NREL Biomass Program Overview

DOE/NSF EPSCoR Program Review 2007

Thomas D. Foust
Technology Manager, Biofuels Program
National Renewable Energy Laboratory
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2006 Advanced Energy Initiative

President George W. Bush visits NREL February 21, 2006, to discuss the Advanced Energy Initiative.

"America is addicted to oil… The best way to break this addiction is through technology.

We'll fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks, or switch grass.

Our goal is to make this ethanol practical and competitive within six years.

To replace more than 75% of our oil imports from the Middle East by 2025."

2007 State of the Union Address

"Tonight, I ask Congress to join me in pursuing a great goal…

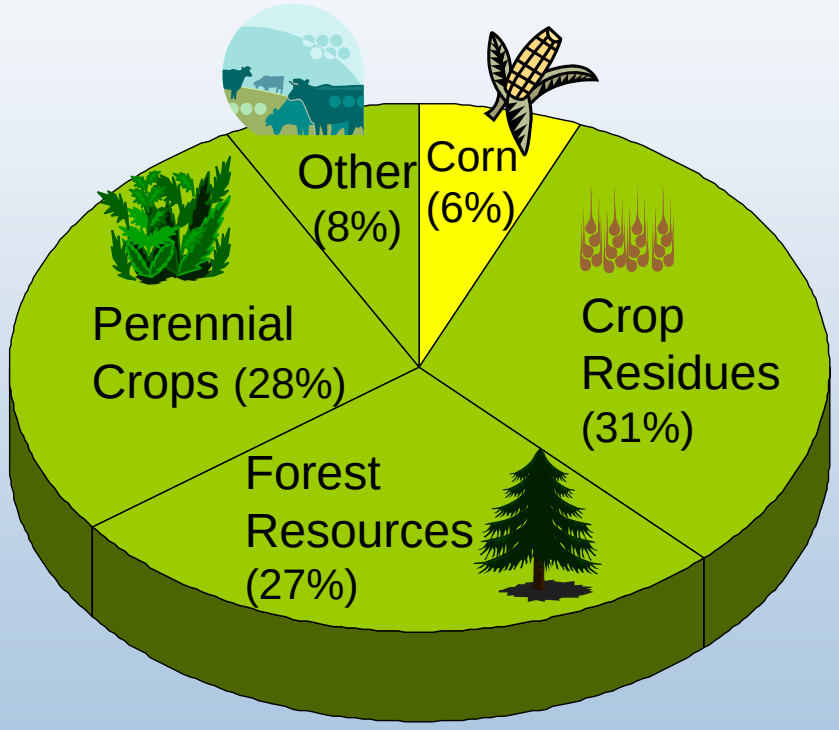
Let us build on the work we've done and reduce gasoline usage in the United States by 20% in the next 10 years."

“20 in 10” Summary

- Increase supply of renewable and alternative fuels
  - Set Alternative Fuels Standards (AFS) at 35 billion gallons/year by 2017
    - 5X the current Renewable Fuels Standard for 2012
    - **15%** of projected annual gasoline use in 2017
- Increase vehicle efficiency
  - Reform and modernize CAFÉ
    - **5%** of projected annual gasoline use in 2017

Source: White House

Resources for Production of Biofuels



Estimated Future Potential U.S. Biomass Resource Base

Today: Nearly all ethanol is made from corn grain

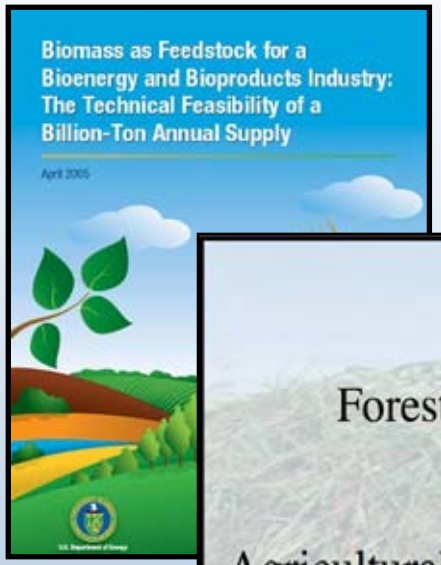
The Future: Cellulosic biomass will be primary source for fuel ethanol

Benefits of Cellulosic Ethanol

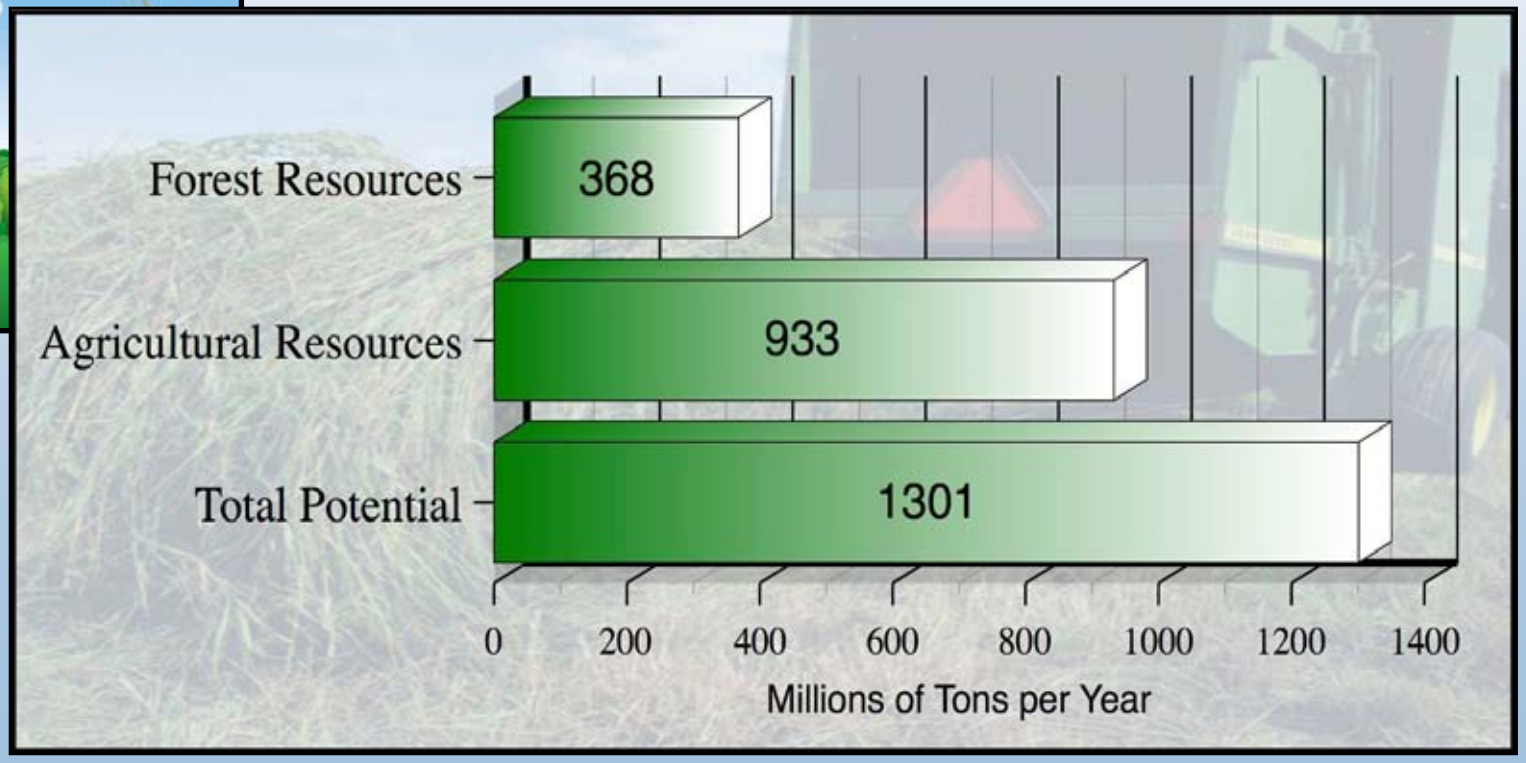
- Emits nearly 60% less greenhouse gases than reformulated gasoline
- Relies on non-food and waste resources

Source: *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion Ton Annual Supply*. 2005. DOE and USDA.

U.S. Biomass Resource Assessment

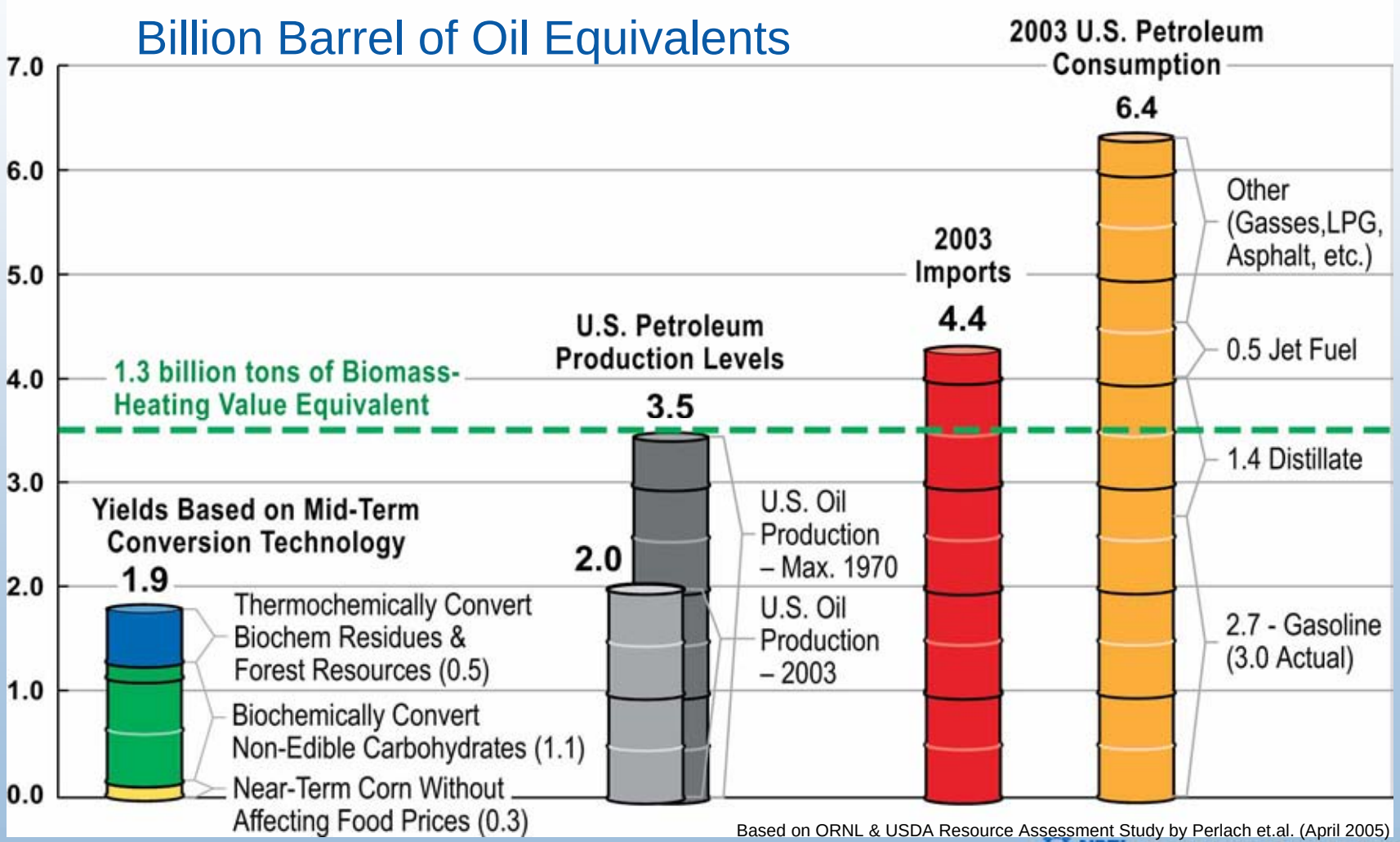


- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the “Billion Ton Study”



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

Significance of the "Billion Ton" Scenario



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http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

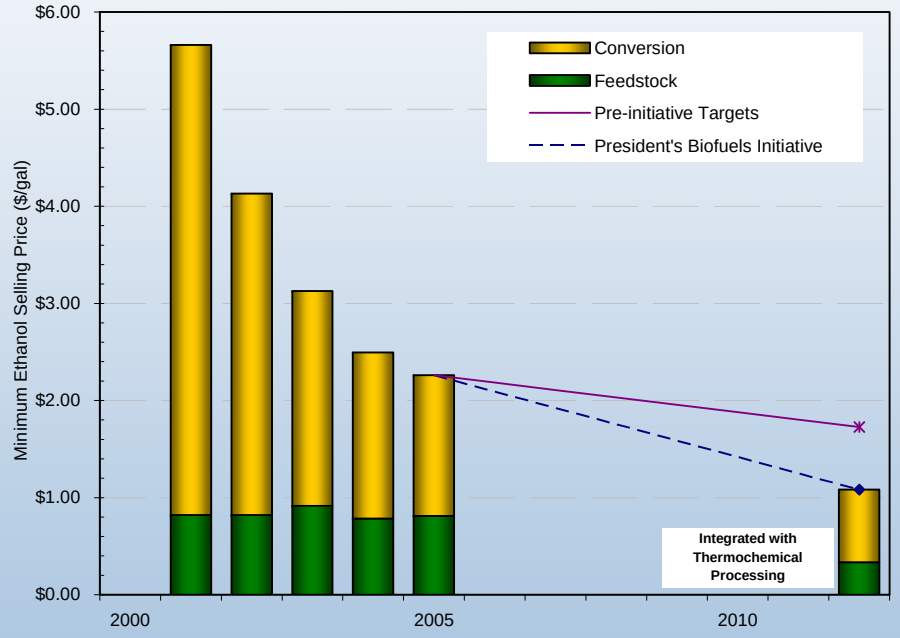
We Must Transition to Cellulosic Biomass

Today & Near Term	Corn Ethanol	Biochemical Conversion	Existing Distribution Infrastructure
2012 and Beyond	Cellulosic Ethanol *Agricultural residues, energy crops, natural oils, wood/forestry resources*	Advanced Biochemical Conversion and Thermochemical Conversion	Expanded, Advanced Distribution Infrastructure

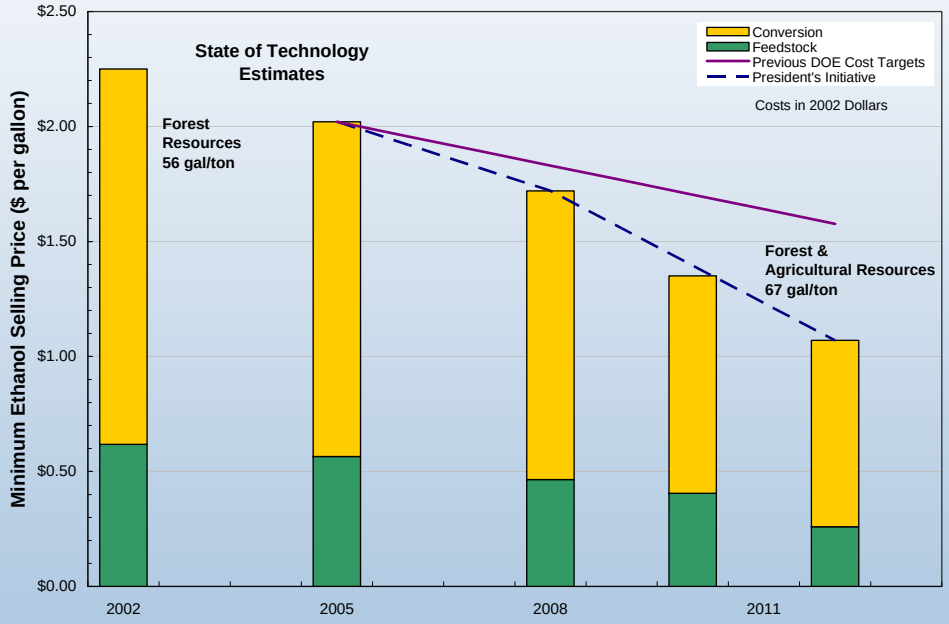
Cellulosic ethanol will help meet future biofuels demand

Achieving the $1.07 Production Cost Target by 2012

Biochemical



Thermochemical



Overview of NREL's National Bioenergy Center Facilities

Thermochemical Conversion

- Micro-reactors to pilot plants

Biochemical Conversion

- Bench scale to ton/day

Genomics Laboratory

- Tools for strain development

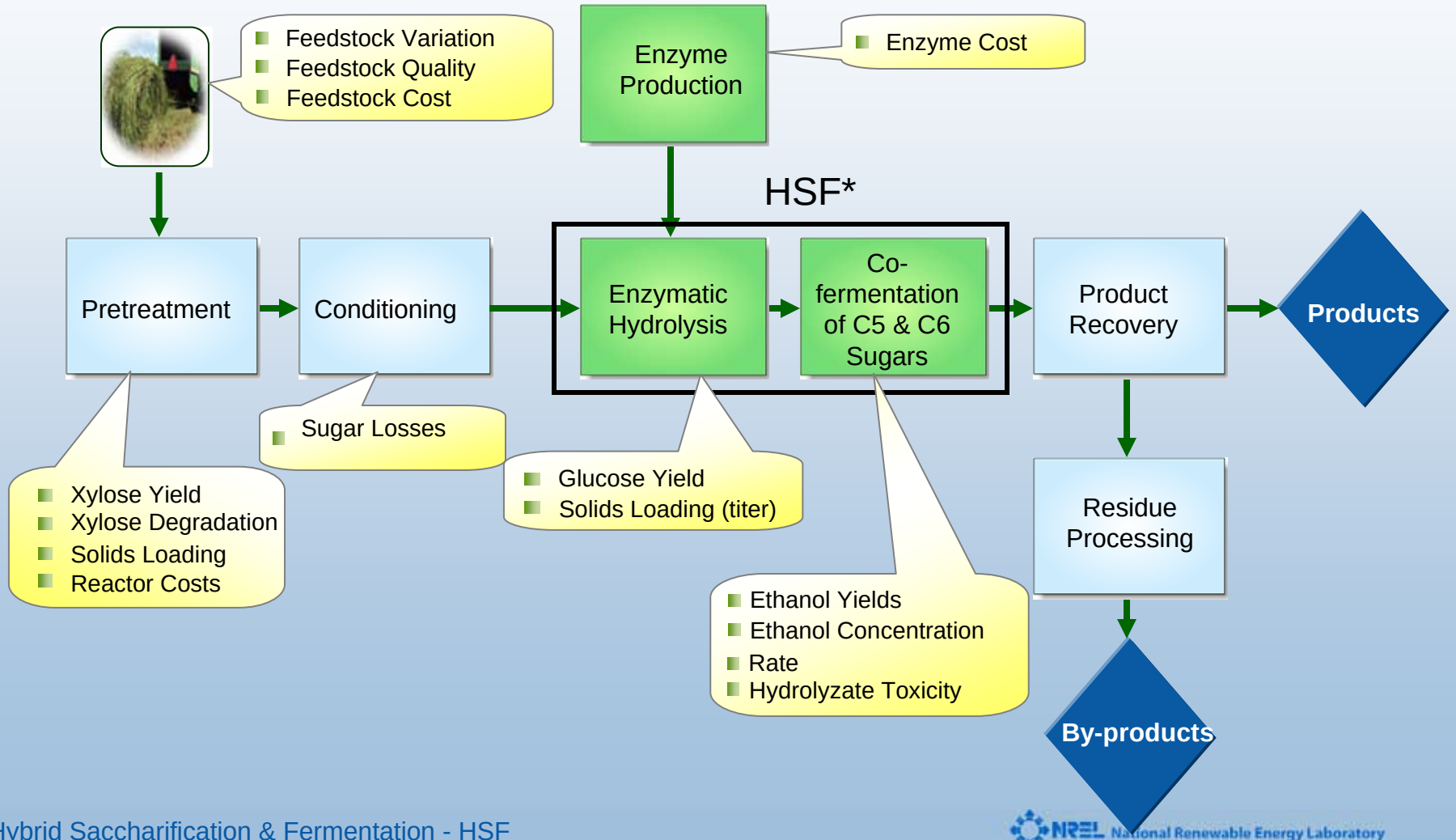
Biomass Characterization

- Wet chemical and NIR

Spectroscopy Facilities

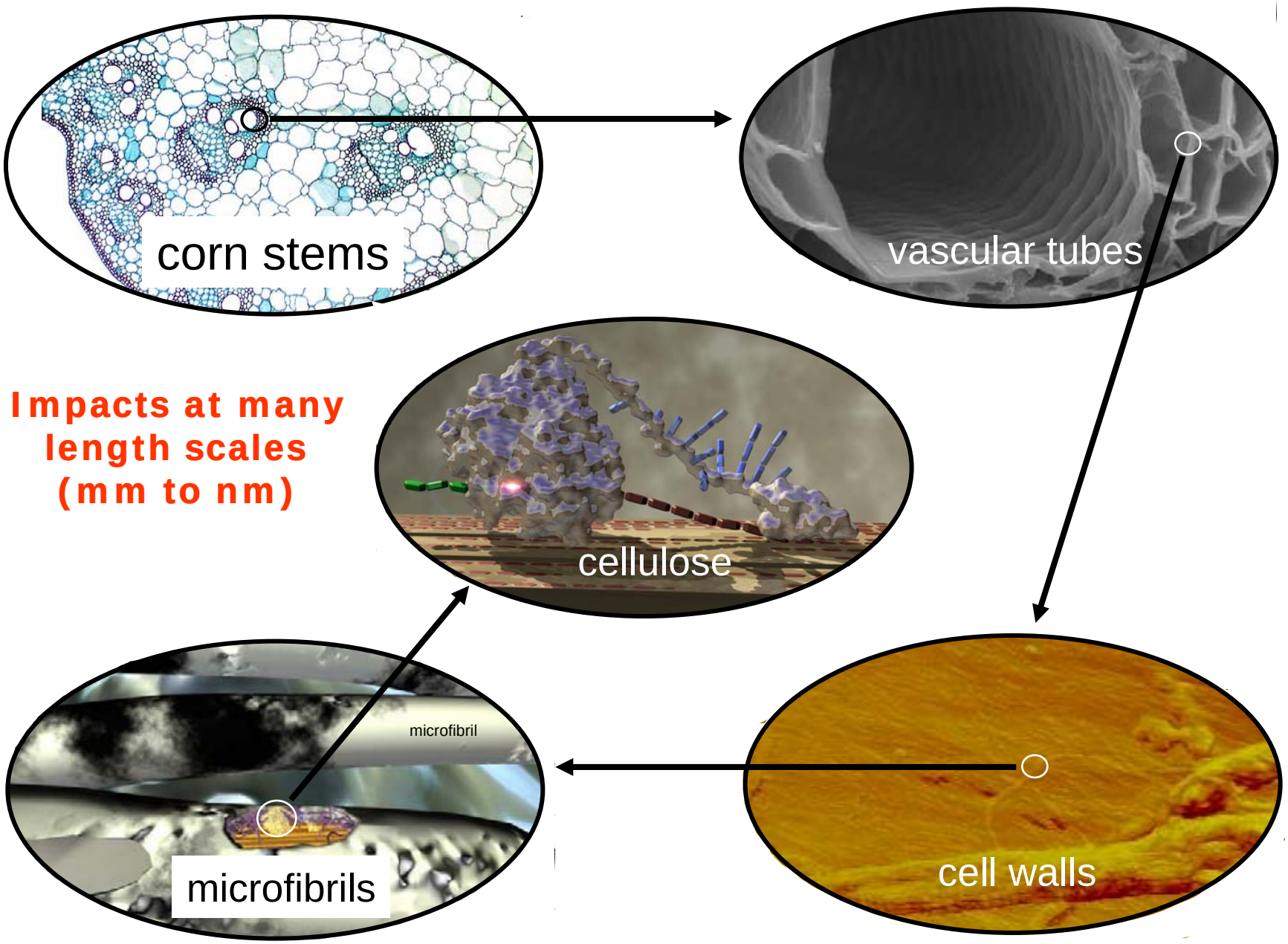
- nmr, IR, LIBS, MBMS

Technical Barrier Areas for $1.07 Biochemical Ethanol



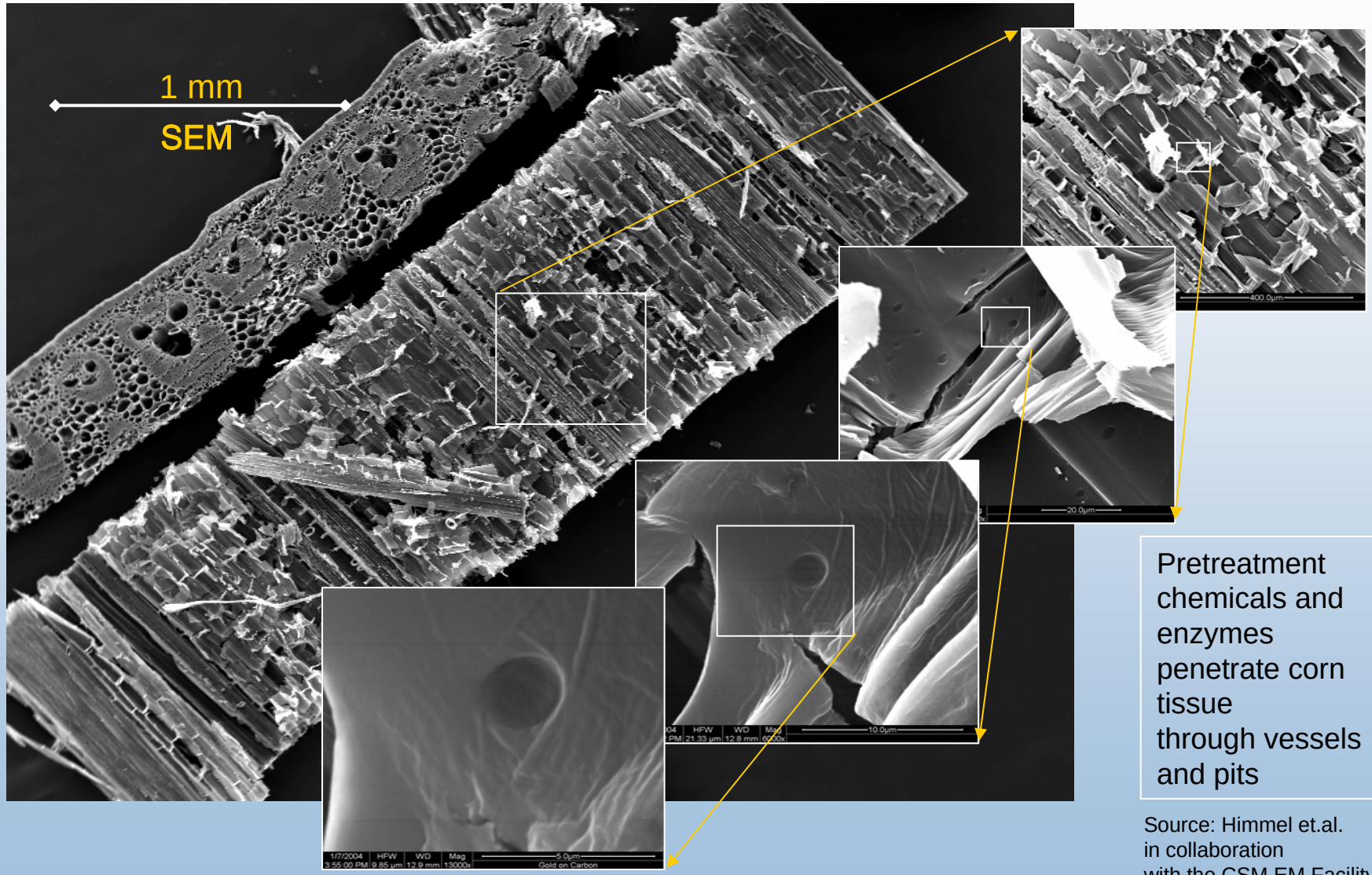
*Hybrid Saccharification & Fermentation - HSF

Biomass Recalcitrance



Impacts at many length scales (mm to nm)

How Do Chemicals Penetrate Biomass?



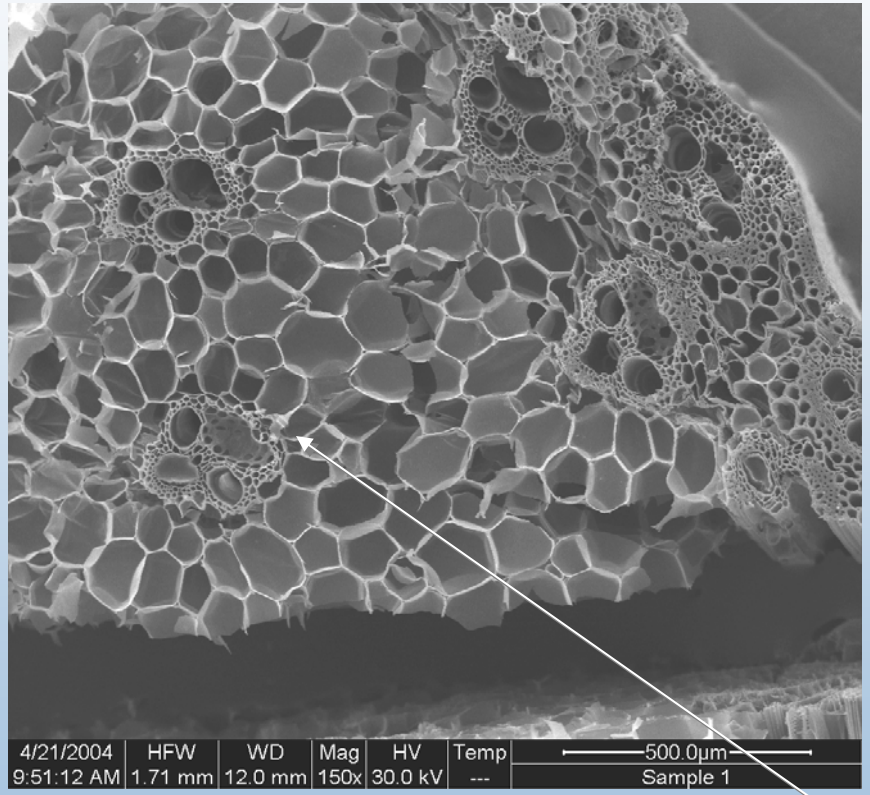
Pretreatment chemicals and enzymes penetrate corn tissue through vessels and pits

Source: Himmel et.al. in collaboration with the CSM EM Facility (2004)

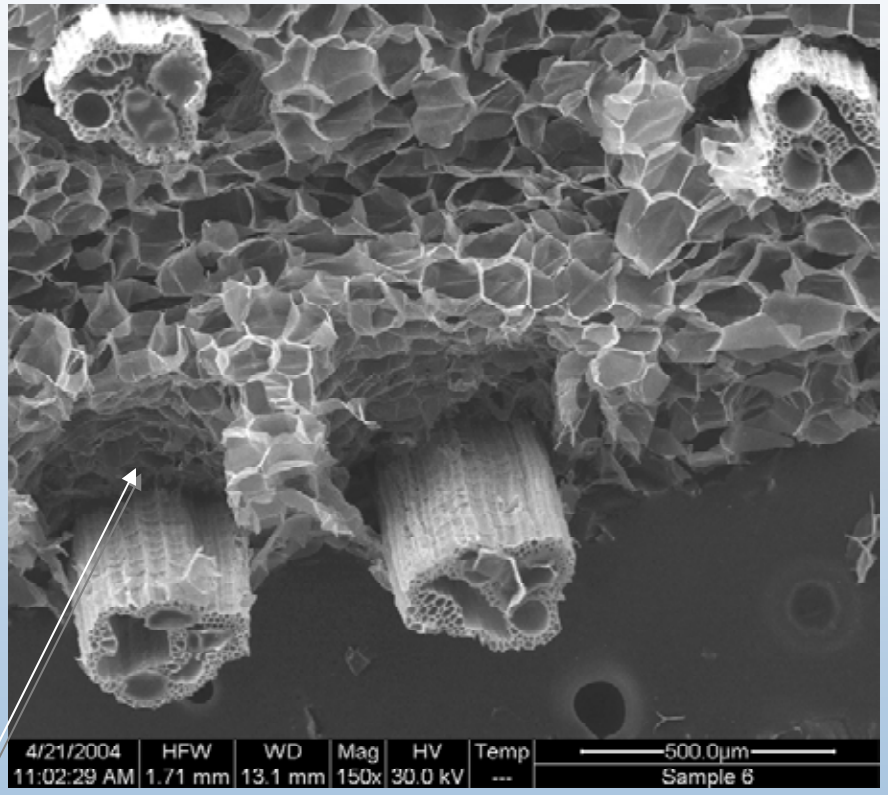
Saccharification

Enzymatic hydrolysis of cellulose or starch to glucose

Buffer treated corn stover



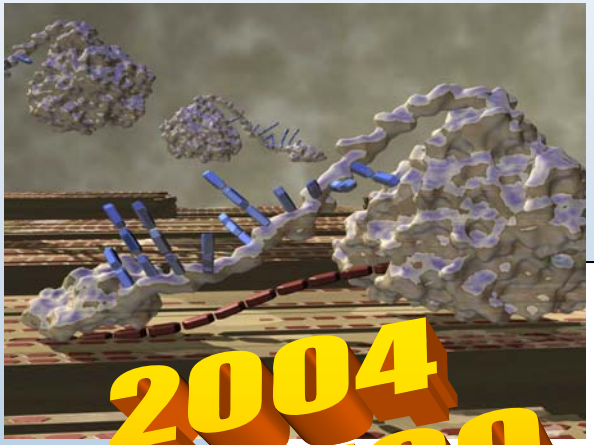
Enzyme treated corn stover



Note: zone around vascular bundle is eroded compared to native (suggests enzymes leak through pores in bundle)

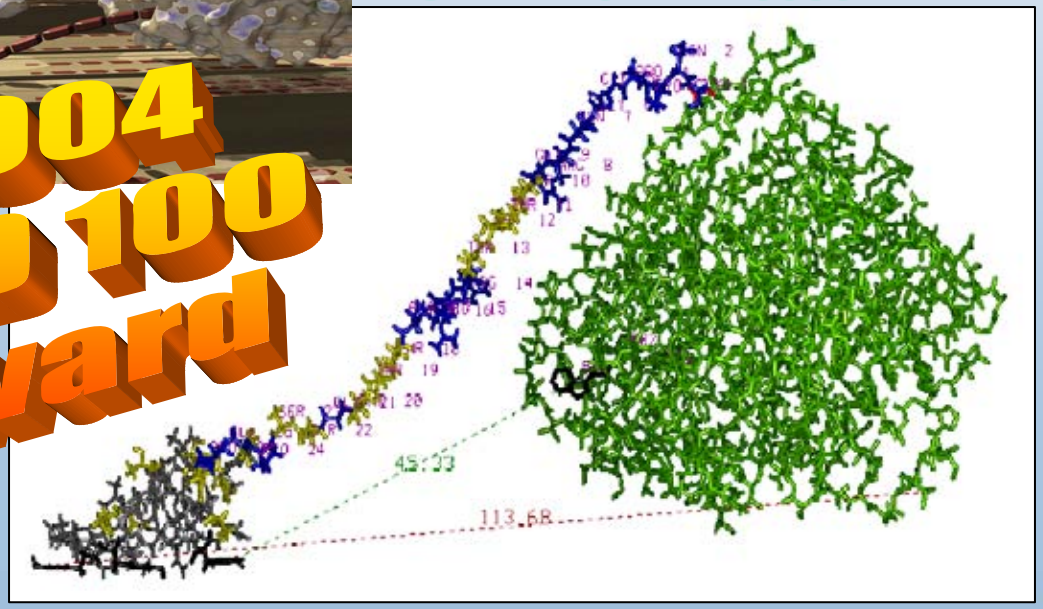
Enzyme Costs Have Fallen Sharply

- **DOE Subcontracts to Genencor and Novozymes (cost-shared)**
  Focus: lower production cost, increase enzyme system efficacy
  - Enzyme cost ($/gallon EtOH) = Prod. Cost ($/kg) x Usage Req. (kg/gallon EtOH)
  - ➢ Cellulase cost reduced 20-30X reduction (by subcontract metric)

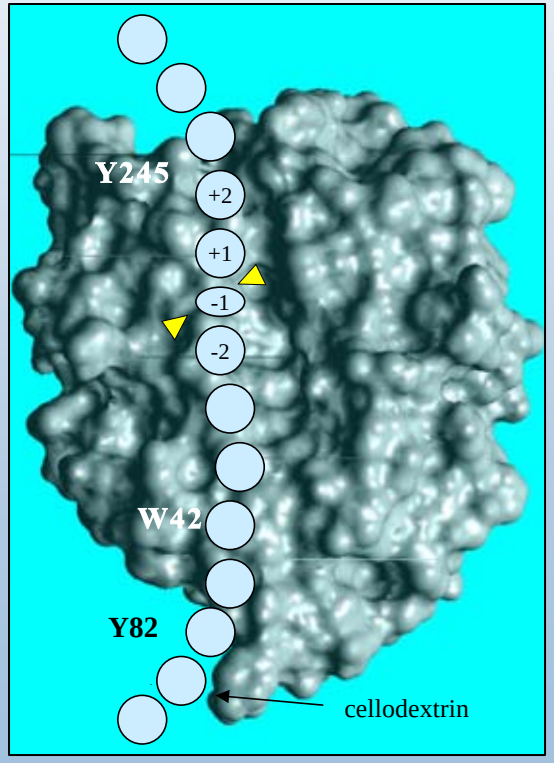


2004 R&D 100 Award

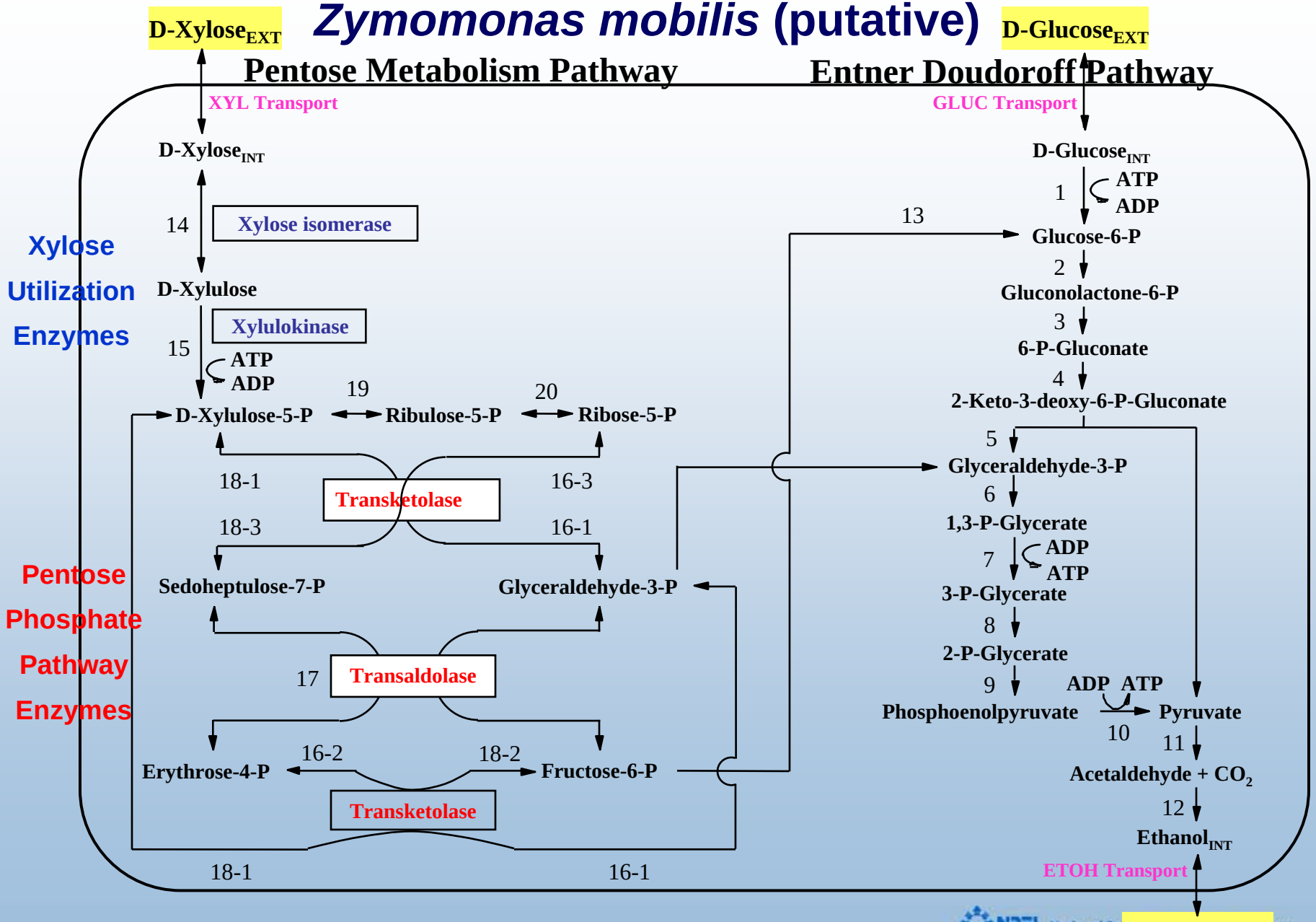
CBH1 from *T. reesei*



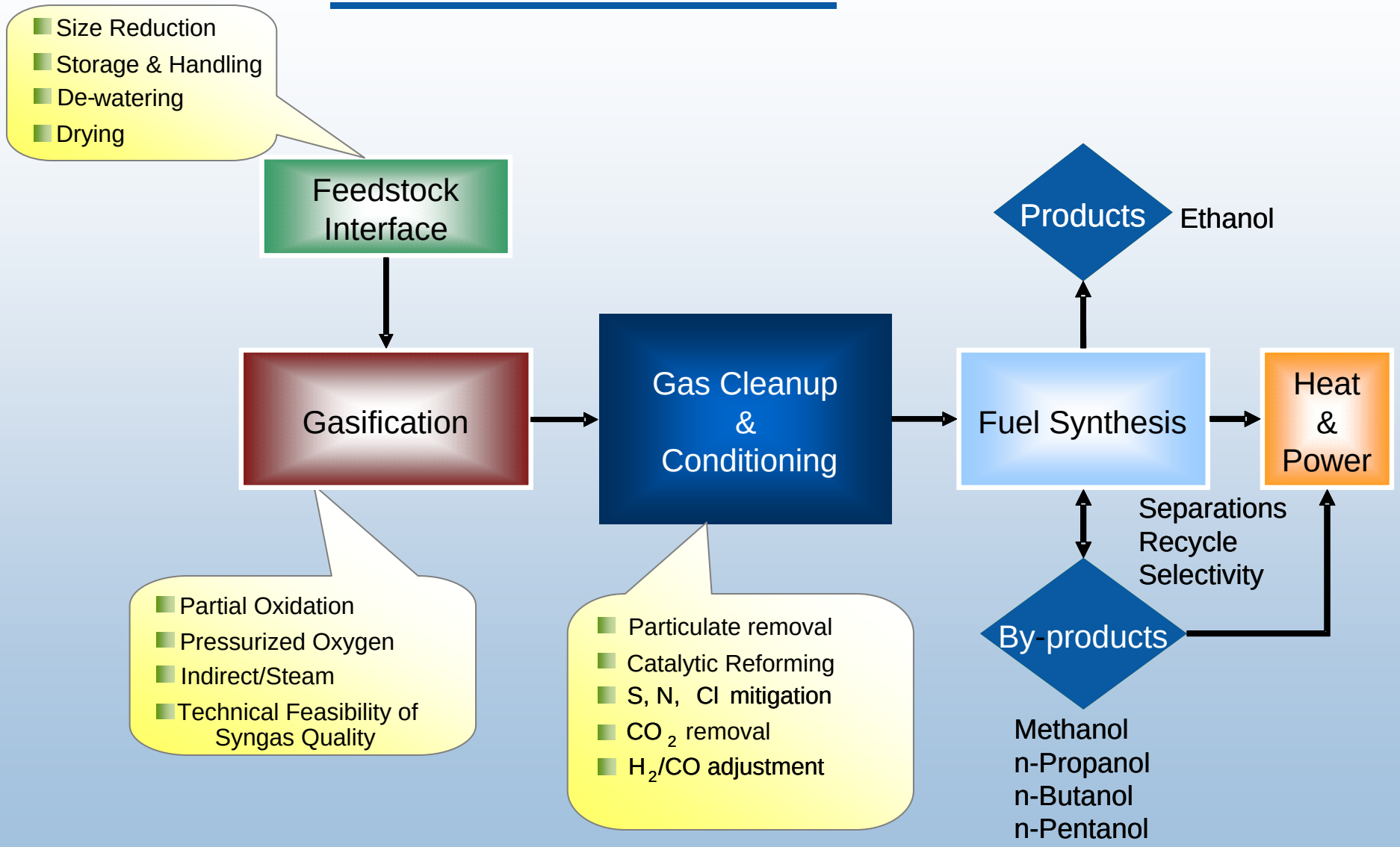
E1 from *A. cellulotiticus*



Cofermentation Pathway in Engineered *Zymomonas mobilis* (putative)



Technical Barrier Areas for $1.07 Thermochemical Ethanol

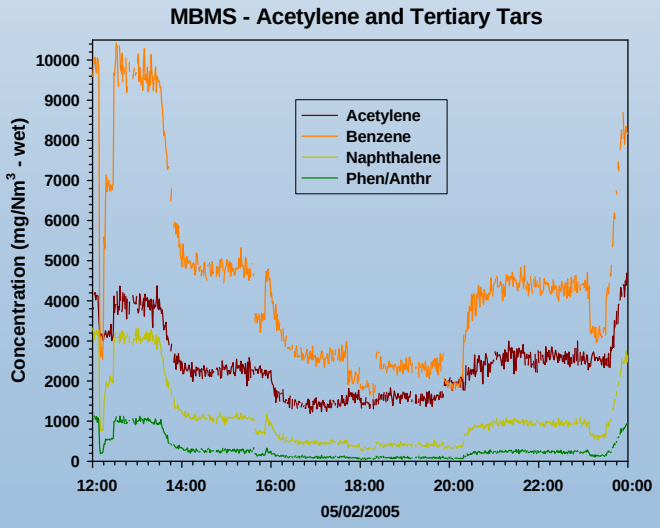


R&D Targets for Thermochemical Conversion

	Barrier	2005	2012 Goal
Overall Process Economics	Minimum Ethanol Selling Price	$1.61	$1.07 (05 dollars)
	Higher Alcohol Co-Product Value (% market value)	85%	BTU Adjusted as a discounted fuel
	Minimum Mixed Alcohol Selling Price ($/gal ethanol equivalent)	$1.80	$1.15
	Installed Capital Cost ($/annual gal MA)	$2.95	$2.31
	Operating Cost ($/annual gal MA)	$0.81	$0.61
	Ethanol Yield (gal/dry ton)	56	76
	Mixed Alcohol Yield (gal/dry ton)	77	89
	Feedstock Type	Wood Chips	Wood Chips
Cleanup & Conditioning	Tar reformer exit methane (mol% - dry basis)	8.25	1.73
	Tar reformer light HC reforming (% CH4 conversion)	20%	80%
	Tar reformer heavy HC reforming (% benzene)	70%	99%
	Tar reformer heavy HC reforming (% tar conversion)	95%	99.9%
	SMR Light HC reforming (% CH4 conversion)	79%	N/A
	Sulfur Removal	1ppmv (SMR)	50ppmv (MA)
Fuel Synthesis	CO2 Recycle (lb/lb dry feed)	1.72	0.66
	Compression for fuel synthesis (psia)	2,000	1,000
	Single pass CO conversion	38.5	50
	Overall CO conversion	96.9	98.1
	CO selectivity to alcohols	80	90

Pilot-scale Biomass Thermochemical Conversion Studies

- Gasification – feed dependent syngas quality, reforming catalyst performance
- Gasification efficiency and carbon conversion
- Gas Clean-Up and Conditioning
- Integrated tar reforming - catalyst lifetime & deactivation kinetics
- On-line tar and product analysis



Gas Conditioning and Tar Reforming

Compound	Current	Goal
Methane (CH_4)	20%	80%
Ethane (C_2H_6)	90%	99%
Ethene (C_2H_4)	50%	99%
Tars (C10+)	95%	99.9%
Benzene (C_6H_6)	70%	99%
Ammonia (NH_3)	70%	90%

Typical Hydrocarbons/Tars Observed

Molecular Weight	Formula	Chemical Name(s)
15,16	CH_4	methane
26	C_2H_2	acetylene
78	C_6H_6	benzene
91,92	C_7H_8	toluene
94	C_6H_6O	phenol
104	C_8H_8	styrene
106	C_8H_{10}	(m-, o-, p-) xylene
108	C_7H_8O	(m-, o-, p-) cresol
116	C_9H_8	indene
118	C_9H_{10}	indan
128	$C_{10}H_8$	naphthalene
142	$C_{11}H_{10}$	(1-, 2-) methylnaphthalene
152	$C_{12}H_8$	acenapthylene
154	$C_{12}H_{10}$	acenaphthene
166	$C_{13}H_{10}$	fluorene
178	$C_{14}H_{10}$	anthracene, phenanthrene
192	$C_{15}H_{12}$	(methyl-) anthracenes/phenanthrenes
202	$C_{16}H_{10}$	pyrene/fluoranthene
216	$C_{17}H_{12}$	methylpyrenes/benzofluorenes
228	$C_{18}H_{12}$	chrysene, benz[a]anthracene, …
242	$C_{19}H_{14}$	methylchrysenes, methylbenz[a]anthracenes
252	$C_{20}H_{12}$	perylene, benzo[a]pyrene, ...
266	$C_{21}H_{14}$	dibenz[a,kl]anthracene, …
278	$C_{22}H_{14}$	dibenz[a,h]anthracene, …

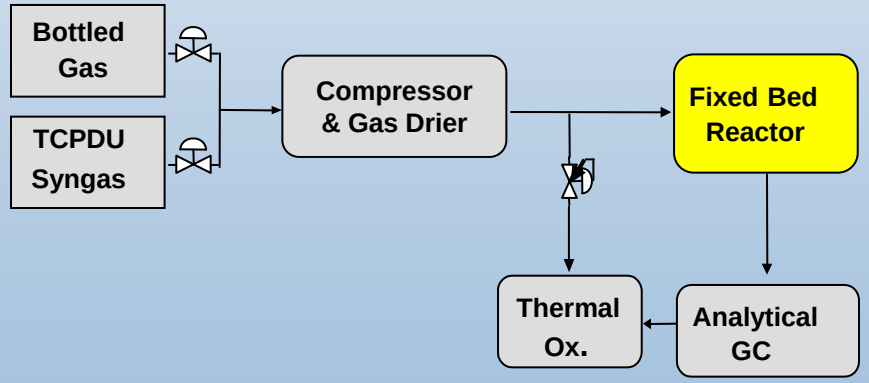
Fuel Synthesis – Phase I -Mixed Alcohols

- Objective:
  Improve the productivity and selectivity of catalysts for making ethanol and mixed alcohols from biomass syngas

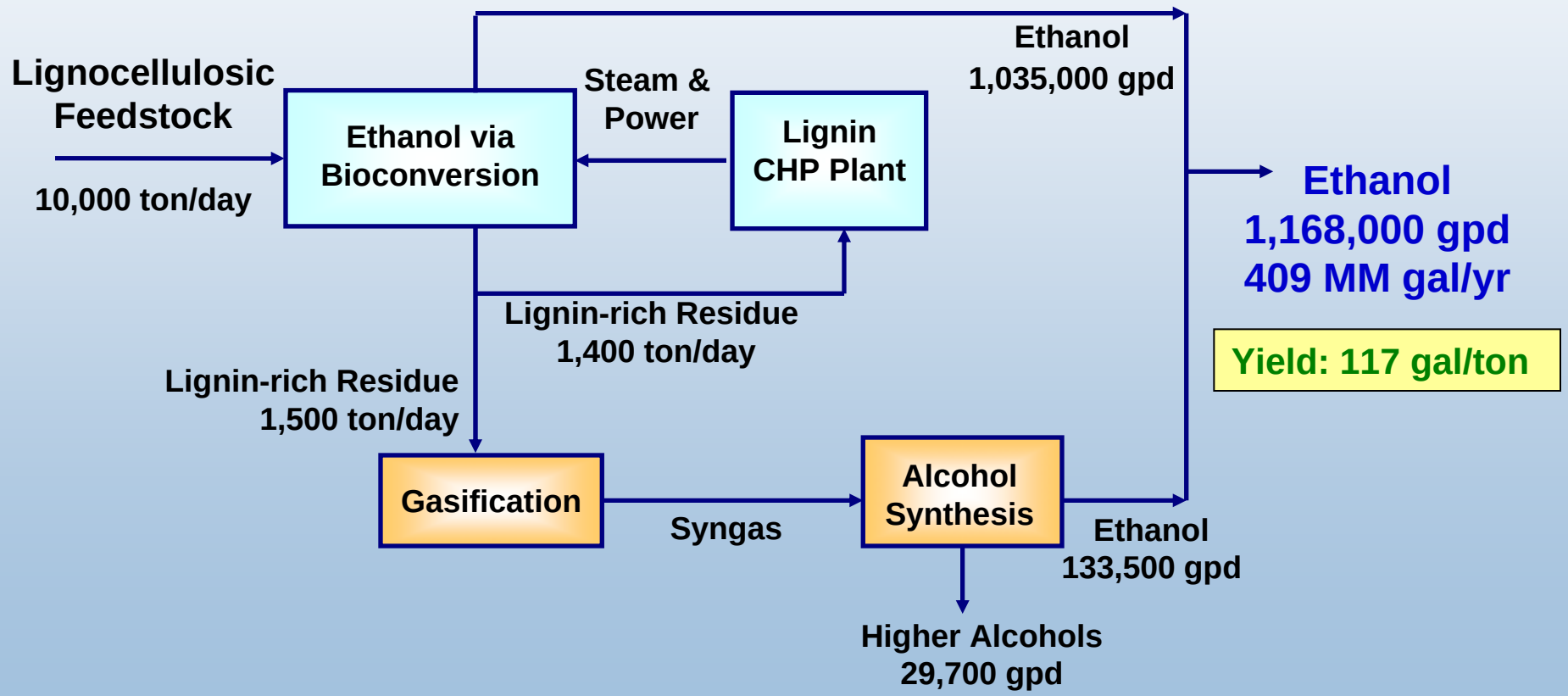
- Partnerships: PNNL, NREL, and selected catalyst companies

- Overview:
  - PNNL is screening new catalysts at small scale using "bottled" syngas
  - NREL is testing promising candidates using syngas from a biomass gasifier

- Importance:
  Improvements in catalyst performance necessary to meet the goal of $1.07/gallon ethanol by 2012.



Advanced State of Technology Target for a Large Cellulosic Biorefinery to Integrate BC & TC Paths



S. Phillips and J. Jechura

Sustainability Challenges

Biomass to Biofuels System

Greenhouse Gas Emissions

Economic Prosperity
- Rural and urban communities
- Industry

Social Well-being

Biofuels and Biomass
- Supply infrastructure
- Fuel production
- Distribution and use

Land
- Use and change
- Competition with food
- Soil

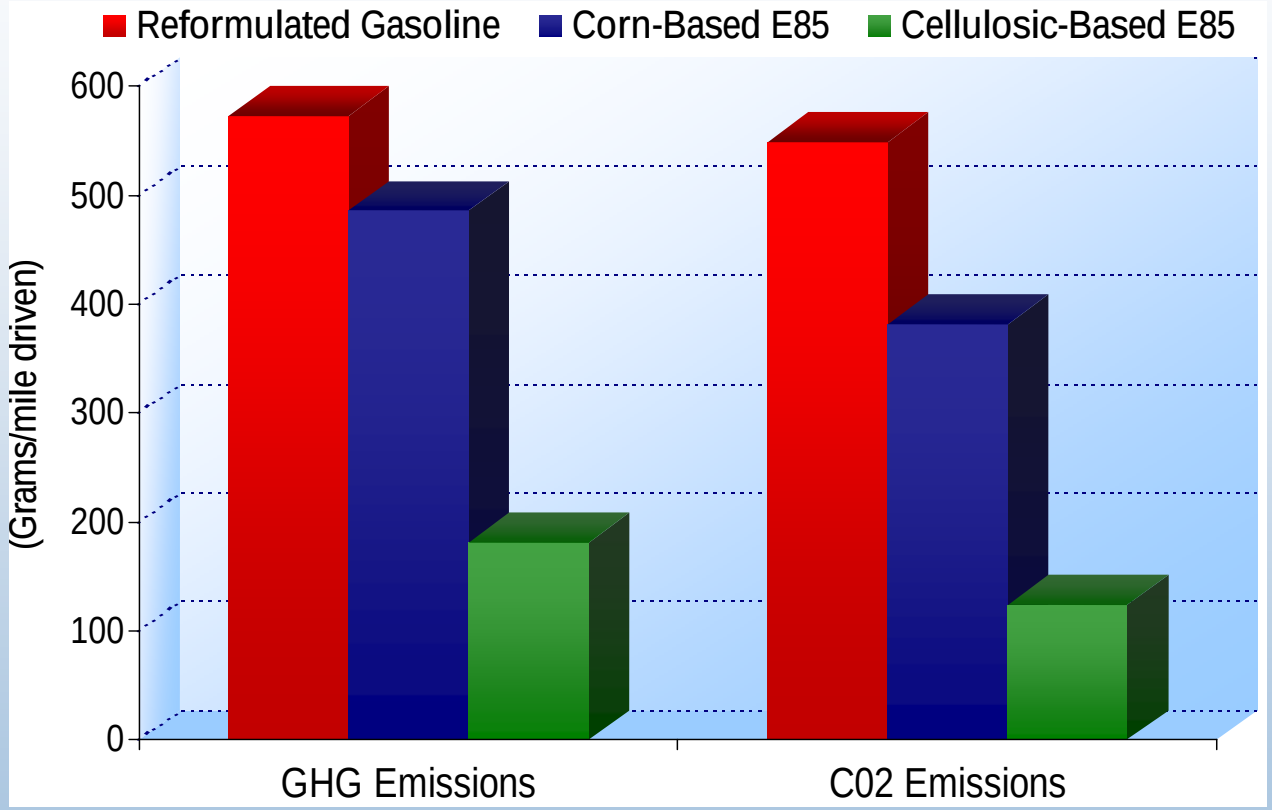
Biodiversity

Water
- Use
- Quality
- Efficiency of use

Environmental Impacts

Increase Food and Energy Security

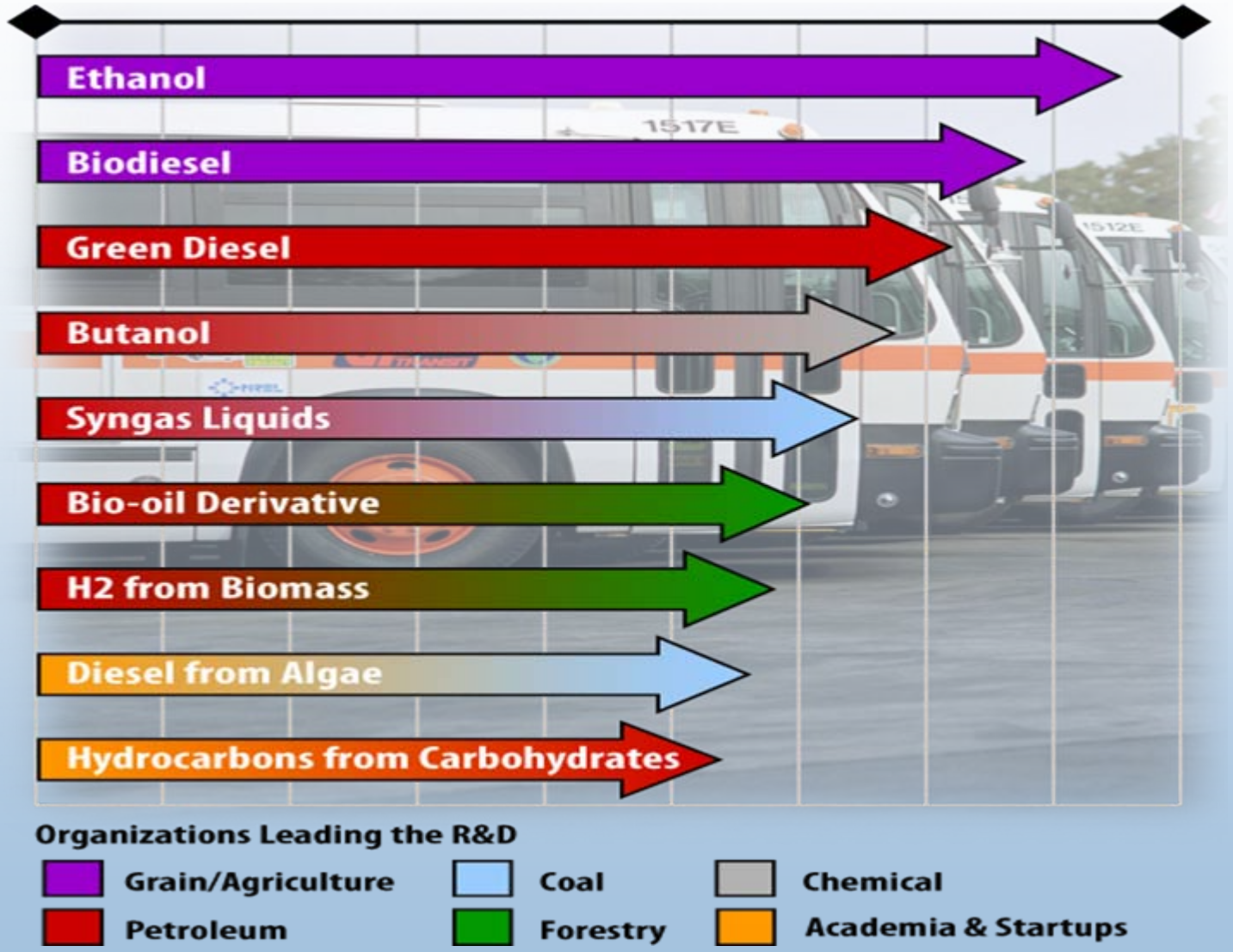
Relative Emissions Impacts



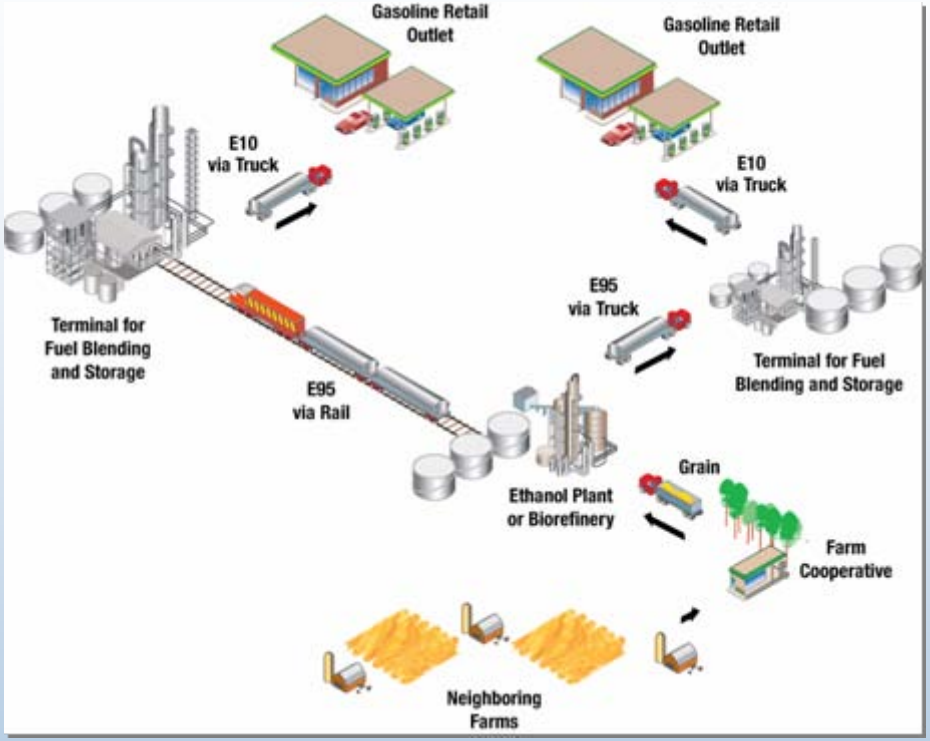
Biofuels can lower our production of greenhouse gases

Source: *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems* May 2005, Argonne National Laboratory.

Technology Maturity Pathways



Infrastructure



Multiple Biofuels and Distribution Infrastructures

–Non-fungible with fossil fuels (e.g., ethanol is the near-term biofuel)

- Require additional infrastructure
- Leverage FFVs and advanced power trains

–Fungible with fossil fuels (e.g., renewable diesel)

- Less infrastructure change

Questions?