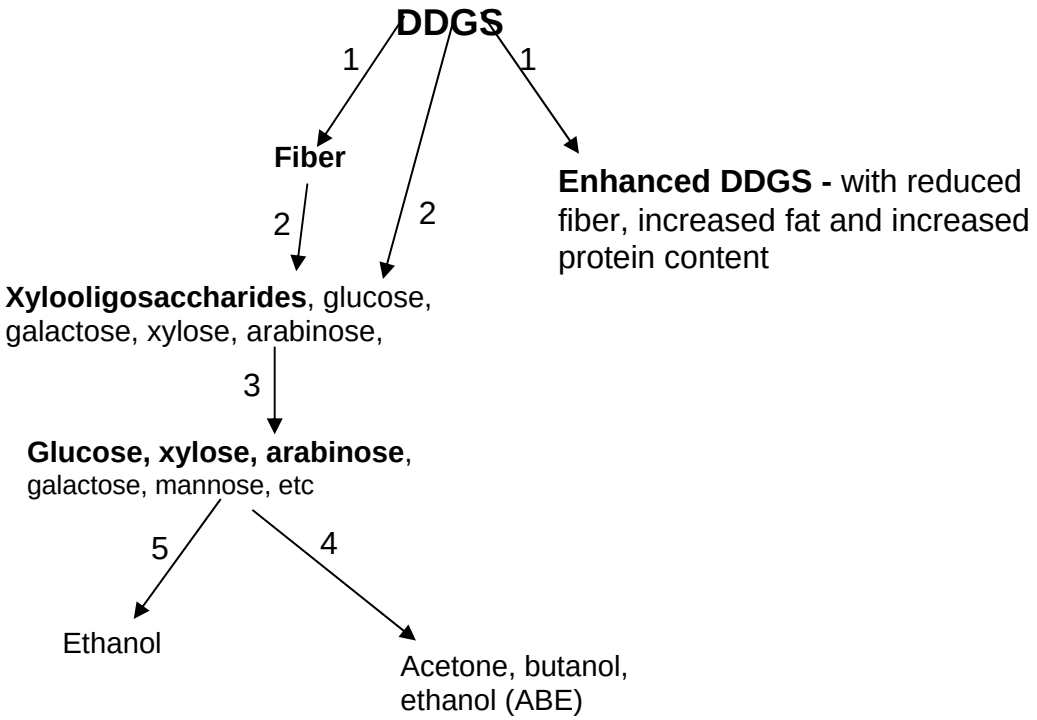
# Why DDGS Utilization?

- Currently, dry-grind ethanol plants produce the majority of fuel ethanol (ca 60%) in the U.S. By-products from dry-grind ethanol include wet and dry distiller's grains with solubles.
- Producers are expected to create more than 7 million metric tons DDGS in the U.S. and 11 million metric tons DDGS in the EU by the end of this year.
- Some industrial experts are predicting that DDGS production in the U.S. will reach up to 15 million metric tons in few years
- By finding alternative uses for DDGS, ethanol plants can improve their profitability and position themselves to withstand stronger competition (from petrochemical industry)

# Composition of DDGS

| | |
|---|---|
| Dry matter content | 88.8 |
| Total glucan | 23.4 |
| Cellulose | 18.3 |
| Starch | 5.1 |
| Xylan | 6.9 |
| Arabinan | 5.3 |
| Ash & others | 29.8 |

# Pre-treatment and conversion steps




# Ethanol from Sugarcane: The Brazilian Experience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# Bagasse is burned for energy

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# Cosan

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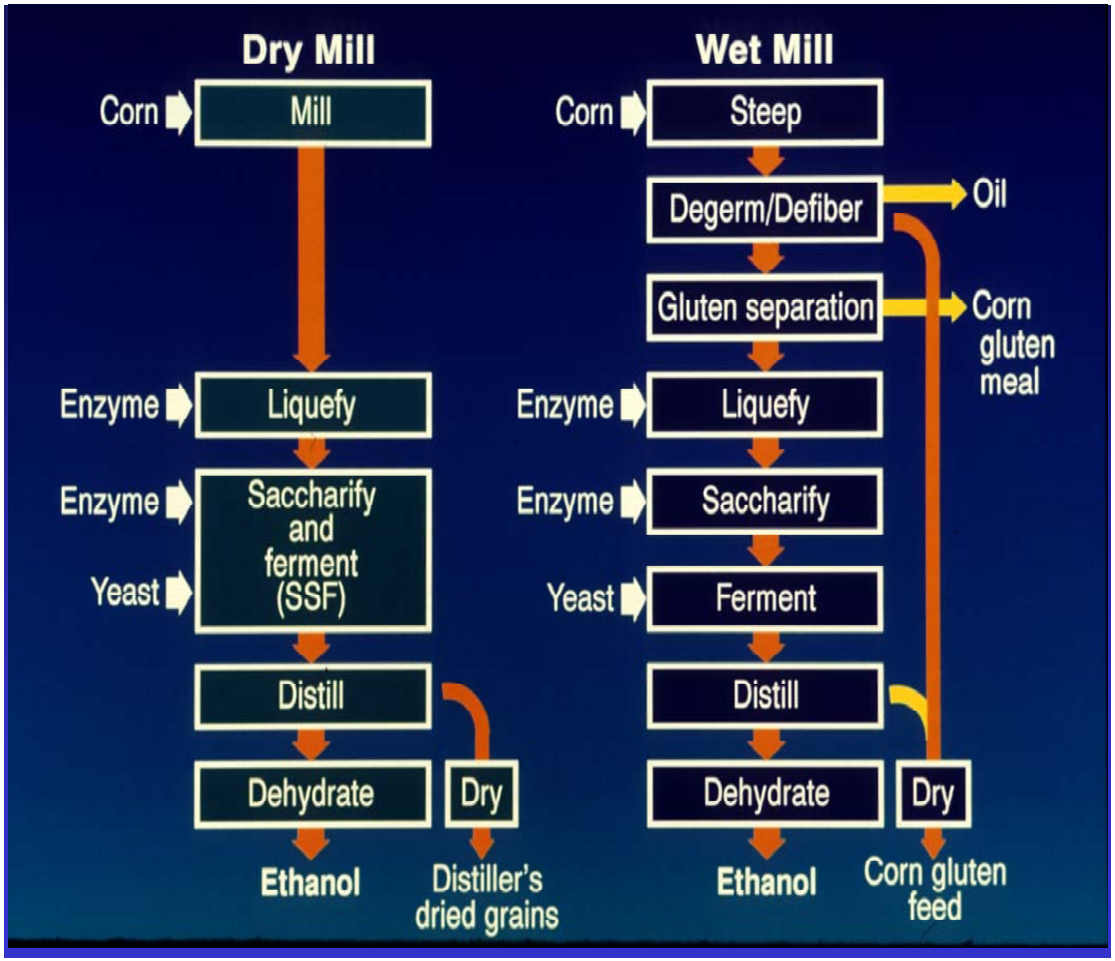
# Examples of Today's Biorefineries




Products:
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Corn Oil
$CO_2$

Co-Products:
DDGS
Fiber
Steep Water
Corn Gluten Feed

# Biofuels Production Cycle


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Thinking Differently About Agriculture

ENERGY

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# The New Biology: An approach

- “Apollo project” like approach
- Utilization of plant and microbial genomic based approaches leading to translational bioengineering
- Focus on agricultural residues and energy-specific crops ideally suited for the Midwest
- Application and integration of systems biology to overcome technical barriers in production of cellulosic ethanol and other biofuels

# IGB Biomass Conversion Theme

- Focus on overcoming limitations to making plant/crop based resources become a viable alternative to petrochemical based systems for chemicals and energy
- These include:
  - Improvements in the efficiency of bioconversion of plant fibers to value added products, and
  - Economical and efficient extraction of high value products

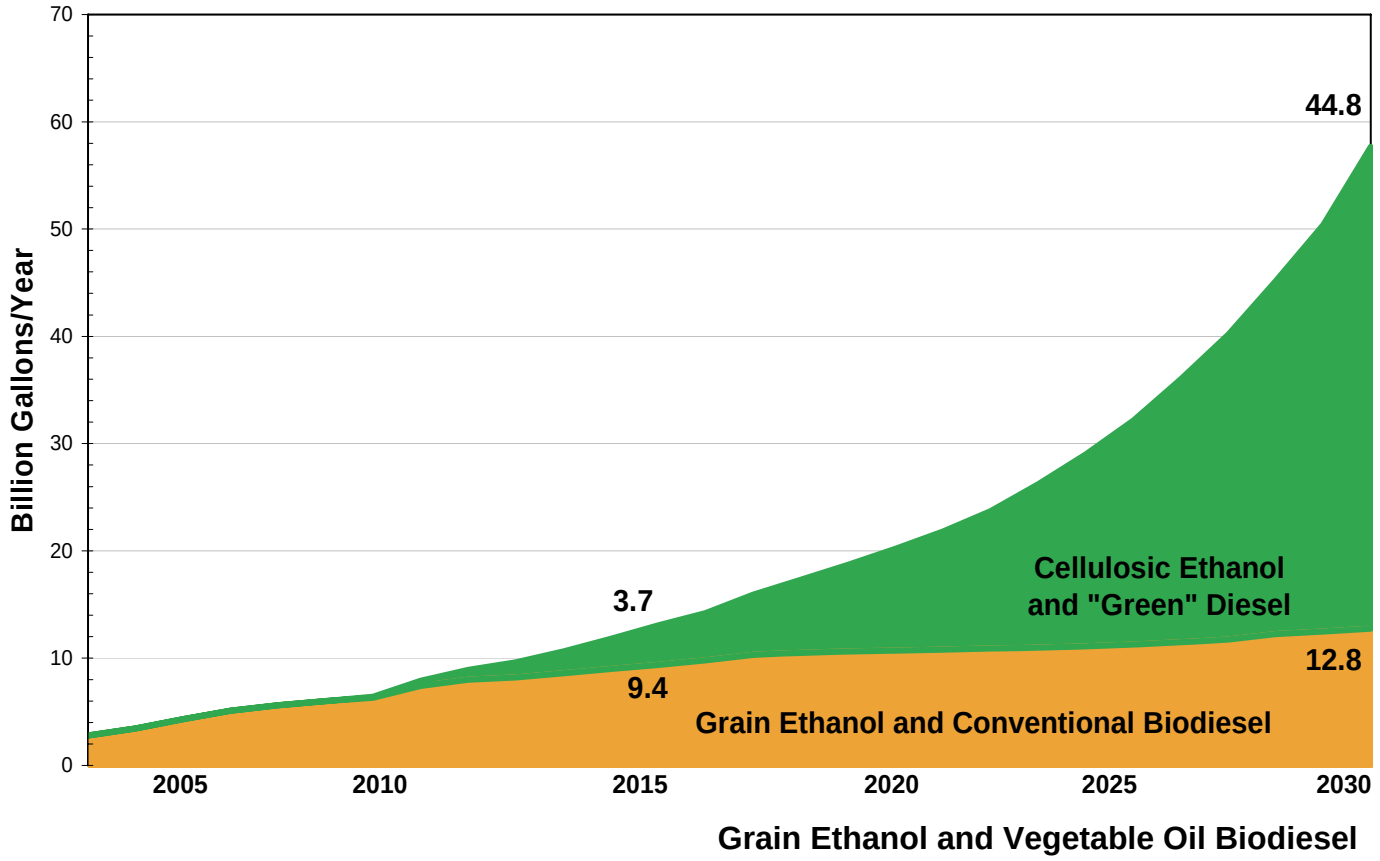
# Integrated Multidisciplinary Research Approach

- Upstream -
- Plant genetics and genomics
- Microbial genomics, biochemistry, ecology, physiology and enzymology
- Central -
- Functional Genomics and Proteomics of specialist plant cell wall degrading bacteria
- Microbial Metabolic engineering of enzymes and fermentation pathways
- Product Separation and Recovery
- Downstream -
- Recovery, Isolation and Purification of targeted biomolecules
- Commercialization -
- Economic Modeling and Systems Analysis

# Biomass Basics

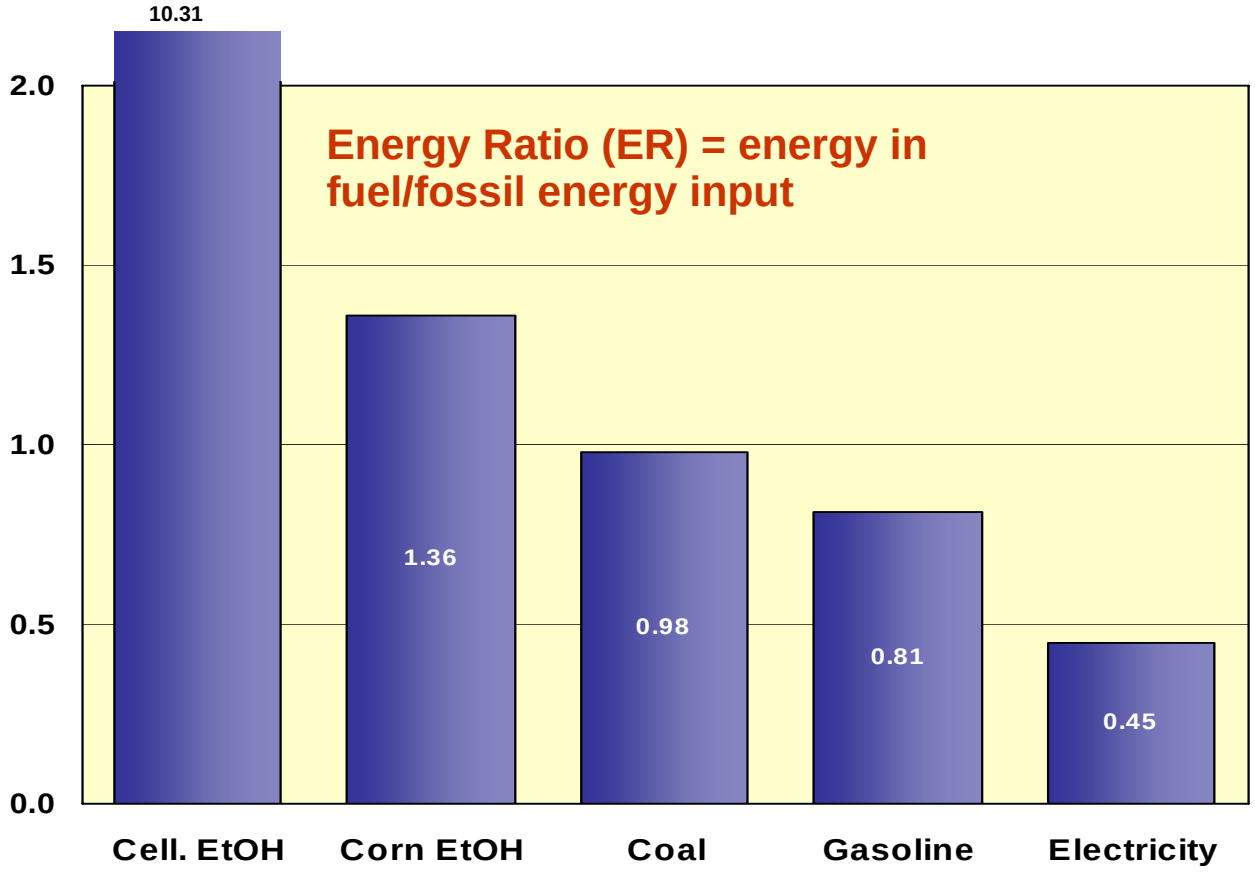
- Today Biomass provides about 3-4% of the energy in the U.S.
- According to studies by Shell Petroleum, biomass could satisfy between 1/4 and 1/2 of the world's demand for energy by the middle of the 21st century
- Chemical industry is moving from the petrochemical to bio-based platform - the Biorefinery
- Corn, soybeans (Midwest) *Miscanthus, Switchgrass*, etc. can serve as regional plant technology platforms for a new biobased economy

# Required growth of cellulosic Ethanol to supply 30% of U.S. Gasoline demand by 2030




Source: Stanley R. Bull, NREL

# Energy in different fuels




Source: Michael Wang, Argonne

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

# Corn Stover — stalks, leaves, and husks — is a major Biomass Program focus as a possible feedstock

It is very large in volume — roughly equivalent to corn grain, our largest crop; and it is already there, largely unused, so requires little additional investment or resources to produce it.

90 M tons of fermentable sugars available for conversion to liquid fuels & chemicals

# Development of New Plant Biomass Sources

- Exploit Maize germplasm diversity with respect to cell wall development and composition
- Screen UIUC maize inbred and germplasm collection for cell wall characteristics impacting microbial fermentations (e.g. lignin content)
- Identify and characterize genes involved in inheritance of characteristics which allow for improved fermentation
- Examine *Miscanthus gigantea* (cold-tolerant fast-growth C4 grass, related to sugar cane)
- Examine Tropical Maize as a substrate

**UIUC maintains ~85% of the entire genetic diversity of the genus *Zea mays***

**Tropical Maize**

**Can grow in temperate regions**

**Low Nitrogen input**

**Contains sucrose, glucose and fructose**

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# Development of New Biomass Sources


- Modify cell wall component genes
- Examine *Miscanthus gigantea* (cold-tolerant fast-growth C4 grass, related to sugar cane)

# WHY DOES PRODUCTIVITY MATTER?

| Feedstock | Harvestable Biomass (t/acre) | Ethanol (gal/acre) | Million acres needed for 35 billion gallons of ethanol | % 2006 harvested US cropland |
|---|---|---|---|---|
| Corn grain | 4.5 | 454.3 | 69.6 | 24.4 |
| Corn stover | 3.0 | 329.6 | 106.0 | 37.2 |
| **Corn Total** | 7.8 | 783.8 | 42.0 | 14.8 |
| **LIHD** | **1.7** | 169.2 | 206.8 | 72.5 |
| **Switchgrass** | **5.6** | 556.7 | 62.9 | 22.0 |
| **Miscanthus** | **13.0** | 1,300.4 | 26.9 | 9.3 |

Source: Heaton, Dohleman & Long (GCB submitted)

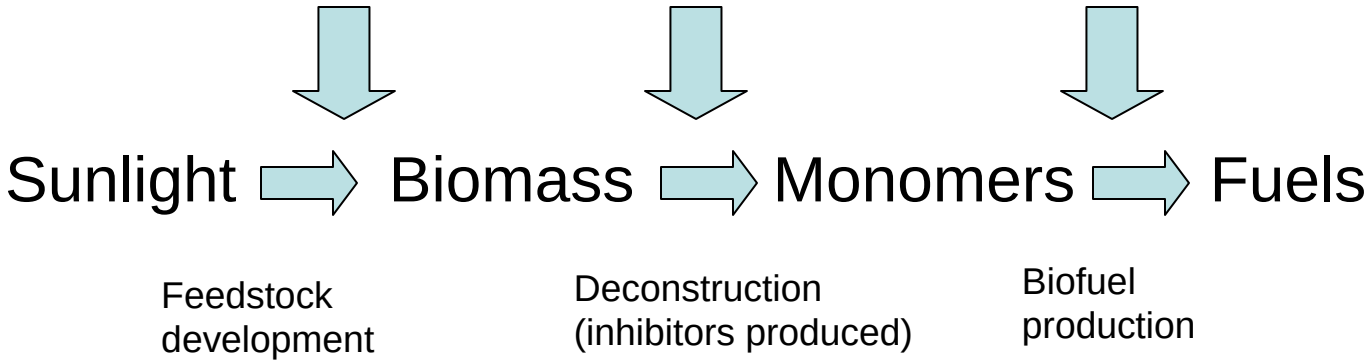
# Bioenergy Value Chain

| Germplasm | Cultivation | Harvest/Transport | Processing | Biofuel |
|---|---|---|---|---|
| Crop Scientists<br>Plant Breeders<br>Plant Genetics | Farmers<br>Agronomists<br>Plant Pathologists<br>Ecologists<br>Soil Scientists | Engineers<br>Economists | Microbiologists<br>Engineers<br>Molecular Biologists | Engineers<br>Chemists |

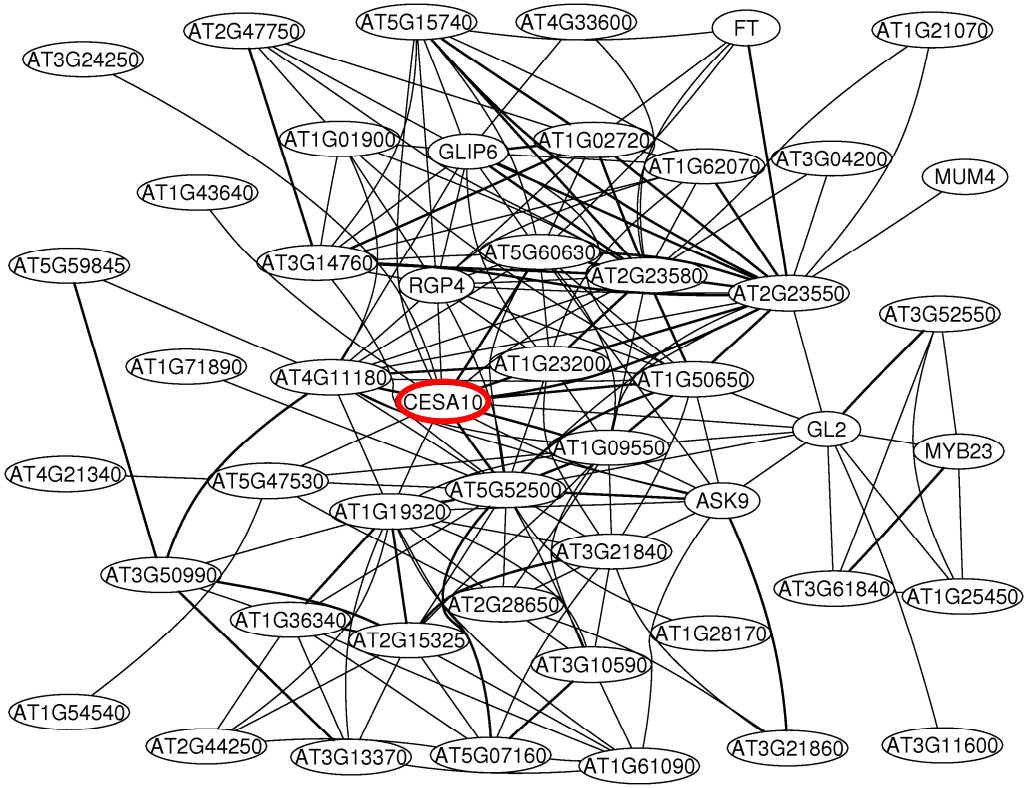
# Horizontal Matrix

| Feedstock | Deconstruction | Design |
| --- | --- | --- |
| Stover<br>Miscanthus<br>Switchgrass<br>DDGS | Anaerobes<br>Thermophiles | Yeast<br>Clostridia<br>E. coli |

# Roadmap and Bottlenecks to Biofuel Production




# Sub-network around CESA10 – involved in plant cell wall biosynthesis




## Description

- Includes several known genes in CW synthesis
- Includes functionally unknown genes with 'relevant' domain structure
- includes un-characterized signaling and transcription components
- Provides hypotheses

## Tasks

- Check genes/expression in maize, Miscanthus, switchgrass
- Use transgenics in Miscanthus and transgenics, and/or marker-assisted breeding in maize

# Sources of fiber-degrading enzymes:

**Genomes of specialist fiber degraders:**

*Fibrobacter succinogenes* S85 (>100 genes)
*Ruminococcus flavefaciens* FD-1
*Ruminococcus albus* 8
*Prevotella ruminicola*

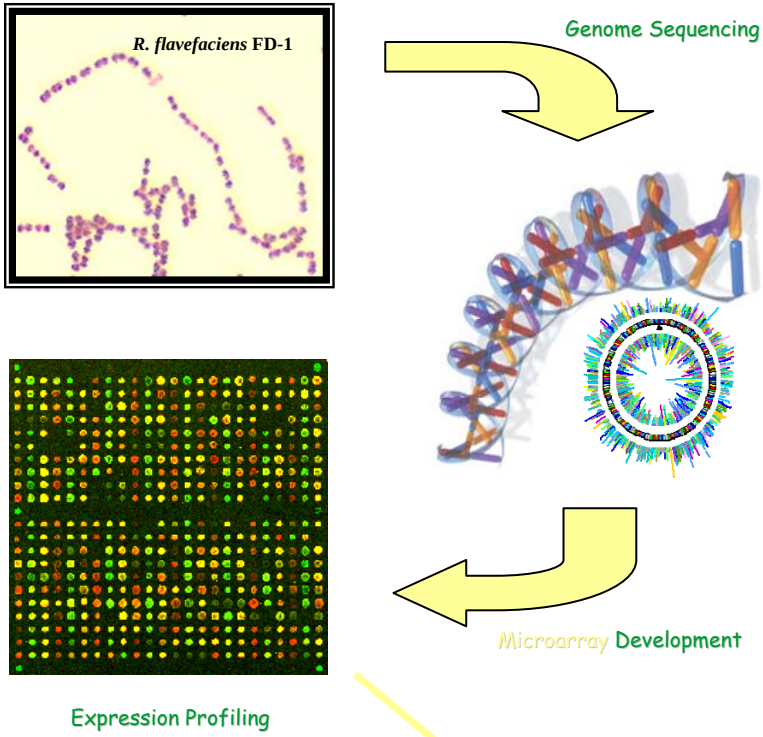
**Enzymes of interest:**

Xylanases/Cellulases
Arabinofuranosidases
Ferulic acid esterases
Proteases

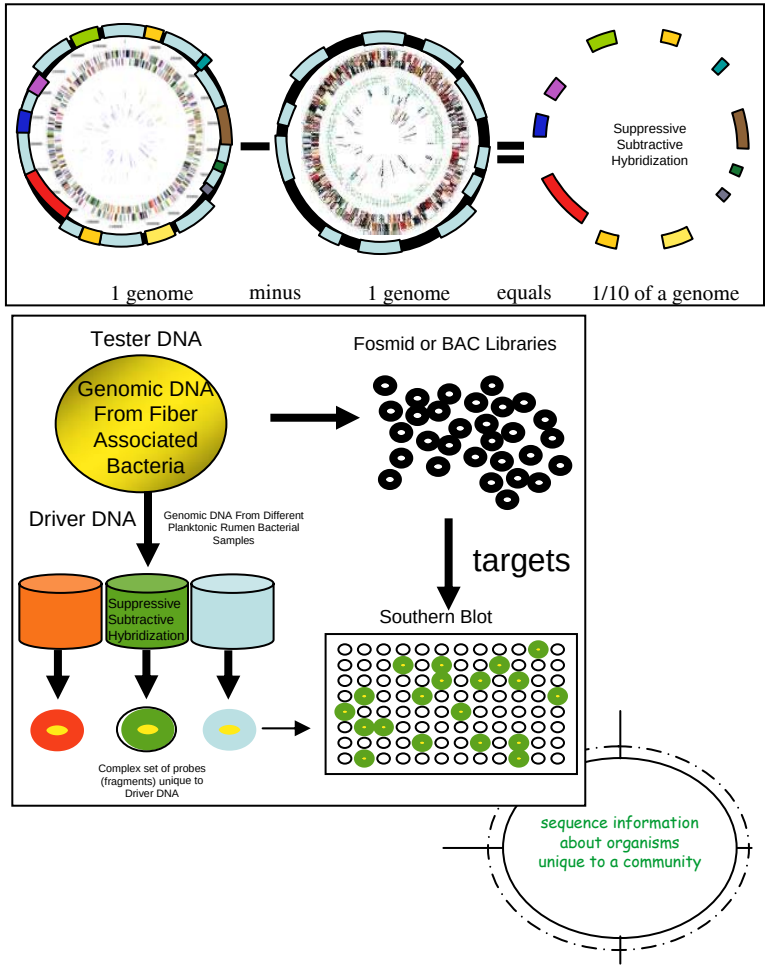
# Genomic and Metagenomic Approaches for Identifying Candidate Genes (Enzymes) for Enhanced Plant Cell Wall Hydrolysis

## Candidate Genes (Enzymes) for Enhanced Fiber Degradation

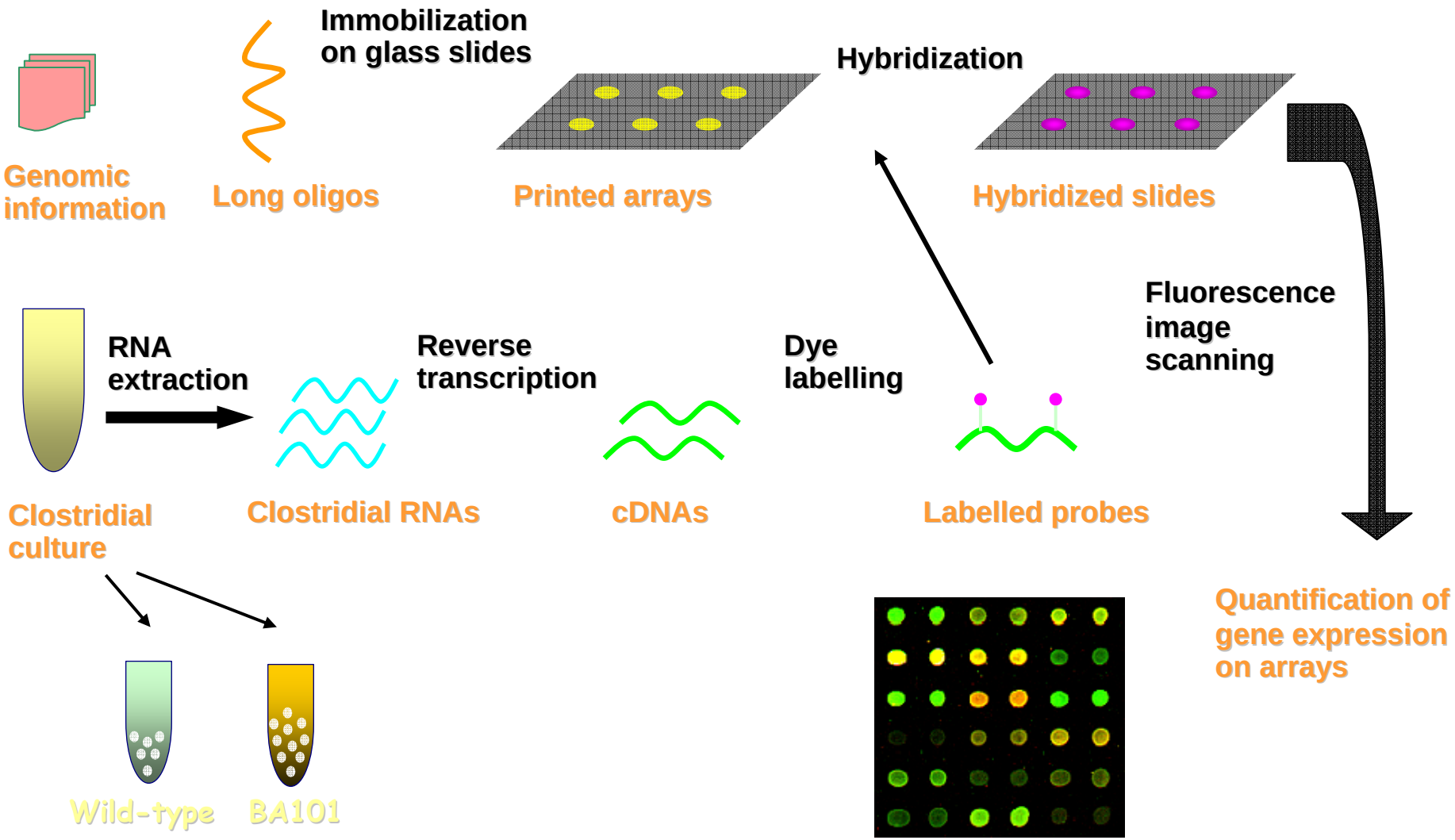
### Genomic Approach




### Metagenomic Approach



# Transcriptional analysis



# Biological Conversion

- Fermentation - utilization of 5-carbon sugars
- Examples:
  - *Zymomonas mobilis* engineered to ferment xylose and arabinose,
  - *S. cerevisiae* strains engineered to ferment arabinose,
  - Solventogenic clostridia with ability to simultaneously saccharify and ferment.

# BioButanol: A Second Generation Liquid Fuel

- Higher energy content than ethanol
- Can be stored under humid conditions unlike ethanol
  - -lack of solubility with water (higher flash point and lower vapor pressure)
- Can be used in internal combustion and diesel engines; less corrosive
- Can be shipped through existing pipelines
- Replacement for gasoline or as a chemical

# UI Integrated Bioprocessing Research Laboratory

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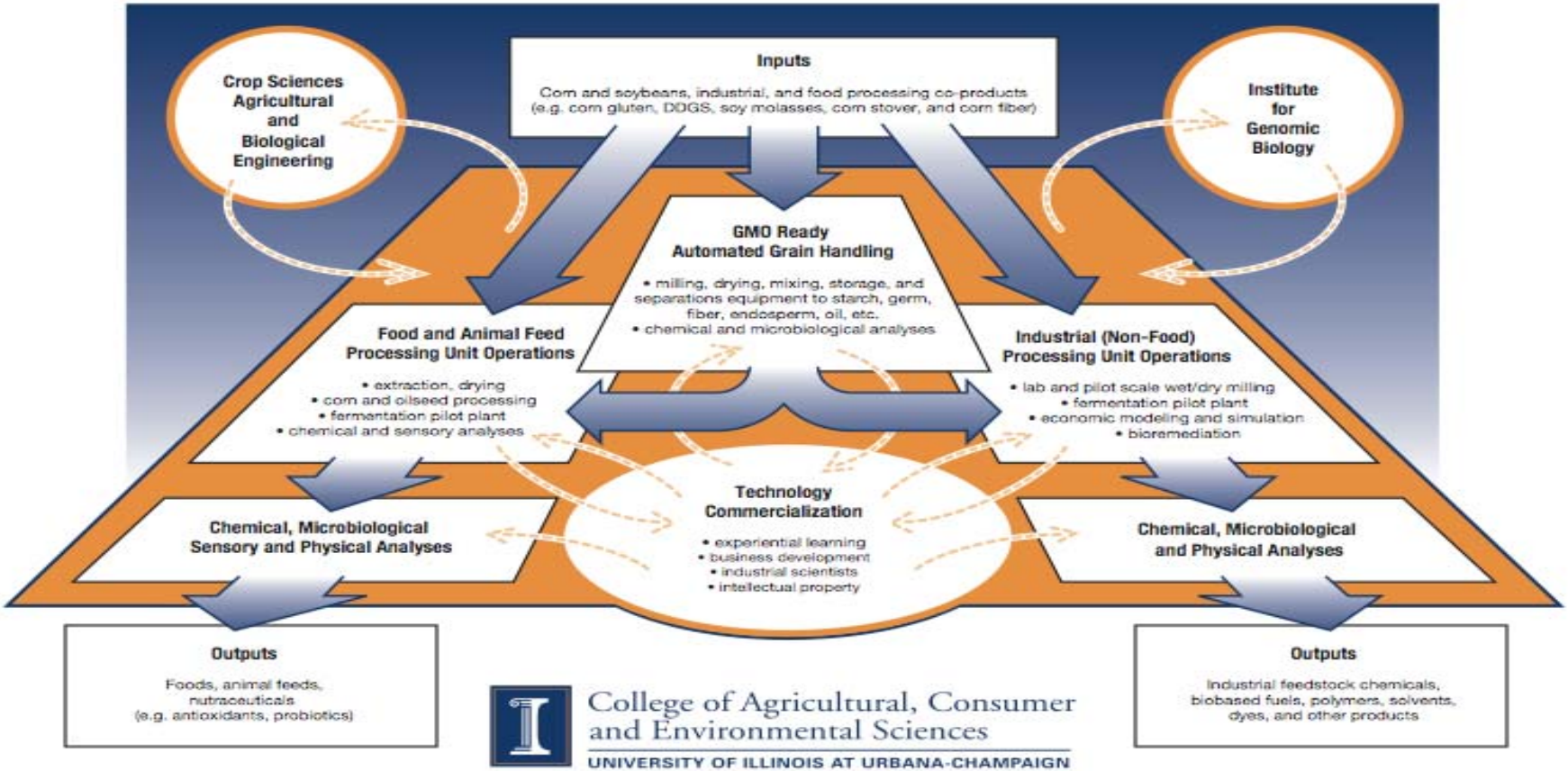
# Vision: IBRL

- Facility focused on the chemical, physical and biological conversion of renewable feedstocks to biofuels and other value-added products.
- Pilot scale operations - fractionation, separations, recovery, processing and fermentation.

## Integrated Post-Harvest Crops Bioprocessing and Research Laboratory

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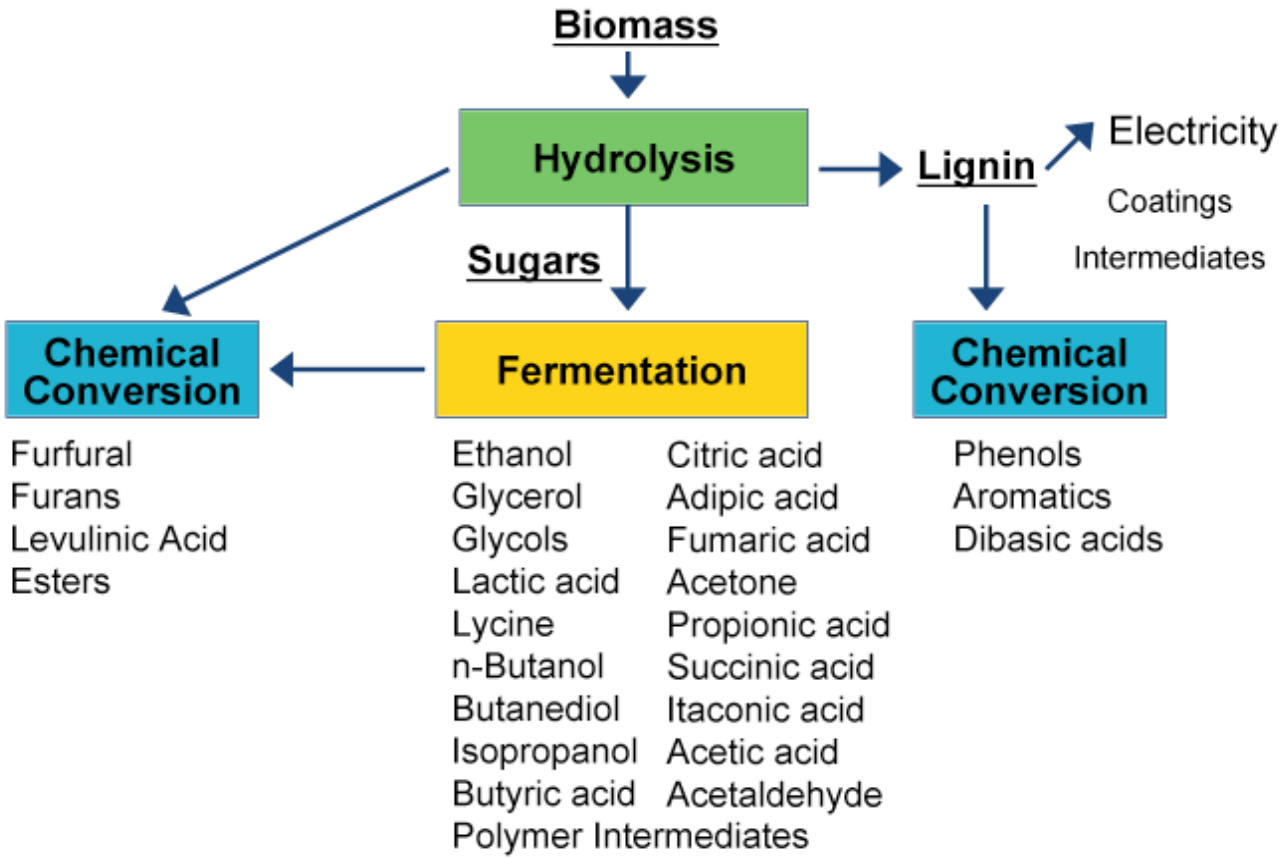
# Biorefinery Development Activities

- Dupont & BP - to commercialize bio-butanol, an advanced 4 carbon biofuel
- Dupont - starch and lignocelluse conversion to 1,3 propanediol as a polymer platform
- Cargill-Dow - build pilot scale biorefinery to produce polylactide (PLA) polymers and ethanol from grain
- NCGA-ADM - separation and pilot scale testing of corn fiber as substrate
- Iogen - in partnership with Shell producing ethanol from cellulose

# Biorefinery: Sugar = Ethanol + Other, Higher Value Chemicals




# The New Bio-Industry

**Biomass Feedstock**

– Trees
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

**Conversion Processes**

- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/ Ferm

## USES

**<u>Fuels:</u>**
– **Ethanol**
– **Renewable Diesel**

**<u>Power:</u>**
– **Electricity**
– **Heat**

**<u>Chemicals</u>**
– **Plastics**
– **Solvents**
– **Chemical Intermediates**
– **Phenolics**
– **Adhesives**
– **Furfural**
– **Fatty acids**
– **Acetic Acid**
– **Carbon black**
– **Paints**
– **Dyes, Pigments, and Ink**
– **Detergents**
– **Lubricants**
– **Etc.**

**<u>Food and Feed and Fiber</u>**

Source: Stanley R. Bull, NREL

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