Bioenergy: From Concept to Commercial Processes

Biorefinery Process Economics

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

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Biorefinery Process Economics

Agenda

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

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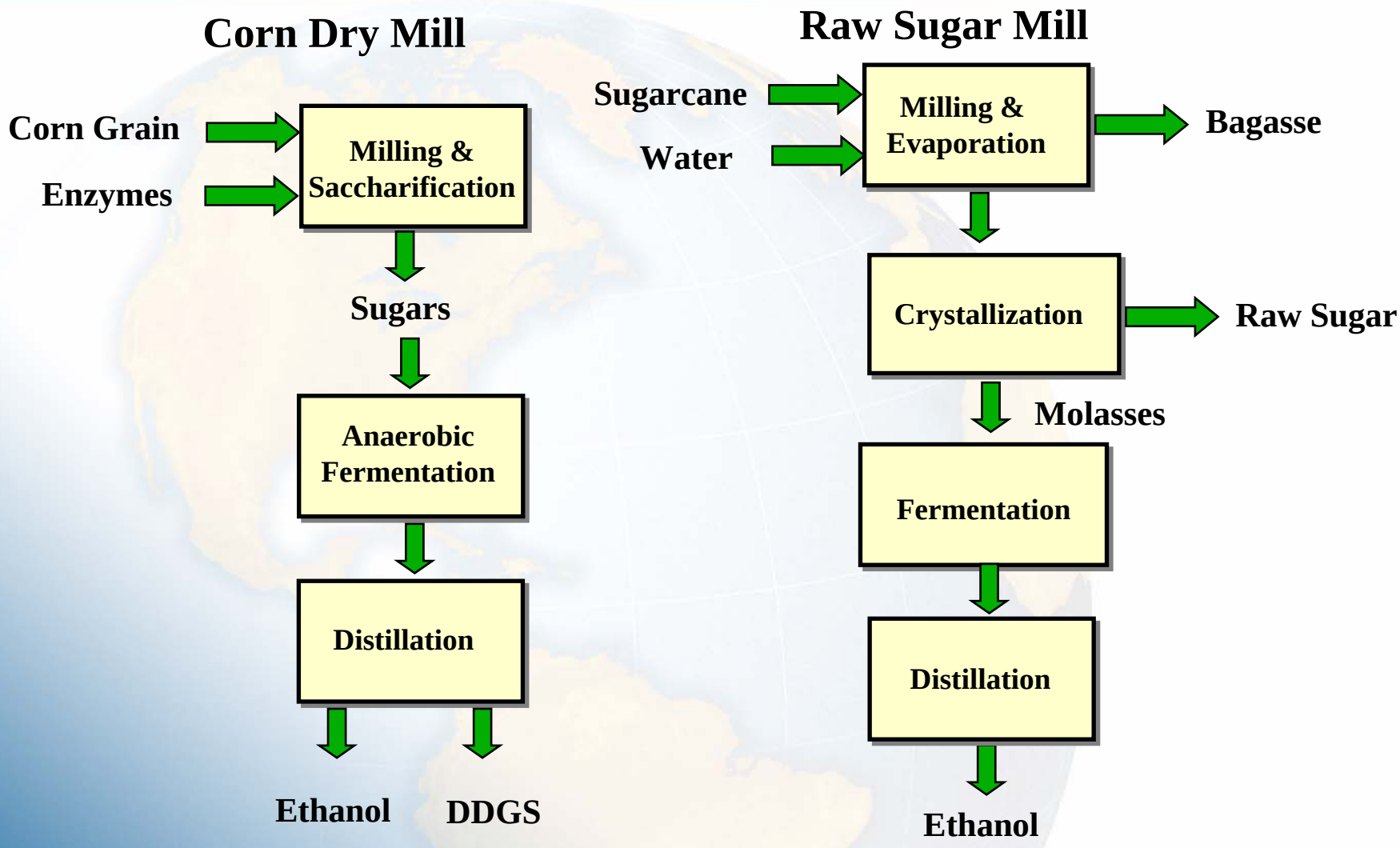
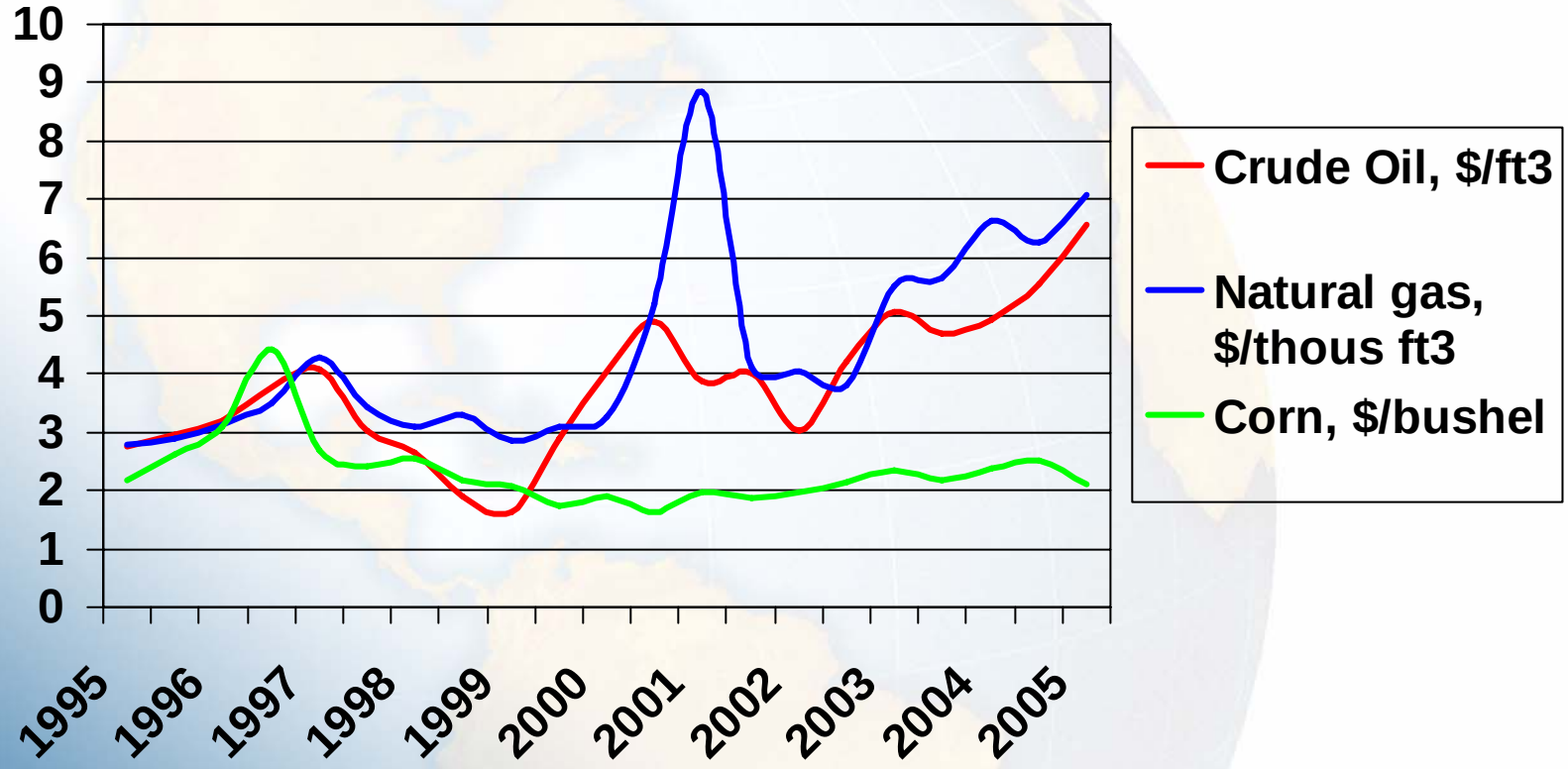
Early Biorefineries



Feedstock Price as Driving Factor

Opportunity grows for renewable resources



Biorefinery Research

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

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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

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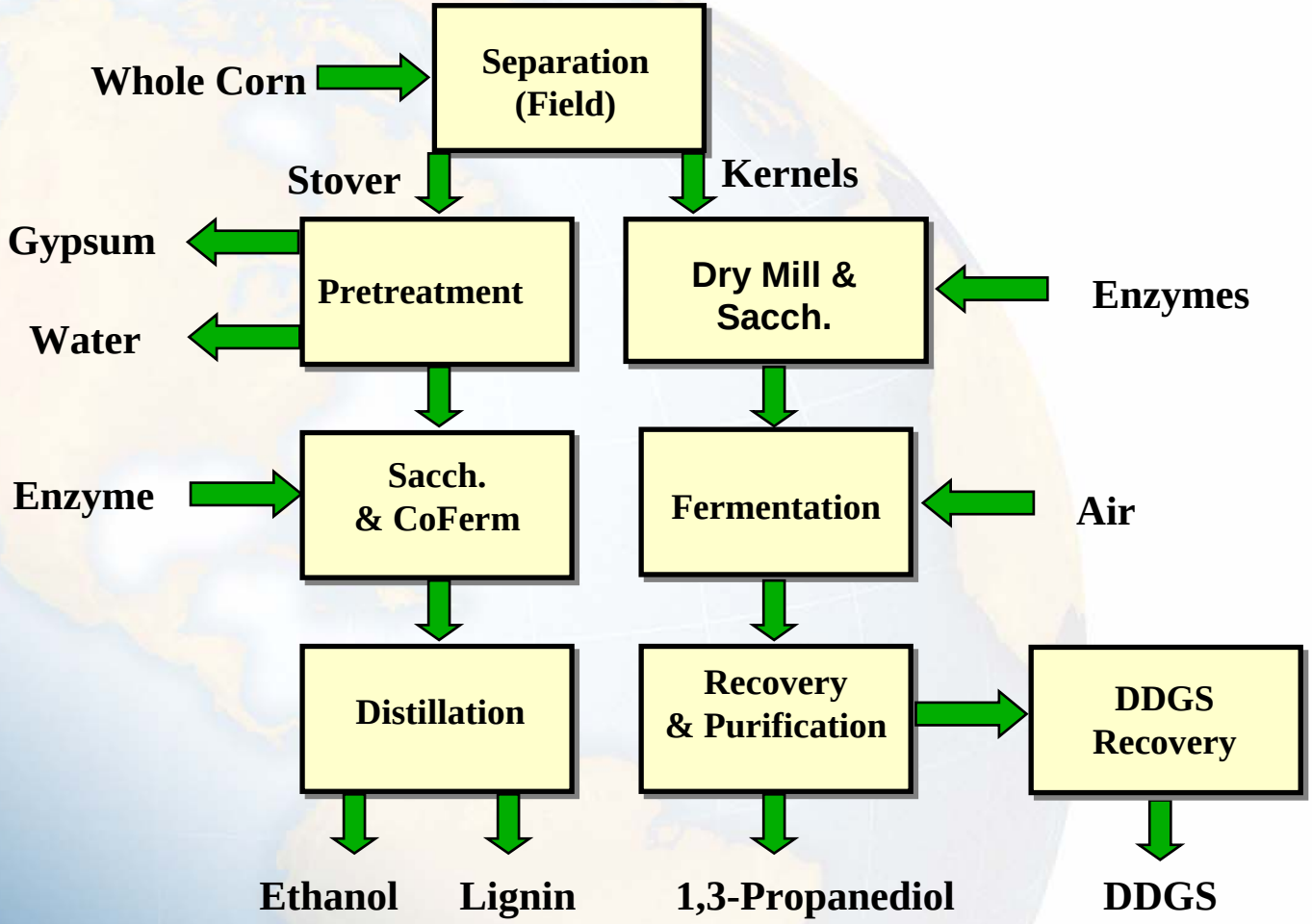
Whole Corn Biorefinery



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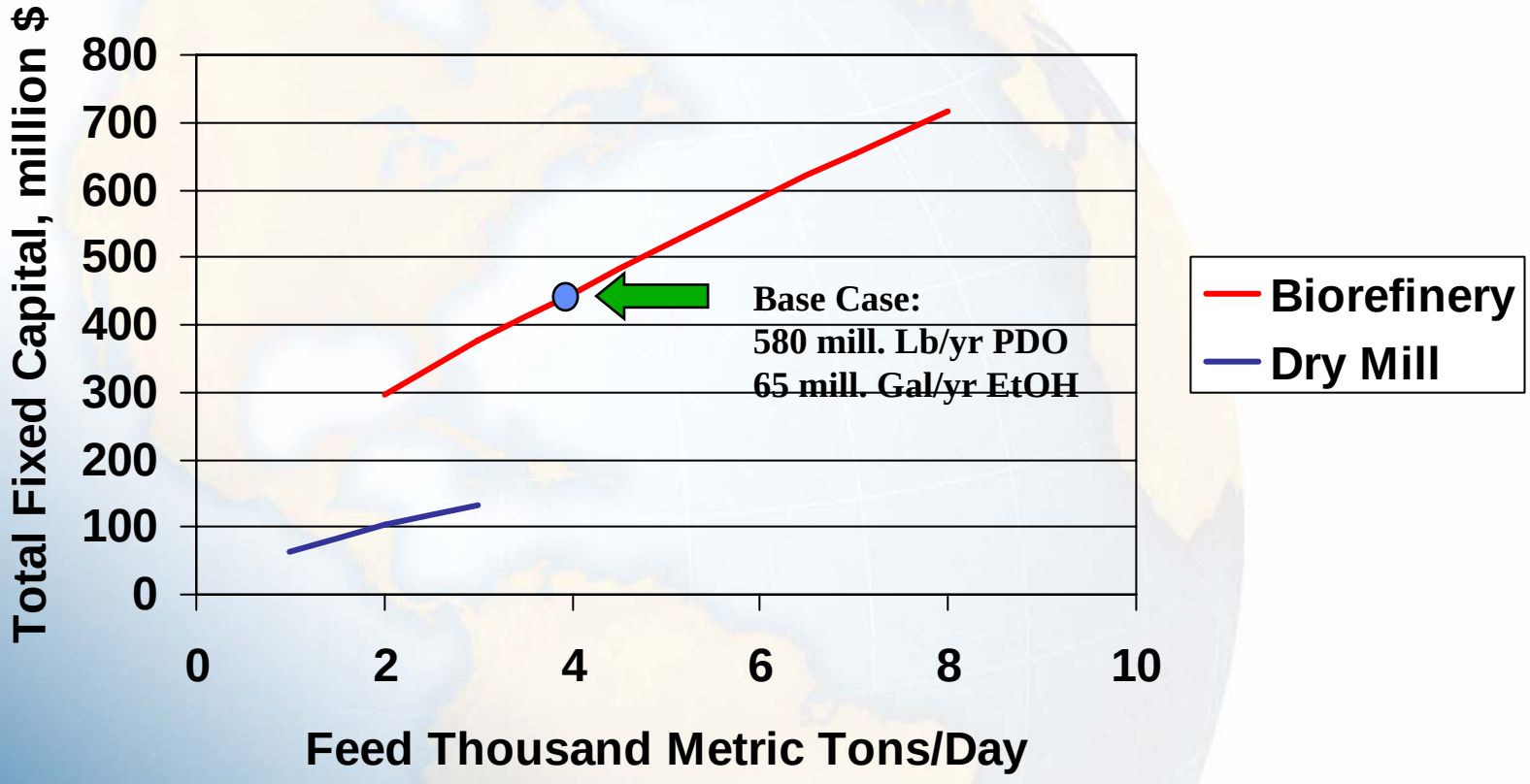
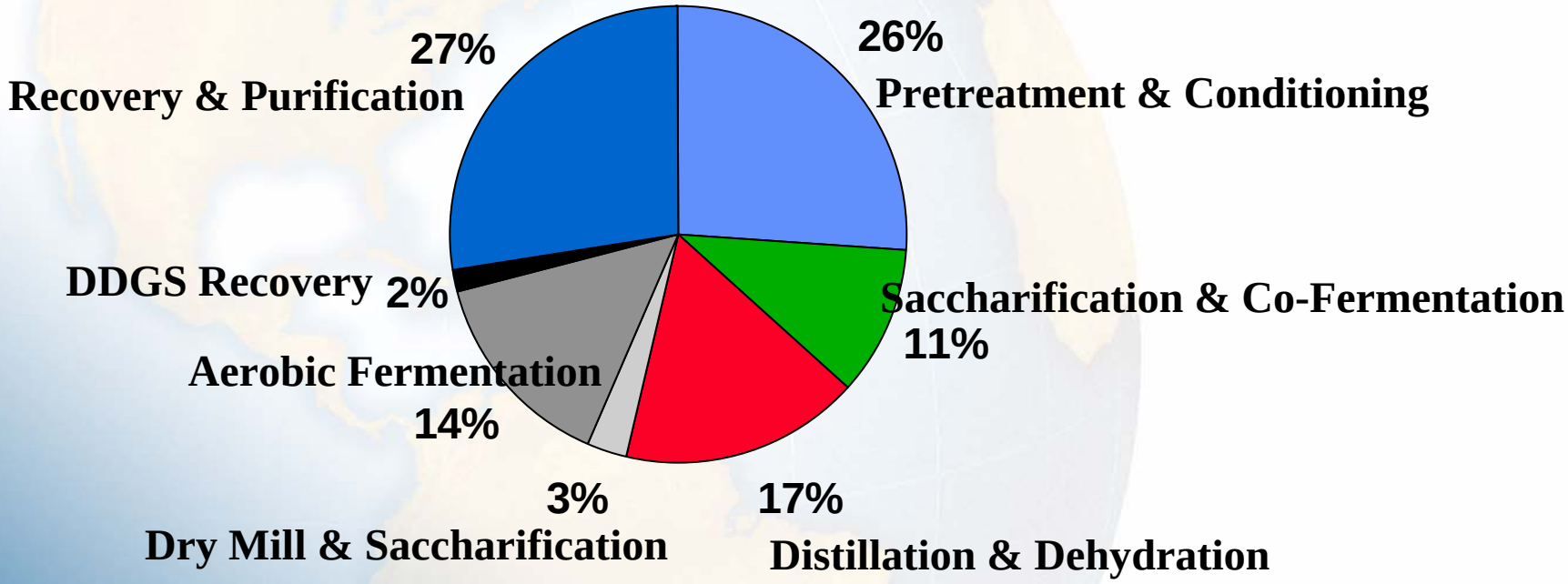
Capital Costs

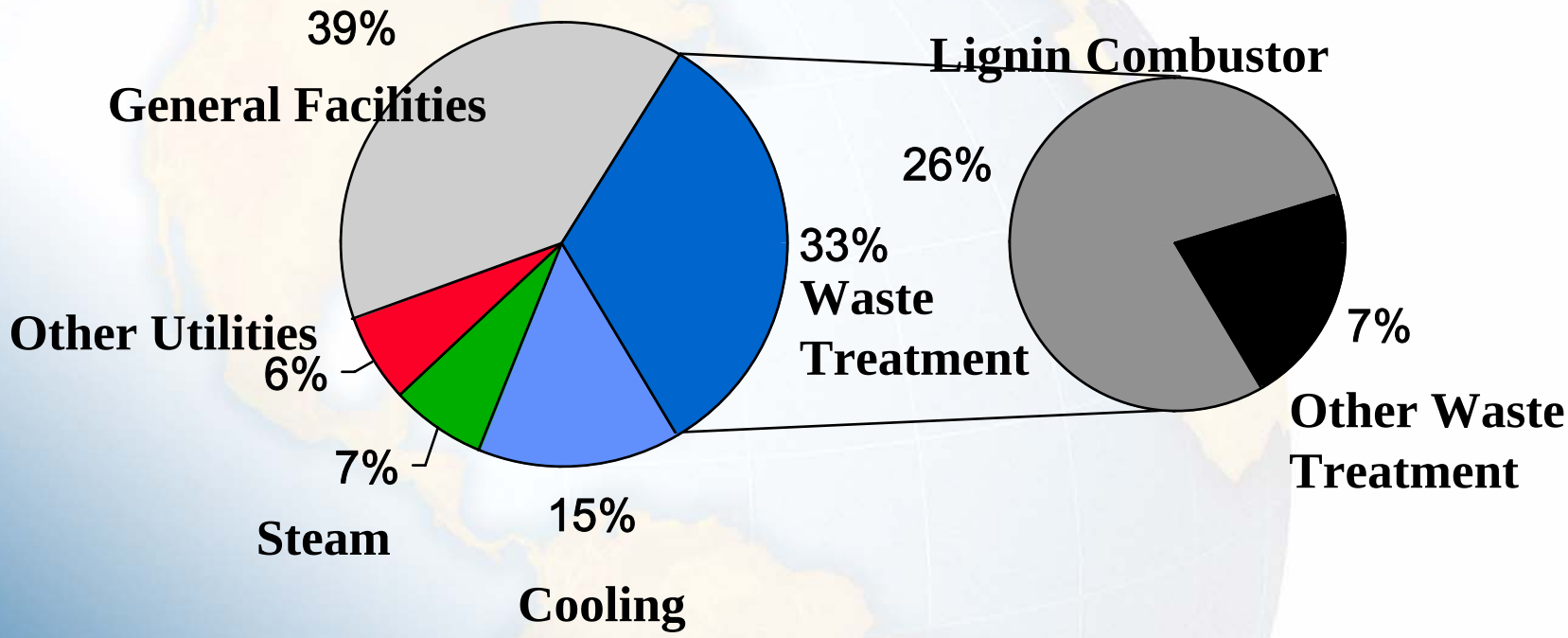


Source: PEP Report 257

Whole Corn Biorefinery Battery Limits Investment



Biorefinery Off-Sites Capital



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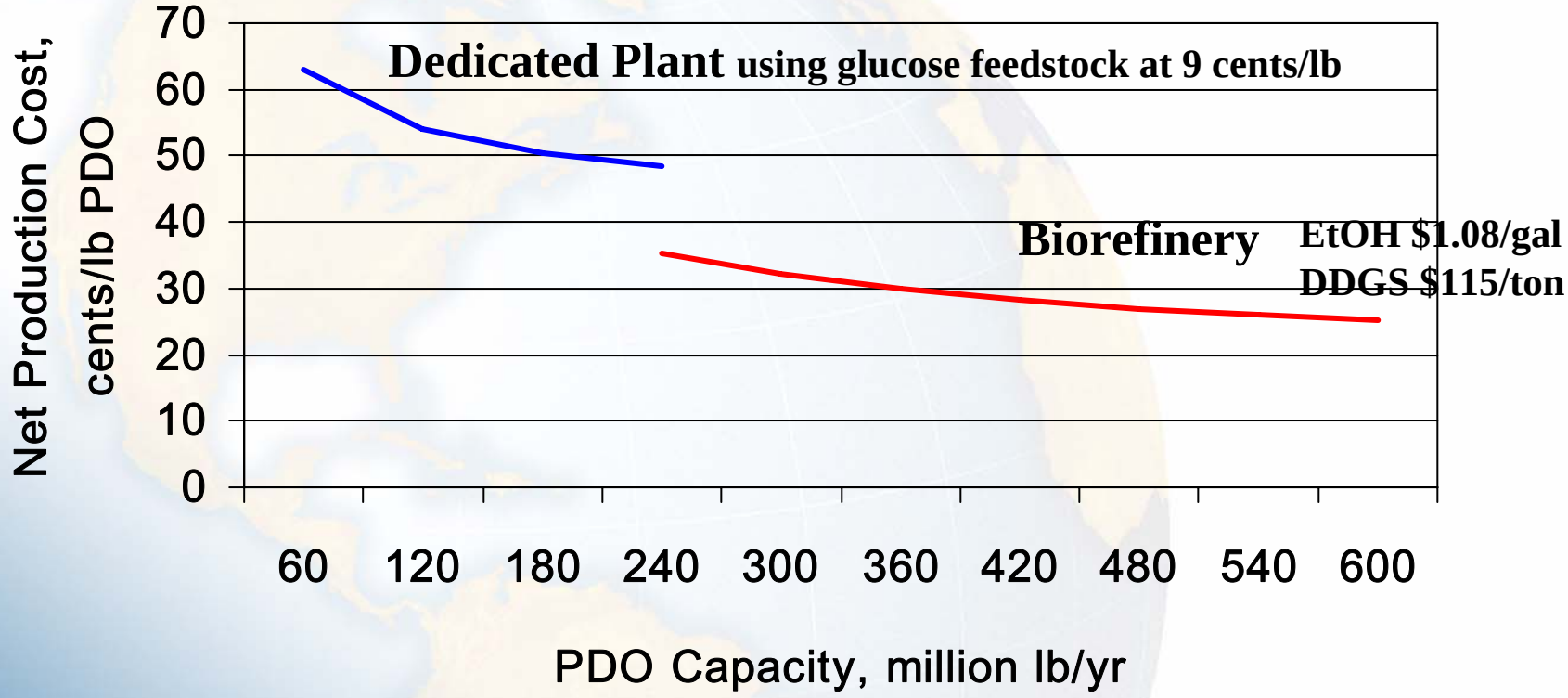

Source: PEP Report 257

Process Economic Issues

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

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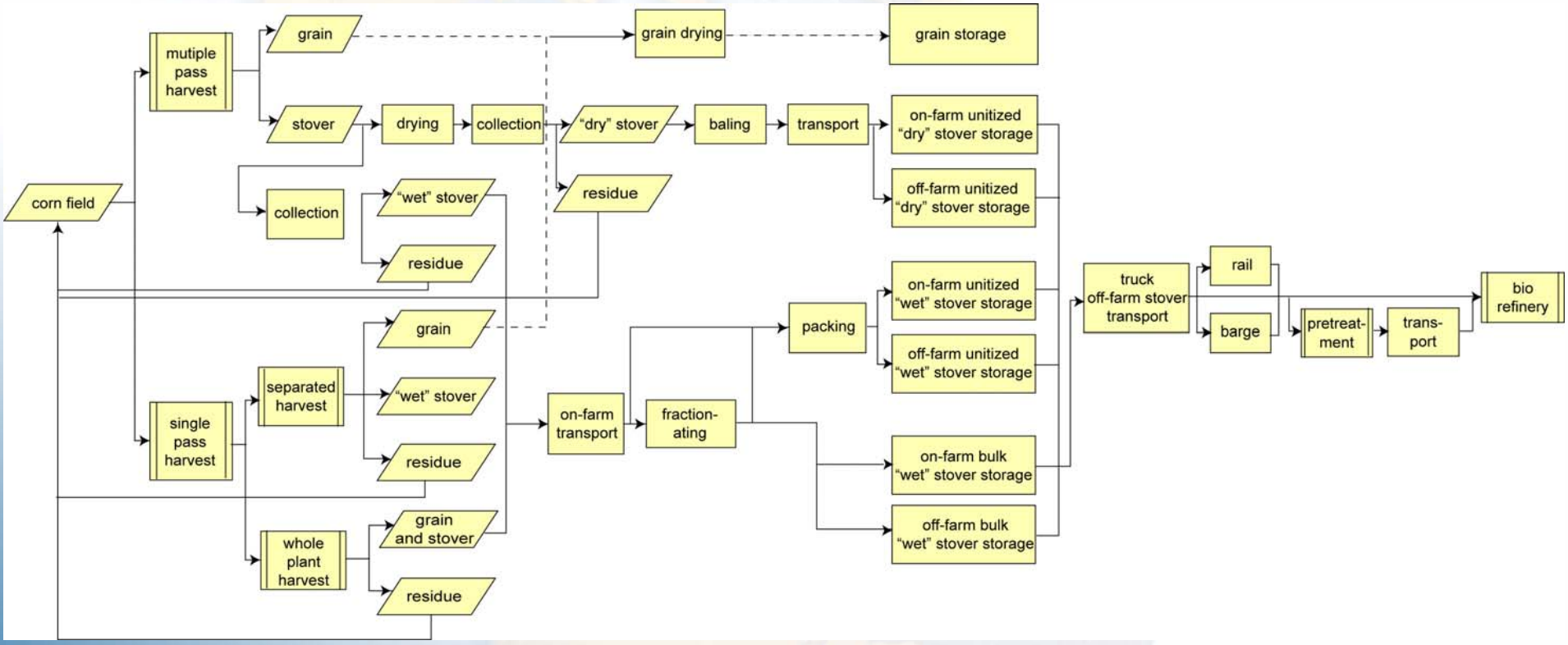
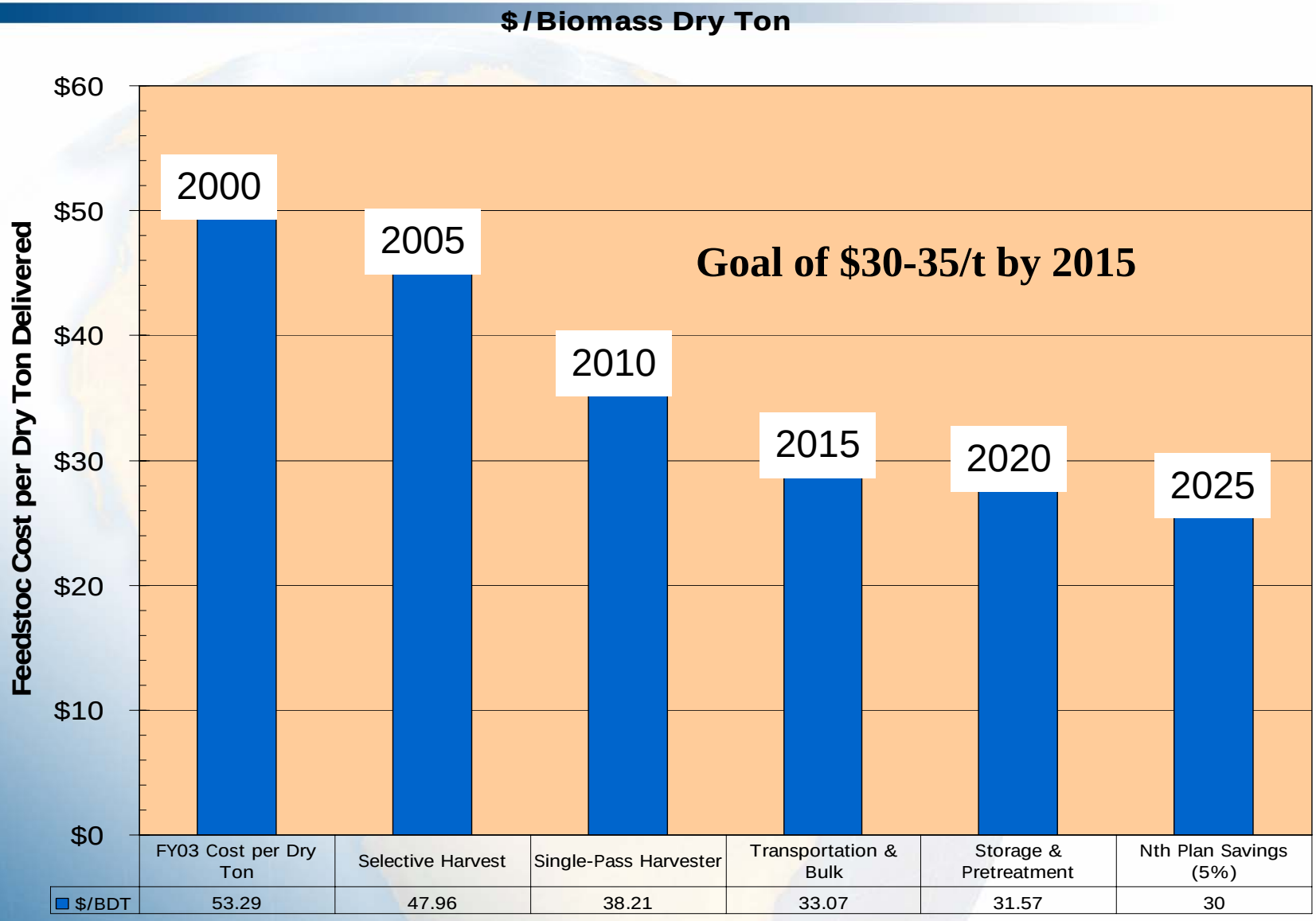
Feedstock from Cornfield to Biorefinery



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



Source: Sokhansanj and Turhollow, ORNL 2005

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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

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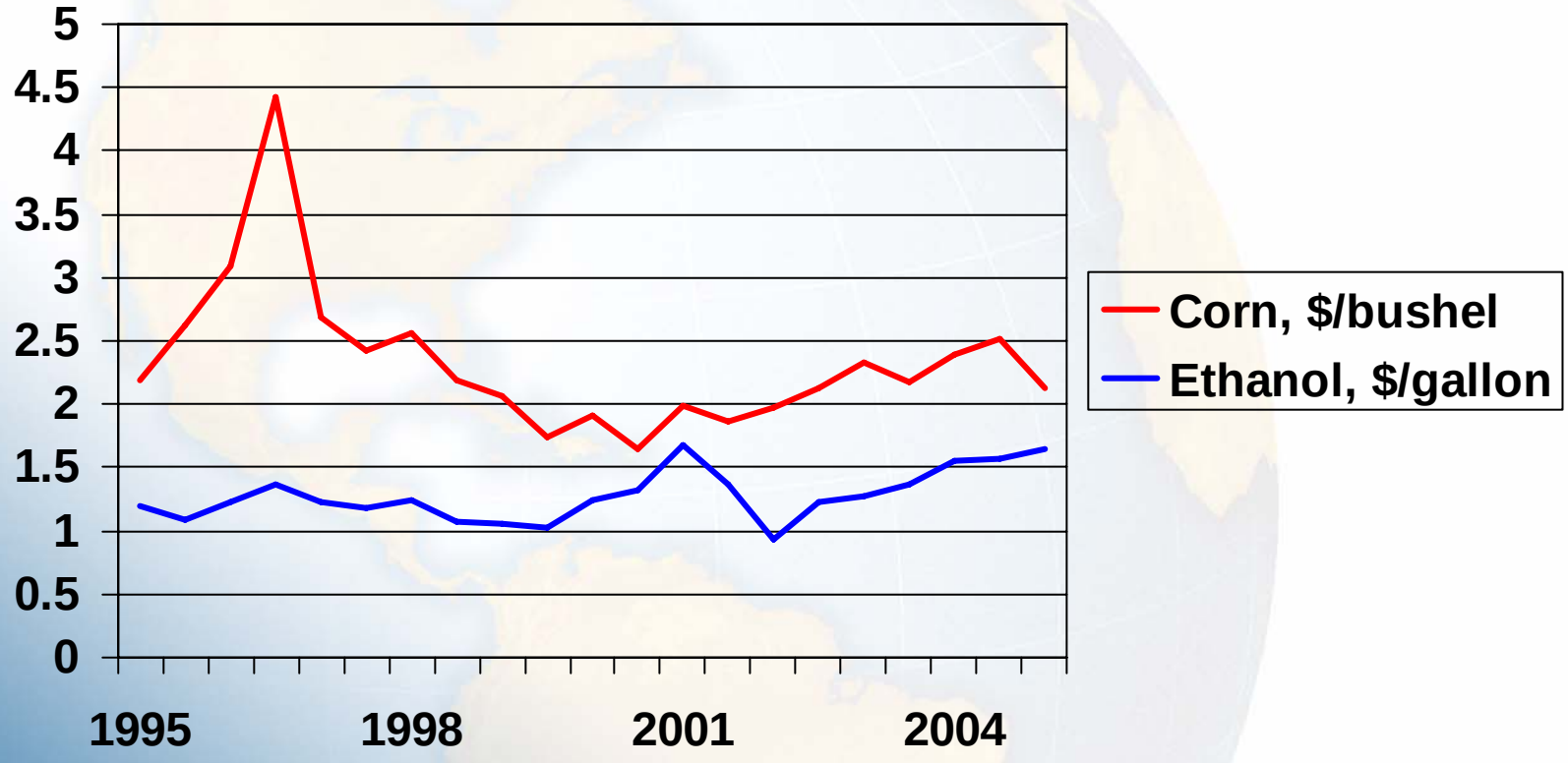
Ethanol Price History



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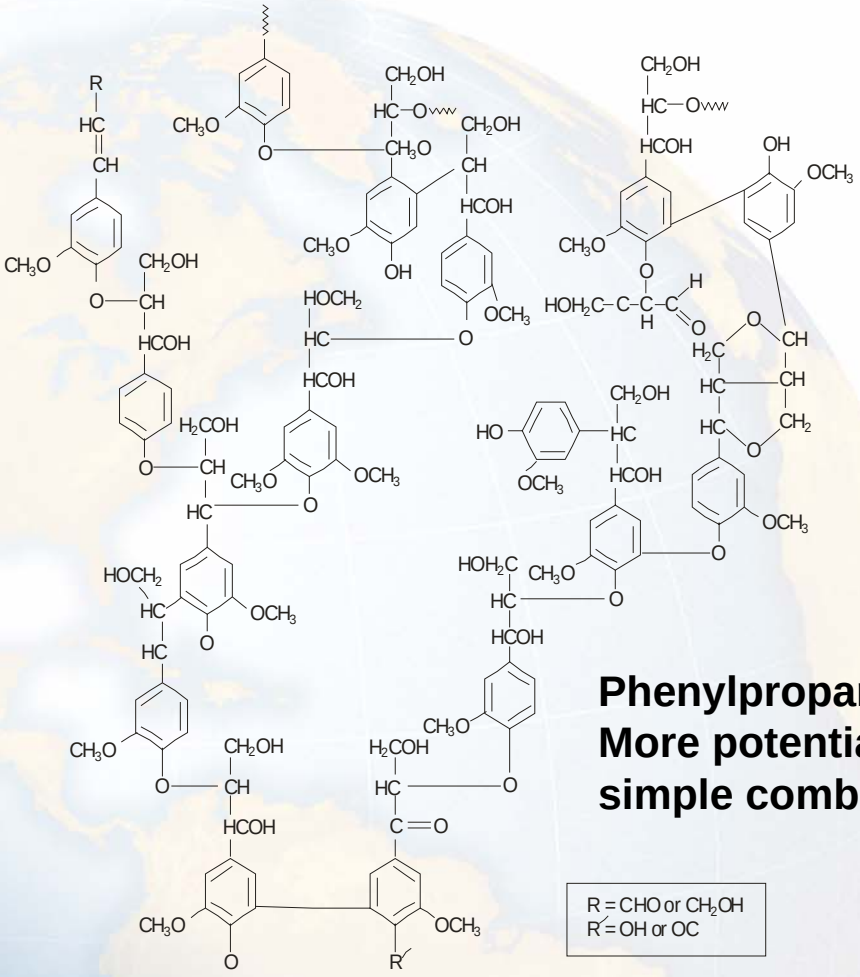
Lignin (Partial Structure)



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

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

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Thank you for your attention

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