The National Bioenergy Center and Biomass R&D Overview

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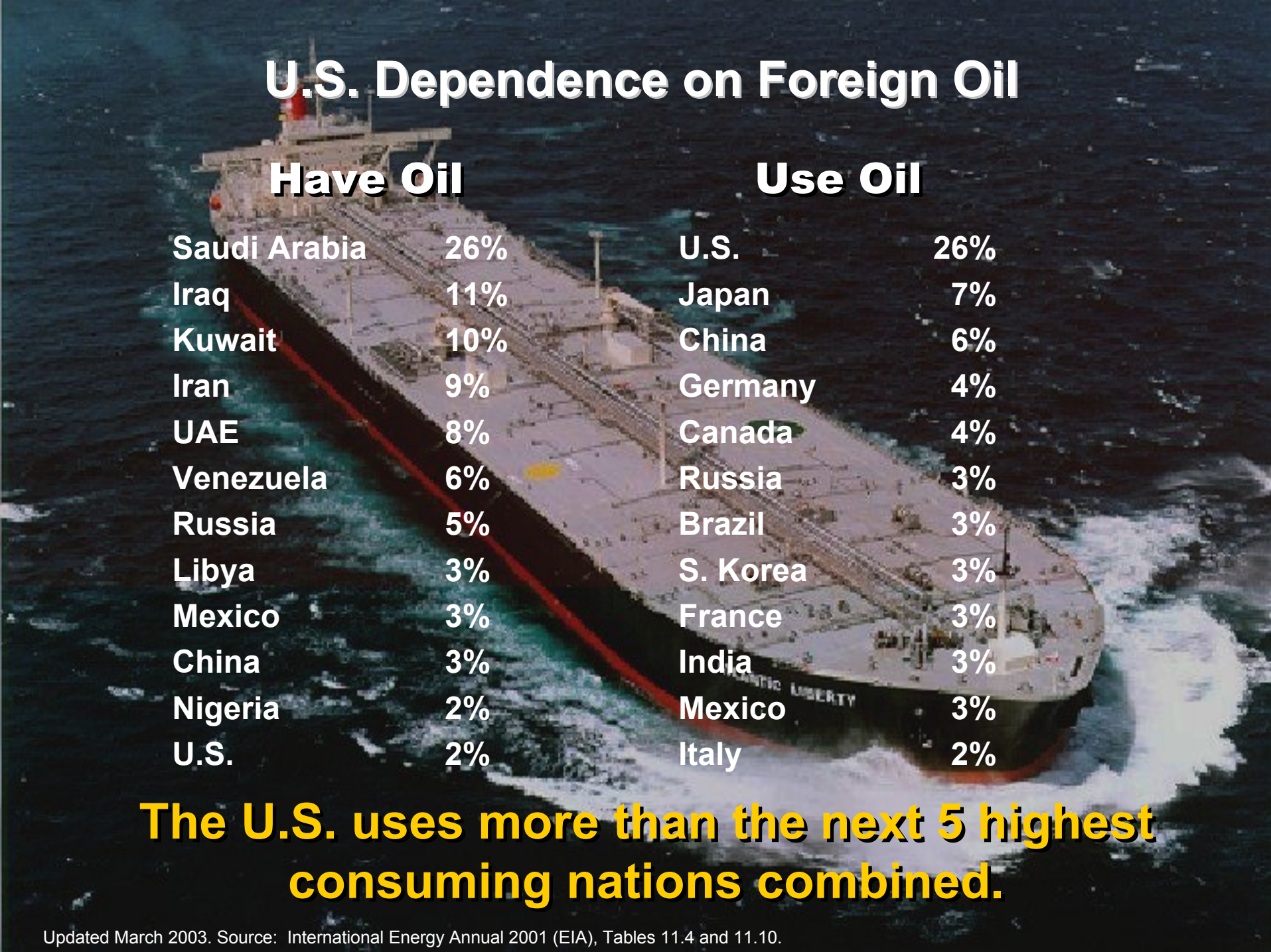
May 20, 2004

Why Bioenergy?

- **Greenhouse warming**
  - Natural CO_2 cycle is 10X fossil fuels
- **National security**
  - 60% of our petroleum is imported
- **Sustainability**
  - Potential to replace petroleum-derived fuels and chemicals
- **Rural economic benefit**

U.S. Dependence on Foreign Oil



Have Oil		Use Oil	
Saudi Arabia	26%	U.S.	26%
Iraq	11%	Japan	7%
Kuwait	10%	China	6%
Iran	9%	Germany	4%
UAE	8%	Canada	4%
Venezuela	6%	Russia	3%
Russia	5%	Brazil	3%
Libya	3%	S. Korea	3%
Mexico	3%	France	3%
China	3%	India	3%
Nigeria	2%	Mexico	3%
U.S.	2%	Italy	2%

The U.S. uses more than the next 5 highest consuming nations combined.

Updated March 2003. Source: International Energy Annual 2001 (EIA), Tables 11.4 and 11.10.

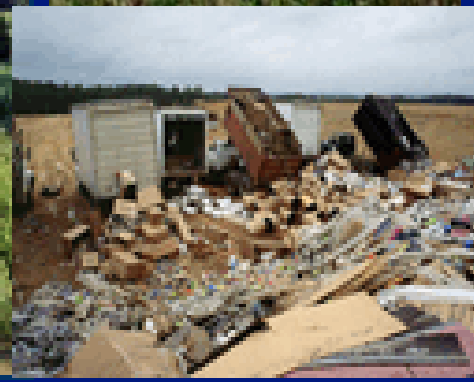
The Unique Role of Biomass

While the growing need for sustainable electric power can be met by other renewables…





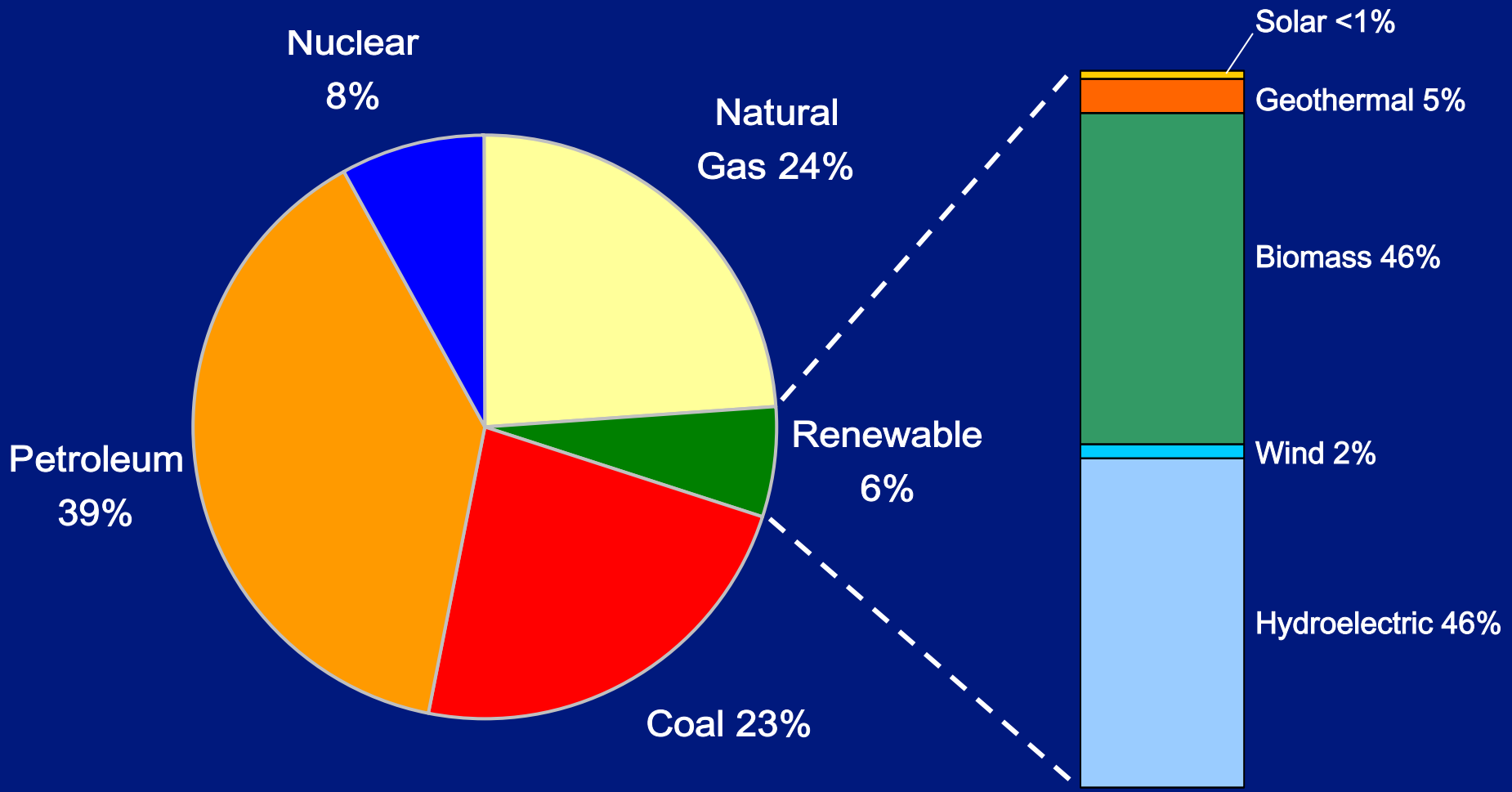


Biomass is our only renewable source of carbon-based fuels and chemicals

Biomass Share of U.S. Energy Supply

(data for 2002)



Source: AEO 2004 tables (released in December 2003) based on US energy consumption. Overall breakdown Table A1 (Total Energy Supply and Disposition), and Renewable breakdown Table A18 (Renewable Energy, Consumption by Section and Source).

National Bioenergy Center

Announced by Dept of Energy Secretary Bill Richardson at the Kansas City Board of Trade on October 31, 2000

NREL Role: *Research Leadership and Coordination of research at DOE labs*

NETL

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

INEEL
Idaho National Engineering and Environmental Laboratory

Argonne National Laboratory
Operated by The University of Chicago

Oak Ridge National Laboratory

NREL

Bioenergy Strategic Goals

U.S Dept of Energy

Protect national and economic security by promoting a diverse supply of reliable, affordable, and environmentally sound energy

- Reduce our dependence on foreign oil
- Create the new domestic bioindustry

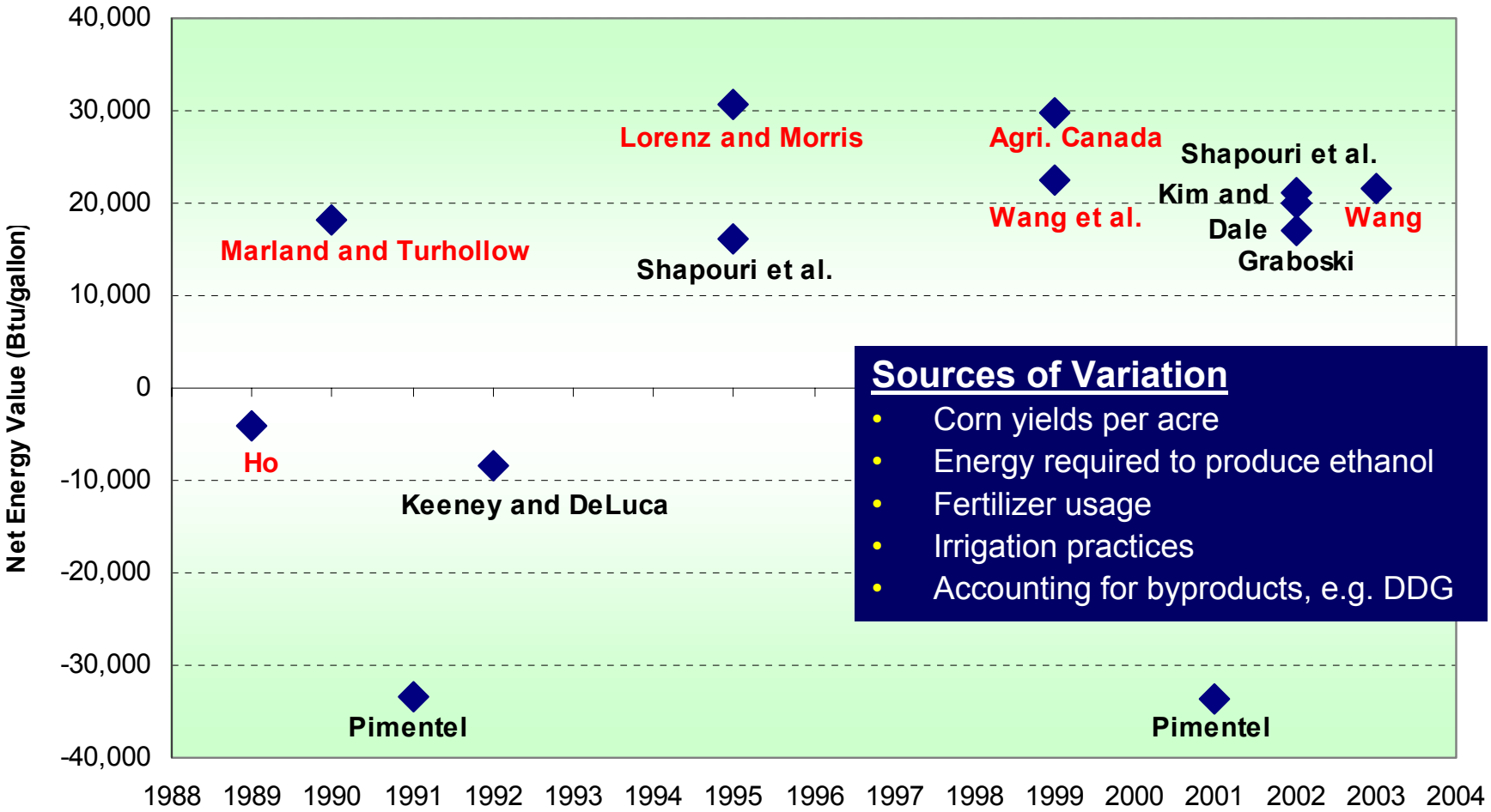
National Bioenergy Center

Develop biomass-based technologies that will be used by the U.S. transportation fuel, chemical and power industry

Specific Goal

Help establish technology for large-scale biorefineries based on agricultural residues by 2010

Concern: *Energy Balance of Corn Ethanol*
(Btu in EtOH Minus Btu Used)



Source: M. Wang (2003)

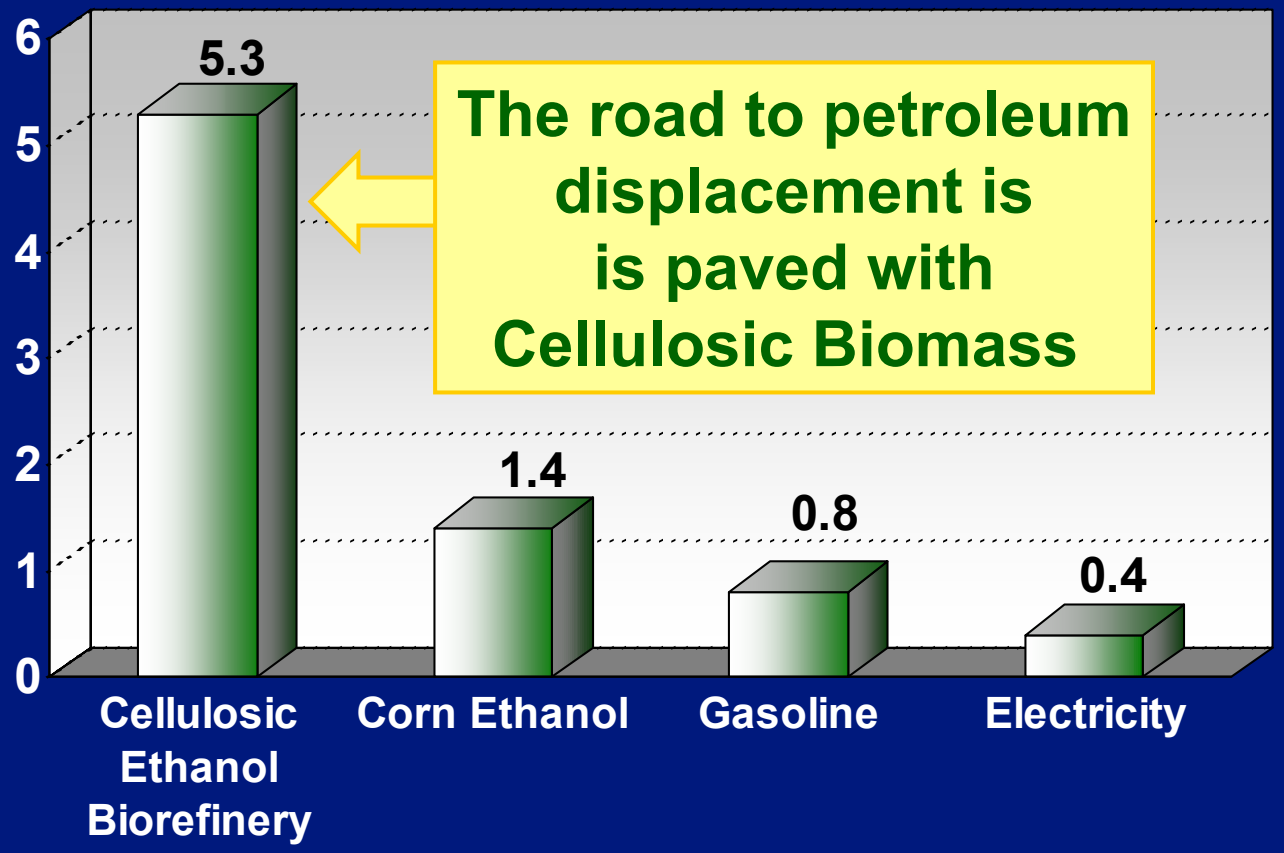
Renewable energy - More energy in than out?

Critics of renewable energy contend it takes more energy to make

This ignores the question of renewable sources

Fossil Energy Replacement Ratio

$$\text{Fossil Energy Ratio (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$



Source: J. Sheehan & M. Wang (2003)

NREL's R&D Focuses on:

Lignin: 15-25%

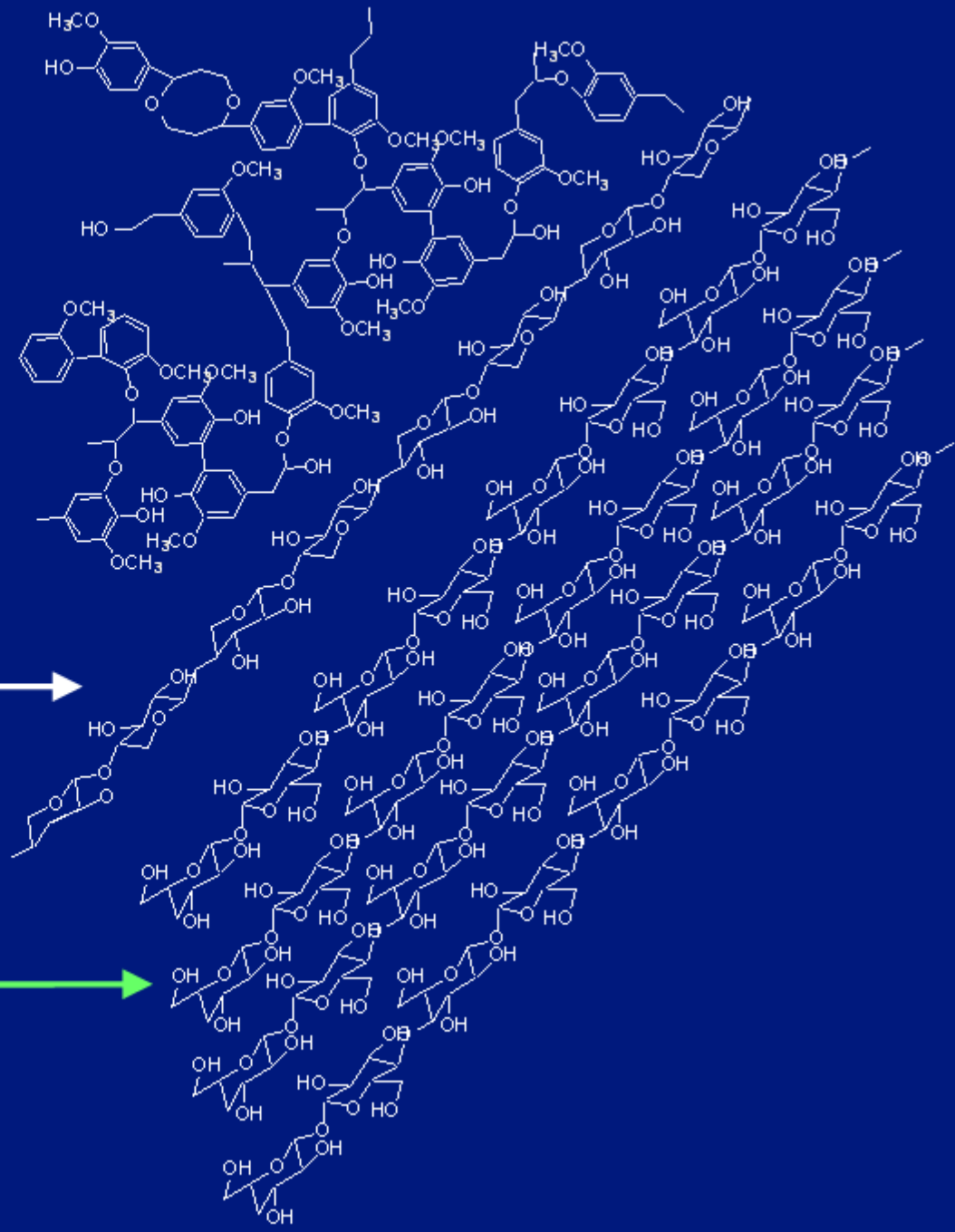
- Complex aromatic structure
- Resists biochemical conversion
- Requires high temperatures to convert

Hemicellulose: 23-32%

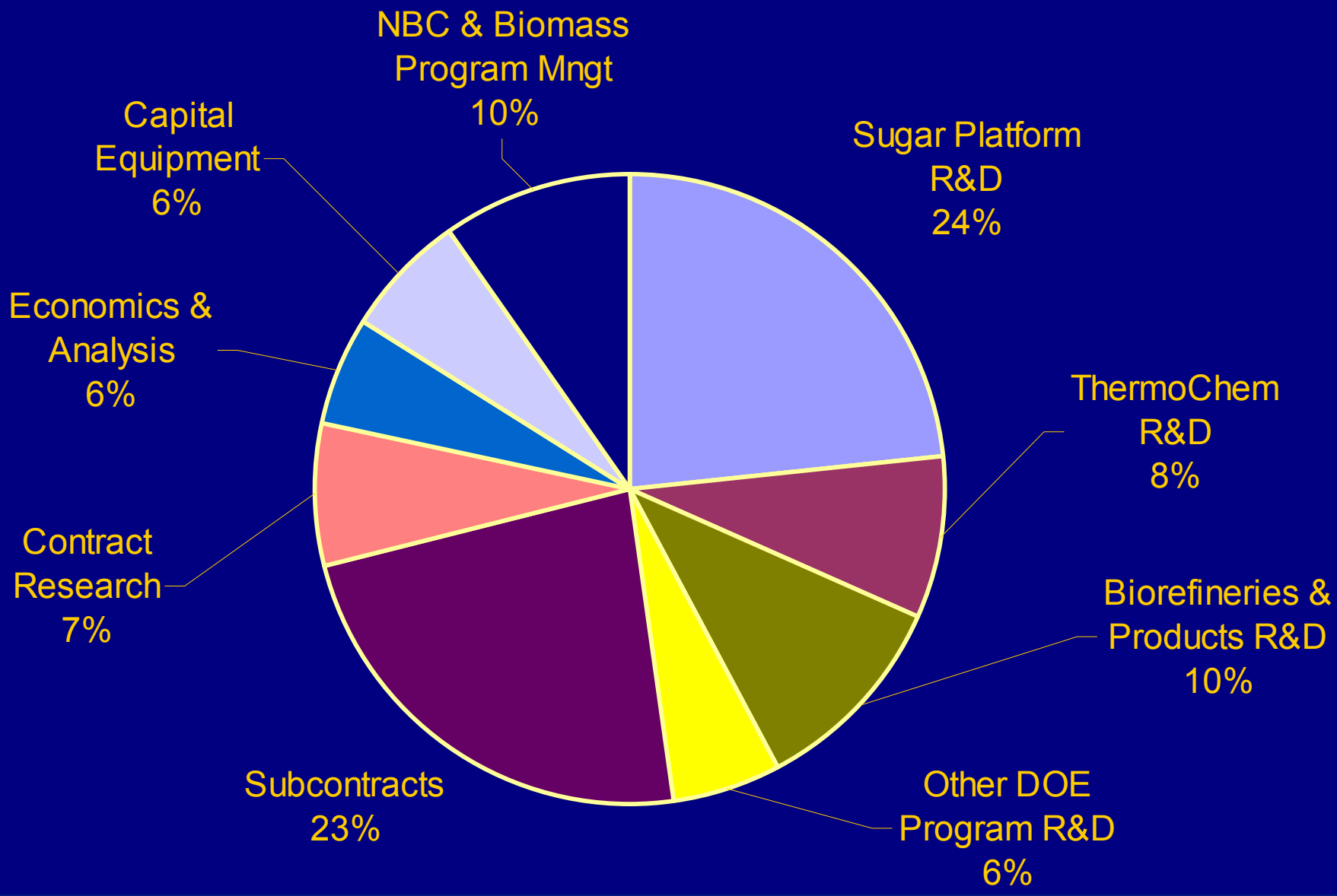
- Polymer of 5- and 6-carbon sugars
- Easily depolymerization
- 5-carbon sugars hard to metabolize

Cellulose: 38-50%

- Polymer of glucose
- Susceptible to enzymatic attack
- Glucose easy to metabolize



NREL NBC FY05 Budget ($ 31.4 Million)



Over 20 Years of Process Development Activities at NREL on Various Cellulosic Feed Stocks for Biomass Ethanol

WOODY BIOMASS AND RESIDUES

Basic process development on various hardwoods

Amoco CRADA—Paper fraction of MSW

Integrated process dev./scale-up on hardwood sawdust

Collaborative process development on softwood thinnings and residues (Quincy, CA and Sealaska)

Advanced pretreatment R&D on hardwood sawdust

CAFI pretreatment collaboration on poplar

1980 1985 1990 1995 2000 2005

AGRICULTURAL RESIDUES

Bioenergy CRADAs—corn fiber and corn stover

Integrated process dev./scale-up on corn stover

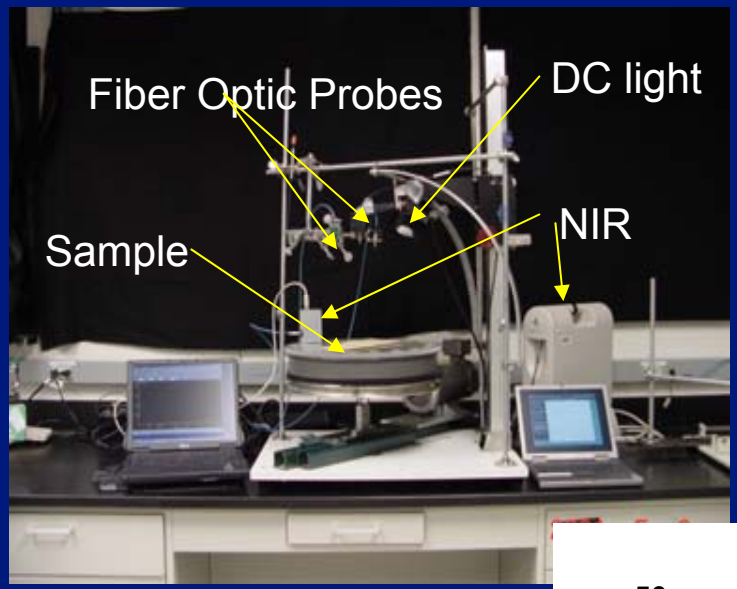
Collaborative process dev./scale-up on rice straw (Gridley, CA)

Amoco CRADA (corn fiber from wet mill)

New Energy CRADA (corn fiber from dry mill)

Basic process development on various residues (straws, stover)

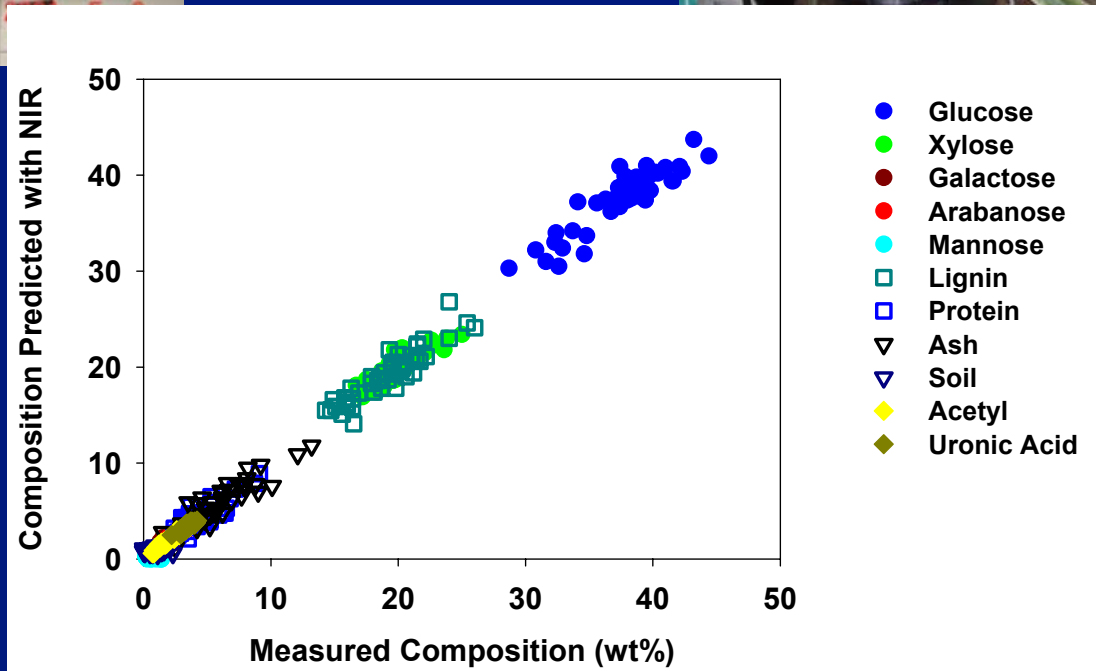
Rapid Analysis Methods for Biomass



Predicts biomass feed performance in biorefinery

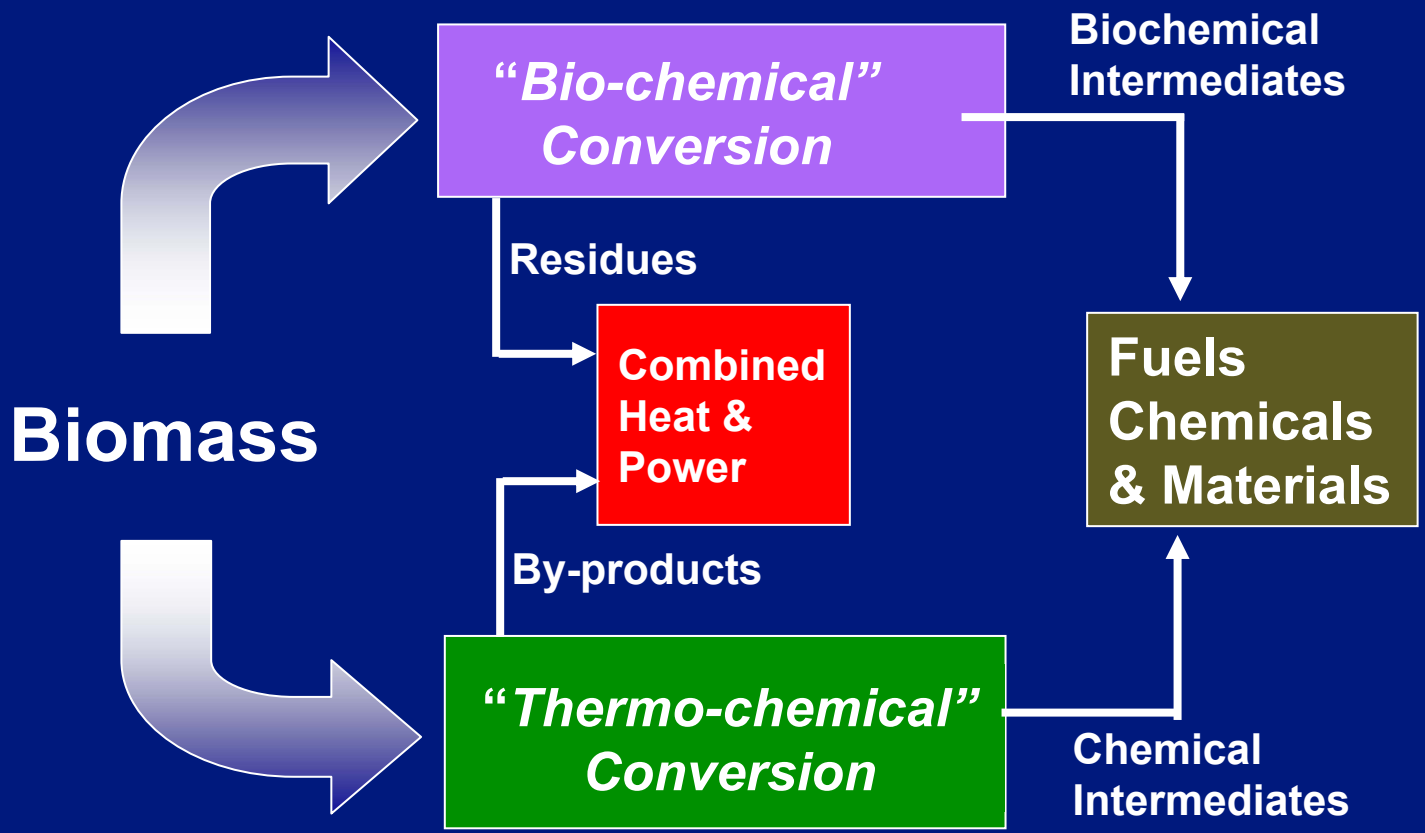
Feed quality measurement in the field

Near Infrared combined with multivariate methods



NREL led research

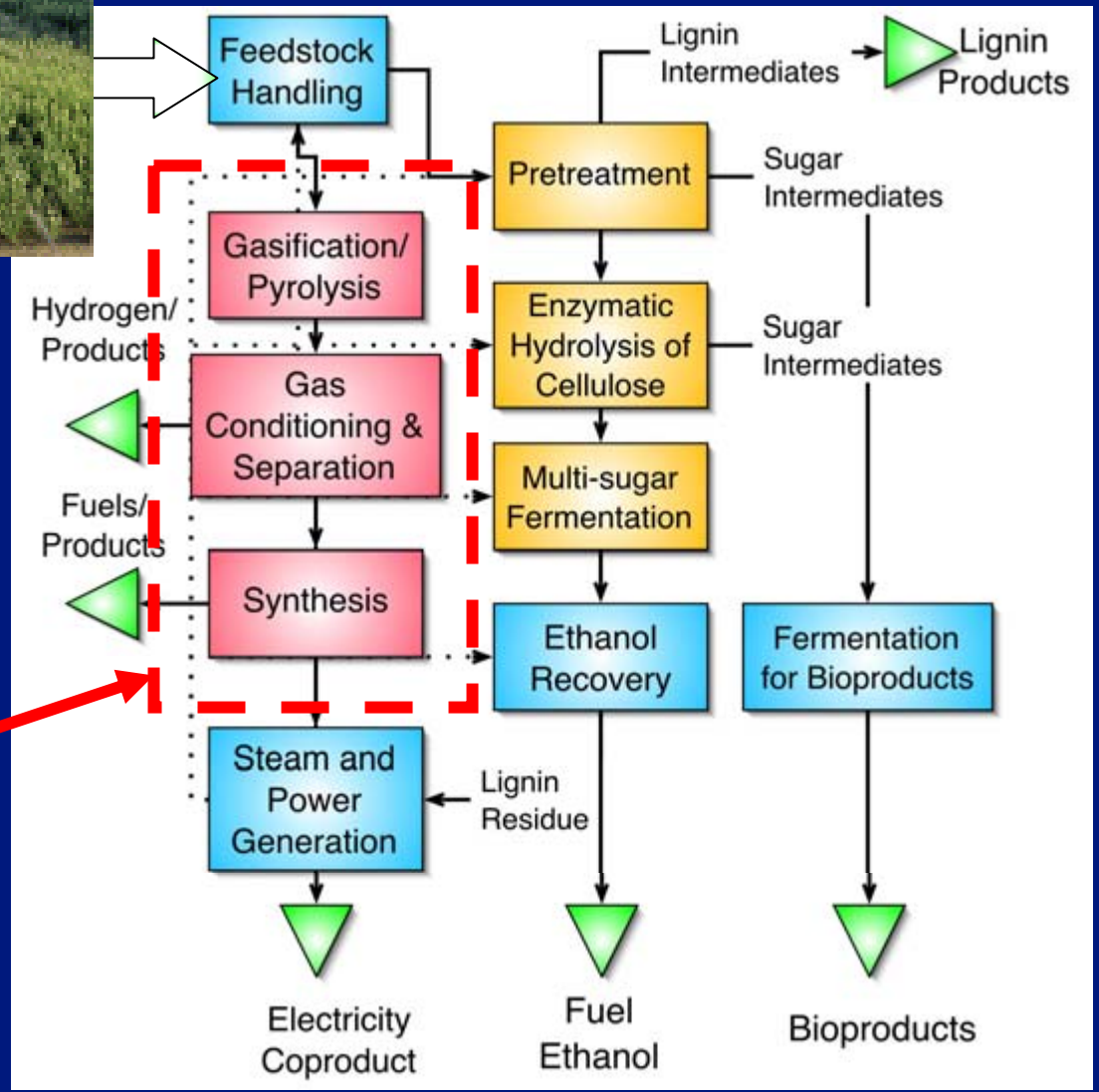
"Conversion Platforms"
Drive Biomass R&D Priorities at NREL



NREL Technology for Future Biorefineries

An integrated biorefinery will make use of:

- Thermochemical conversion technology
- Biochemical conversion technology
- Existing technology



NREL's Thermochemical User Facility

- Simulates thermochemical conversion processes
  - Pyrolysis
  - Combustion
  - Gasification
- Fully integrated
- Accommodates testing of close-coupled biomass conversion with upgrading
- Various size scales
  - 0.1 kg/h bench-scale reactors to 20 kg/h

Thermochemical Conversion Projects

Example: *Gasification to Power*

3 Small Modular Power Systems installed in 2003

Example: North Park High School Walden Colorado

Strong Community Support

Power & Heat for Greenhouse

Fuel: forest thinning residues

Load: 8 kW

Maintenance: 30 minutes per week

Operated by Students

Thermochemical Conversion Projects

Example: *Pyrolysis to Phenolic Resins*

- Multi-year $2.4 million DOE project
- Builds on 15+ years of R&D at NREL
- Commercial pyrolysis partner - Ensyn
- Cost share by resin manufacturers
- CRADA with Wood Product companies
  LP, Weyerhaeuser, Tembec

-Successful "mill trial" at OSB mill

- Product certification complete

NREL Technology for Future Biorefineries

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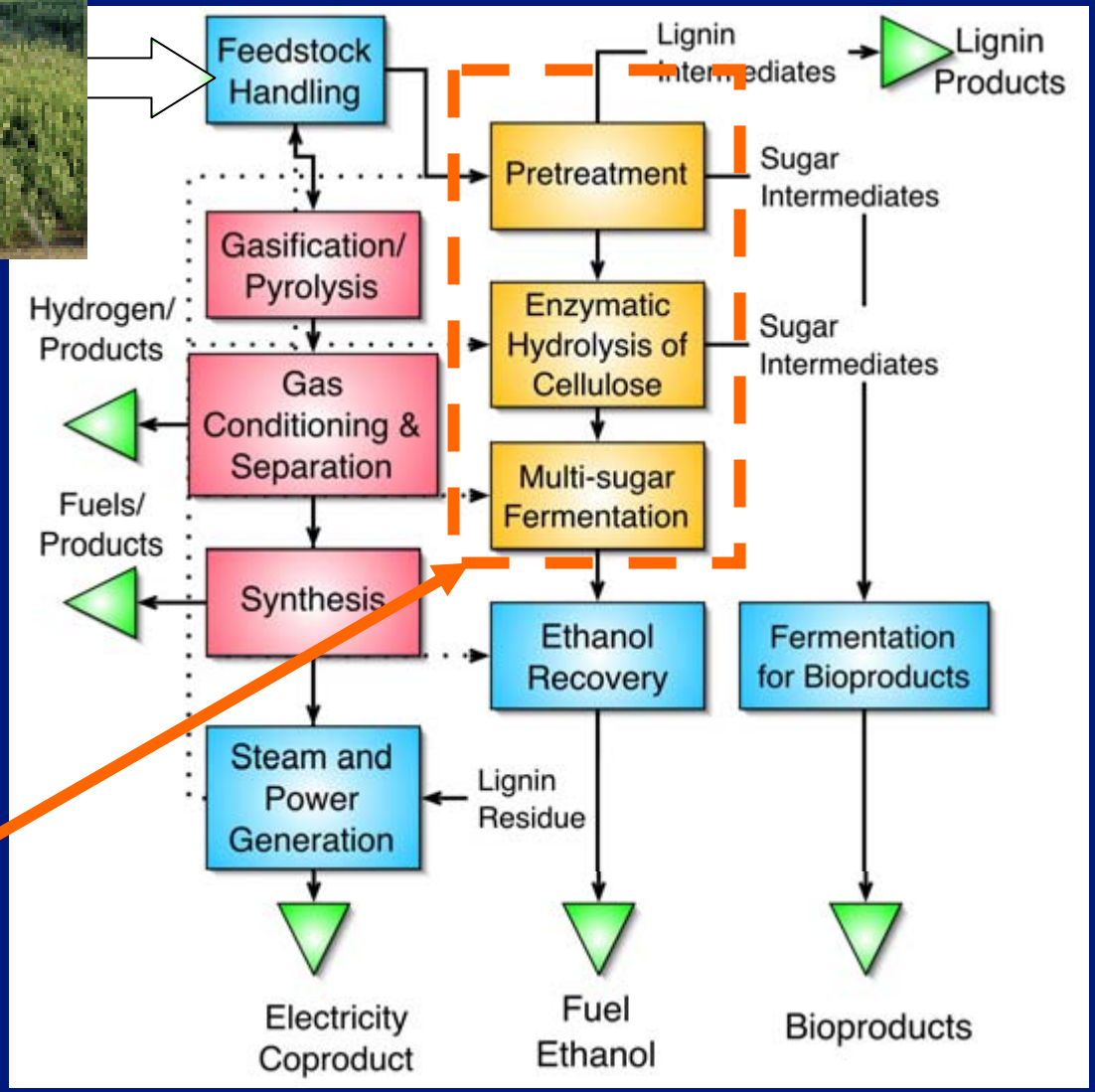
Available today

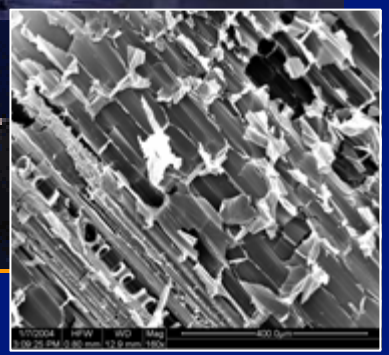


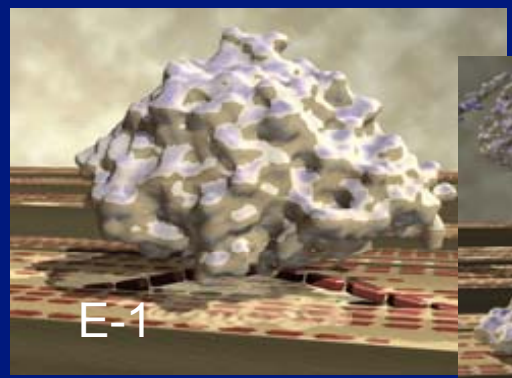
NREL's Alternative Fuels User Facility

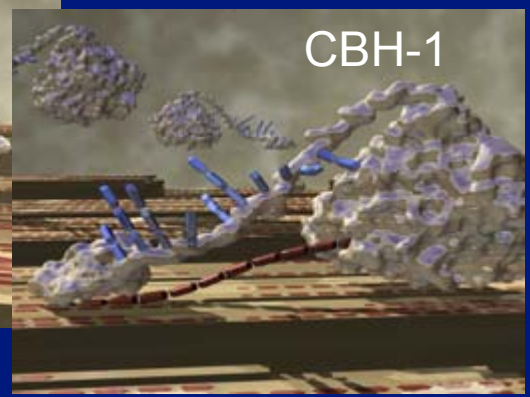
- Laboratory scale fermentation
- 1 ton/day bioethanol PDU
- Extensive pre-treatment research
- Flexible integration & configuration
- Frequent industry utilization

Biomass Pretreatment & Enzyme Fundamentals at NREL

- Biomass Pretreatment & Enzymology
- Utilization of latest surface science techniques
- Target fundamental breakthroughs in biomass conversion technology







Dilute Acid Pretreatment Of Lignocellulosic Biomass

1 ton/day Sunds Continuous Pretreatment Reactor

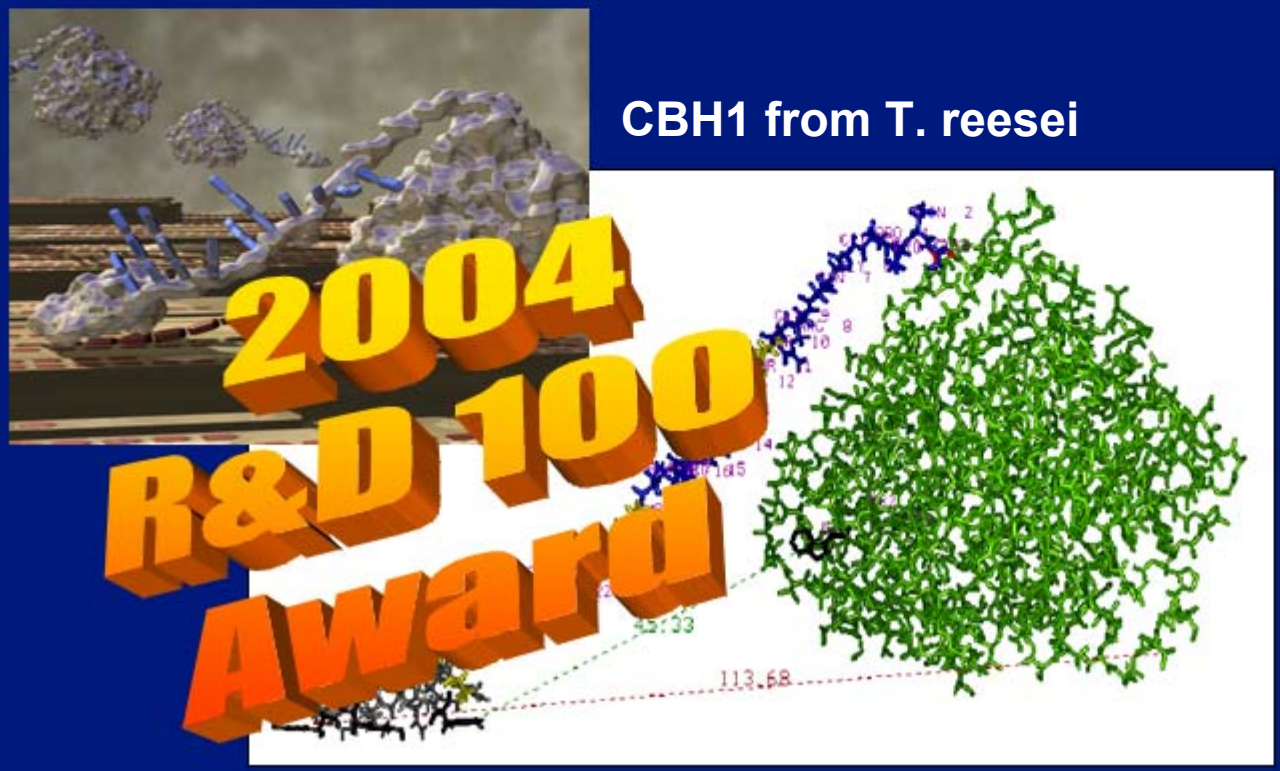
Untreated Corn Stover

Pretreated Corn Stover at 35% solids loading

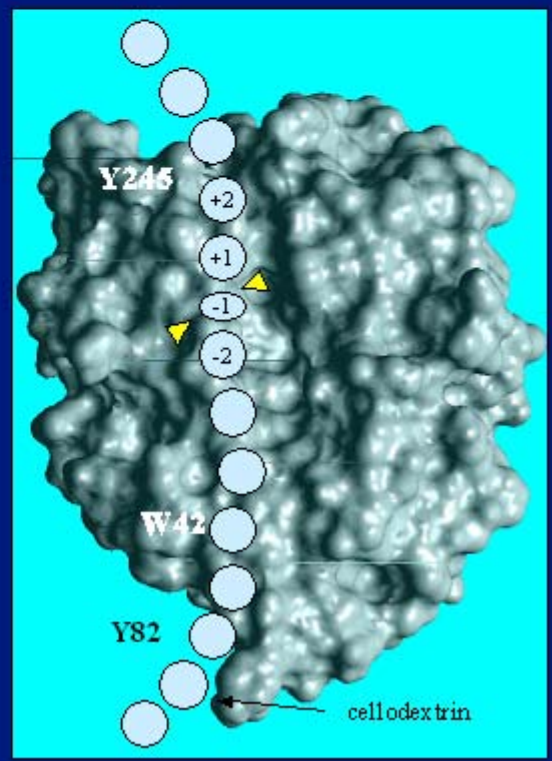
NREL's Enzymatic Hydrolysis Research

- 3-year Partnerships with Genencor & Novozymes
  - Focus on enzyme biochemistry, cost, and specific activity
  - Investigate enzyme - substrate surface interaction
  - 10-fold reduction in cost of enzyme production

E1 from *A. cellulotiticus*



CBH1 from T. reesei



Biomass Surface Characterization Laboratory

Planned for November 2004 Start-up

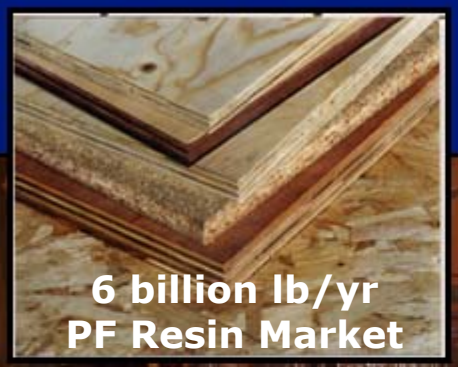
AFM

- NSOM
- AFM
- SEM
- STEM

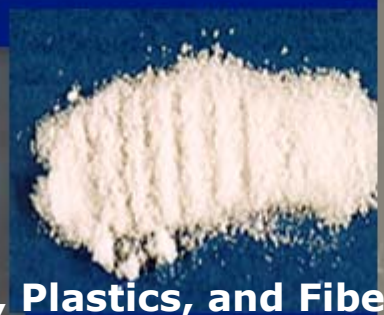
Genomics, Proteomics & Bioinformatics

- Essential to improve organisms for biofuels and bioproducts
- Critical to understand and optimize:
  - yield, rate, and titer
- Miniature sugar biorefineries of the future

NBC Biobased Products Research



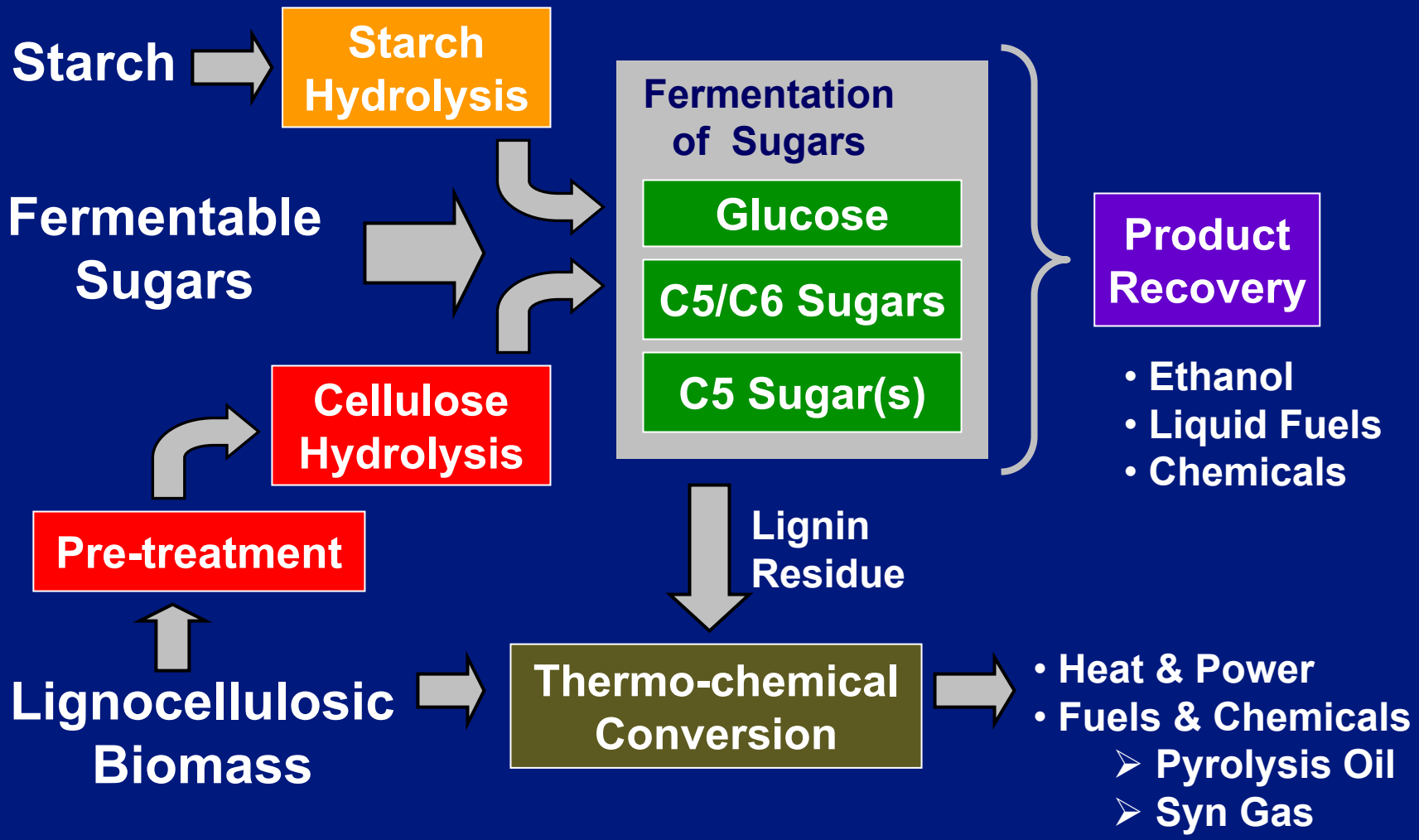
- Critical to Biorefinery Economics
- Continued Leadership in:
  - Pyrolysis oil to products
  - Sugars to fuels and chemicals
  - Lignin to aromatics and octane enhancers



Green Chemicals, Plastics, and Fibers

Research at all NBC labs in area of bio-based products

Combined Biorefinery Elements



NREL's Role: *Support the Development of New Industrial Biorefinery Concepts*

Biomass Feedstock

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

Conversion Processes

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

USES

Fuels:
– Ethanol
– Renewable 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

Life Cycle Assessment

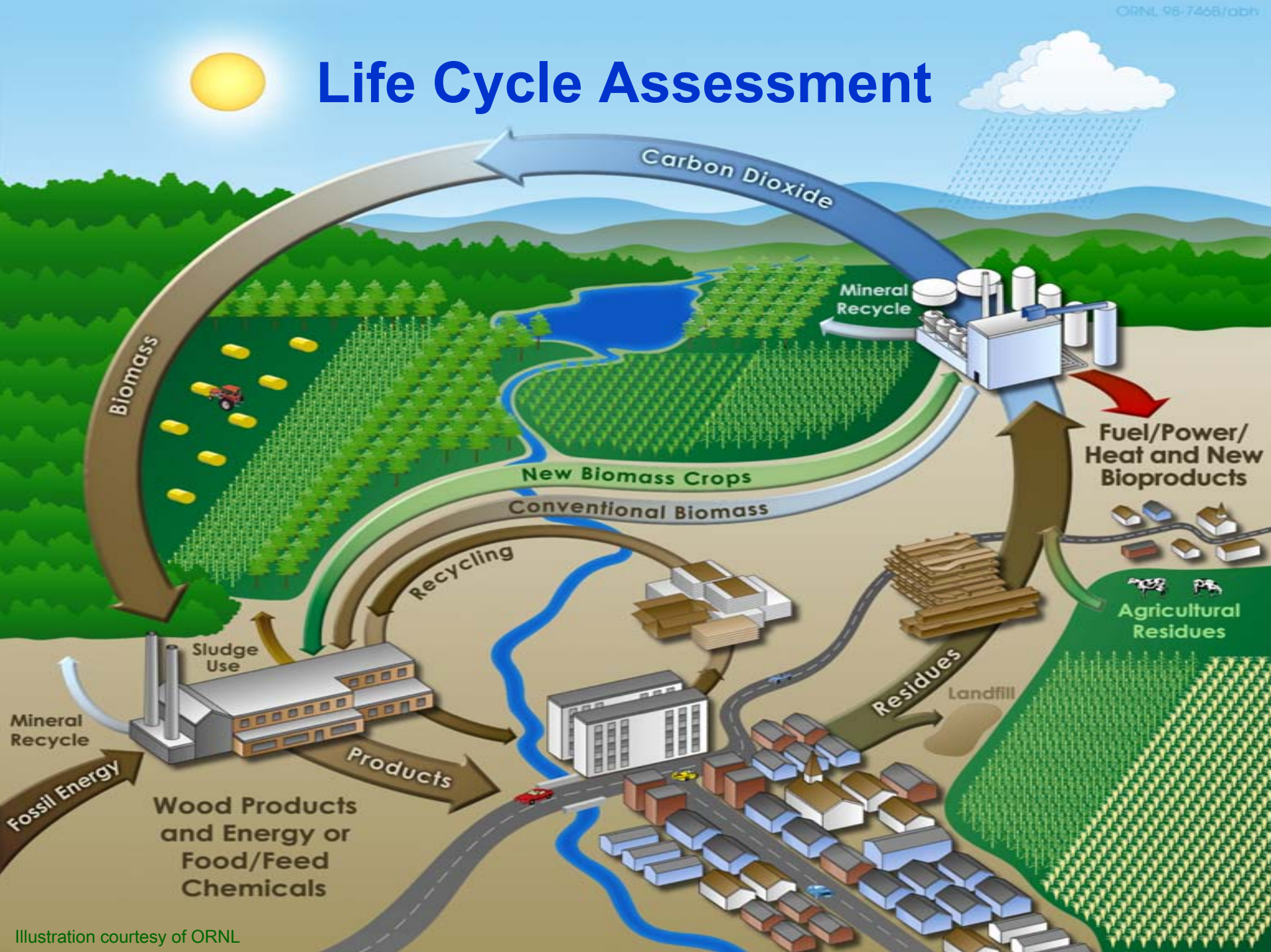
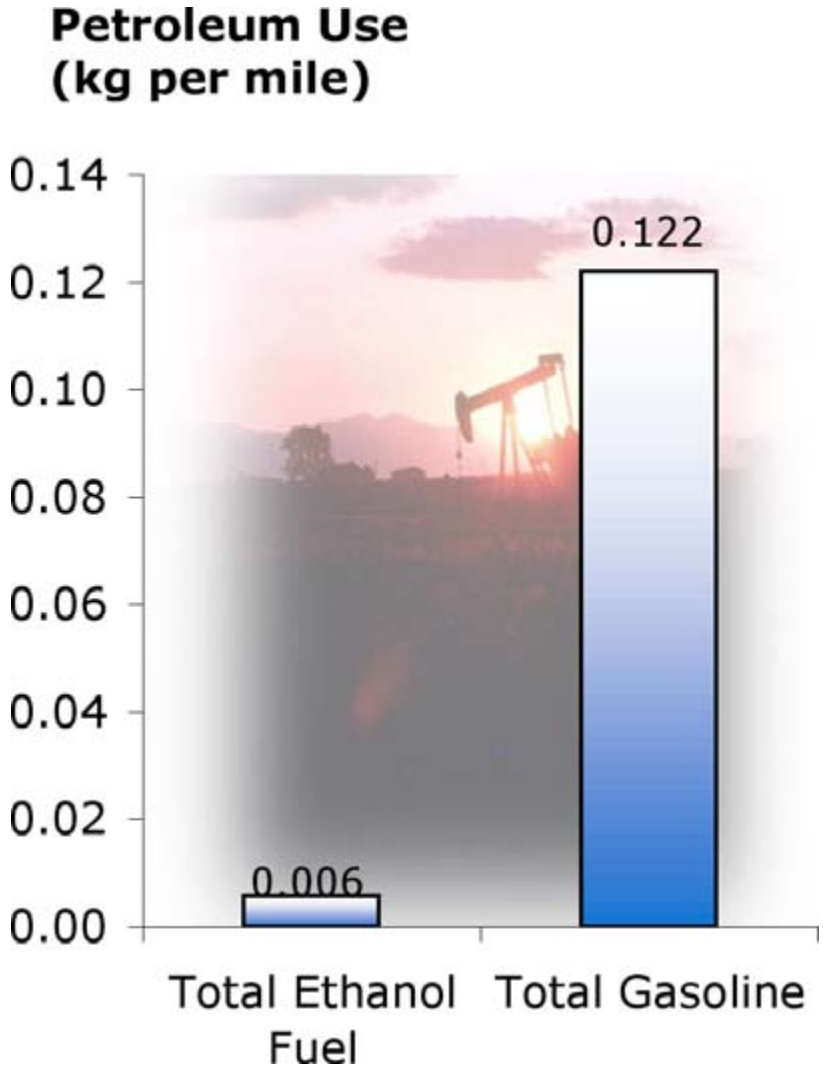
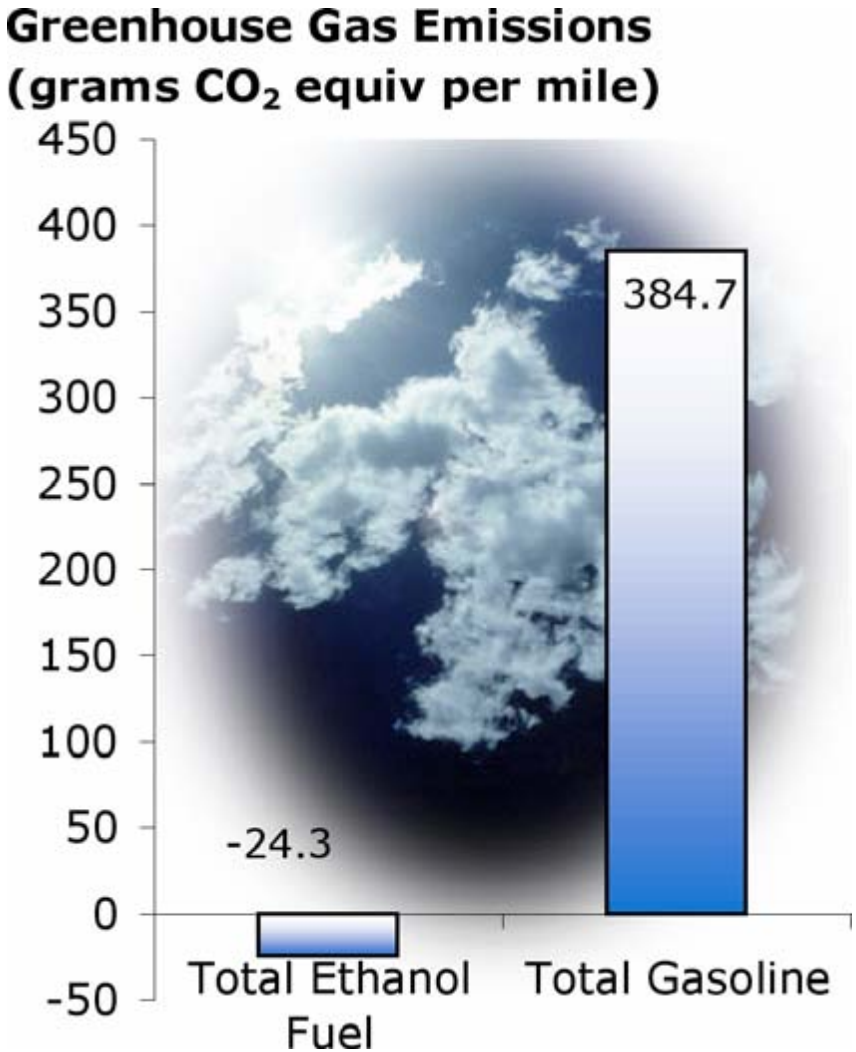


Illustration courtesy of ORNL

Potential Benefits of Cellulosic Ethanol





J. Sheehan, 2003

Agricultural Residue Opportunity

- **Candidate for commercialization of biorefinery in 5-10 year horizon**
  - Corn stover: 100 million tons per year of available feedstock
  - Suitable for lignocellulosic biorefinery demonstration
- **Synergy with fuel industry issues**
  - MTBE phase-out
  - Impending Renewable Fuel Standard

Partnership Example
Dupont-NREL: *Integrated Corn Biorefinery*

- $38 million (50% from DOE)
- $8 million to NREL
- Goal:
  - *develop a Process Design Package for farmers to produce fuels, chemicals and power from entire corn plant*
- License to use NREL organism
- 4-yr timeline

building block for Sorona™ polyester

Sorona™

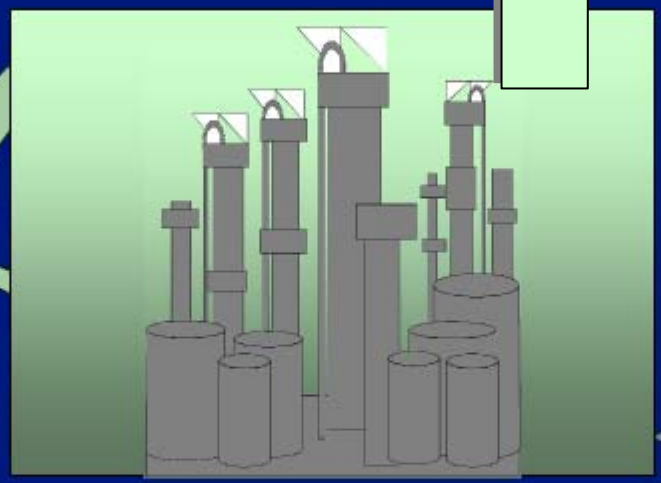
400% AAGR

Pulp & Paper Mill Diversification Opportunity

- Source of dilute xylose upstream of pulping
  - Simplify pulping step & reduce use of pulping chemicals
  - Large year-round source of fuels and/or chemicals
- Black liquor gasification
  - More efficient use of forestry resources
  - Produce Synthesis Gas from biomass
  - Products options: MeOH, DME, FTL, and chemicals
- Diversification of revenue to pulp mill
  - Provides U.S. mills with competitive advantage in international markets

NBC Expertise Applied to a Forest Biorefinery

Syngas



NBC Technology Expertise

- *Syngas Clean-up*
- *Power production*
- *Catalytic synthesis of Fuels and Chemicals*

Black Liquor & Residuals

Pulp & Paper Products

NBC Technology Expertise

- *BL Gasification*
- *Wood Residual Gasification*
- *Tar Formation & Destruction*

NBC Technology Expertise

- *Extract Hemicellulose*
- *Oligomer hydrolysis*
- *Conversion to Ethanol and Chemicals*

Summarizing The Biomass and Biorefinery Value Proposition

- Only sustainable source of hydrocarbon-based fuels, petrochemicals, and plastics
- Large U.S. and worldwide potential biomass resource base
- Reduction of greenhouse gas emissions
- Reinvigorate and diversify rural economy
- Near-term biorefineries will utilize residues from existing industries & high value products

The National Bioenergy Center is led by NREL for the Office of Biomass Program within the U.S. Department of Energy