Bioenergy: From Concept to Commercial Processes

Process Economics Program

Biorefinery Process Economics

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

Gregory M. Bohlmann
gbohlmann@sriconsulting.com

March 9,2006

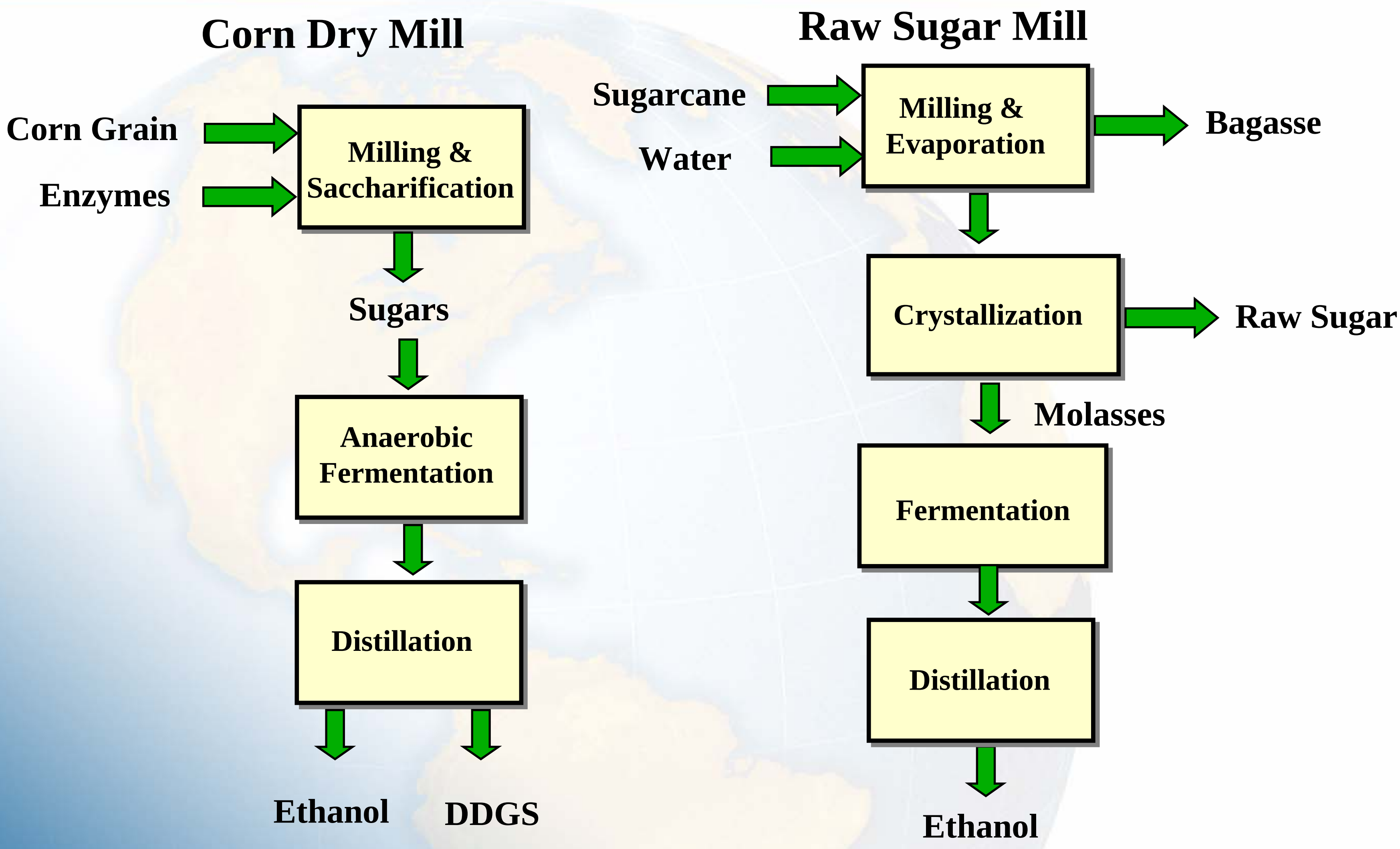
SRI CONSULTING
A Division of Access Intelligence, LLC

Biorefinery Process Economics

Agenda

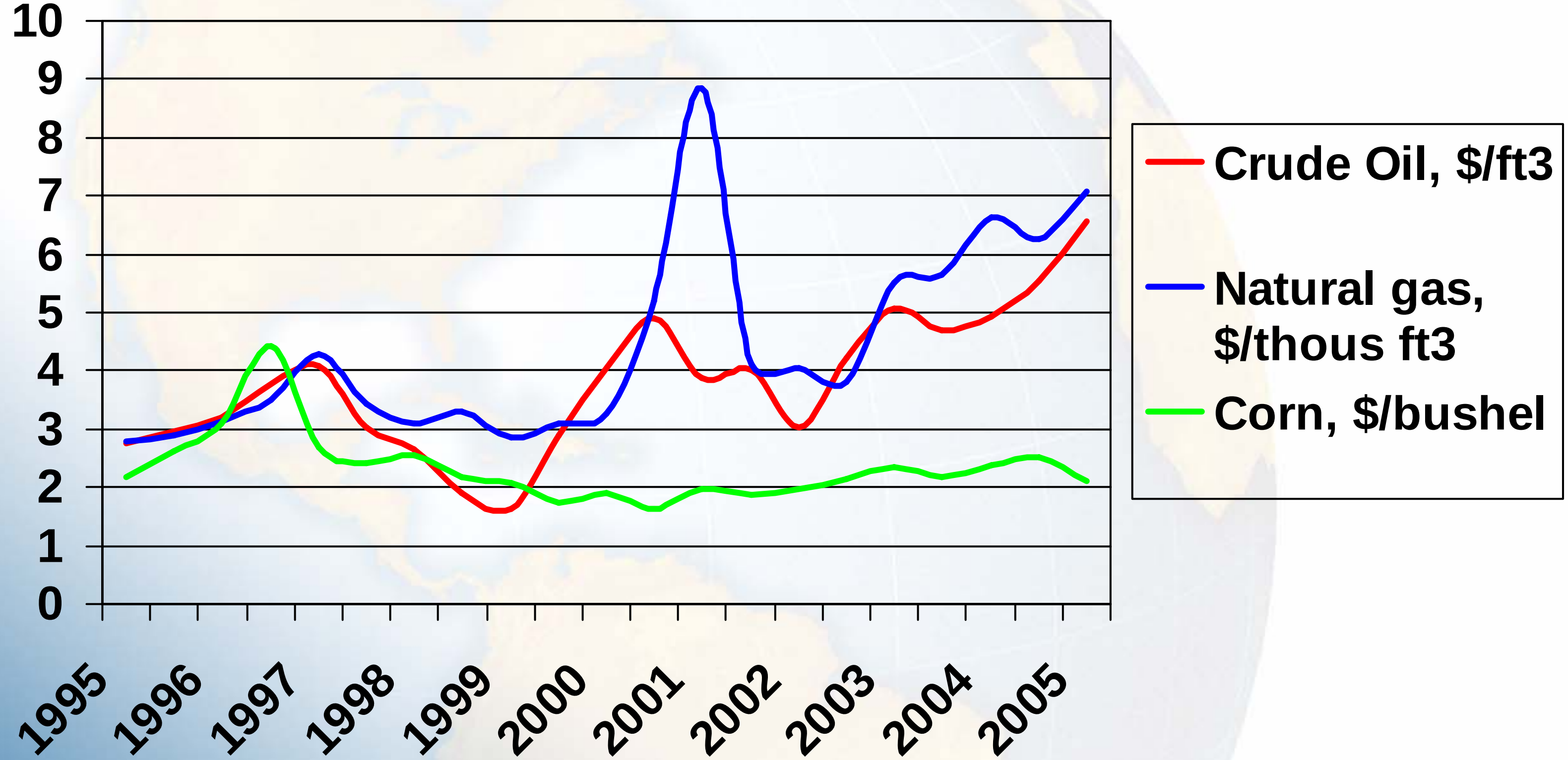
- Biorefinery Research
- Whole Corn Biorefinery
  - Core Conversion Technologies
  - Capital Costs
  - Process Economics
- Economic Issues
  - Feedstock
  - Coproducts
- Waste Issues
- Conclusions

Early Biorefineries



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)

U.S. Biorefinery Research

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

Whole corn biorefinery utilizes entire corn plant

Grain	% Dry Basis	Stover	% Dry Basis
Starch	72.0	Cellulose	37.3
Celluloses	10.5	Xylan	20.6
Protein	9.5	Lignin	17.5
Oil	4.5	Galac./Man.	1.4
Sugars	2.0	Arabinan	2.1
Ash	1.5	Ash	6.1
		Acetate	2.0
		Extractives	13.0
Source: McAloon et al., 2000.			

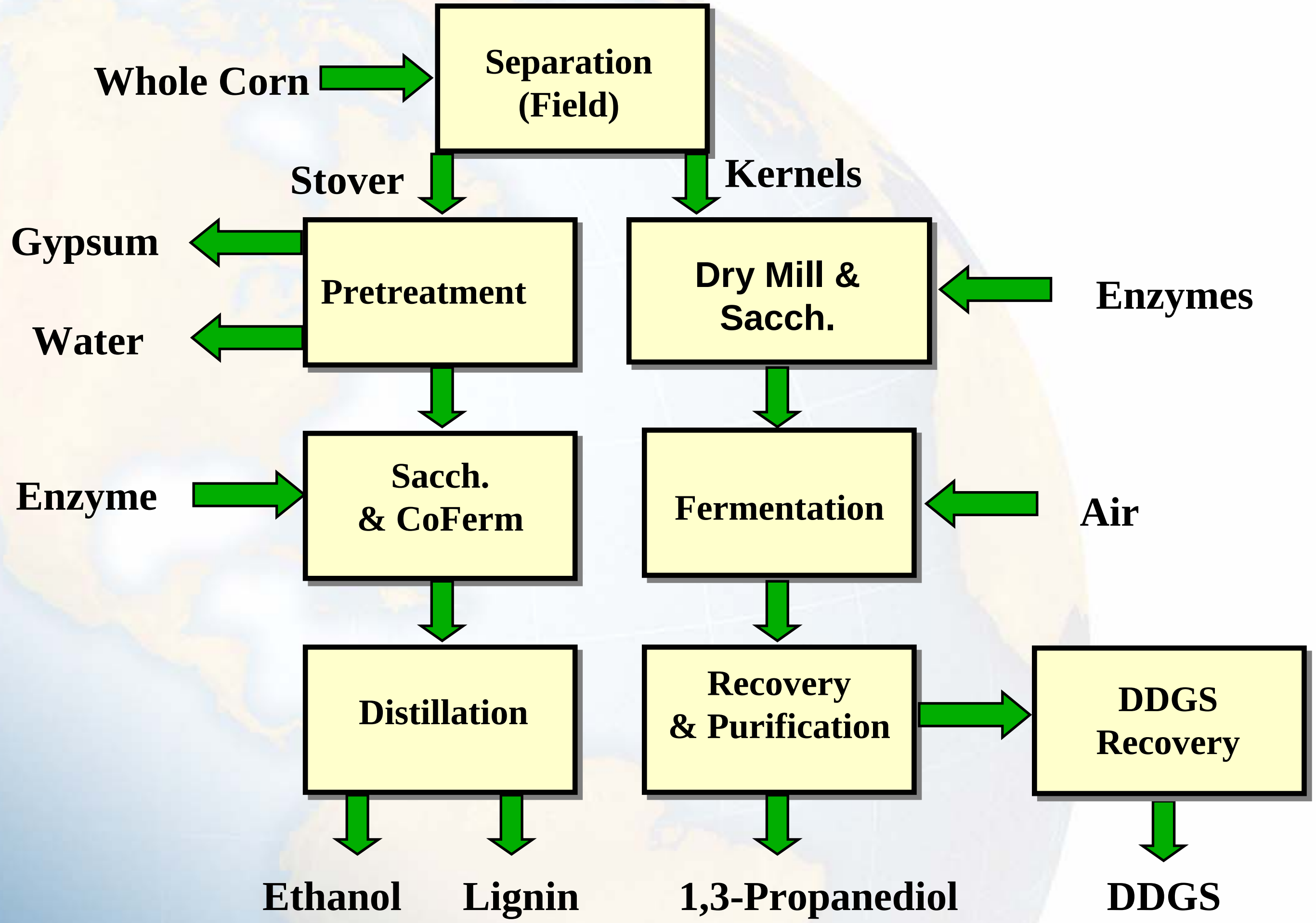
Whole Corn Biorefinery

Core Conversion Technologies

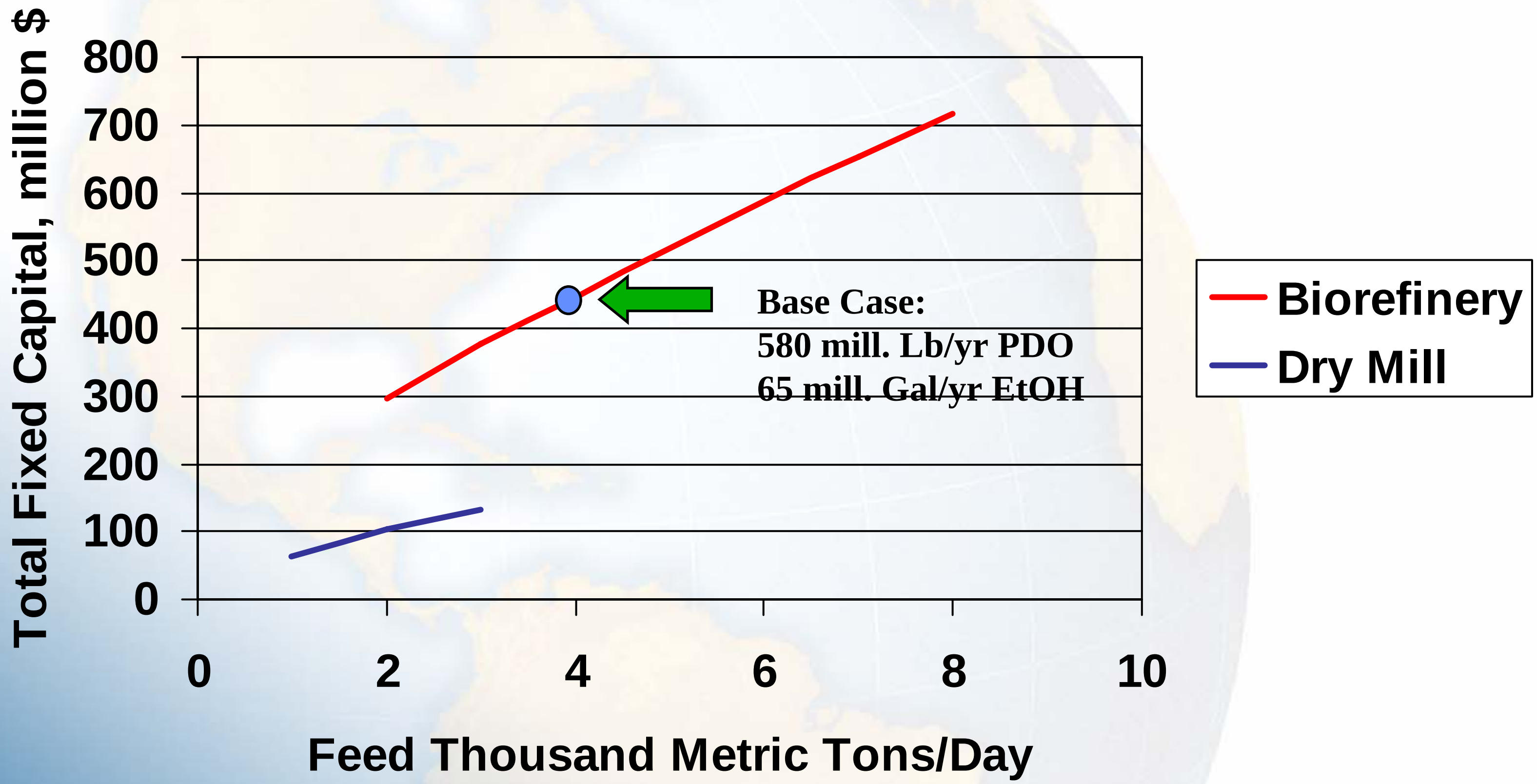
- **Sugar platform technologies**
  - **Pretreatment**
  - **Saccharification**
- **Fermentation technologies**
  - **Engineered microorganisms**

    e.g. *S. cerevisiae, Z. mobilis* and *E. coli*
- **Milling technologies**
  - **Starch conversion to sugar**

Whole Corn Biorefinery

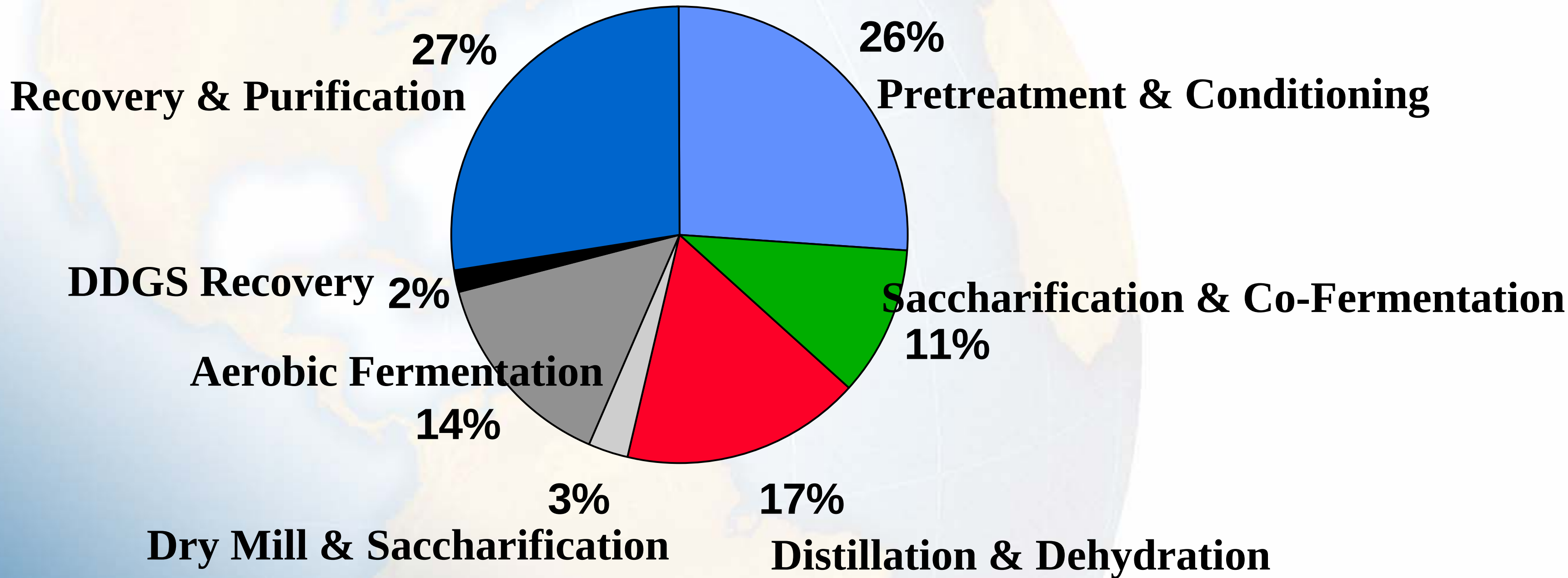


Capital Costs

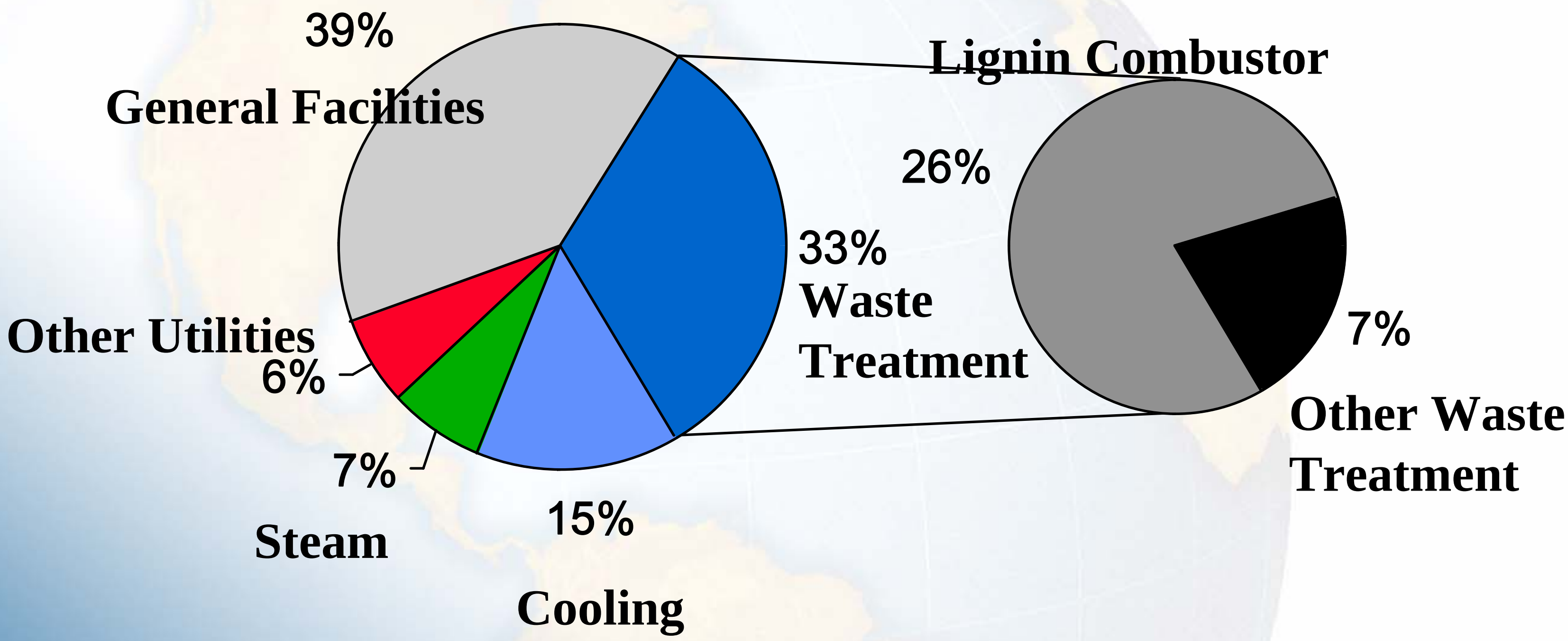


Source: PEP Report 257

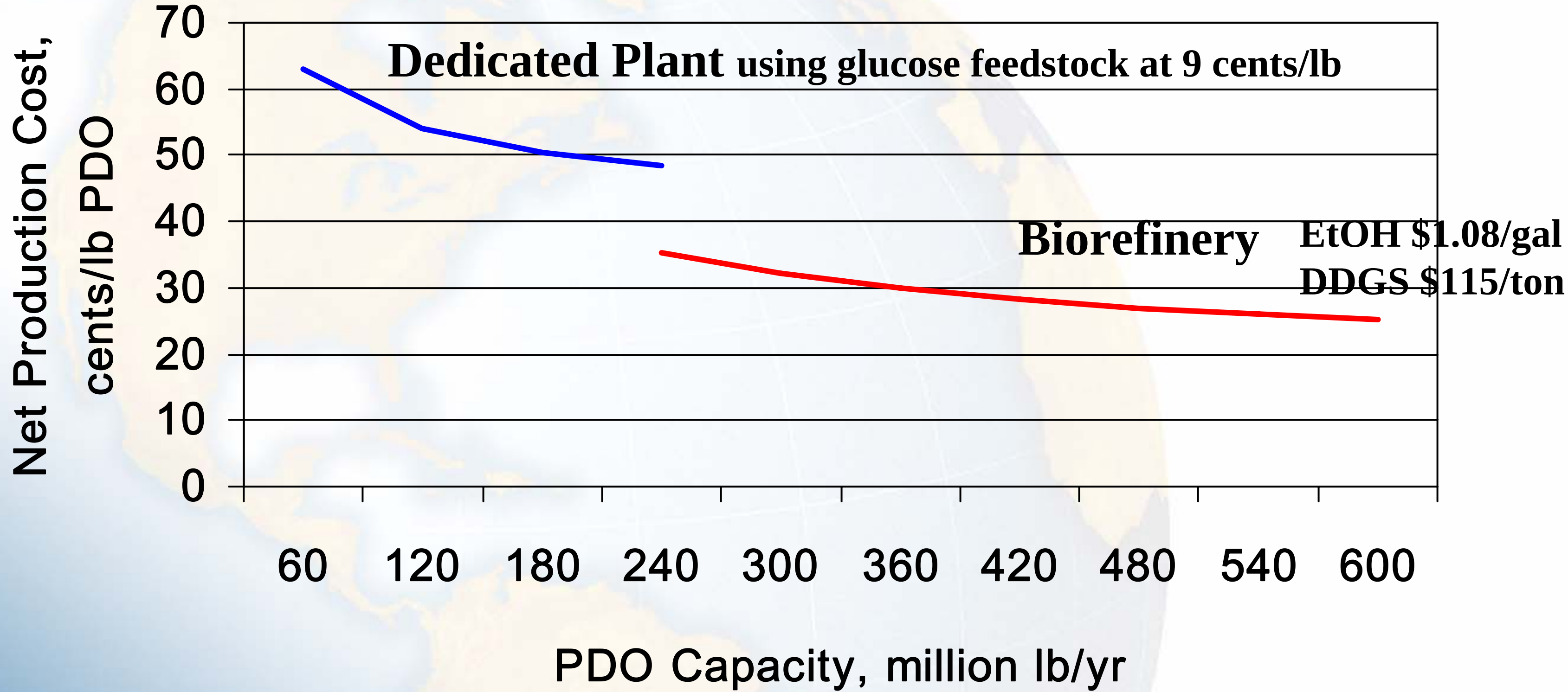
Whole Corn Biorefinery Battery Limits Investment



Biorefinery Off-Sites Capital



Process Economics

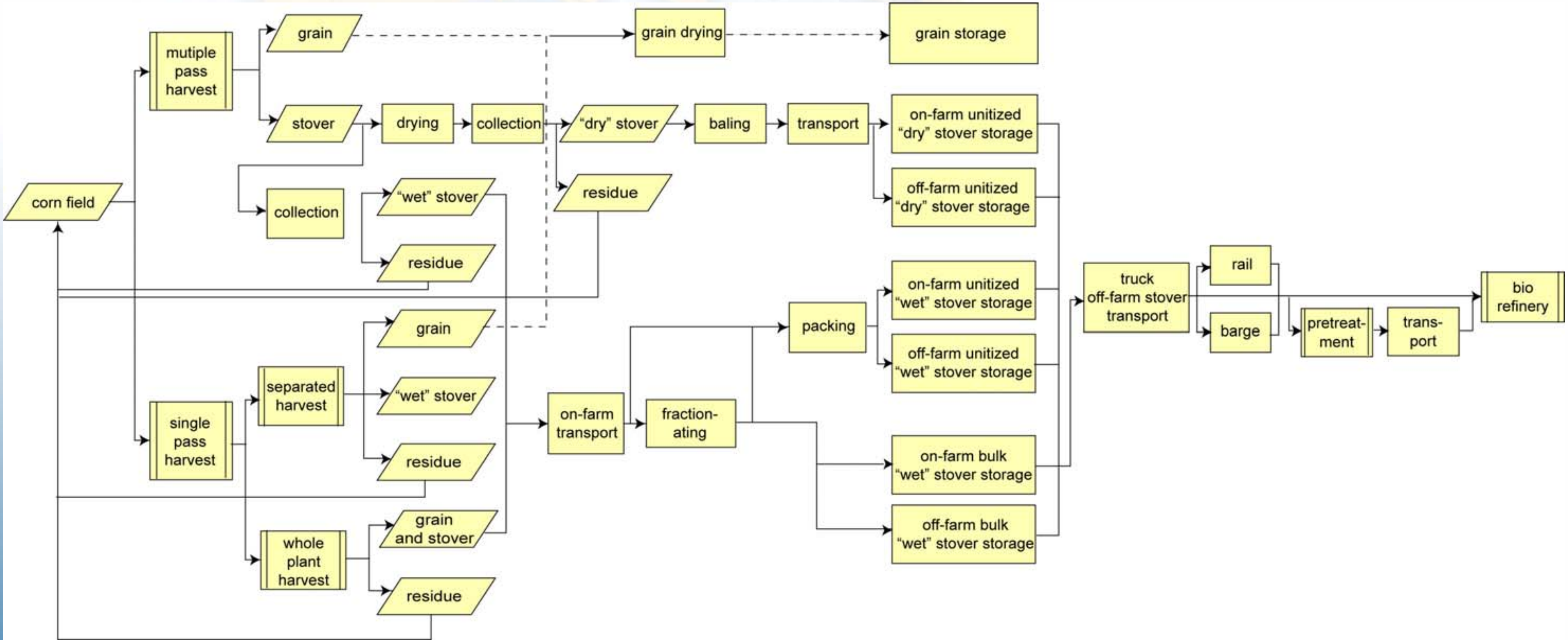


Source: PEP Report 257

Process Economic Issues

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

Feedstock from Cornfield to Biorefinery

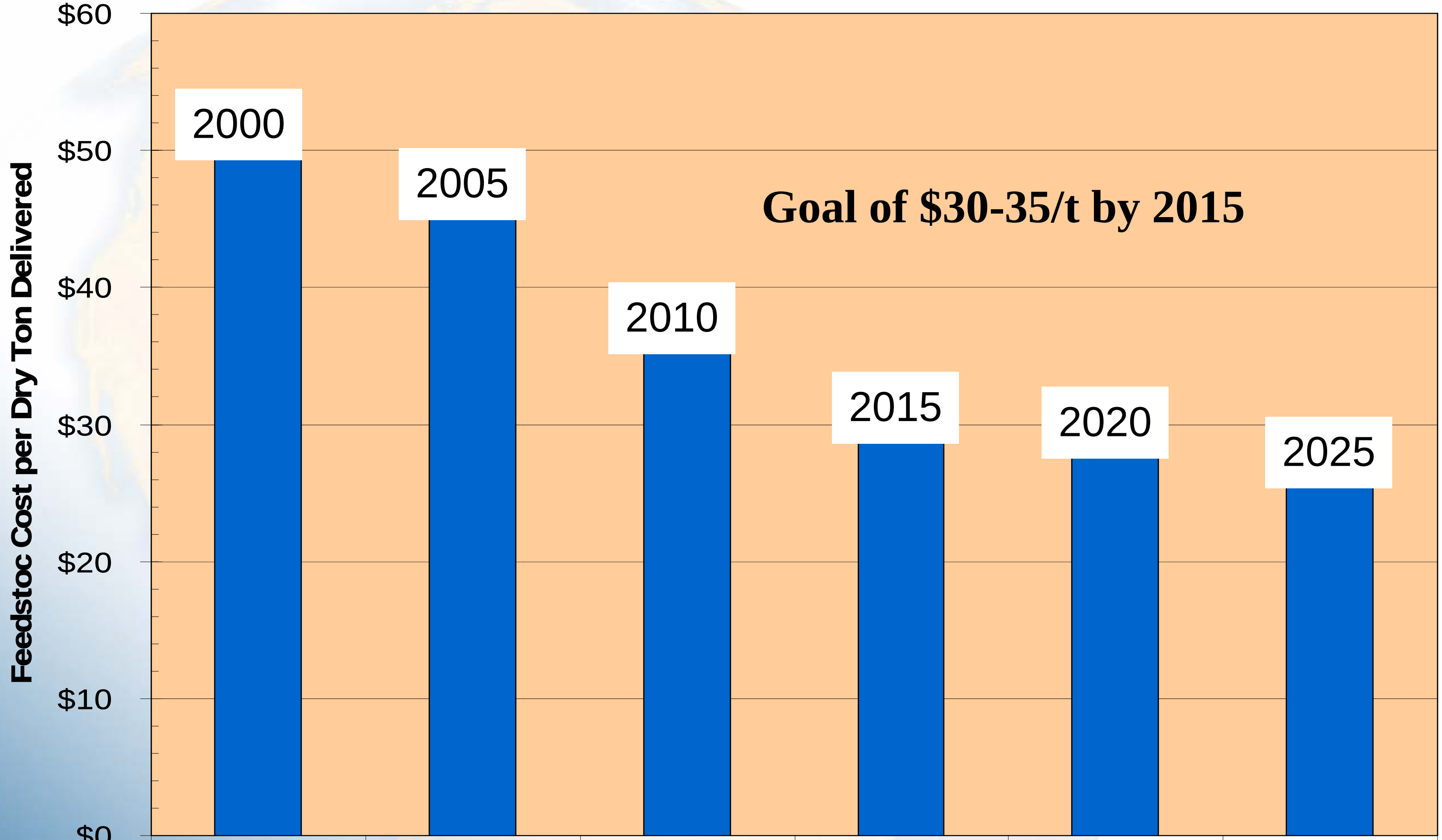


Source:
Department of Agricultural and Biosystems Engineering
Iowa State University.

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



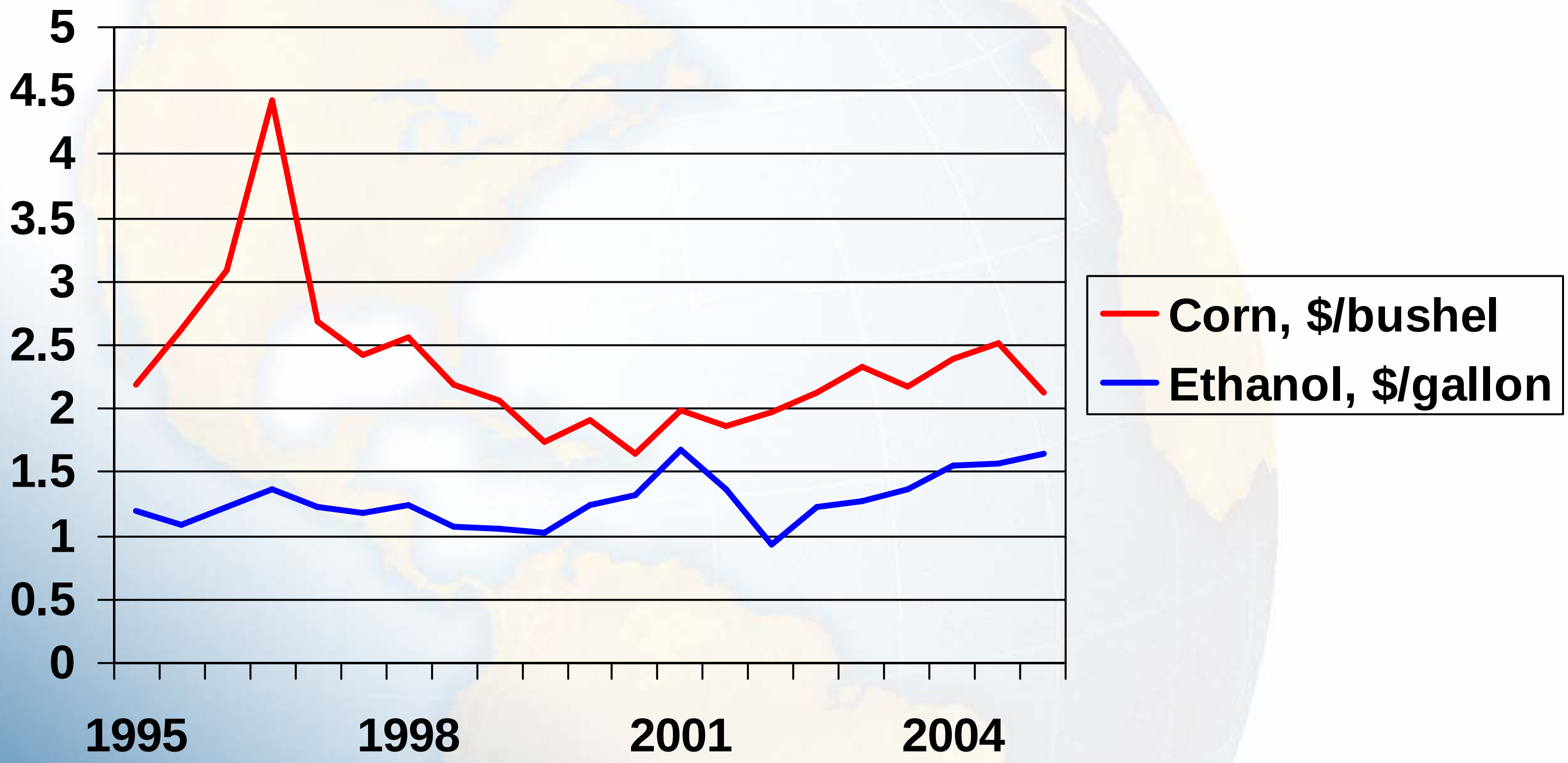
	FY03 Cost per Dry Ton	Selective Harvest	Single-Pass Harvester	Transportation & Bulk	Storage & Pretreatment	Nth Plan Savings (5%)
$/BDT	53.29	47.96	38.21	33.07	31.57	30

Source: Sokhansanj and Turhollow, ORNL 2005

Coproducts

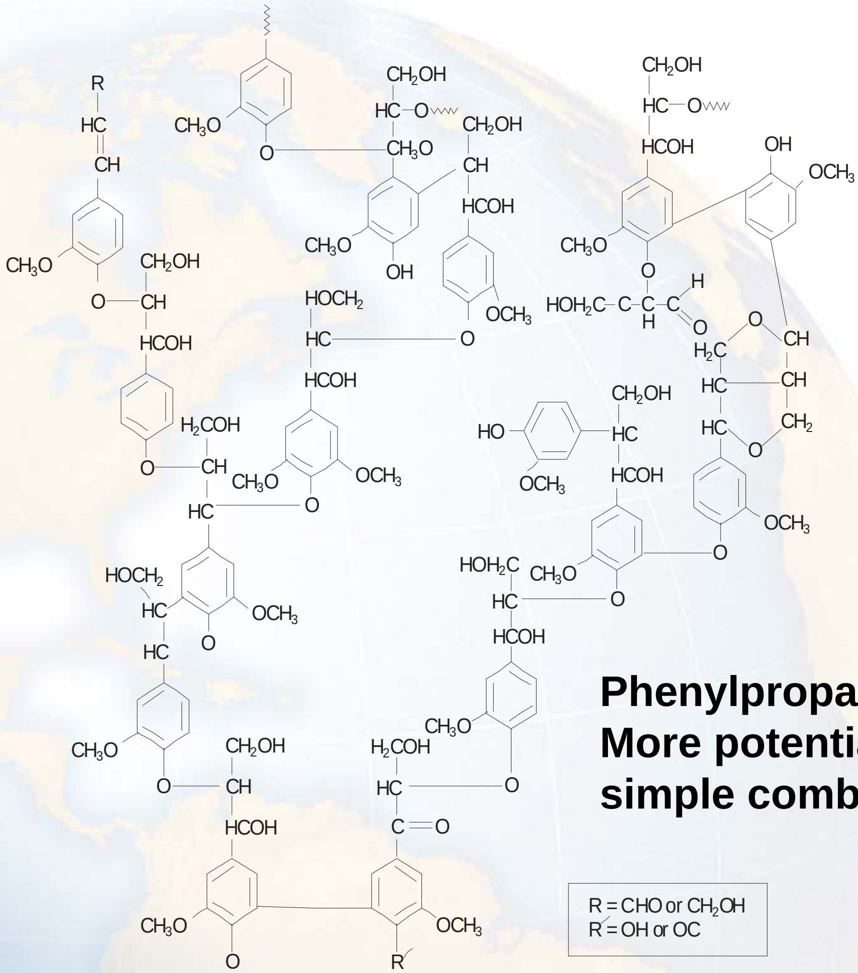
- 1,3-Propanediol
  - Monomer for PTT
- Ethanol
  - Established commodity as fuel
- Lignin
  - Energy value
  - Potential chemical derivatives
- Protein
  - Established feed markets
- Carbon Dioxide
- Other Byproducts
  - Acetic acid, furfural, other organics

Ethanol Price History



Process Economics Program

Lignin (Partial Structure)



Phenylpropane monomers: More potential value than simple combustion

Aqueous Waste

- **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**

Process Economics Program

Gypsum

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

Conclusions

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

Process
Economics
Program

Thank you for your attention

Gregory Bohlmann
SRI Consulting
gbohlmann@sriconsulting.com
www.sriconsulting.com