

# Bioenergy: From Concept to Commercial Processes



## Biorefinery Process Economics

An in-depth, independent technical and economic evaluation by the **PEP** program

Gregory M. Bohlmann

[gbohlmann@sriconsulting.com](mailto:gbohlmann@sriconsulting.com)

March 9, 2006



## Agenda

### Biorefinery Research

### Whole Corn Biorefinery

Core Conversion Technologies

Capital Costs

Process Economics

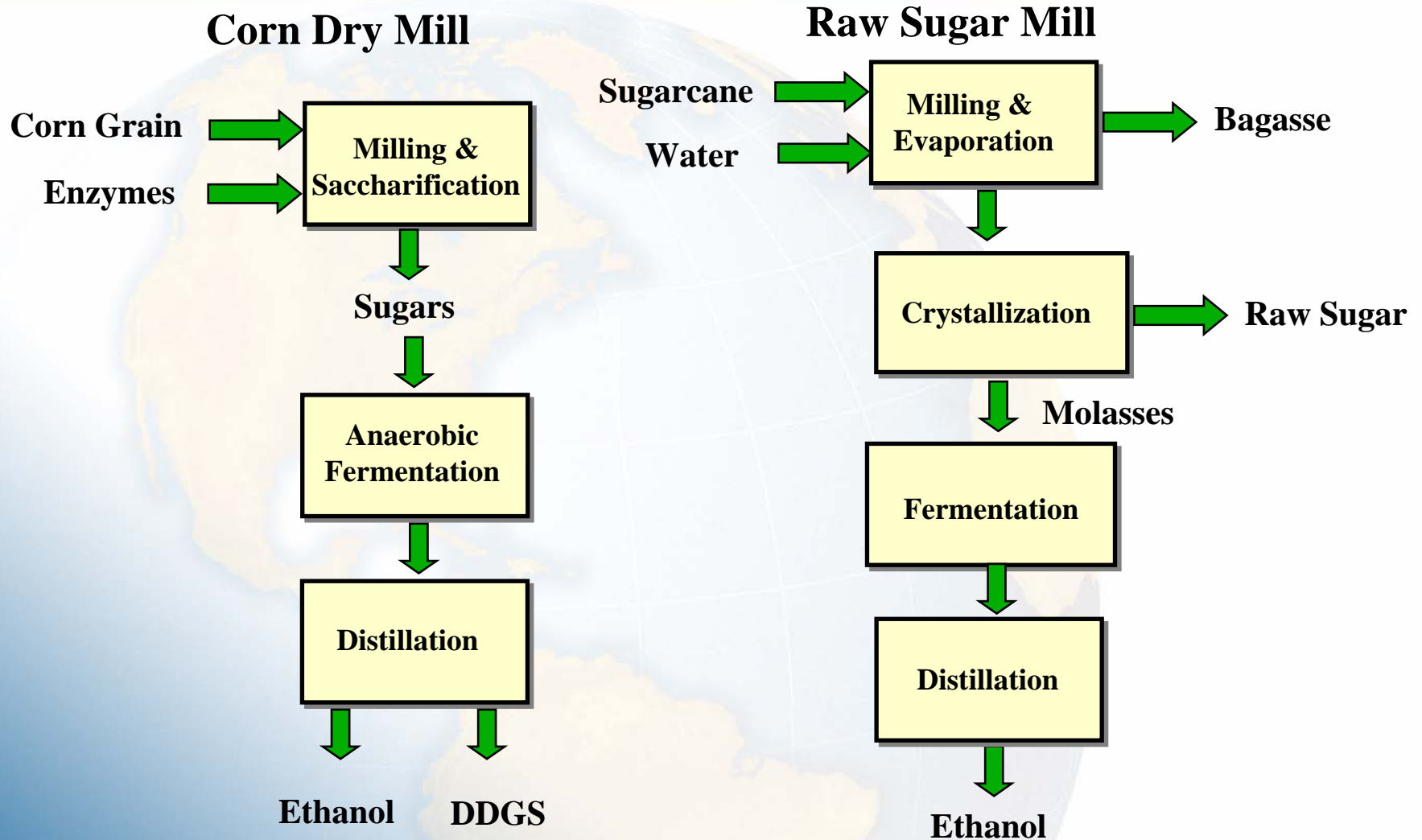
### Economic Issues

Feedstock

Coproducts

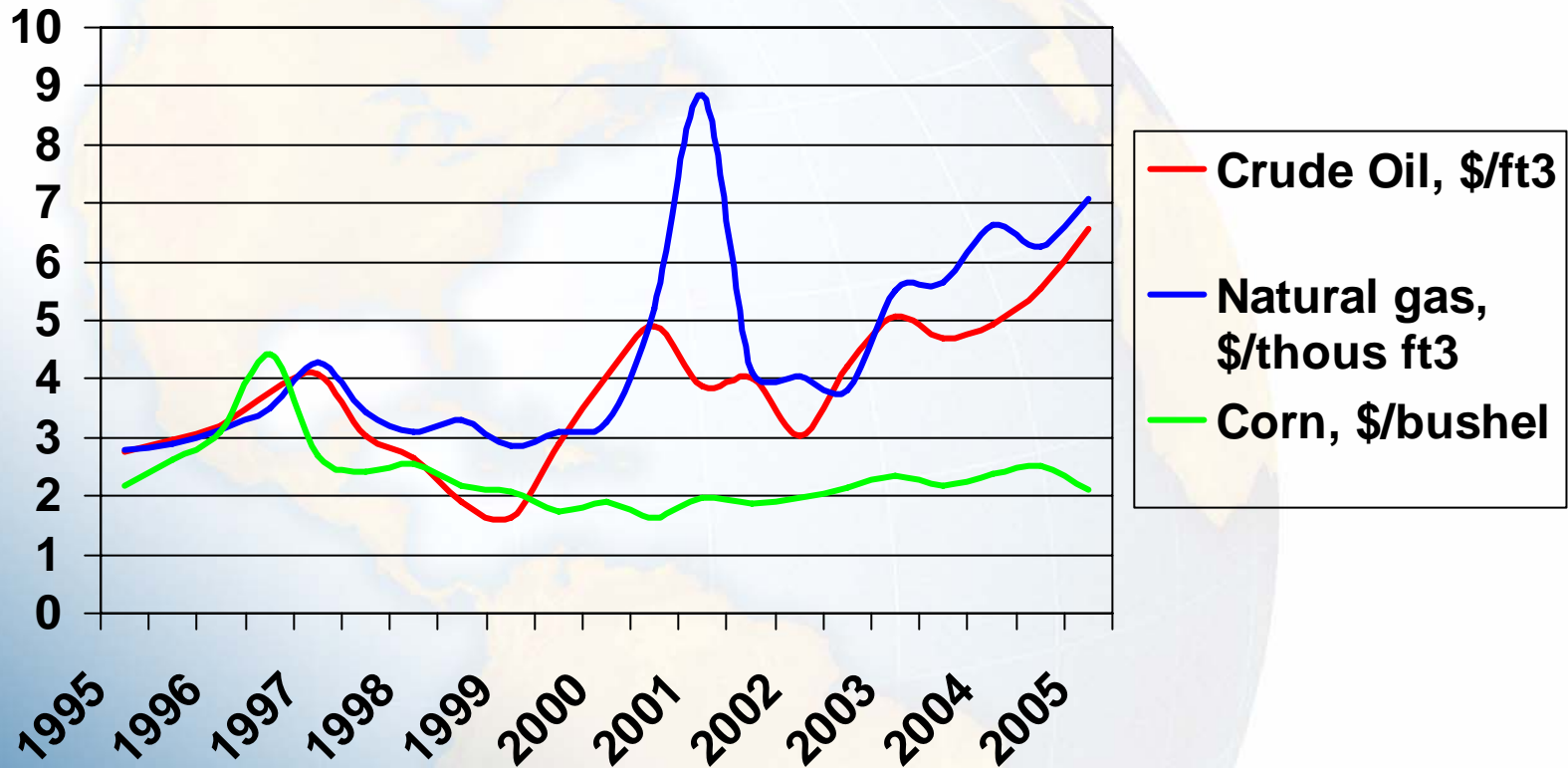
### Waste Issues

### Conclusions



# Feedstock Price as Driving Factor

Opportunity grows for renewable resources



## Worldwide Interest

- **Brazil**
  - Leverage sugar mills
- **Europe**
  - Kyoto driven
  - BREW project funded by EC
- **United States**
  - Leverage corn milling and other agricultural assets
  - Projects funded by Dept. of Energy (DOE) and Dept. of Agriculture (USDA)

## 2003 DOE/USDA Funded Projects

- **Integrated Corn Biorefinery (ICBR)**
  - DuPont, Diversa, NREL, MSU
- **Sugars from lignocellulosics**
  - NatureWorks, Iowa State University
- **Corn fiber separation and conversion**
  - National Corn Growers, ADM, PNNL
- **Starch and biomass conversion pilot plant**
  - Abengoa, Novozymes, NREL
  - Large scale pilot facility in York, Nebraska

## Whole corn biorefinery utilizes entire corn plant

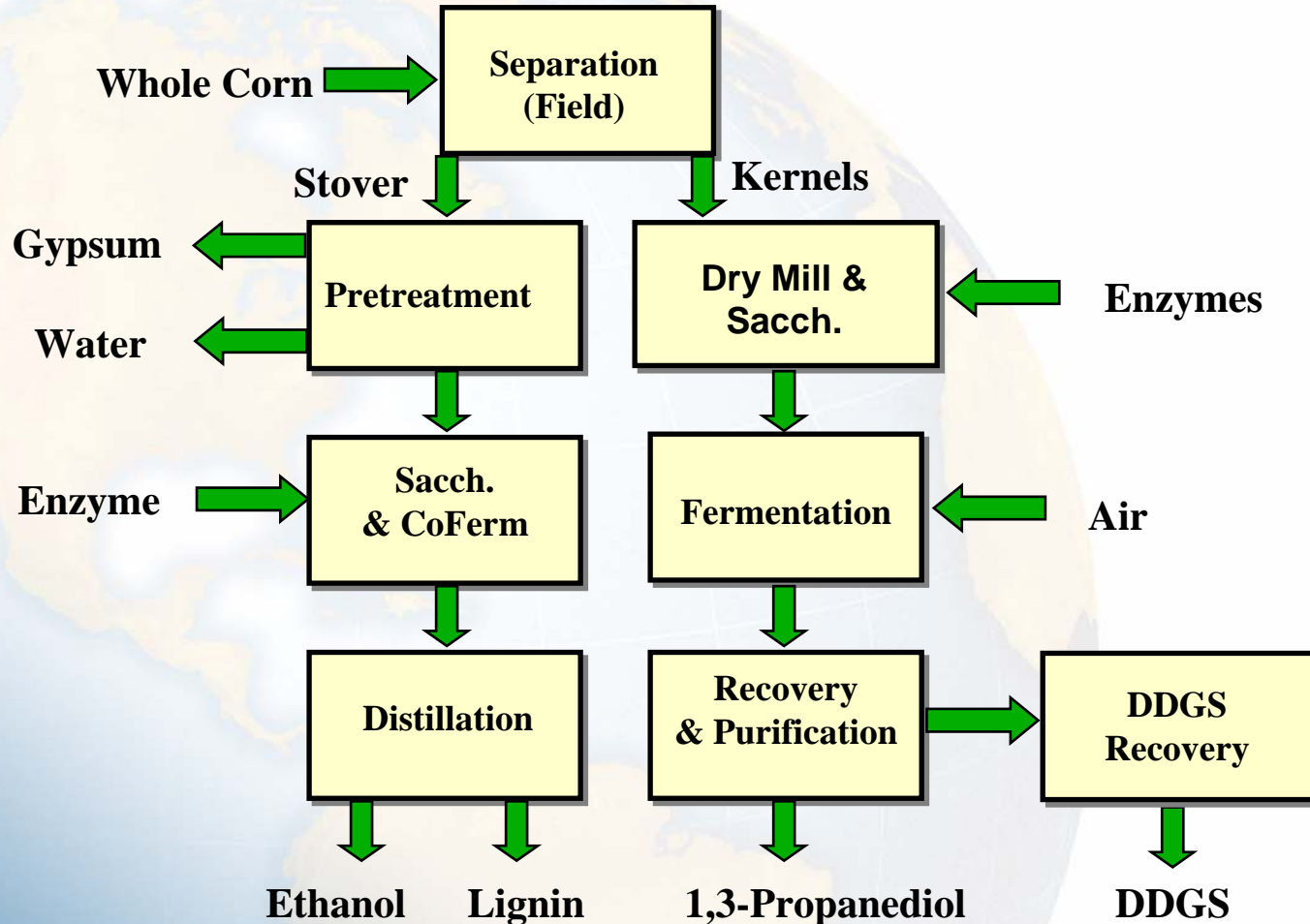
<b>Grain</b>	<b>% Dry Basis</b>	<b>Stover</b>	<b>% Dry Basis</b>
<b>Starch</b>	<b>72.0</b>	<b>Cellulose</b>	<b>37.3</b>
<b>Celluloses</b>	<b>10.5</b>	<b>Xylan</b>	<b>20.6</b>
<b>Protein</b>	<b>9.5</b>	<b>Lignin</b>	<b>17.5</b>
<b>Oil</b>	<b>4.5</b>	<b>Galac./Man.</b>	<b>1.4</b>
<b>Sugars</b>	<b>2.0</b>	<b>Arabinan</b>	<b>2.1</b>
<b>Ash</b>	<b>1.5</b>	<b>Ash</b>	<b>6.1</b>
		<b>Acetate</b>	<b>2.0</b>
		<b>Extractives</b>	<b>13.0</b>

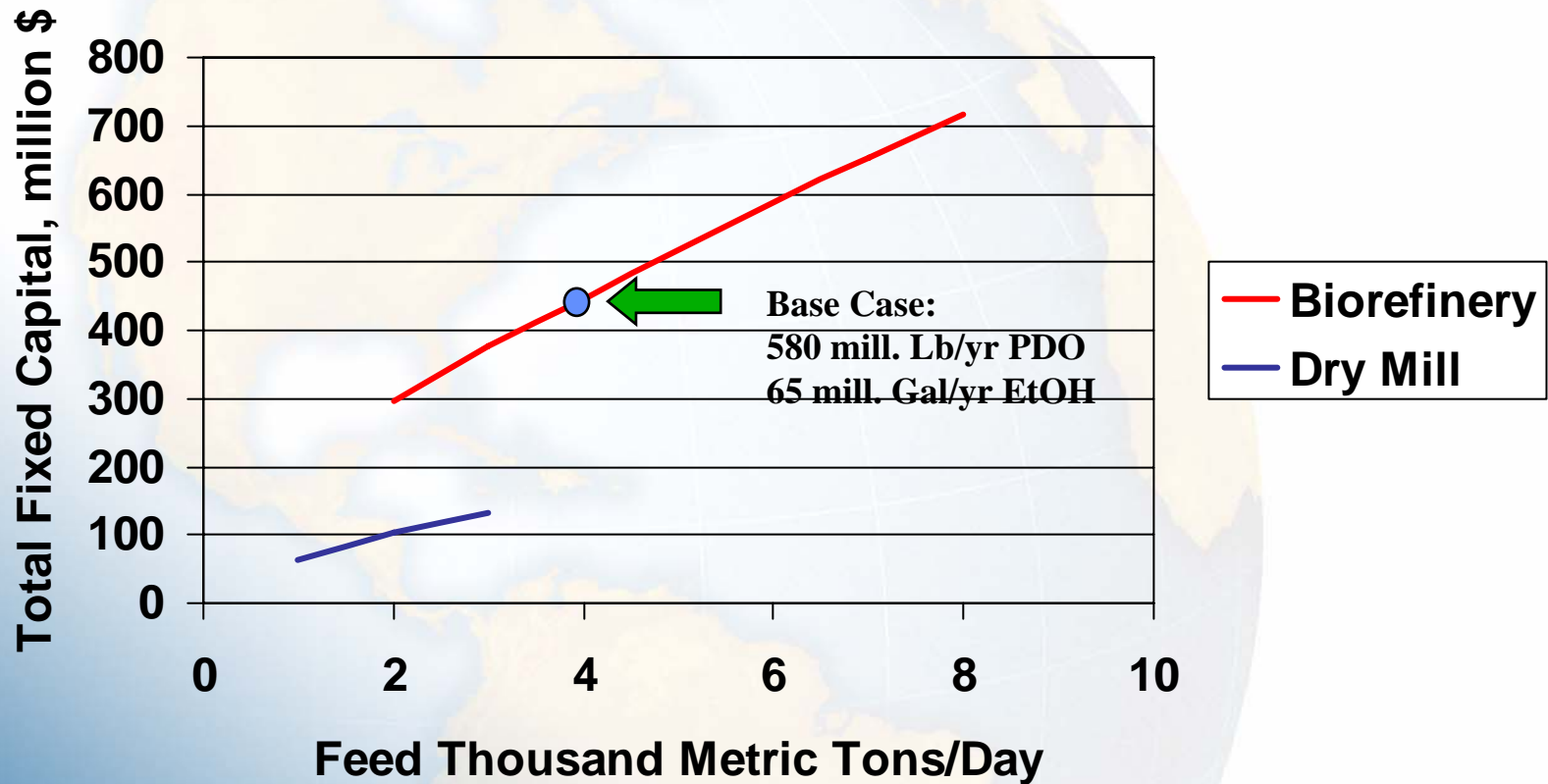
**Source: McAloon et al., 2000.**

## Core Conversion Technologies

- Sugar platform technologies
  - Pretreatment
  - Saccharification
- Fermentation technologies
  - Engineered microorganisms  
e.g. *S. cerevisiae*, *Z. mobilis* and *E. coli*
- Milling technologies
  - Starch conversion to sugar

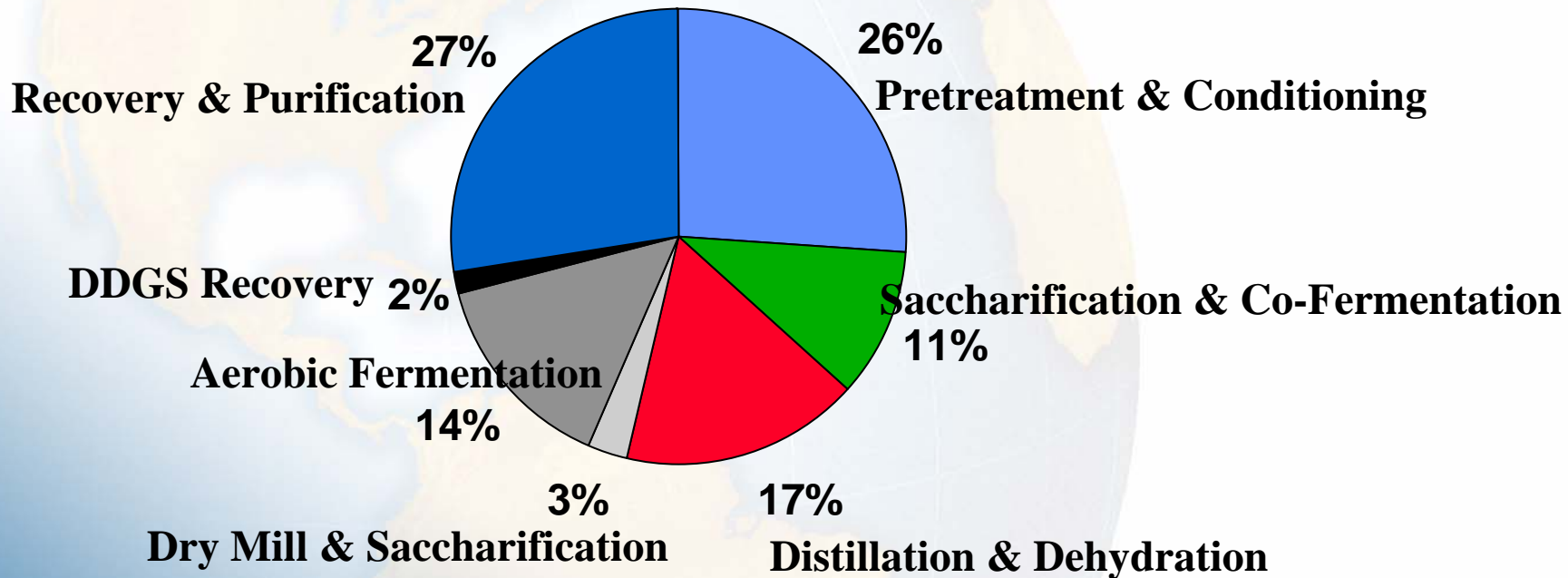
# Whole Corn Biorefinery



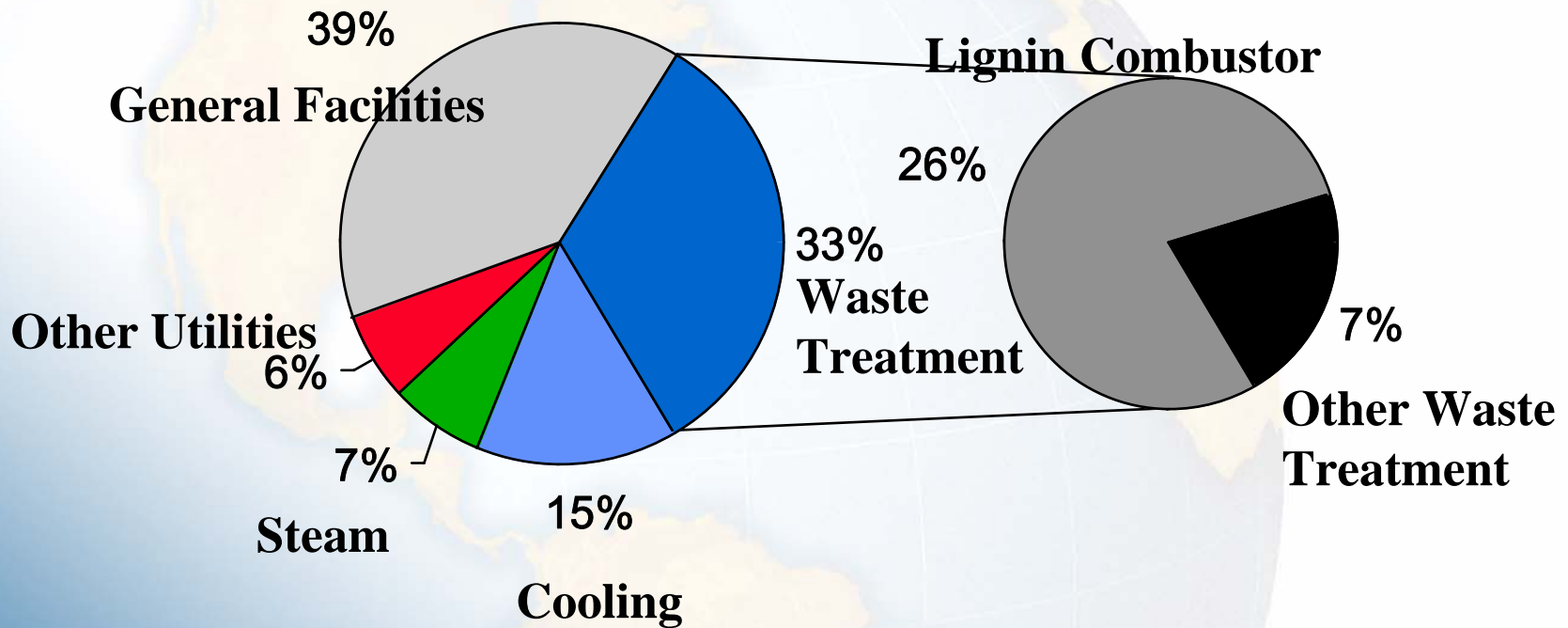


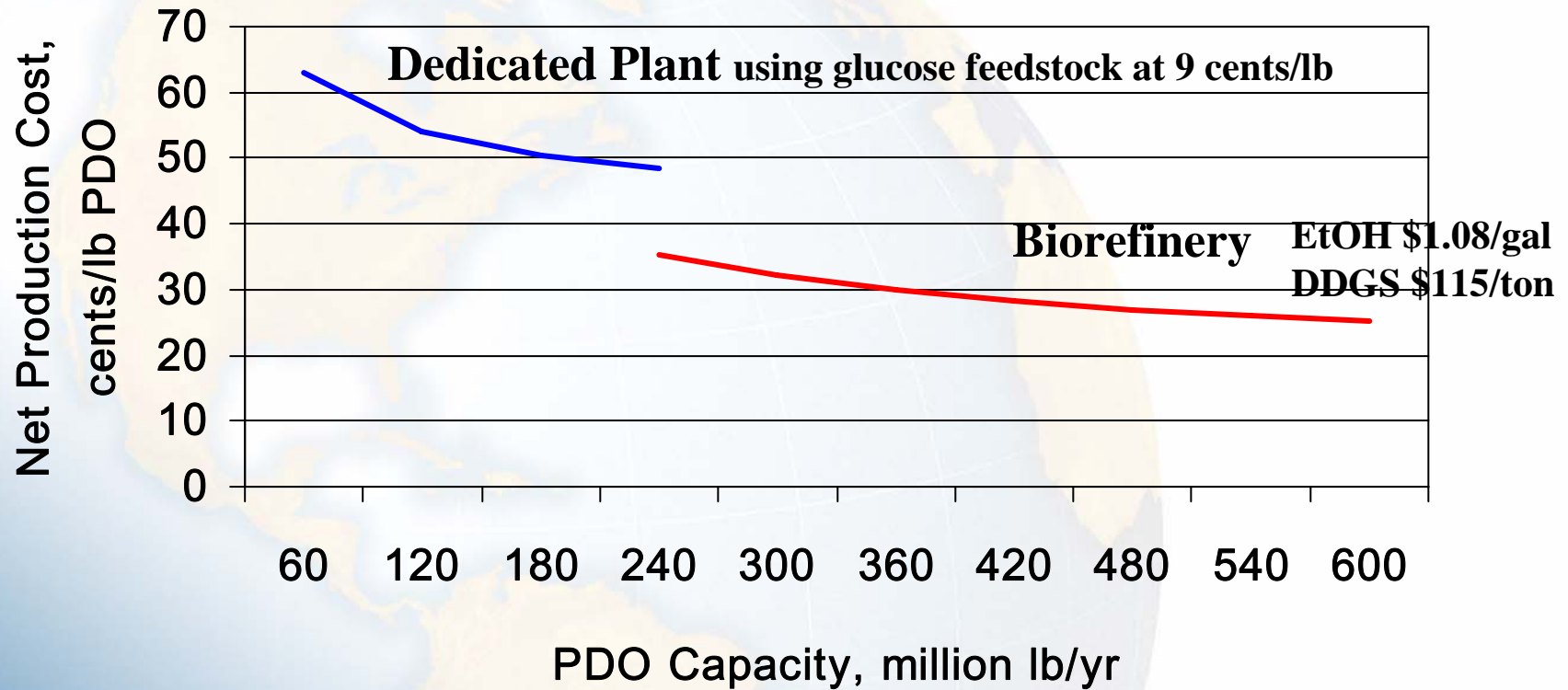
Source: PEP Report 257

# Whole Corn Biorefinery Battery Limits Investment



# Biorefinery Off-Sites Capital

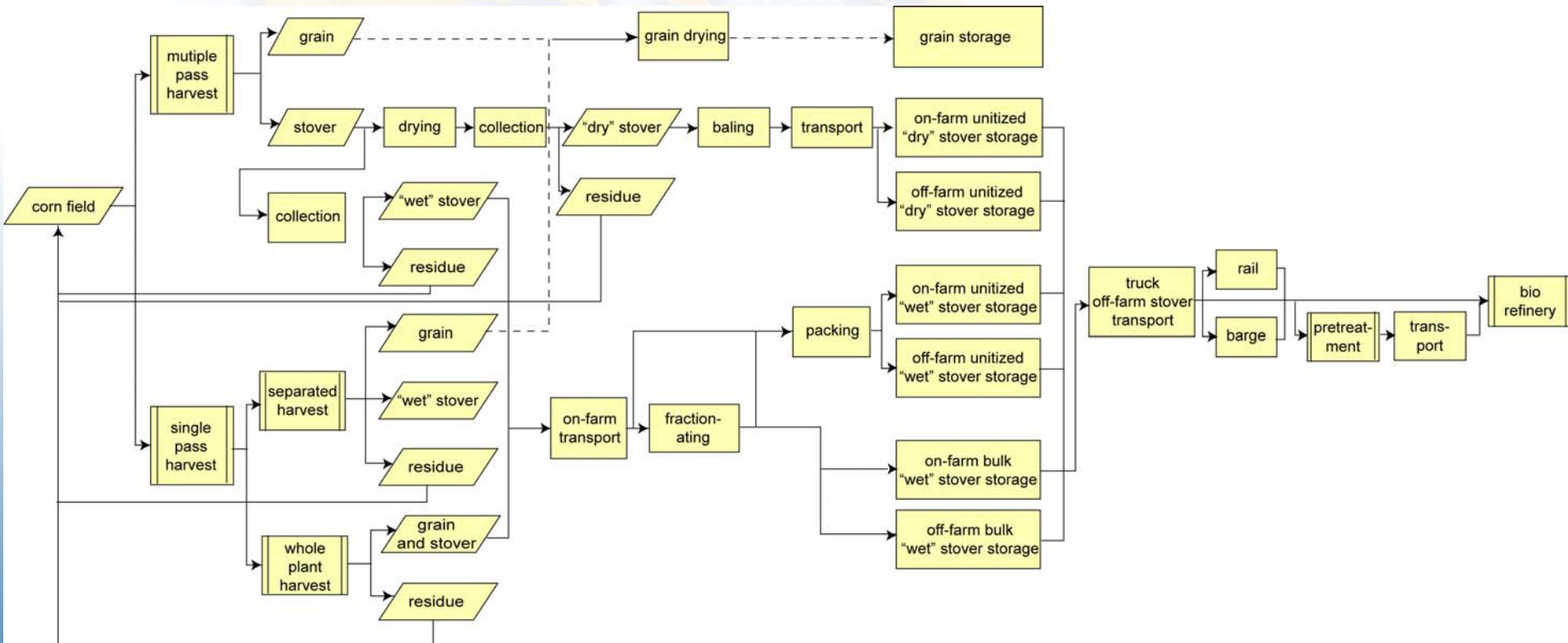




Source: PEP Report 257

- **Feedstock**
  - **Cost and composition**
- **Coproducts**
  - **Recovery costs**
  - **Market value**
- **Enzymes**
  - **Make versus buy**
- **Waste Treatment**
  - **Aqueous**
  - **Solid**

# Feedstock from Cornfield to Biorefinery

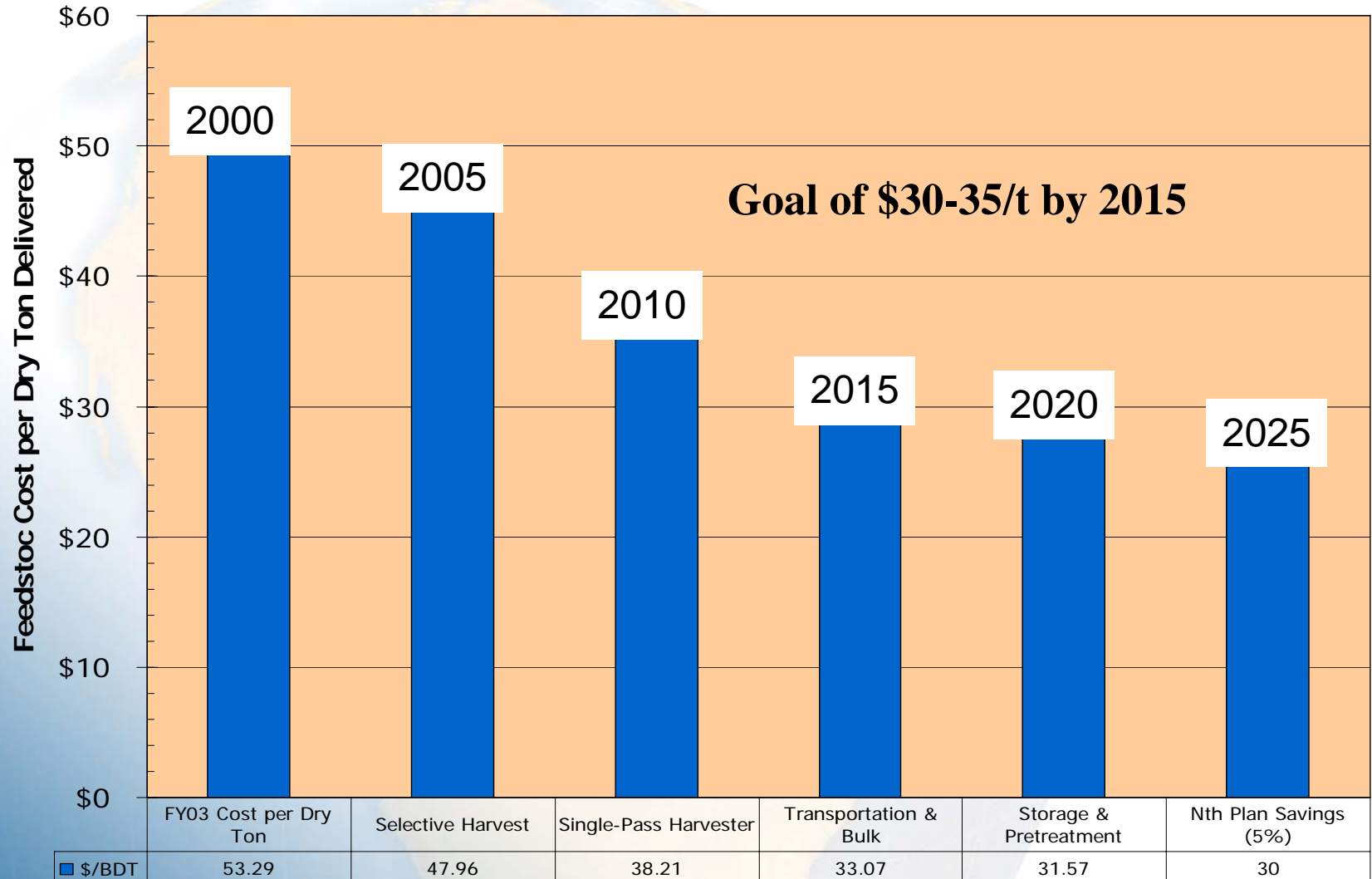


Source:  
 Department of Agricultural and Biosystems Engineering  
 Iowa State University.

Feedstock flow chart for biomass planning tool [I-FARM](#)  
 as planned in Task 8 of the USDA-DOE project.

# Biomass Cost Reduction Target

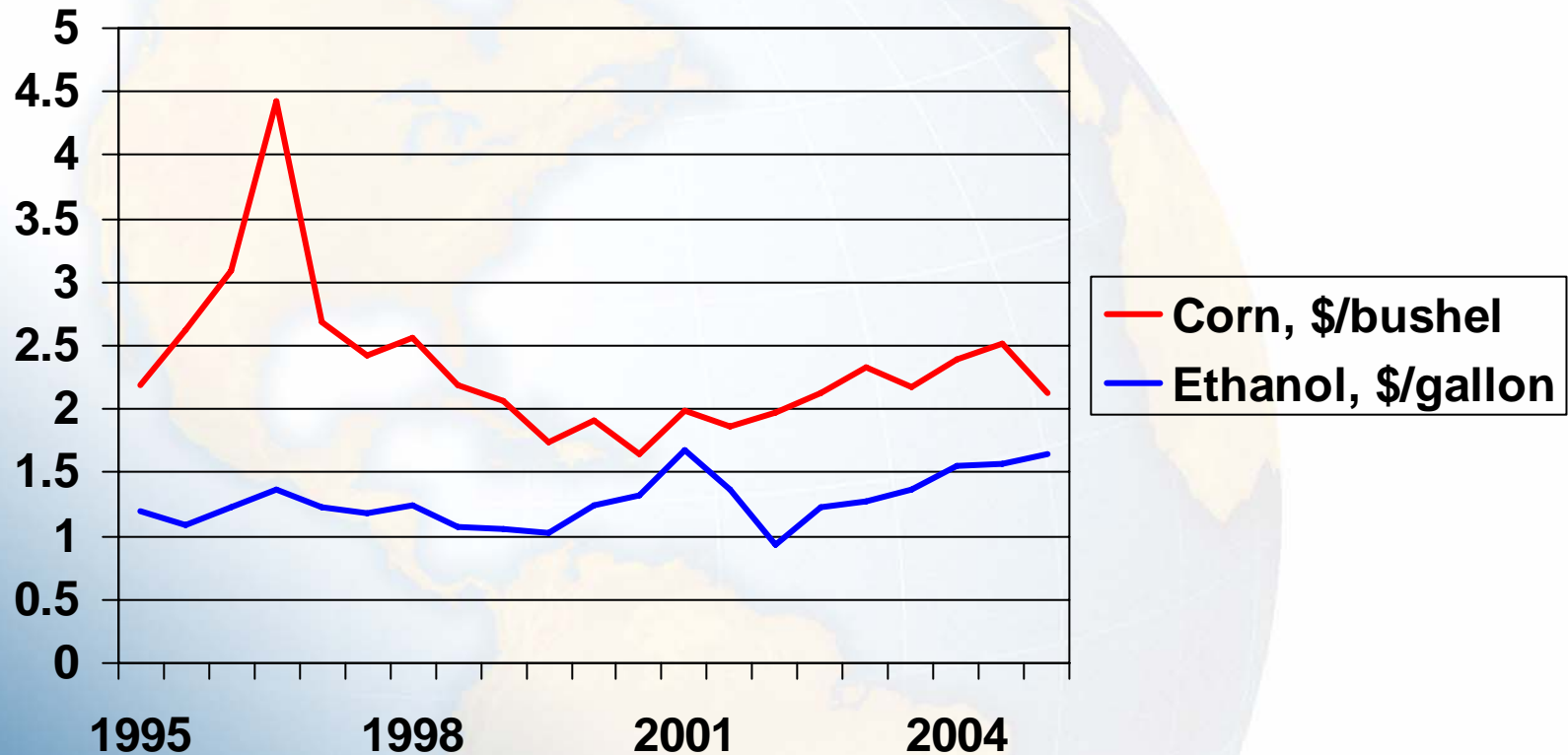
\$/Biomass Dry Ton



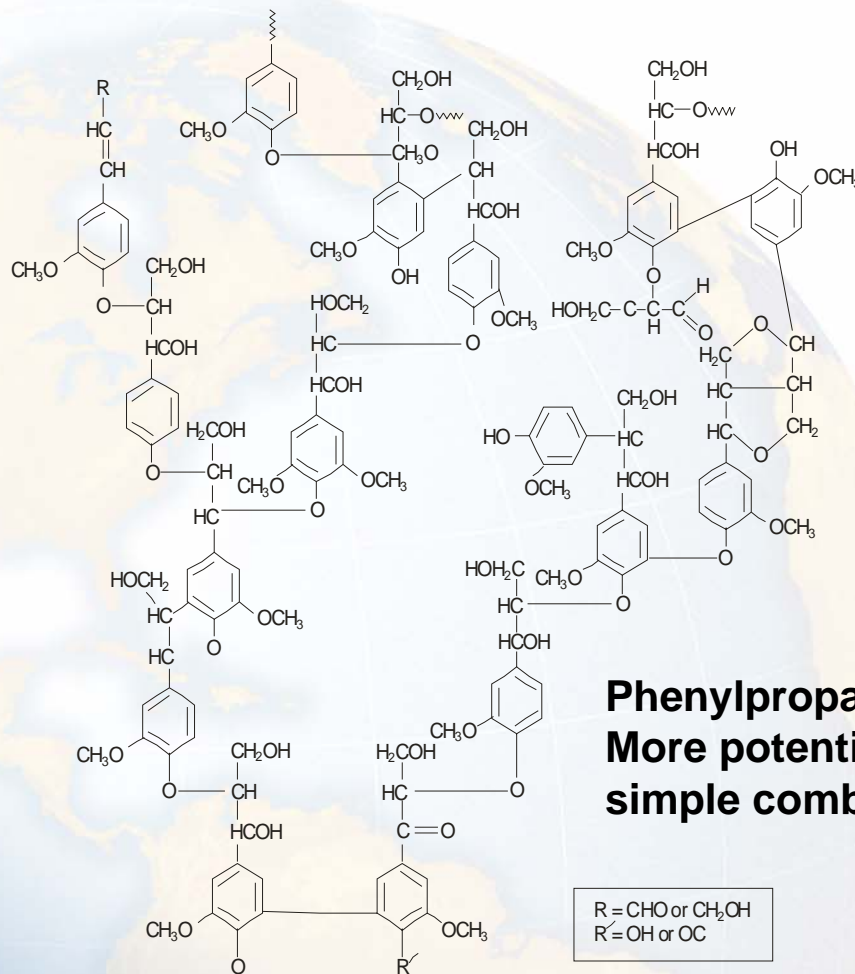
Source: Sokhansanj and Turhollow, ORNL 2005

- **1,3-Propanediol**
  - **Monomer for PTT**
- **Ethanol**
  - **Established commodity as fuel**
- **Lignin**
  - **Energy value**
  - **Potential chemical derivatives**
- **Protein**
  - **Established feed markets**
- **Carbon Dioxide**
- **Other Byproducts**
  - **Acetic acid, furfural, other organics**

# Ethanol Price History



# Lignin (Partial Structure)



**Phenylpropane monomers:  
More potential value than  
simple combustion**

- Fermentation requires large volumes of water
  - *E. coli* produces 135 g/L PDO
  - Water recycle challenging
- Numerous fermentation by-products
  - Feedstock composition variability
  - Organism pathways
    - ◆ Acetic acid and other organics
  - High biological oxygen demand
  - Salts

- **Potential sources**
  - Pretreatment
  - Product recovery
- **Disposal options limited**
  - Land farming
  - Landfilling

## What can we learn from this analysis?

- **Biorefineries are capital intensive**
  - Pretreatment
  - Product recovery
- **Coproducts provide economic synergies**
- **Technical challenges remain for waste issues**
  - Lignin
  - Waste water
  - Gypsum

**Thank you for your attention**

**Gregory Bohlmann**

**SRI Consulting**

**[gbohlmann@sriconsulting.com](mailto:gbohlmann@sriconsulting.com)**

**[www.sriconsulting.com](http://www.sriconsulting.com)**