Biomass and Biofuels: Technology and Economic Overview

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May 23, 2007

NREL/PR-510-41793
Presented at the 2007 Global Energy Technology Strategy Project (GTSP) Technical Workshop held May 23, 2007 in College Park, Maryland

Outline

- Current Biofuels (Ethanol, Biodiesel)
  - Technology
  - Economics / Markets
- Other potential biofuels
  - Butanol
  - Methanol / DME / FTL
  - Algae-derived Oils
- Dept of Energy (DOE) Goals
- 2^{nd} Generation (Cellulosic Ethanol)
  - Technology / Players
  - Projected Economics

Energy Efficiency & Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal

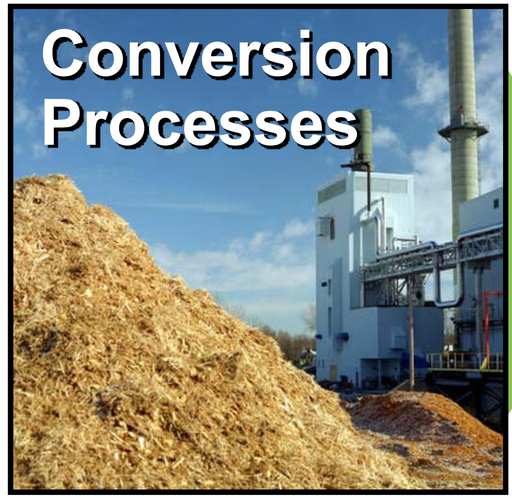
Energy Delivery & Storage

- Electricity Transmission & Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science

Range of Biorefinery Concepts

- Trees
- Grasses
- Agricultural Crops
- Residues
- Animal Wastes
- Municipal Solid Waste
- Algae
- Food Oils



- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/ Fermentation
- Gasification
- Combustion
- Co-firing
- Trans-esterification

Products

Fuels

- Ethanol
- Biodiesel
- “Green” Gasoline & Diesel

Power

- Electricity
- Heat

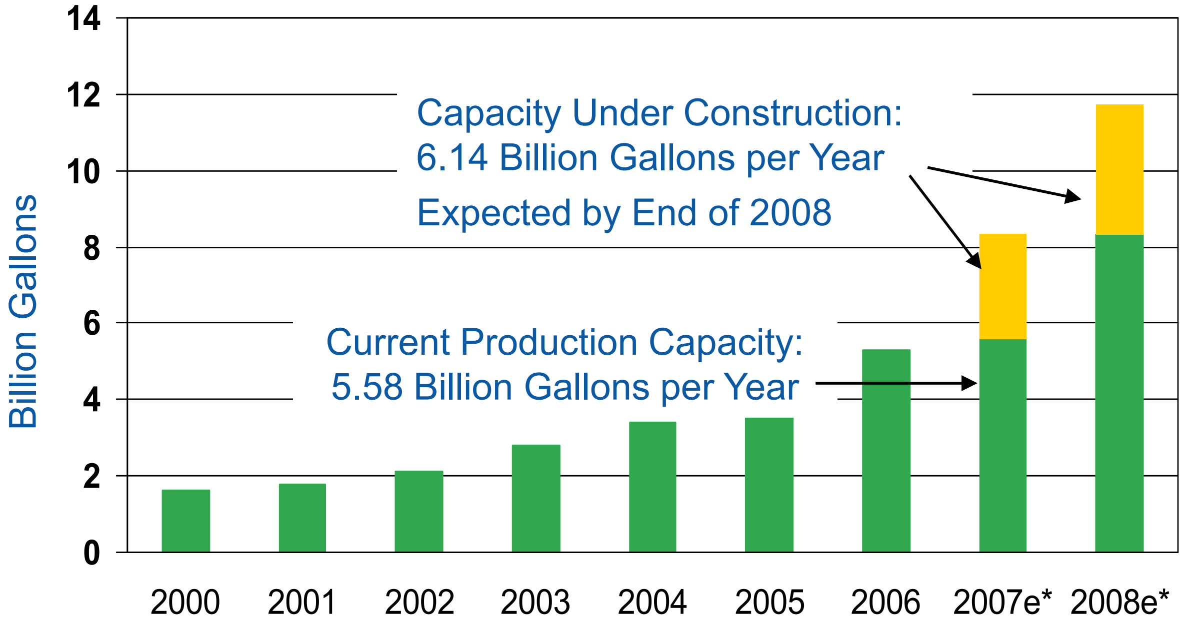
Chemicals

- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty Acids
- Acetic Acid
- Carbon Black
- Paints
- Dyes, Pigments, and Ink
- Detergents
- Etc.

Food and Feed

U.S. Ethanol Production Capacity

While Biofuels Represent Only 3% of Transportation Fuels Today, Production Is Growing Rapidly



Total Capacity with Current and New Construction: 11.7 BGPY

*Estimated as of February 7, 2007.

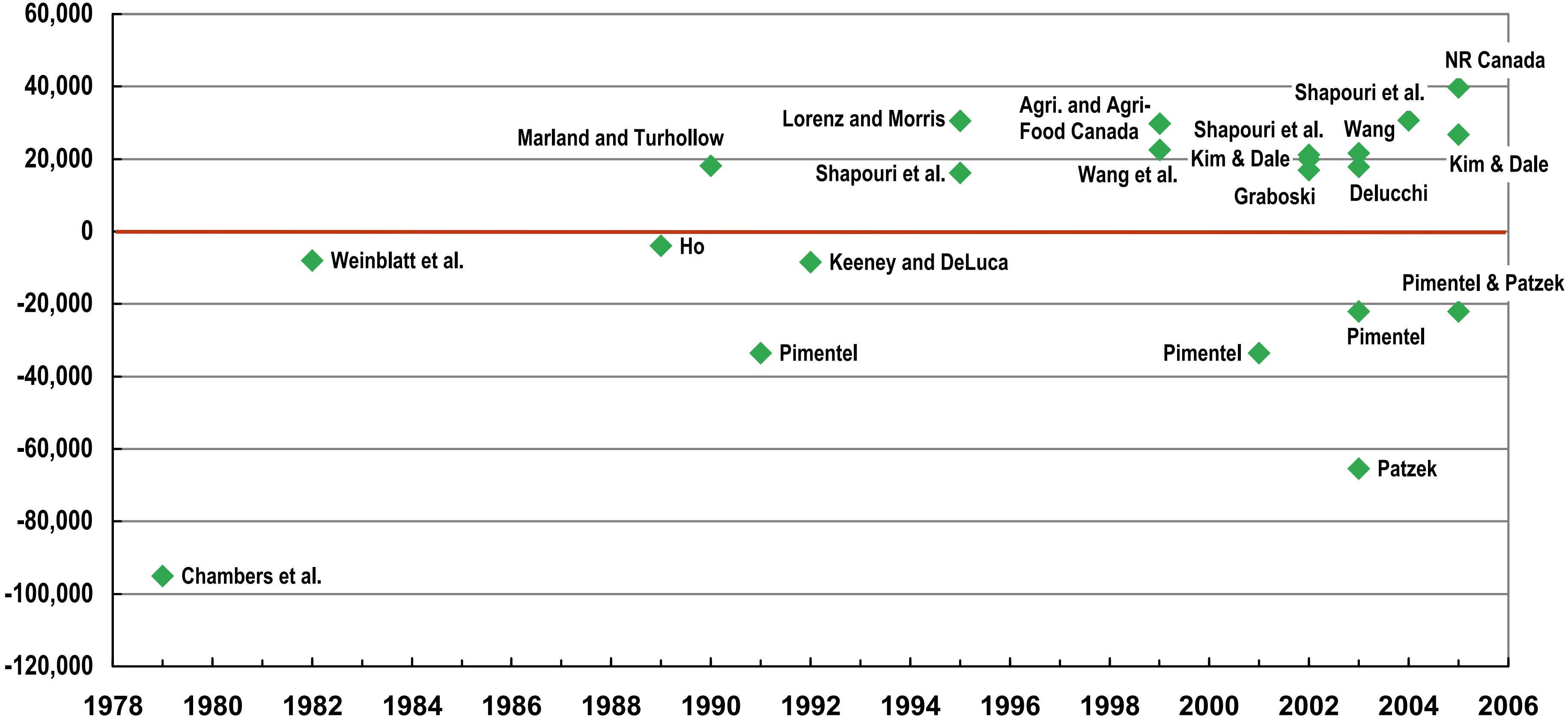
Data Source: Renewable Fuels Association.

Increasing use of biofuels is currently driven by corn ethanol capacity expansion

Corn Ethanol Energy Balance

Results among completed studies show an upturn.

Net Energy Value (NEV) = Energy in Ethanol – Fossil Energy Required



Energy balance here is defined as Btu content a gallon of ethanol minus fossil energy used to produce a gallon of ethanol.
Source: Argonne National Laboratory's review of past completed studies

Ethanol Technology & Economics

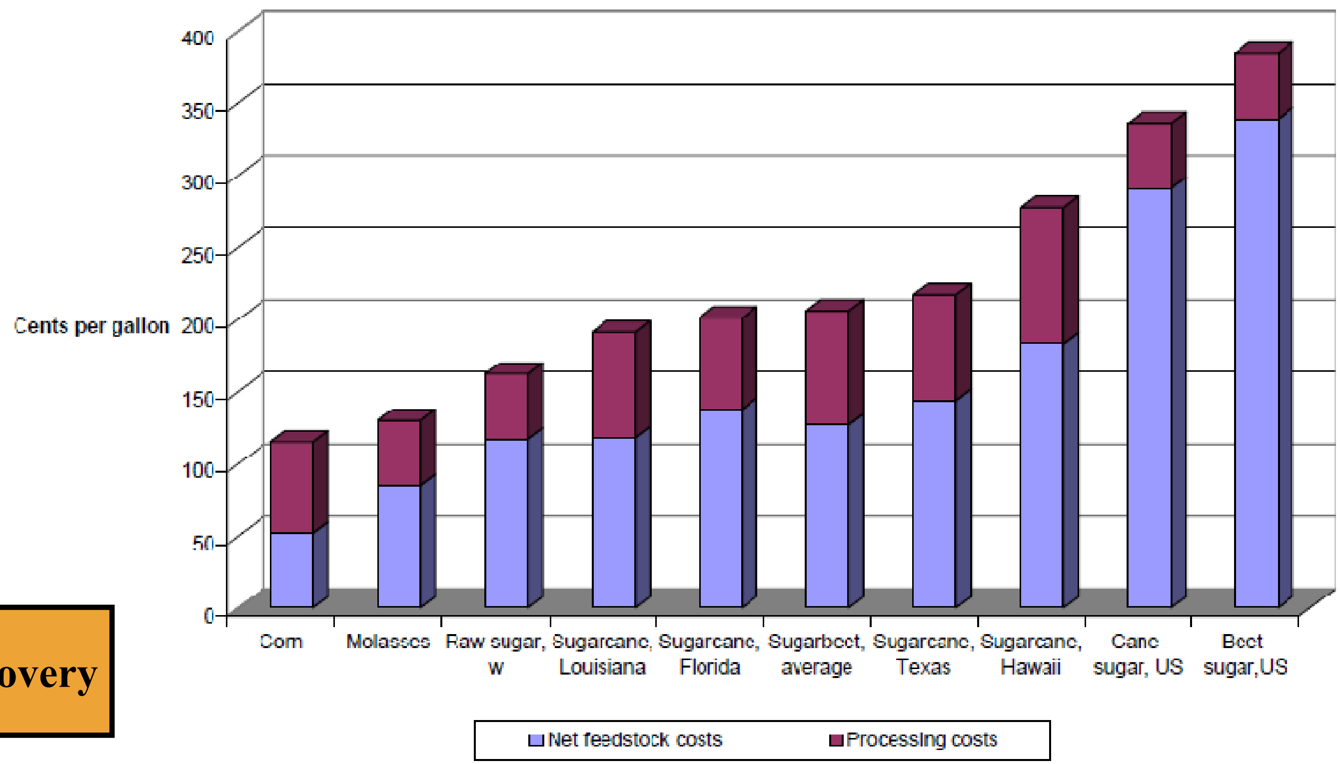
Cleaning & Milling — Preparation — Fermentation — Ethanol Purification

Milling — Cooking — Liquefaction — Saccharification — Fermentation — Ethanol Purification

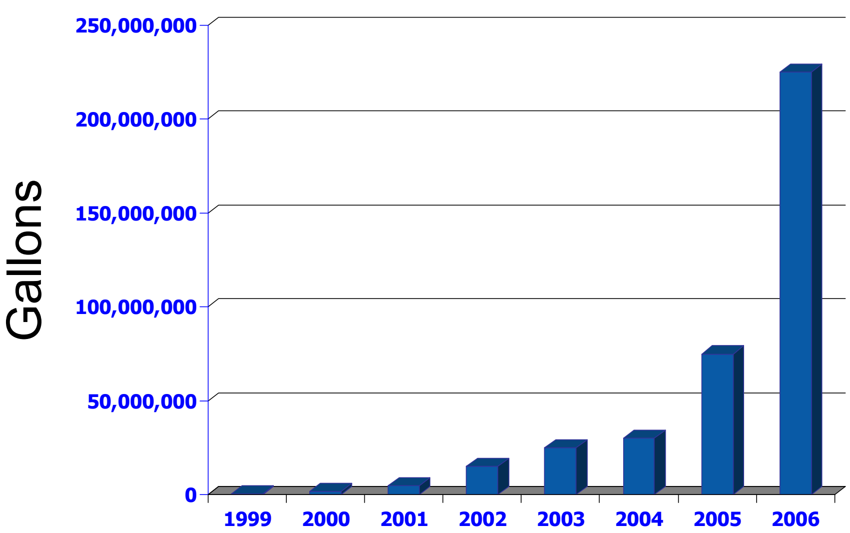
DDG Recovery

Courtesy: Shapouri, USDA

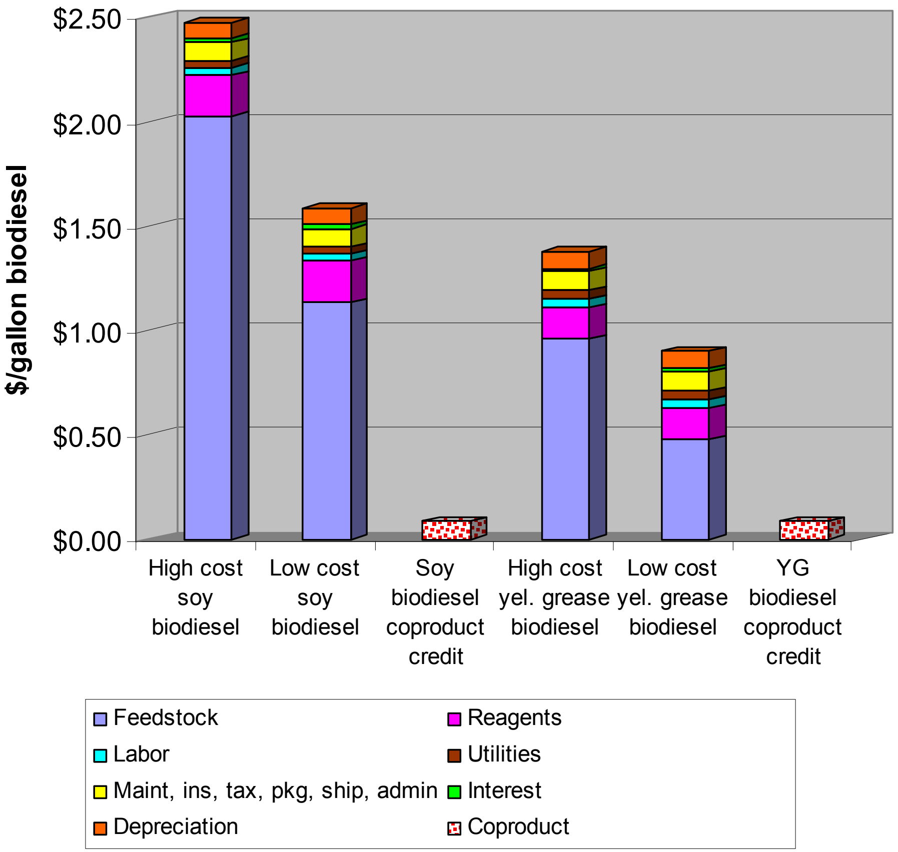
Ethanol Production costs, starch and sugar (5 year-average)

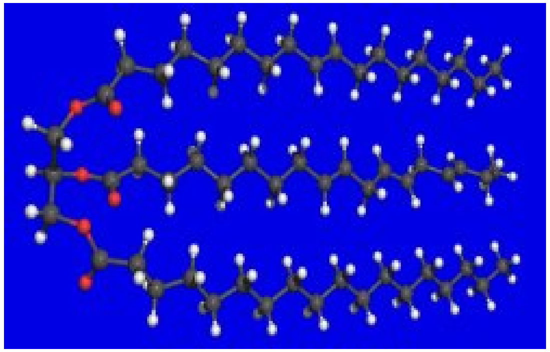


US Biodiesel Production & Economics



Data Source: National Biodiesel Board, April 2007





100 lb triglyceride + 10 lb alcohol methanol = 10 lb glycerine (byproduct) + 100 lb Mono-alkyl ester Biodiesel

Biofuel Technology Options

Near Term

Ethanol – as a blending agent from either grain or cellulosic material from Ag and/or Forestry industry

Biodiesel – Transesterified vegetable oils blended with diesel

Green Diesel/Gasoline – fats, waste oils, or virgin oils blended with crude oil as a feedstock for making low-sulfur diesel/gasoline in petroleum refinery

Pyrolysis Liquids – as alternative feedstock to petroleum refinery or gasification facility, also a future source of aromatics and/or phenols

Synthesis Gas – for conversion to Fischer Tropsch liquids, MeOH/DME, or mixed alcohols

Algae – as alternative source of triglycerides for biodiesel or green diesel

Alkanes – from hydrogenation of carbohydrates, lignin, or triglycerides

Long Term

Biobutanol

- During the first half of the 20th century, butanol was produced by fermentation via ABE process (acetone, butanol, ethanol)
  - Then petroleum ramped up and became the preferred option
  - Butanol used largely as a solvent and/or plasticizer
- Technical issues are all related to cost:
  - Toxicity. Butanol becomes toxic to fermentation beyond 20 g/L
  - Yields. Butanol traditionally yields 1.3 gallons from 1 bushel of corn
  - Purification. Butanol at 2% concentration makes distillation cost prohibitive
- Today, there are new tools available that can be applied towards this process
  - Biotechnology
  - Engineer unit operations
- Benefits of butanol as a fuel
  - Higher energy content than ethanol
  - Lower reid vapor pressure
  - Better water miscibility and corrosion properties than ethanol
- Active researchers
  - DuPont
  - EEI (David Ramey)
  - USDA / University of Illinois (H. Blaschek)

Biomass Strengths

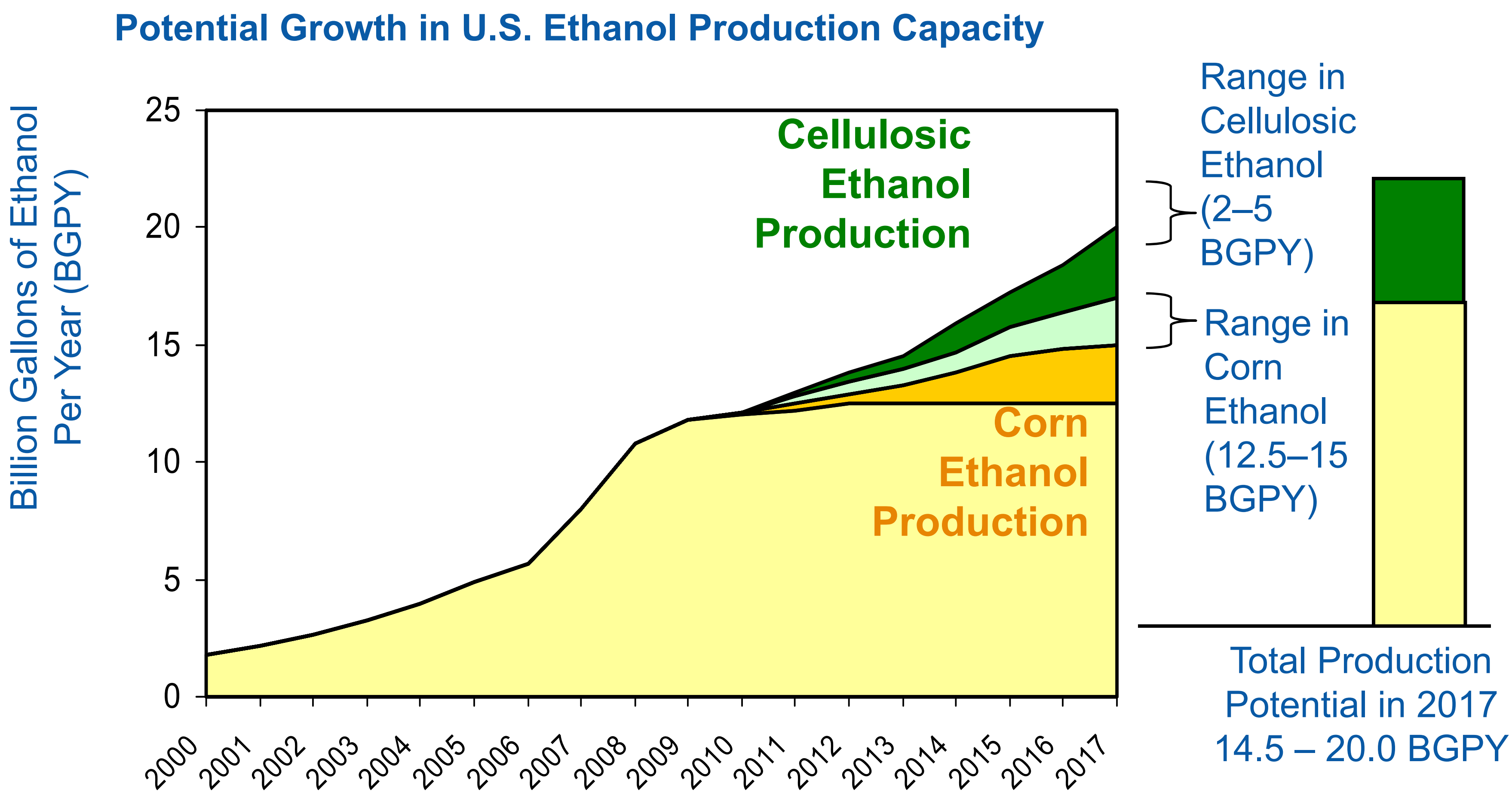
Biomass is:

- Abundant
- Renewable
- Carbon-neutral
- The only sustainable source of hydrocarbons.

Biomass can:

- Fill the gap between energy demand and petroleum availability in the near term.
- Be a renewable source of hydrogen in the long term.

Cellulosic Will Begin Contributing After 2010



Advances in technology will enable commercial production of cellulosic ethanol by 2012.

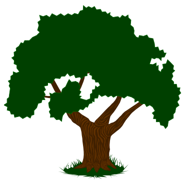
Department of Energy Goals

- Cellulosic ethanol cost competitive by 2012
  - 2006 President's State of the Union Address
  - Established President's Energy Initiative
  - $1.07/gal cost target established

- Reducing U.S. Gasoline Usage 20% by 2017
  - 2007 President's State of the Union Address
  - Nicknamed "20 in 10"

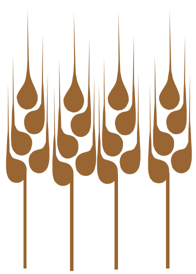
- Replace 30% of 2004 gasoline usage by 2030
  - Equates to roughly 60 billion gallons ethanol (starch plus cellulosic)
  - Nicknamed 30x30

What is Lignocellulosic Biomass?

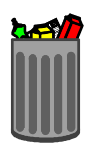


Hardwoods

Grasses



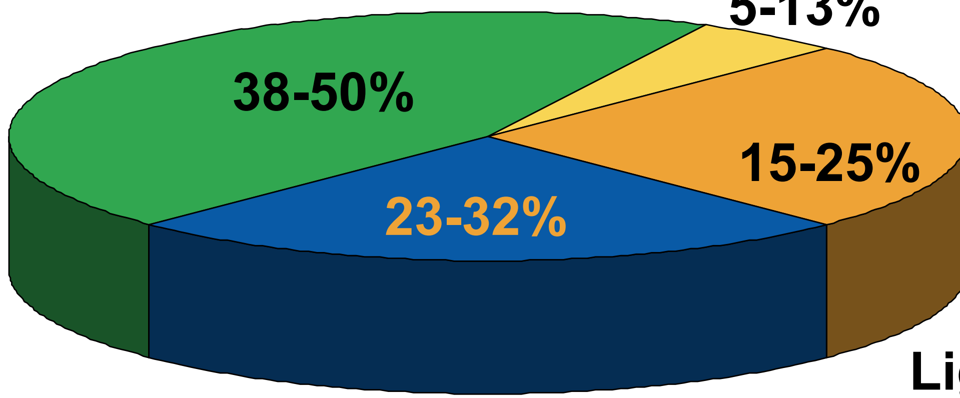
Crop residues



MSW

Cellulose
(Glucose sugar)

Other
(Extractives, ash, etc.)



Lignin
("Young clean coal")

Hemicellulose
(Pentose sugars)

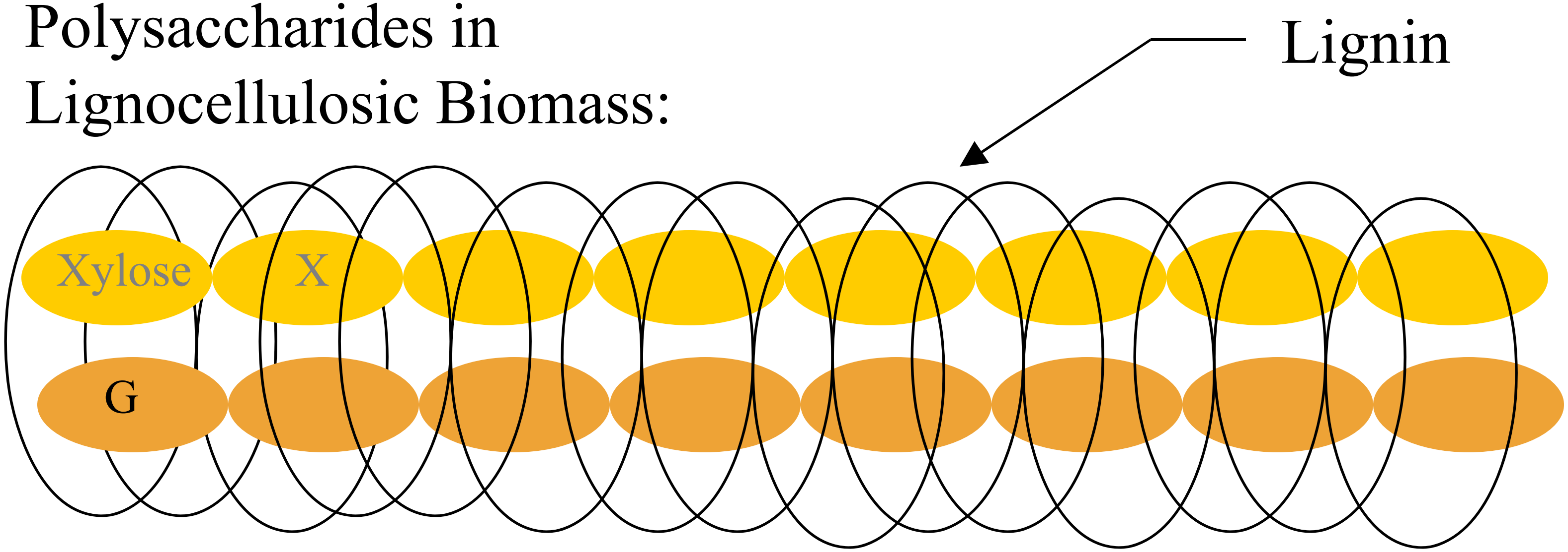
Softwoods

The Structure Is More Complex

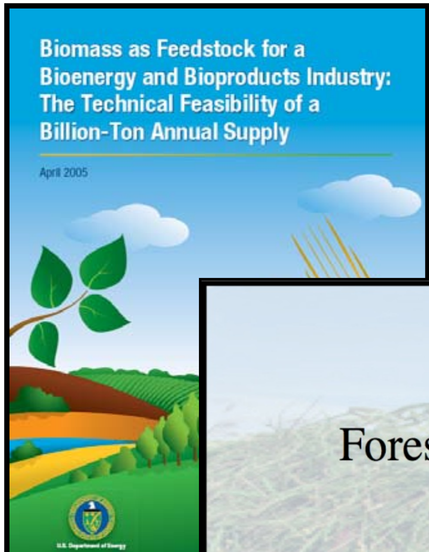
Sugars: Glucose

Starches: GlucoseGlucose

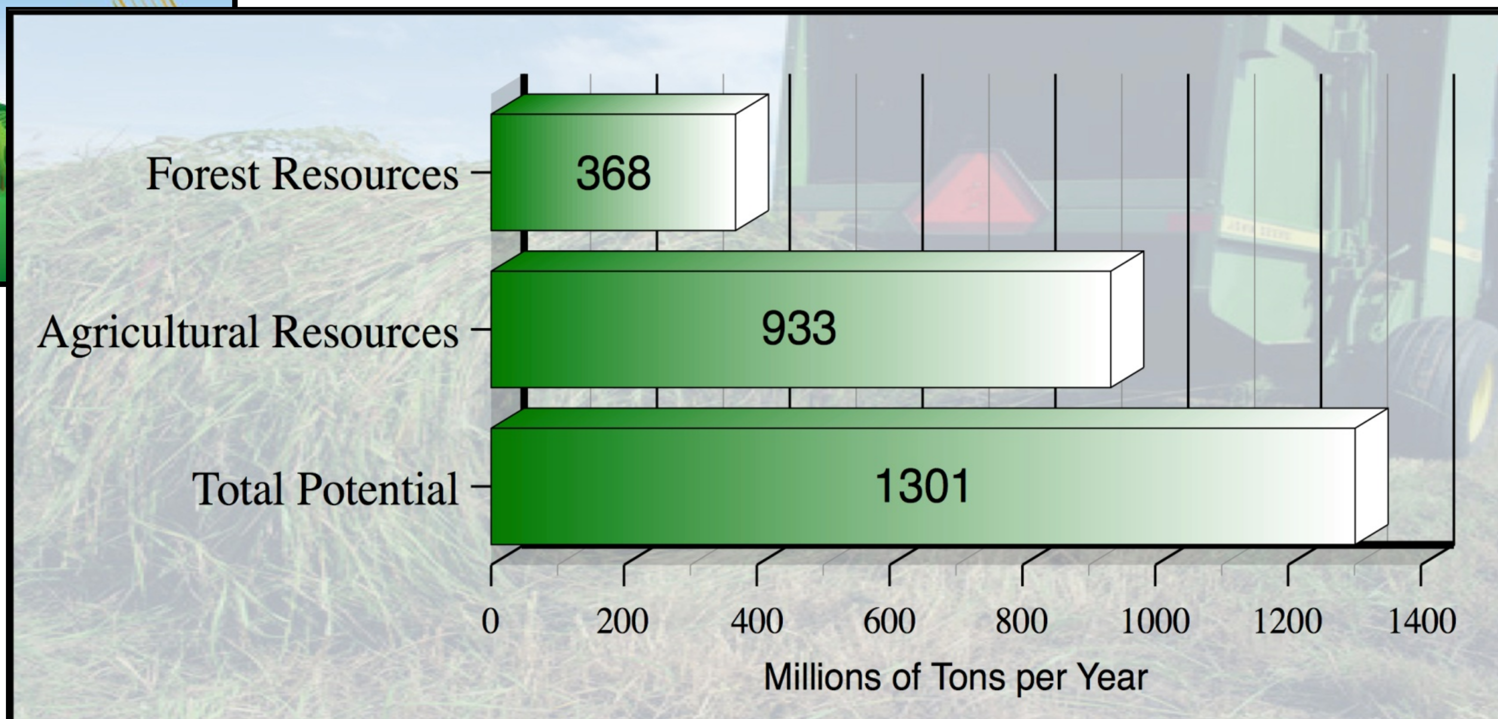
Polysaccharides in Lignocellulosic Biomass:



U.S. Biomass Resource Assessment



- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the "Billion Ton Study"



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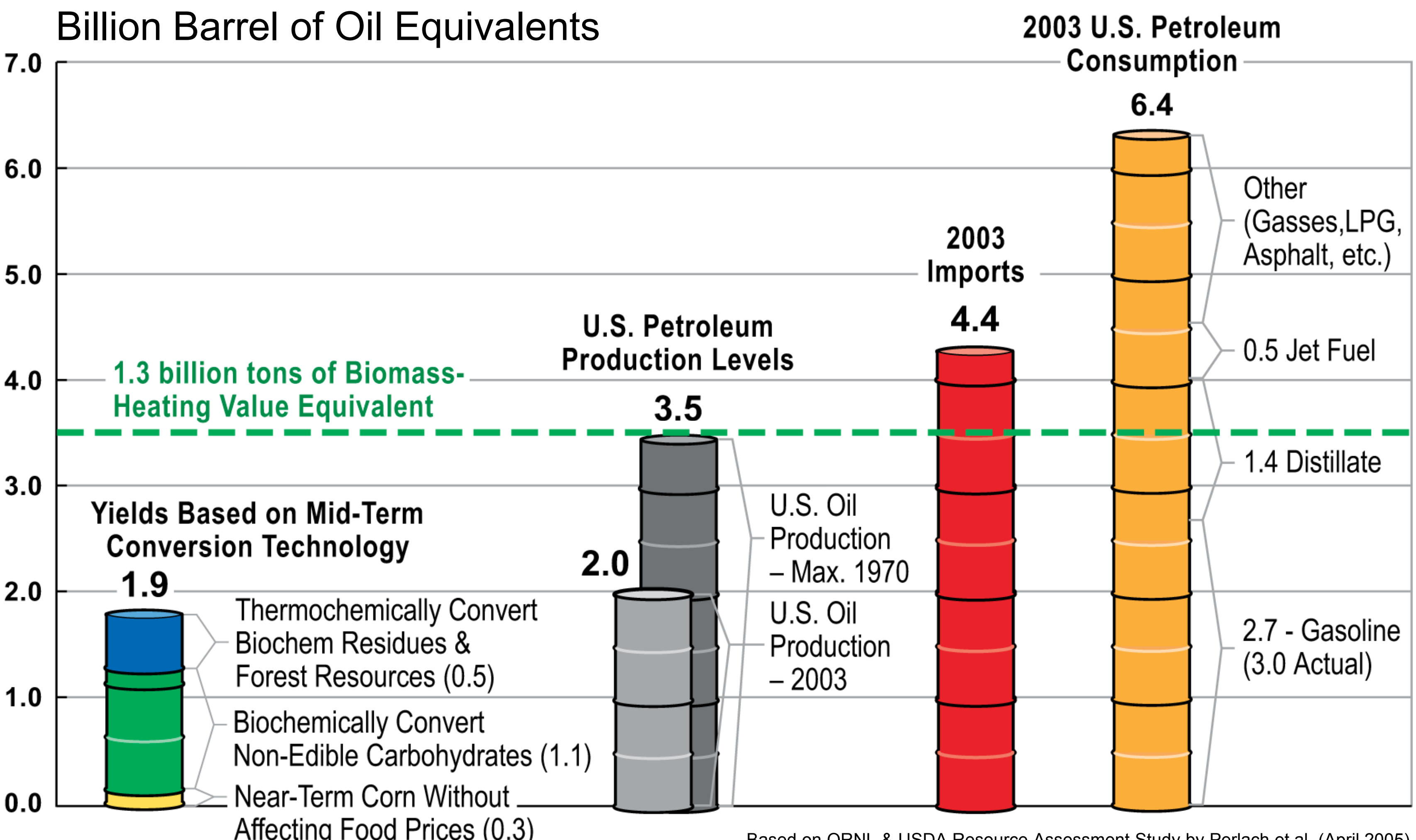
The 1.3 Billion Ton Biomass Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Primary Conversion Routes

Transformation through Intermediates (sugars)

"Biochemical conversion"

Reduction to building blocks (CO, H_2)

"Thermochemical conversion"

General Process Options for Fuels

Biochemical Conversion

- Concentrated acid hydrolysis/Fermentation
- *Pretreatment/Enzymatic Hydrolysis/Fermentation
  - Using any of a variety of different primary fractionation or “pretreatment” methods

Thermochemical Conversion

- Combustion
- *Gasification/Conversion of syngas
- *Pyrolysis/Conversion of pyrolysis oil

*Model processes currently under study by the Biomass Program

2002 NREL "Design Report"

Technical Report

June 2002 • NREL/TP-510-32438

Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover

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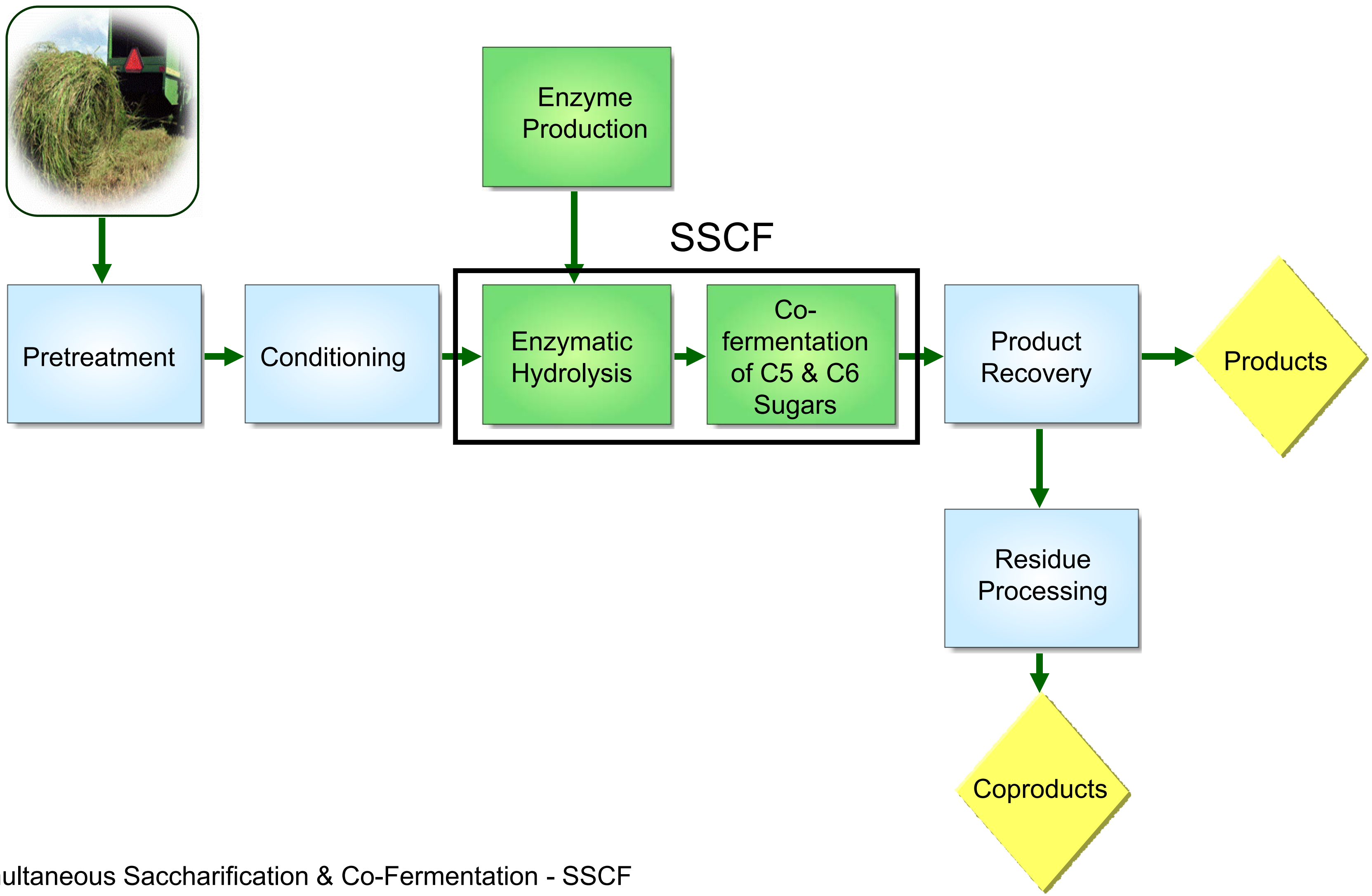
http://www.nrel.gov/docs/fy02osti/32438.pdf

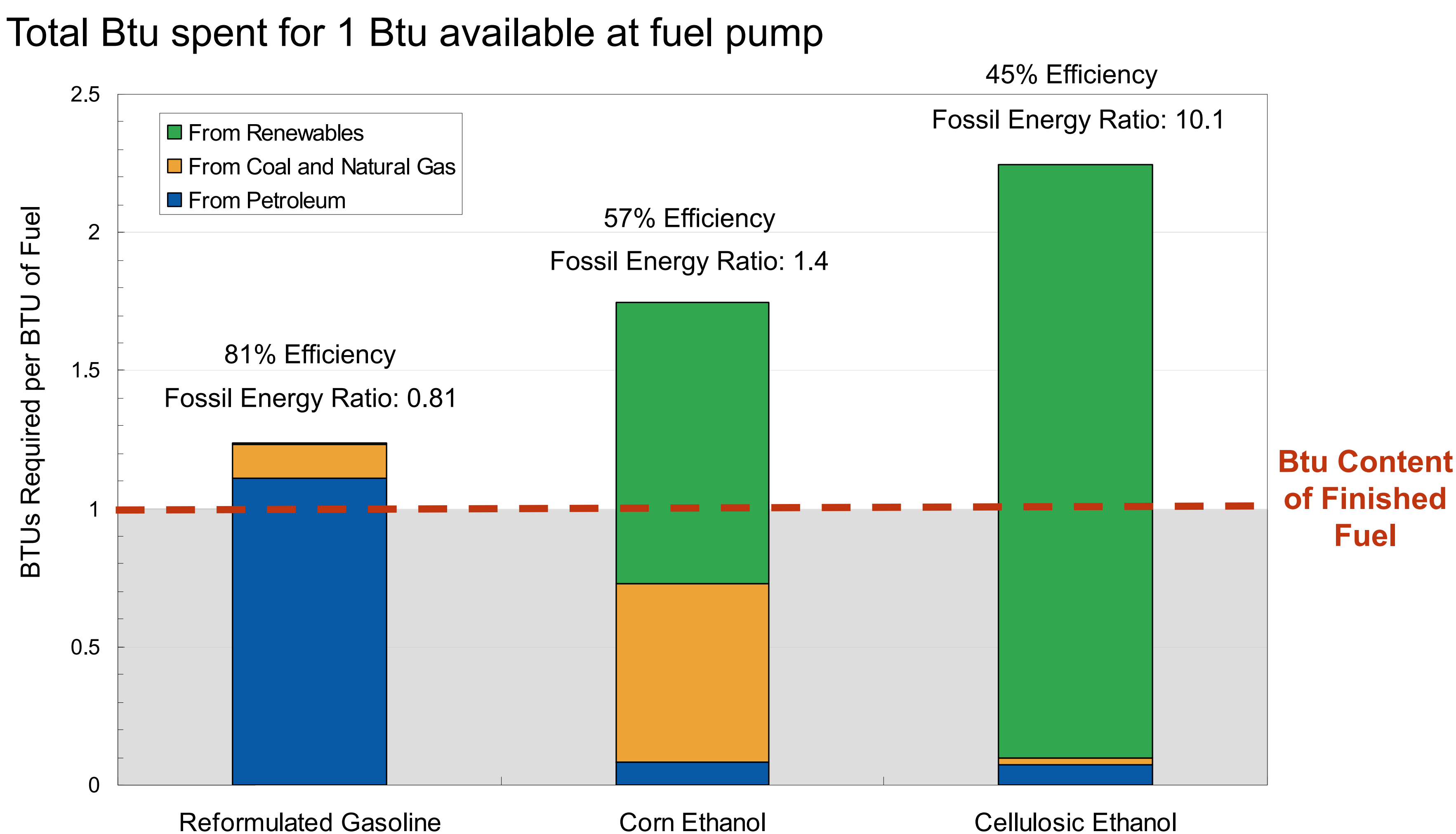
- Reports a single process design
  - No year attached
  - $1.07/gal chosen by DOE
  - Includes 2000/1 data
  - Different scenario types from this
- 3 types of scenarios
  - Target
  - Budget
  - State of Technology
  - Details at Analysis web site: http://devafdc.nrel.gov/biogeneral/OBP-Analysis-HmPg/
- One process design of many
  - Multiple combinations
  - Other types of operations
  - Provides a baseline design

Biochemical Conversion



Simultaneous Saccharification & Co-Fermentation - SSCF

Energy Required to Produce Fuels



Based on “Well to Wheels Analysis of Advanced Fuel/Vehicle Systems” by Wang, et.al (2005).

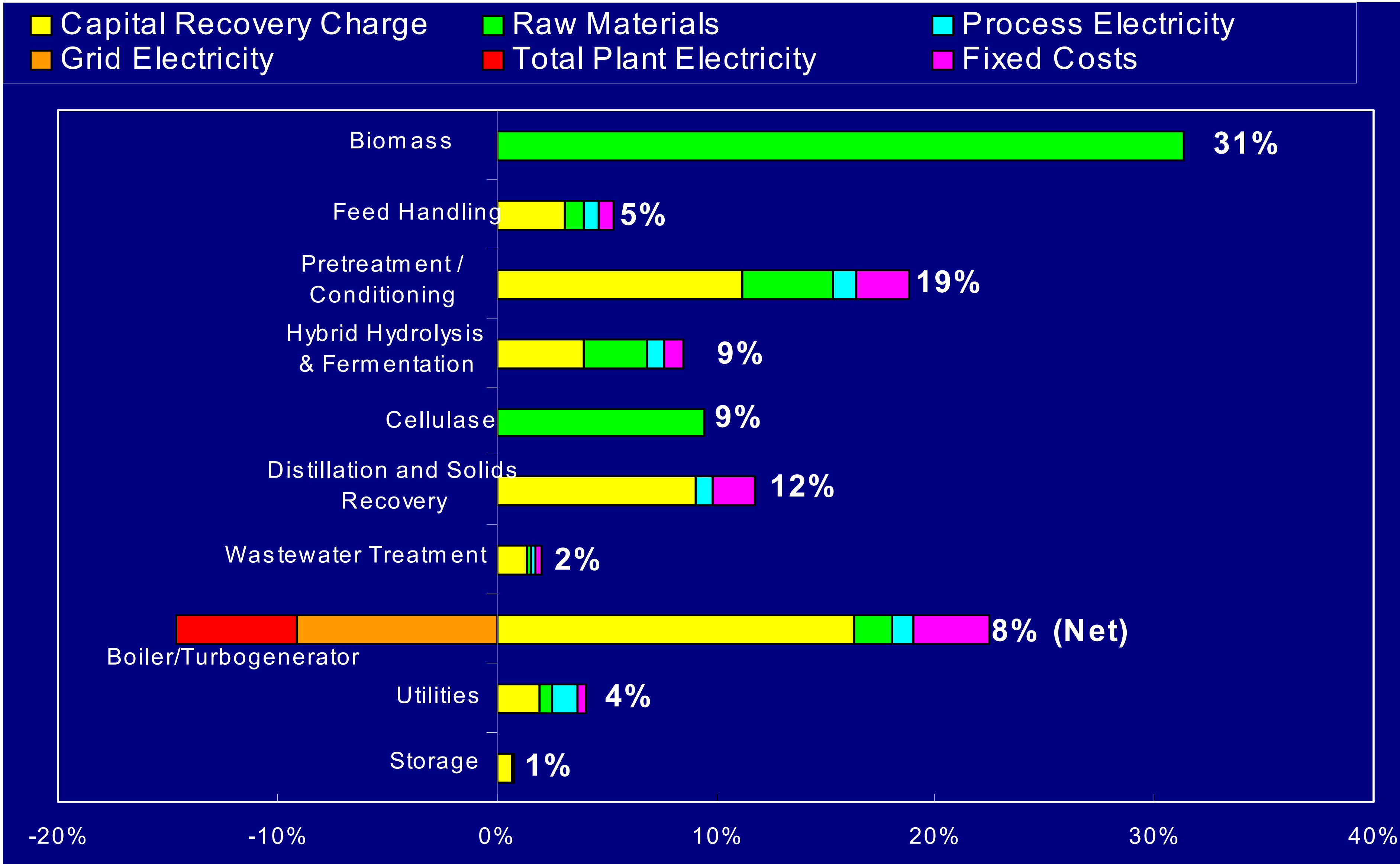
Estimated Process Economics

Plant Size: 2000 MT Dry Corn Stover/Day (Greenfield Site)
Corn Stover Cost: $30/dry ton

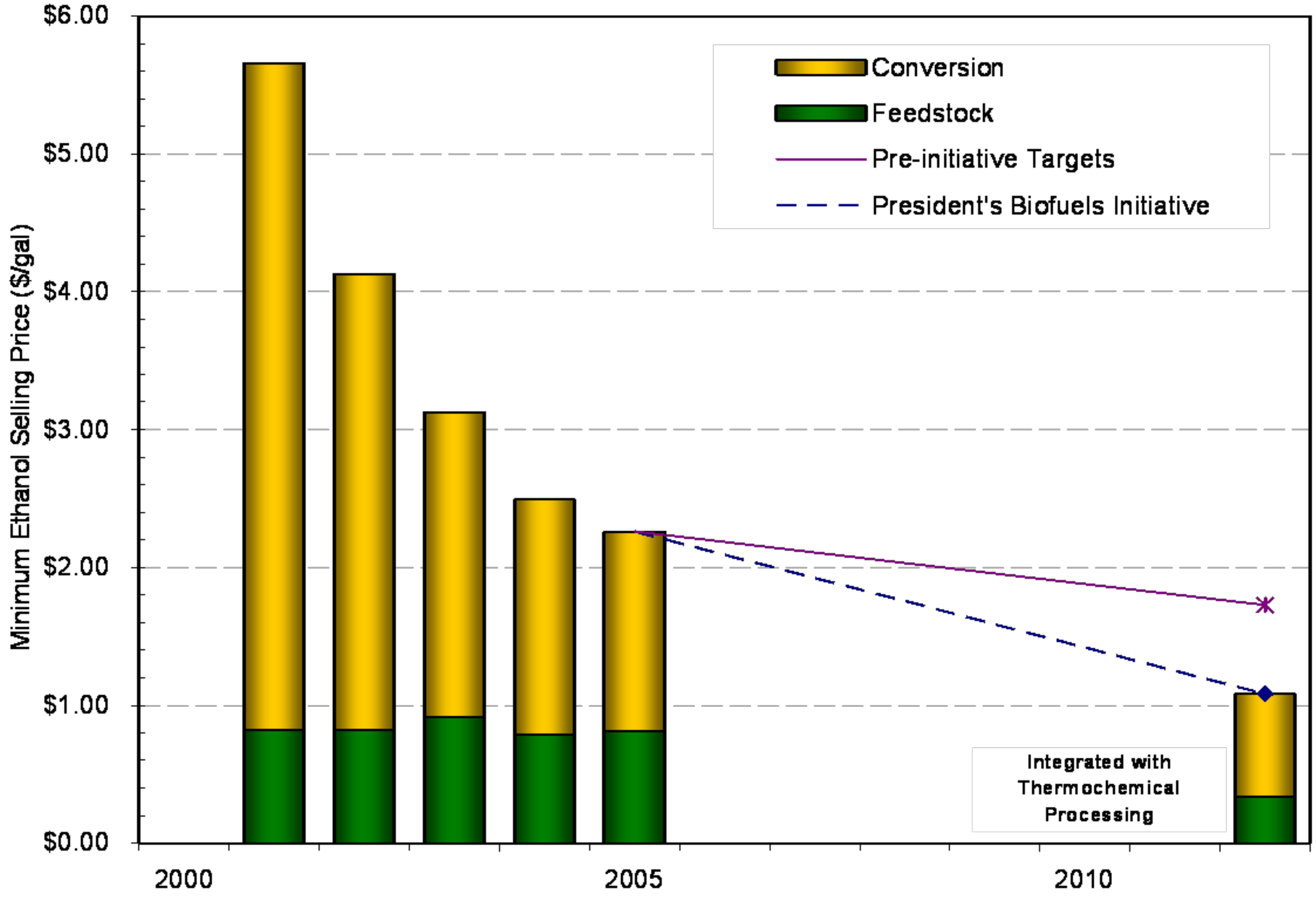
Economic Parameter (Units, $2000)	Value
Min. Ethanol Selling Price ($/gal)	$1.07
Ethanol Production (MM gal/yr)	69.3
Ethanol Yield (gal/dry ton stover)	89.7
Total Project Investment ($ MM)	$197
Total Installed Capital ($MM)	$114
TPI per Annual Gallon ($/gal)	$2.85
TIC per Annual Gallon ($/gal)	$1.64
Net Operating Costs ($/gal)	$0.58

* Assuming 100% equity financing and 10% Internal Rate of Return (IRR)

Relative Cost Contribution by Area



Biochemical conversion and feedstock costs are the major components



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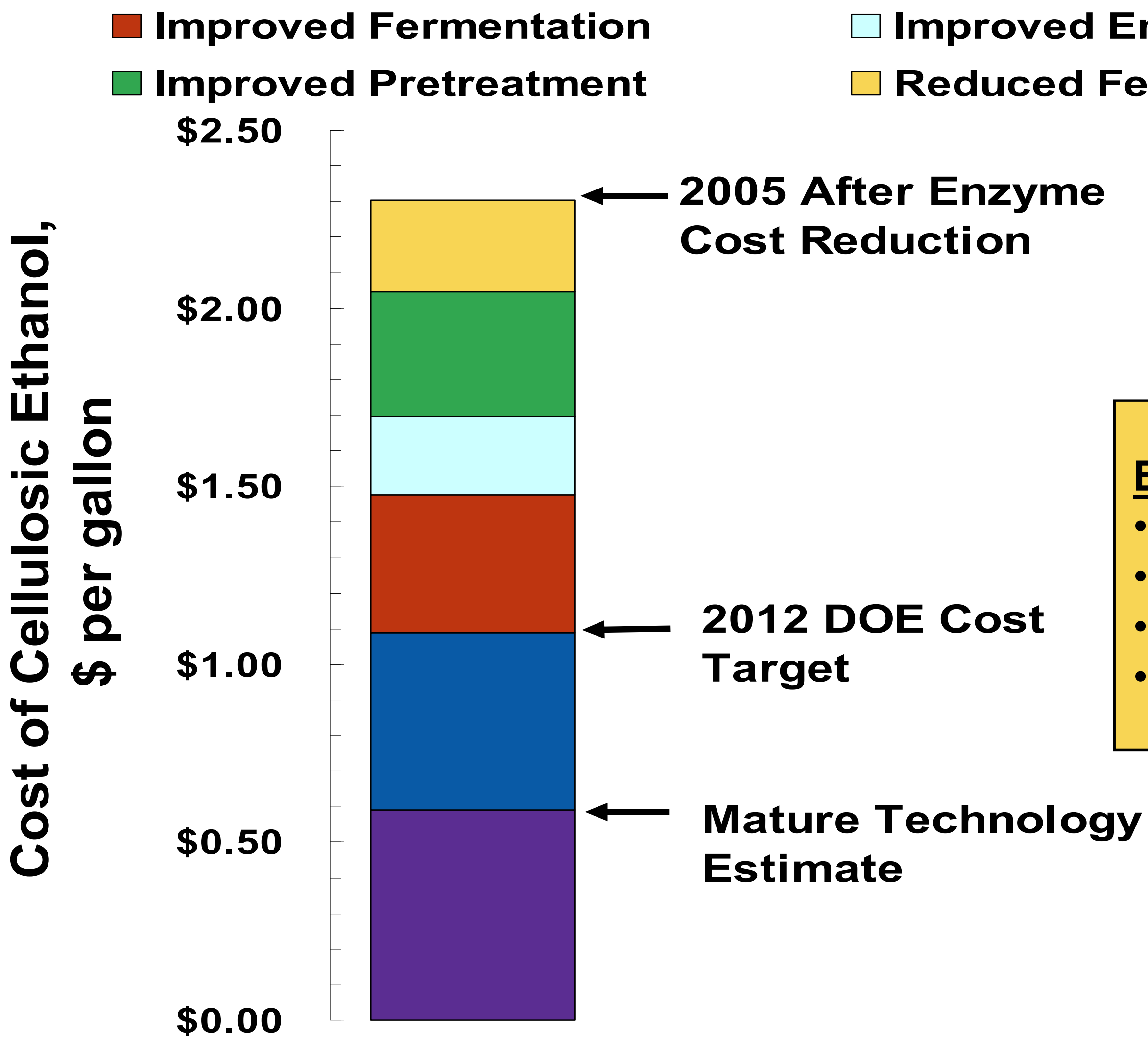
Remaining Technology and Cost Barriers



Barriers to Lower Cost

- Feedstock Cost
- Biomass Pretreatment
- Enzymatic Hydrolysis
- Fermentation

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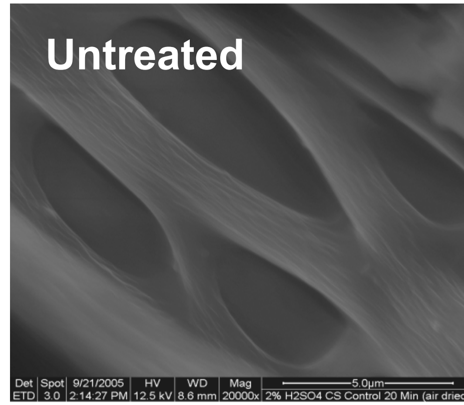
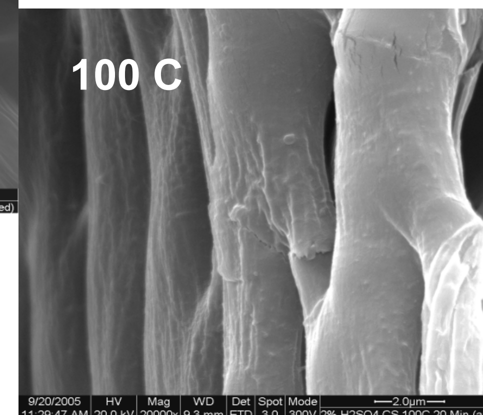
Biomass Surface Characterization

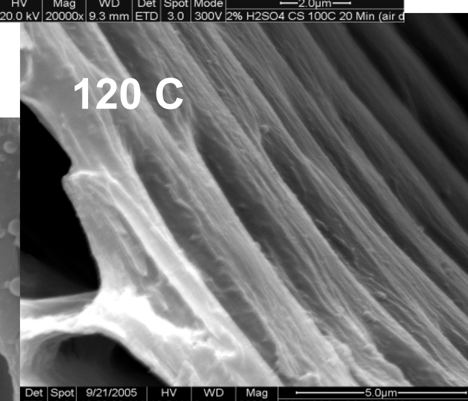
Plant Cell Wall Deconstruction/Exploratory Pretreatment joint effort

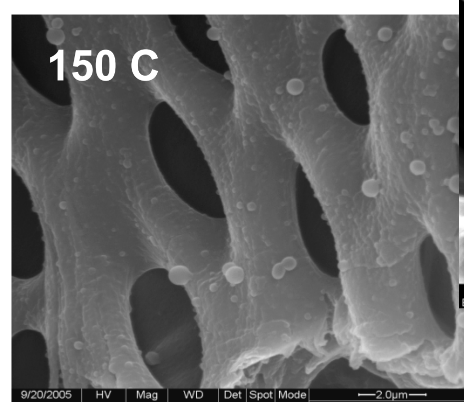
- Created native, pretreated and hydrolyzed samples
- Developed imaging methods
- Identified probes for mapping
- Probes from
  - Weizmann Institute (CBMs)
  - University of Georgia (MoAbs)



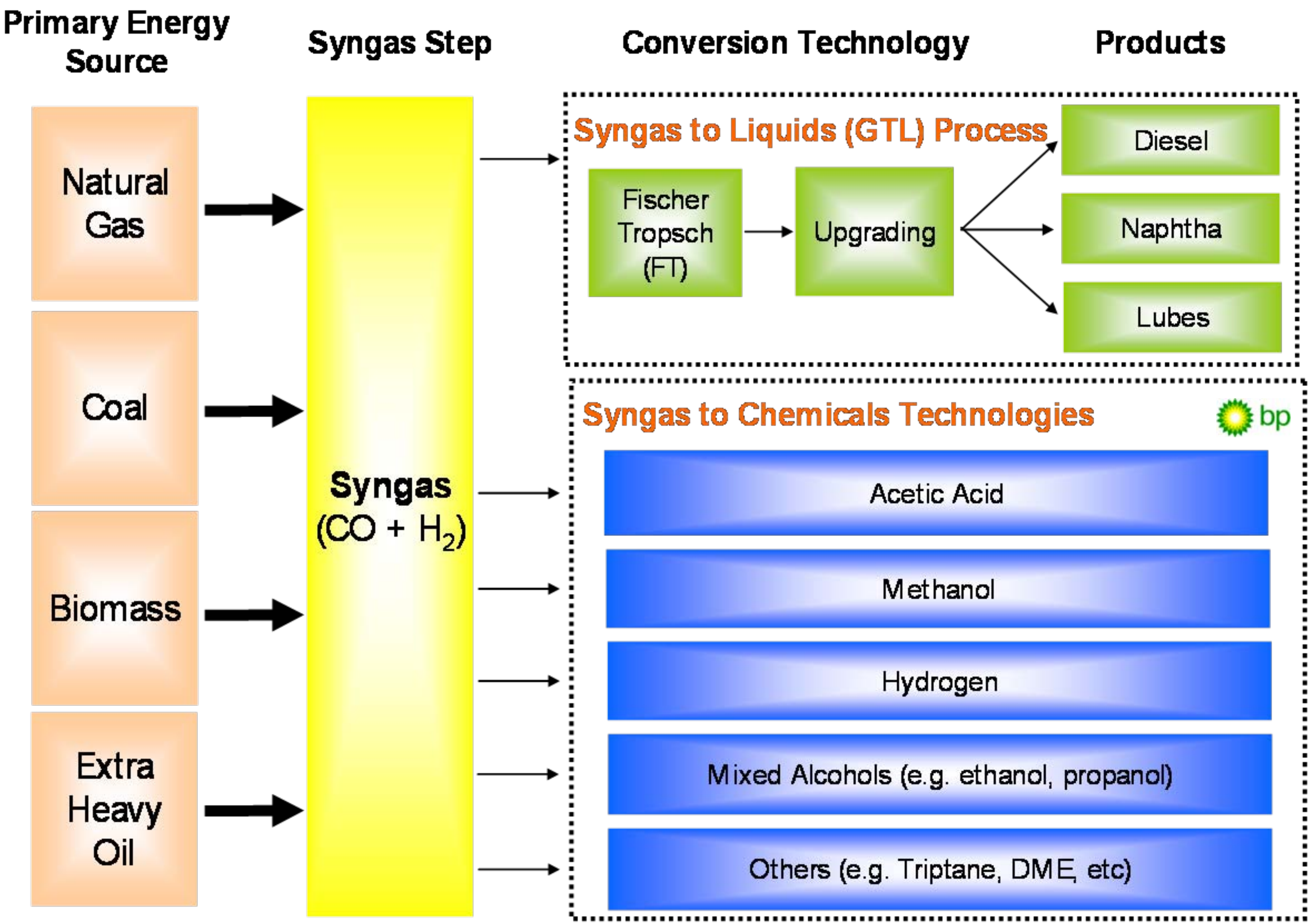


20000x (SEM) images of secondary cell wall on native and pretreated samples





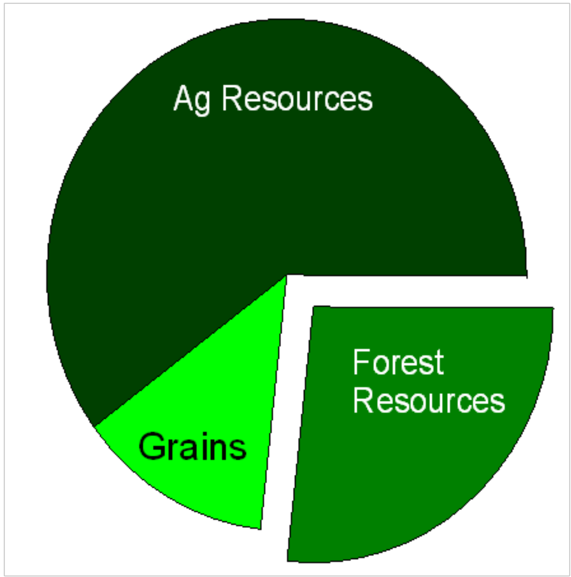
Hydrocarbon fungibility will be a key technology



Opportunities for Thermochemical Conversion Technologies

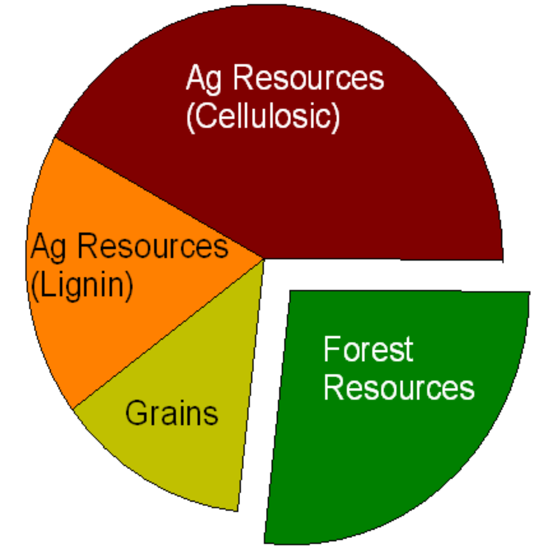
Mitigates risk of achieving $1.07 by 2012 by providing a second technology option:

- Utilize entire biomass resource base to achieve 30x30
  - Forest Residues not optimum for BC (~27%)
- Option for processing off-spec or non-fermentable biomass resources or “de-localized” resources
  - Lignin-rich residues from BC account for 20-30% of fermentable biomass (~18% - ~20 billion gal/yr of EtOH)
- Regionally specific biomass conversion options
- Maximize Fuel Production in Future Integrated BC/TC biorefineries by converting lignin-rich residues to fuel

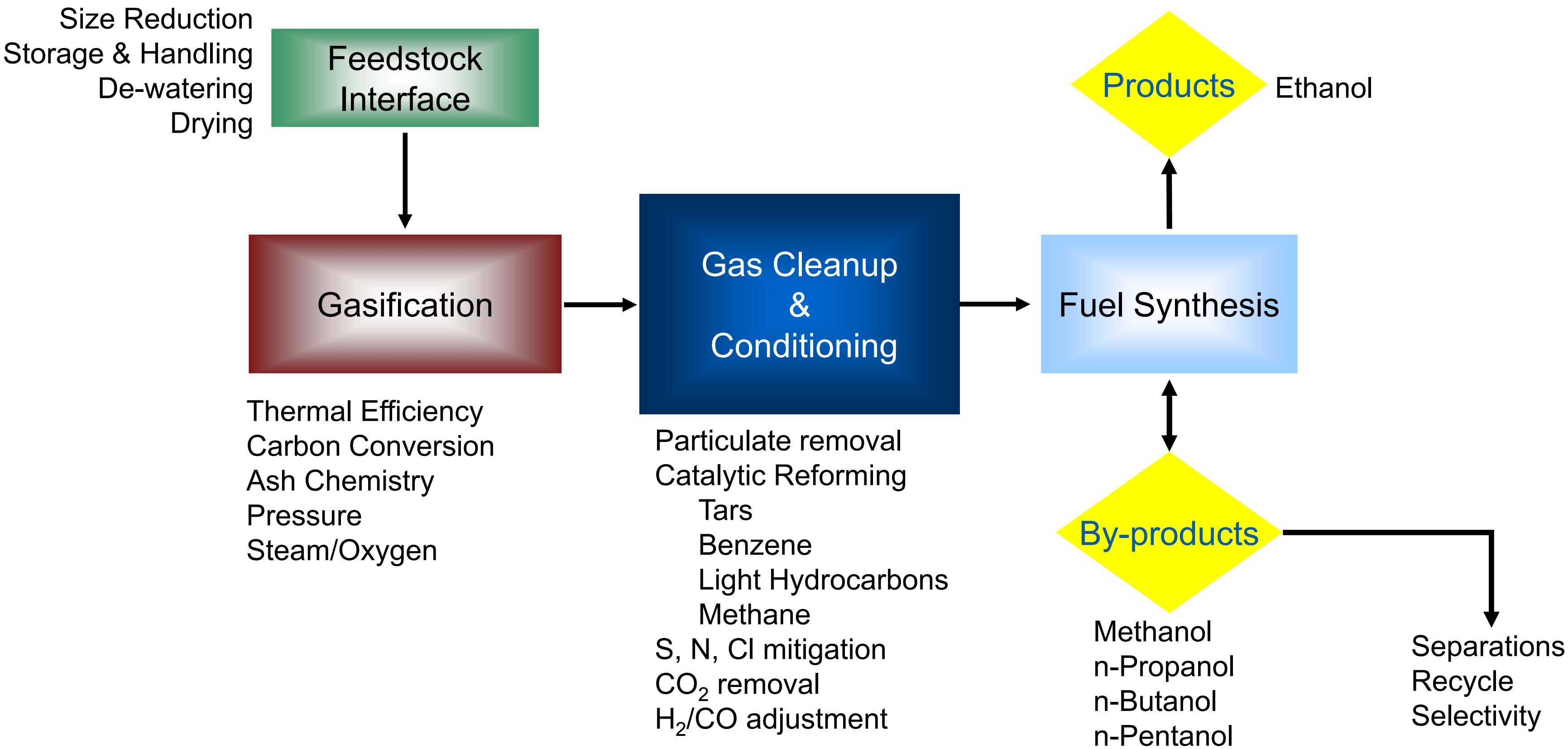


Billion Ton Vision

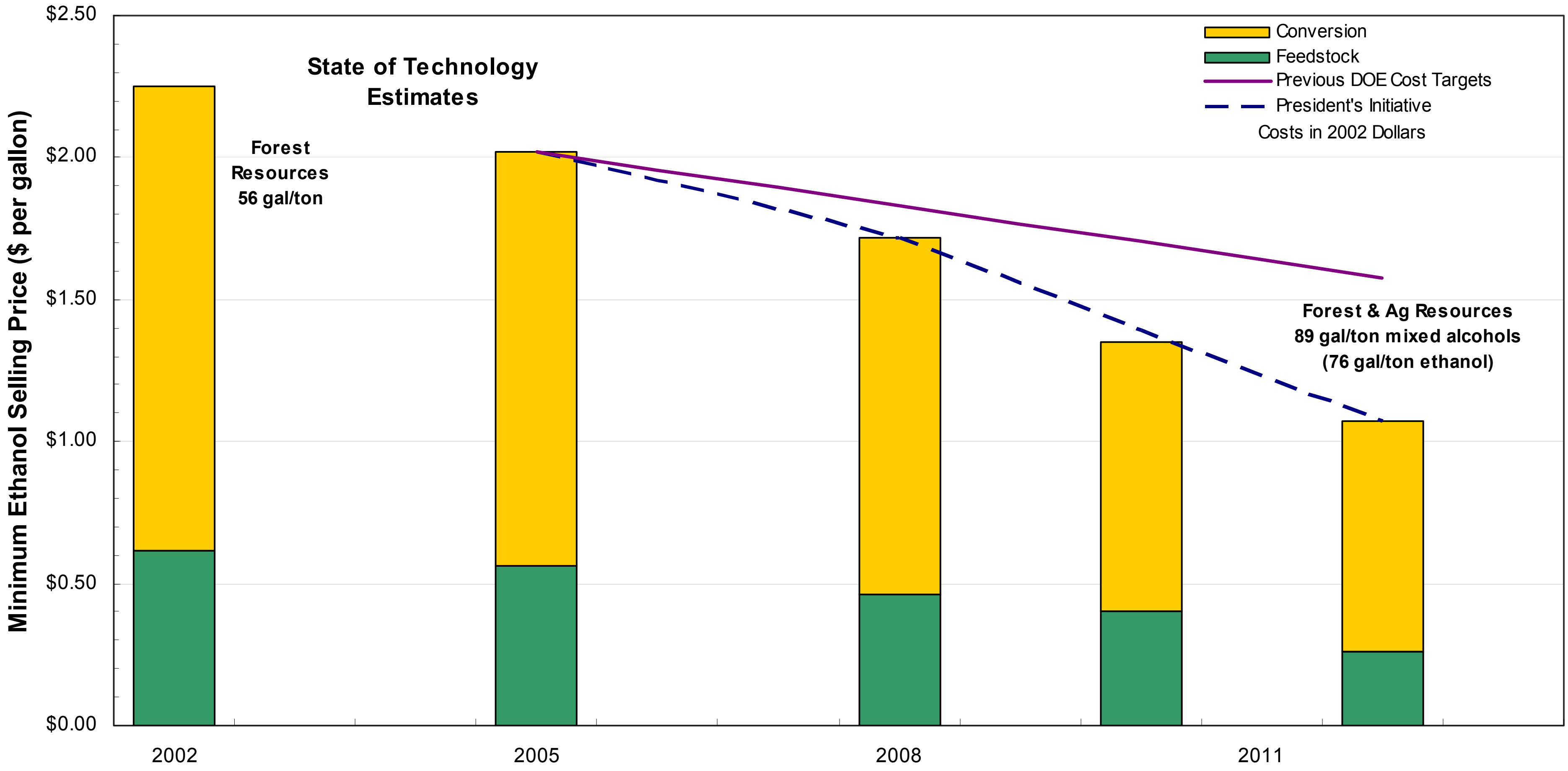
High Yield Increase



Gas Cleanup & Conditioning has the largest economic impact on Thermochemical Ethanol



Research state-of-technology assessments for thermochemical ethanol production to reach the $1.07/gallon market target



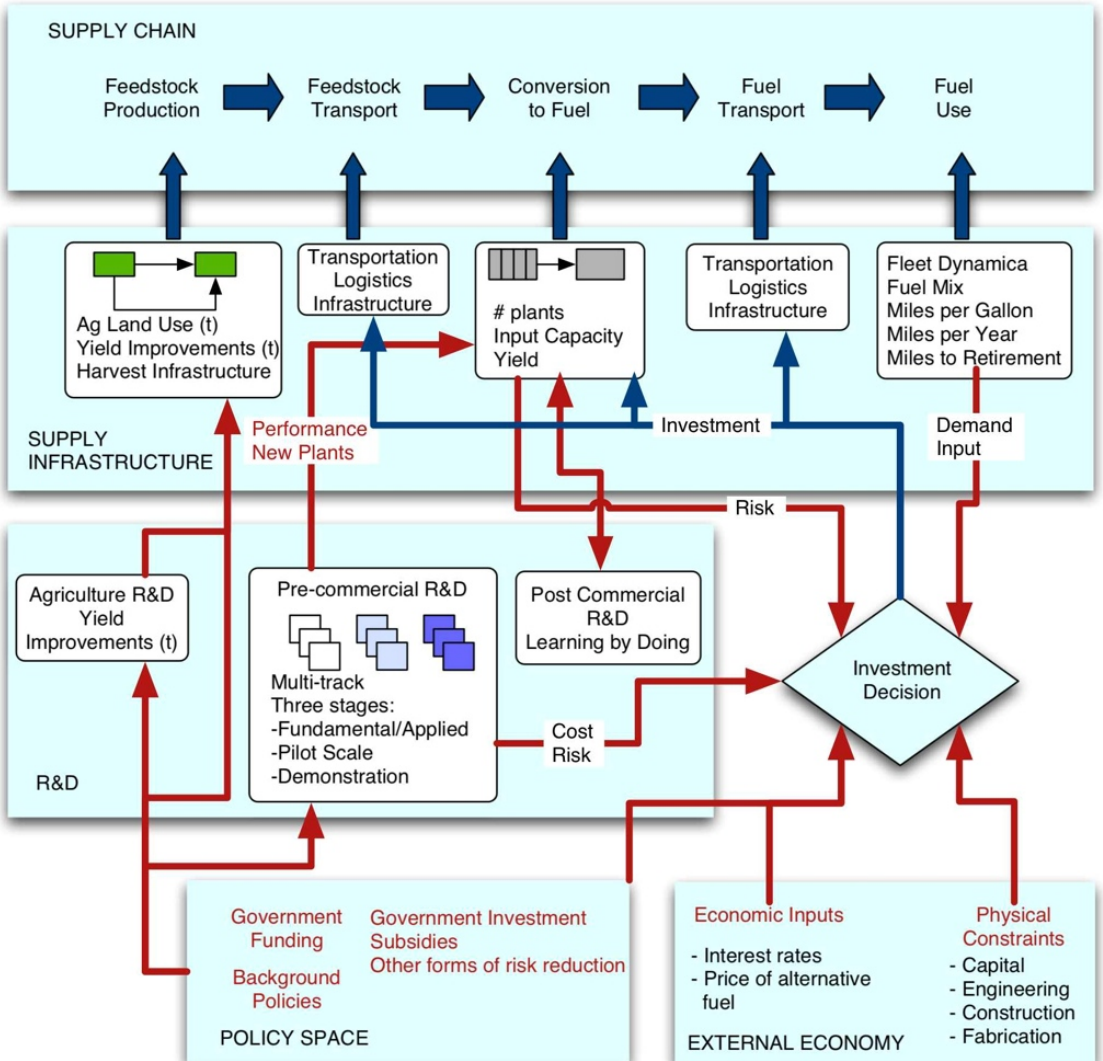
Estimated Process Economics

Plant Size: 2000 MT Dry Wood Chips/Day (Greenfield Site)
Corn Stover Cost: $35/dry ton

Economic Parameter (Units, $2005)	Value
Min. Ethanol Selling Price ($/gal)	$1.01
Ethanol Production (MM gal/yr)	61.8
Ethanol Yield (gal/dry ton stover)	80.1
Total Alcohol Yield	94.1
Total Project Investment ($ MM)	$191
Total Installed Capital ($MM)	$137
TPI per Annual Gallon ($/gal)	$2.22
TIC per Annual Gallon ($/gal)	$3.09

* Assuming 100% equity financing and 10% Internal Rate of Return (IRR)

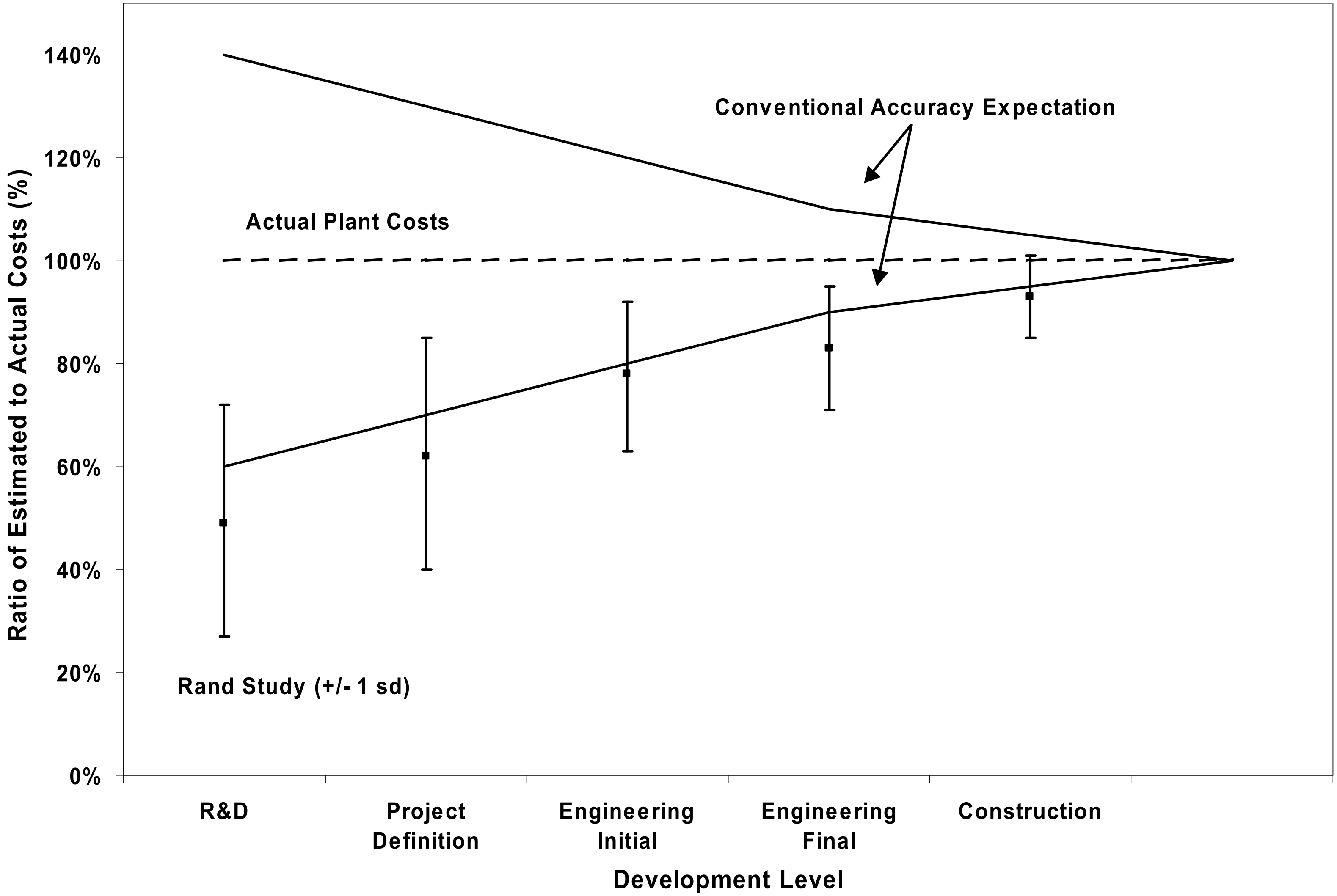
Systems Dynamic Modeling for Ethanol Market Penetration



- Reducing risk is key to utilization
- Supply chain for fuels
- Dynamics of Infrastructure build up
- R&D activities
- Govt policies/spending
- The external economy

Risk must be addressed as early as possible

Experience of Pioneer Plants in Estimation Accuracy (Data Source: Rand 1981)



Latest News….

DOE awards up to $385MM for 6 biorefinery demonstrations

- Abengoa, Alico, Bluefire Ethanol, Broin/DuPont, Iogen, Rangefuels
- Wide variety of technology options, feedstocks, and geography

DOE awards up to $23MM for 5 projects to enhance fermentation organisms

- Cargill, Celunol, DuPont, Mascoma, Purdue/ADM

DOE announces solicitation for up to $200MM for small-scale biorefinery demonstrations

Industry is in significantly staffing up

DOE proposes regulations for loan guarantee program

Sustainability Issues at the Forefront

- Water usage in ethanol plants 3-5 gallons/gallon ethanol
- At 50 MM gal/yr, that's 150-250MM gal water per year per plant
- Multiply by hundreds of plants and decades of operation

Thank you!

DOE Biomass Program Web Site

http://www.eere.energy.gov/biomass/

NREL Biomass Web Site

http://www.nrel.gov/biomass

Biomass Research and Development Initiative

http://www.bioproducts-bioenergy.gov/