NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Cellulosic Biomass Conversion to Fuels: The Sorghum Opportunity & Ongoing NSP/NREL Research Activities

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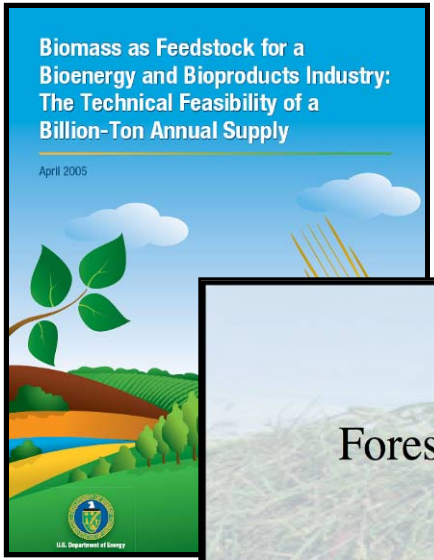
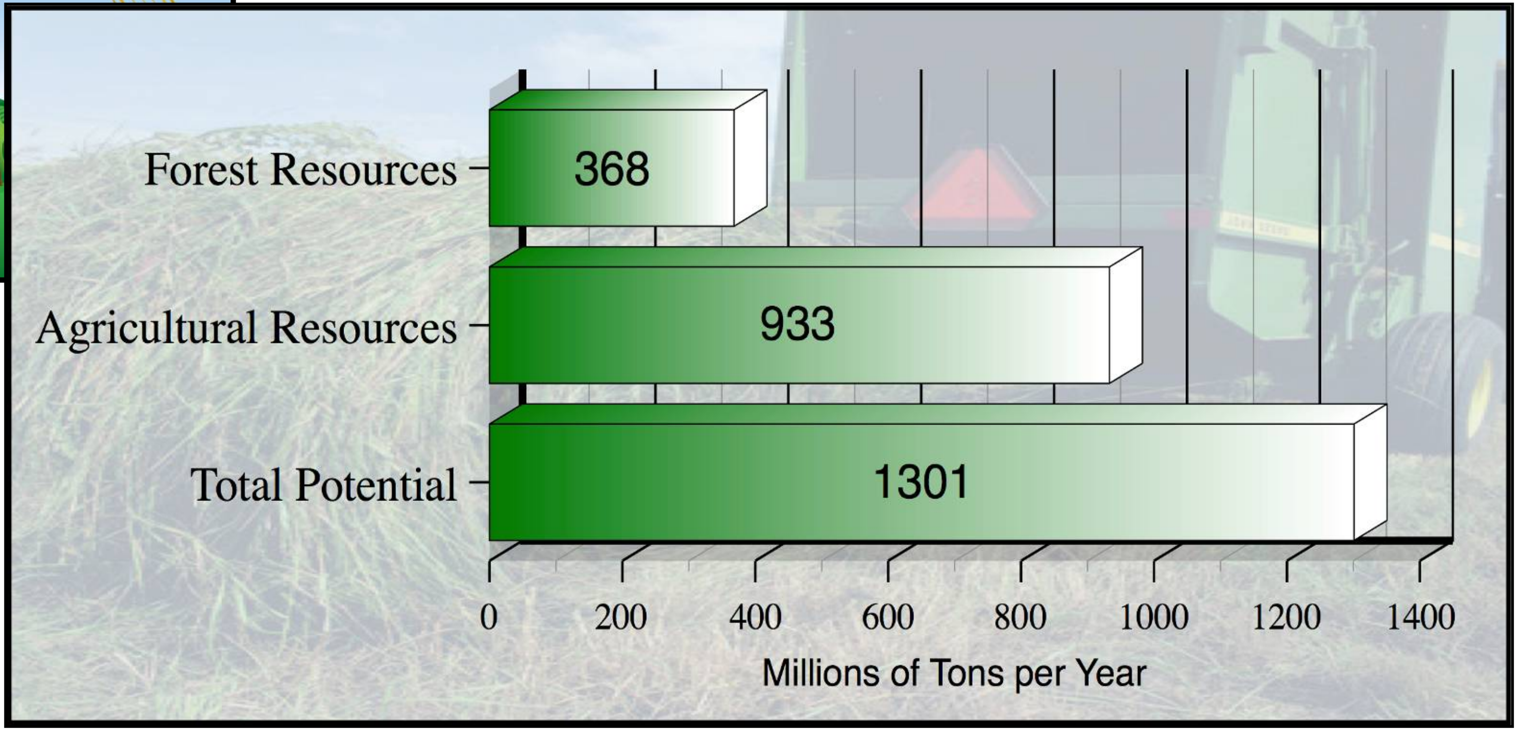
August 18, 2008

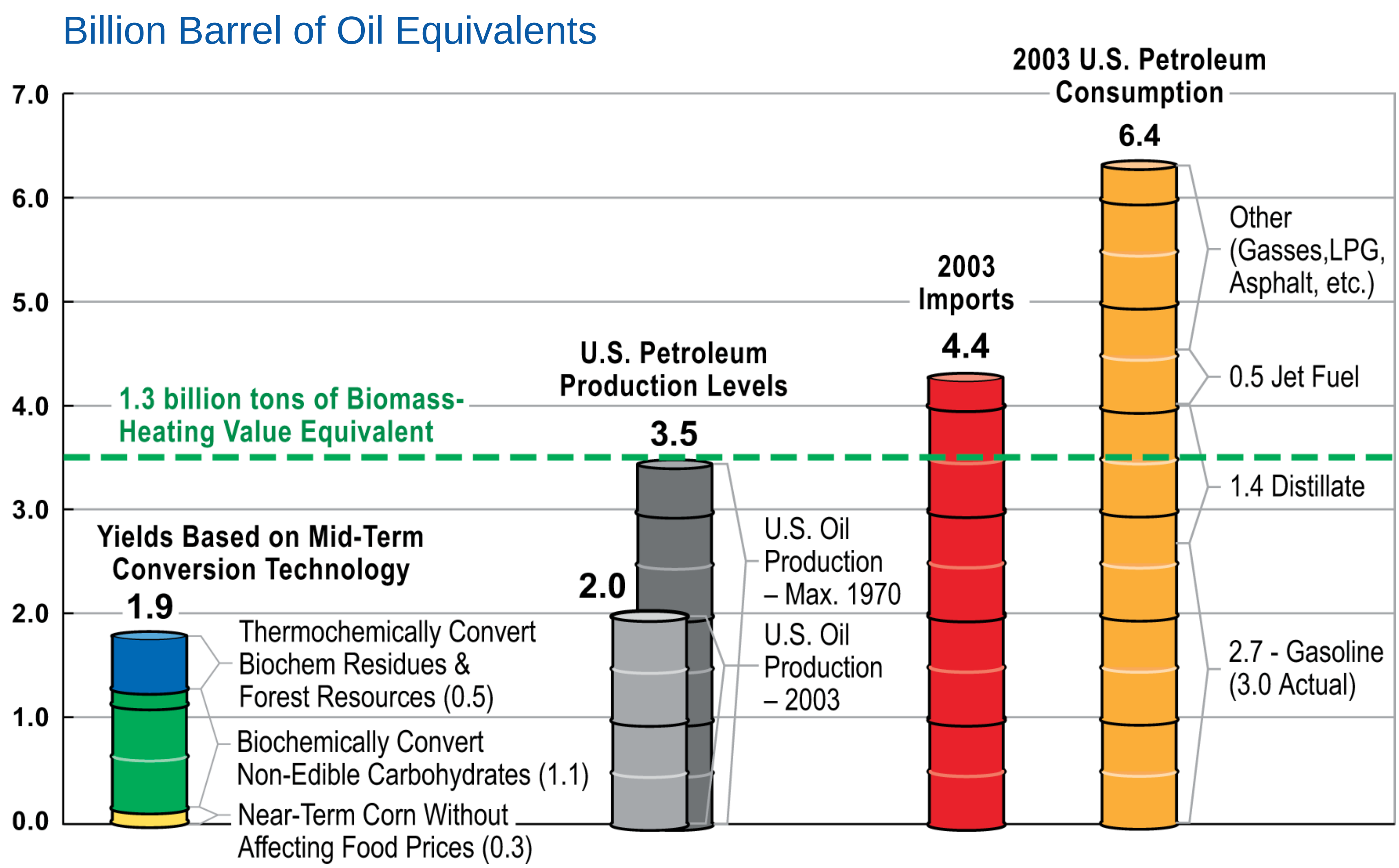
U.S. Biomass Resource Assessment



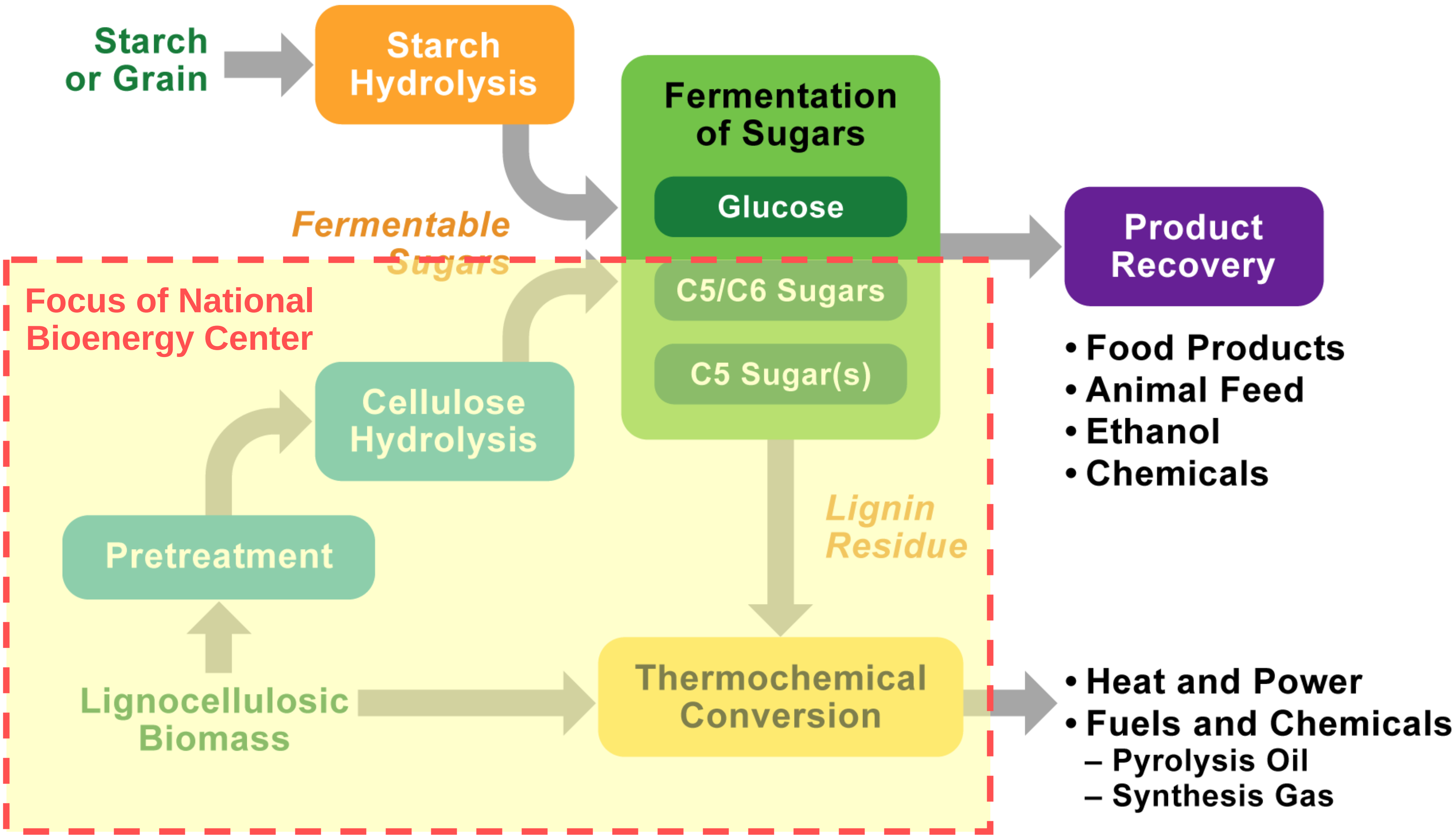
- Updated resource assessment - April 2005
- Jointly developed by U.S. DOE and USDA
- Referred to as the "Billion Ton Study"



Significance of the "Billion Ton" Scenario

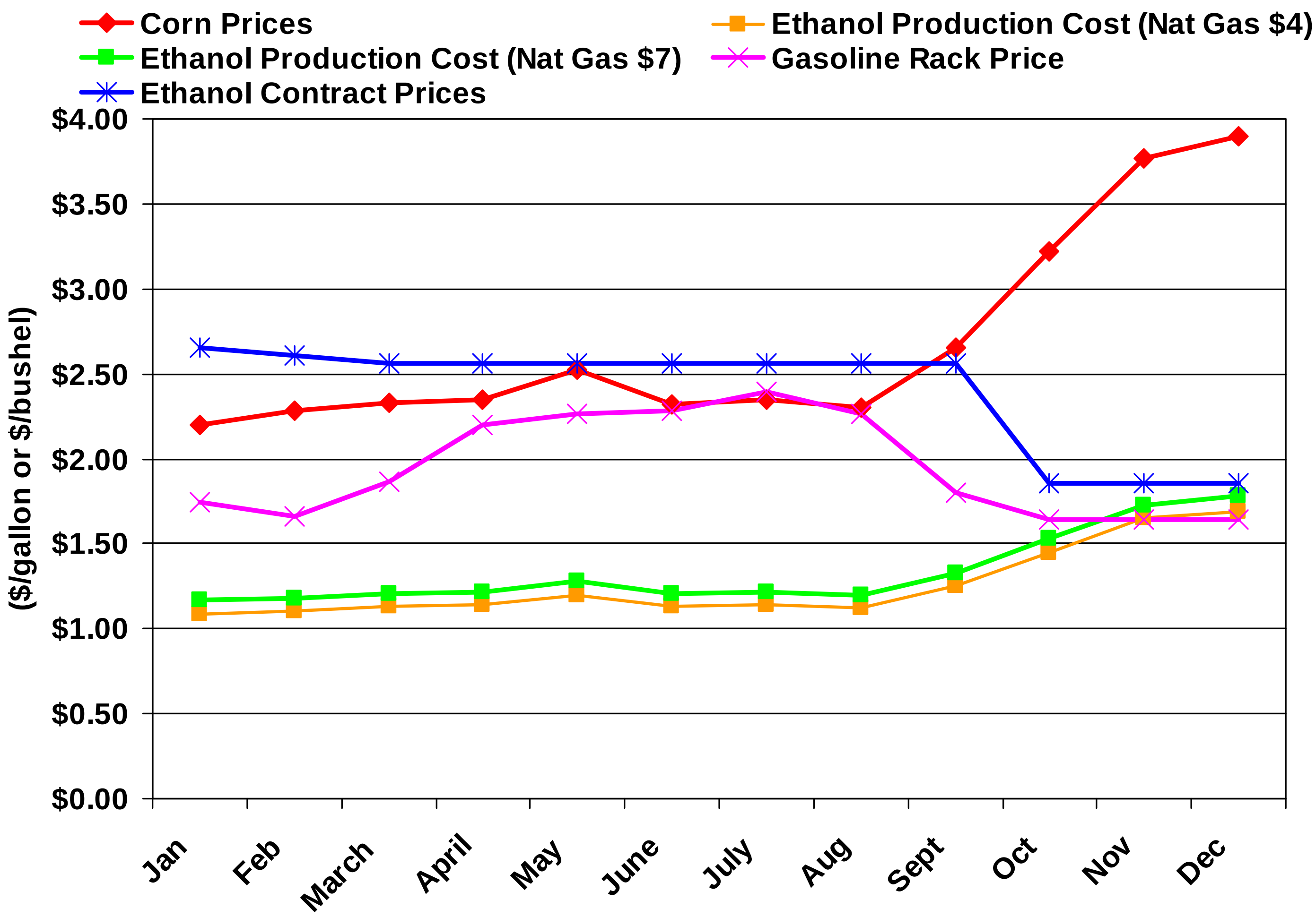


Integrated Cellulosic Ethanol Biorefinery



The Problem

Corn Prices and Ethanol Prices are Decoupled – the Example of 2006



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

The NSP/NREL Ongoing Research

- Characterize in detail the cellulose, hemicellulose, lignin and "other" components for
  - 85 U.S. forage sorghum varieties
  - 5 grain sorghum varieties
  - 5 sweet sorghum varieties
  - 5 hay sorghum varieties
  - Collect Near-IR spectra on each sample for future equation development
- Characterize proximate and ultimate analysis for 10 varieties that could be considered for thermochemical processing
- Undertake micro-reactor bench-scale pretreatment and saccharification screening of a subset (20) of these varieties, looking for those with the best conversion
  - 16 forage varieties
  - 2 grain sorghum varieties
  - 2 sweet sorghum varieties
- Undertake larger scale (Zipperclave) pretreatment trials and optimization on three promising varieties

The NSP/NREL Ongoing Research (cont.)

- Undertaking pilot-scale (1 ton/day) pretreatment, saccharification, and fermentation on one or two of the most promising varieties
- Develop detailed Aspen+ technoeconomic models for
  - Grain sorghum conversion
  - Forage sorghum conversion (cellulosic conversion)
  - Sweet sorghum conversion (including cellulosic fraction)
- Models will provide
  - projected commercial plant capital
  - Operating and feedstock costs, and
  - product prices for each potential feedstock.
- Models will provide basis for Life-cycle Analysis needed to qualify as Advanced Biofuel (50% or more reduced Greenhouse Gas emissions vs. gasoline)

Importance of Analysis in Biomass Utilization

NREL has more than 25 years of experience in biomass analysis.

- Experience in the analysis of a wide variety of biomass types
- Standard Methods published through ASTM E48 Biotechnology
- Standard Reference Materials available through NIST.

History

NREL LAPs are based on the Uppsala Method for the analysis of dietary fiber.

- Summative analysis
- Micro method
  - Furda, I; *Simultaneous analysis of soluble and insoluble dietary fiber,* The Analysis of Dietary Fiber in Food, W.P. T. James and O. Theander(Eds), Marcel Dekker, New York, 1981, pp.163 –172.
- Used for Validation of NIST biomass Standard Reference Materials in International Energy Agency sponsored Round Robin
  - Milne, T. A.; Chum, H. L.; Agblevor, F. A.; Johnson, D. K.; *Standardized Analytical Methods,* Proceedings of International Energy Agency Bioenergy Agreement Seminar, Vol 2(1-6), April, 1992, (341-366).

NIST Standards

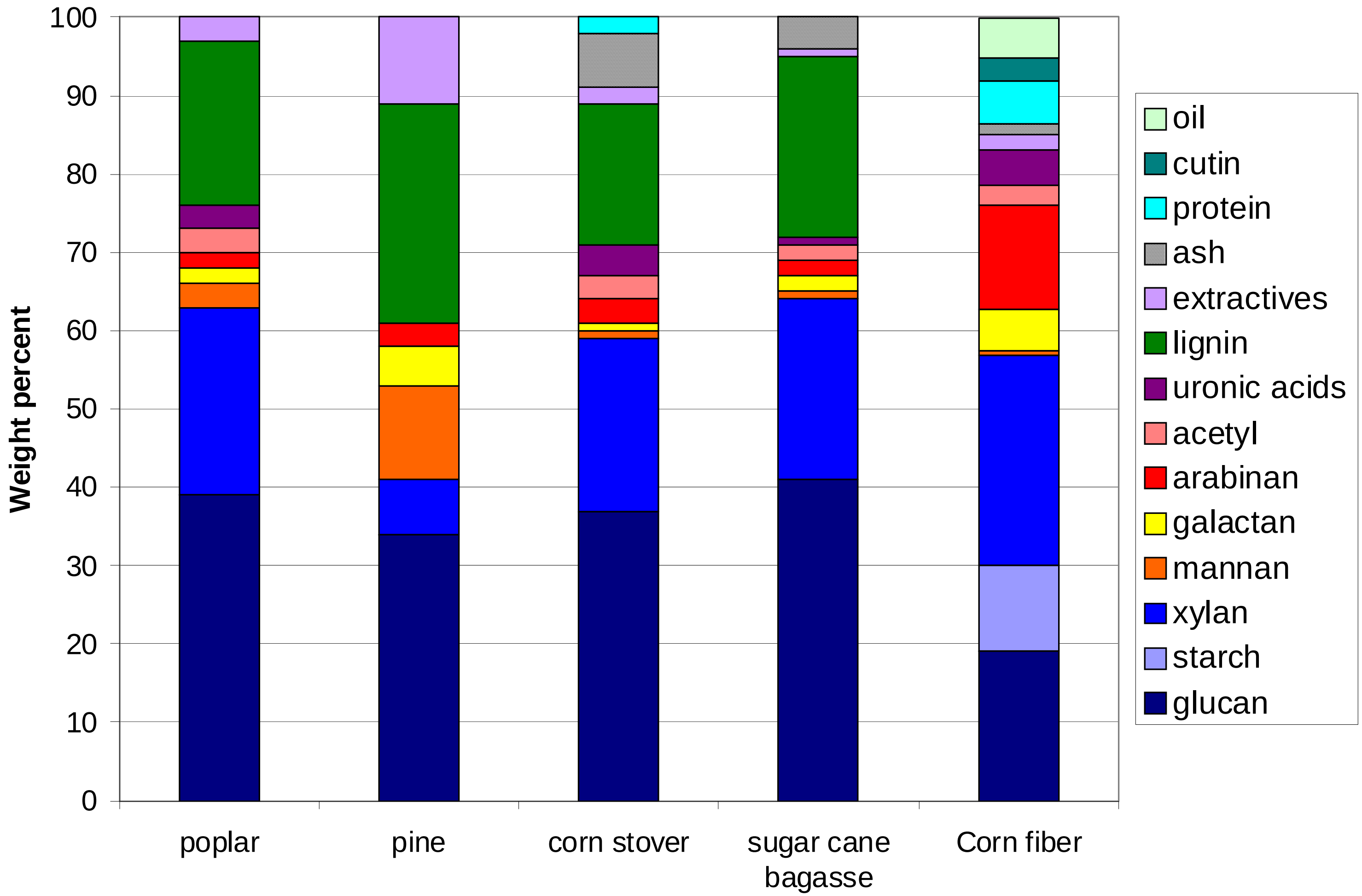
Web-Based Biomass Analysis Resources

*www.nrel.gov/**biomass**/analytical_procedures.html*

NREL Laboratory Analytical Procedures (LAPs) are available for download

LAPs are updated continuously

Feedstock Comparison



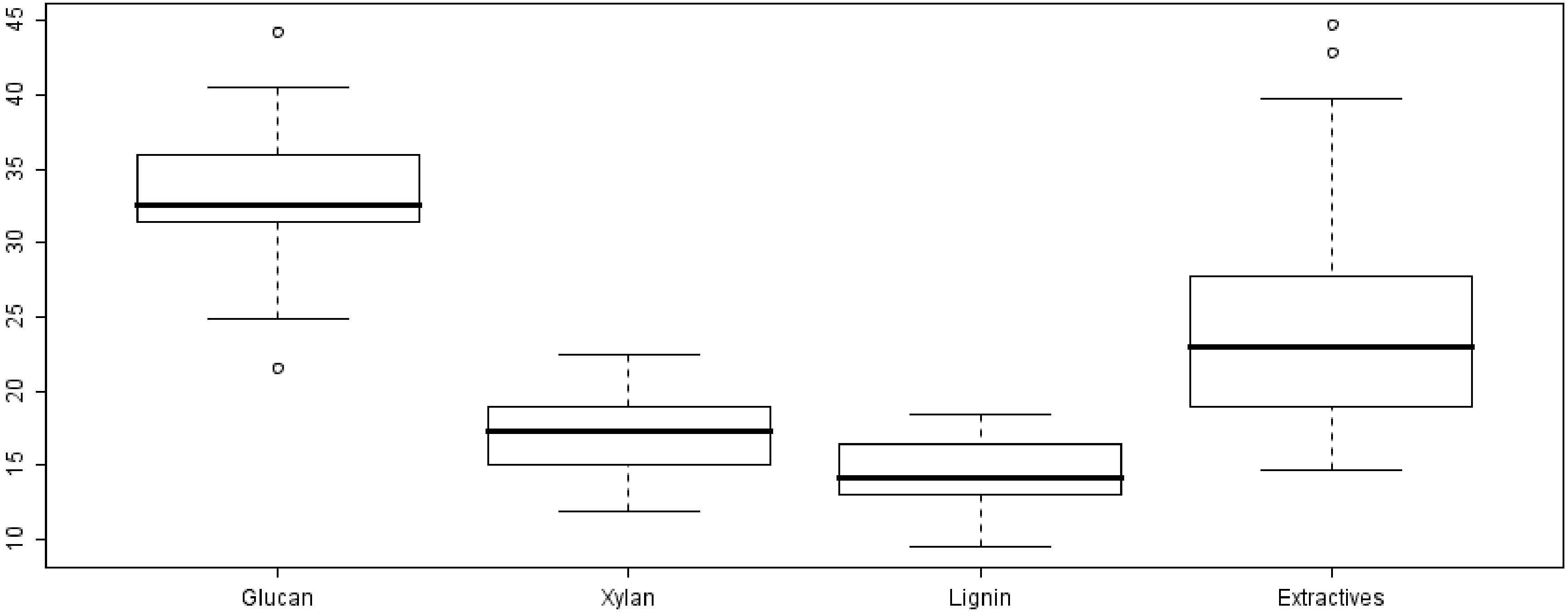
Each biomass feedstock has a unique combination of constituents

Initial Sorghum Compositional Data

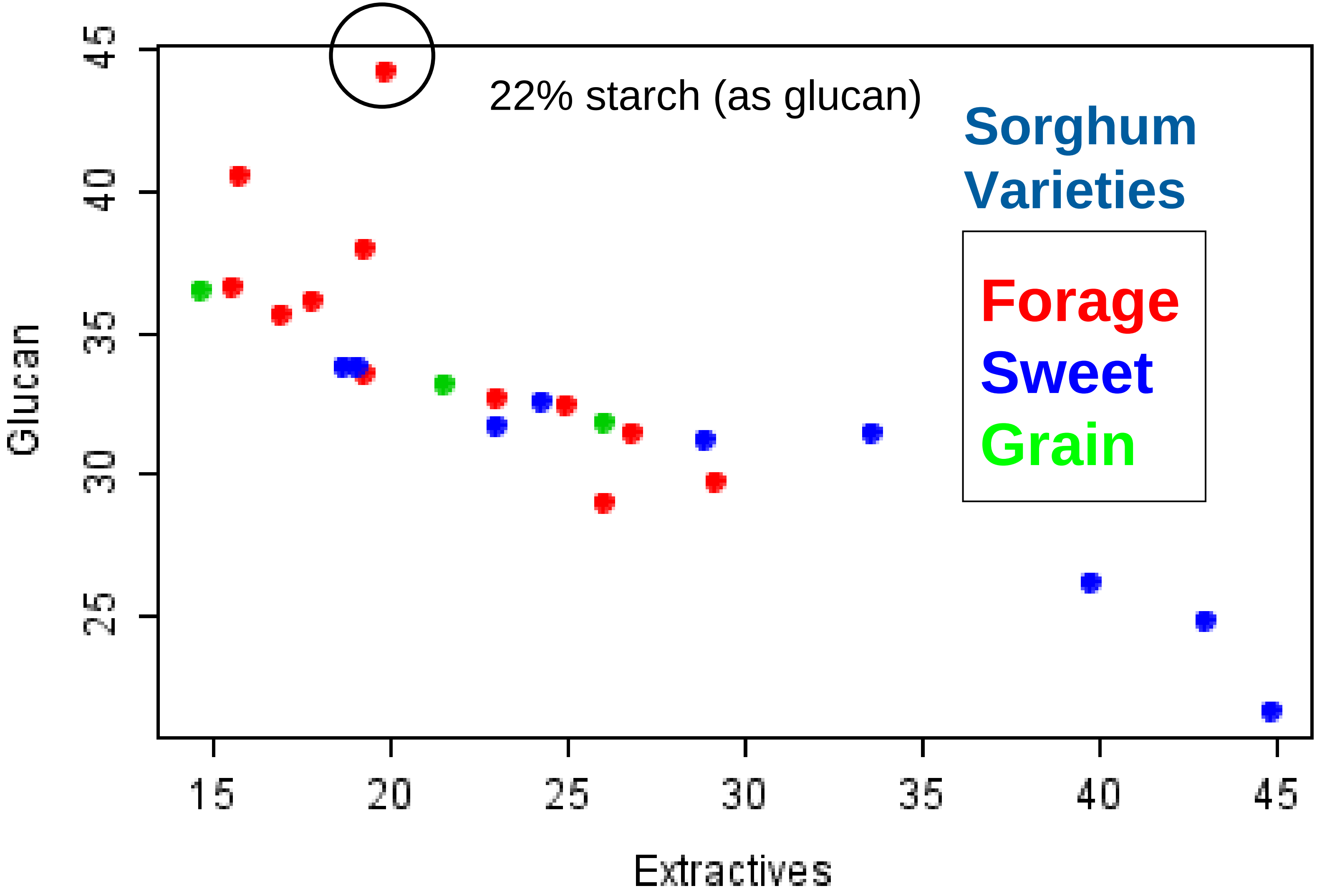
- NREL have done detailed wet chemistry on 24 samples provided by NSP as of August 11, 2008 – others in progress
- To date, NREL has analyzed:
  - 12 forage sorghums
  - 9 sweet sorghums
  - 3 grain sorghums
- Initial findings:
  1. Large Variability in Composition; largely due to extractives variability
  2. Trends in Variability with sorghum type

Large Compositional Variability

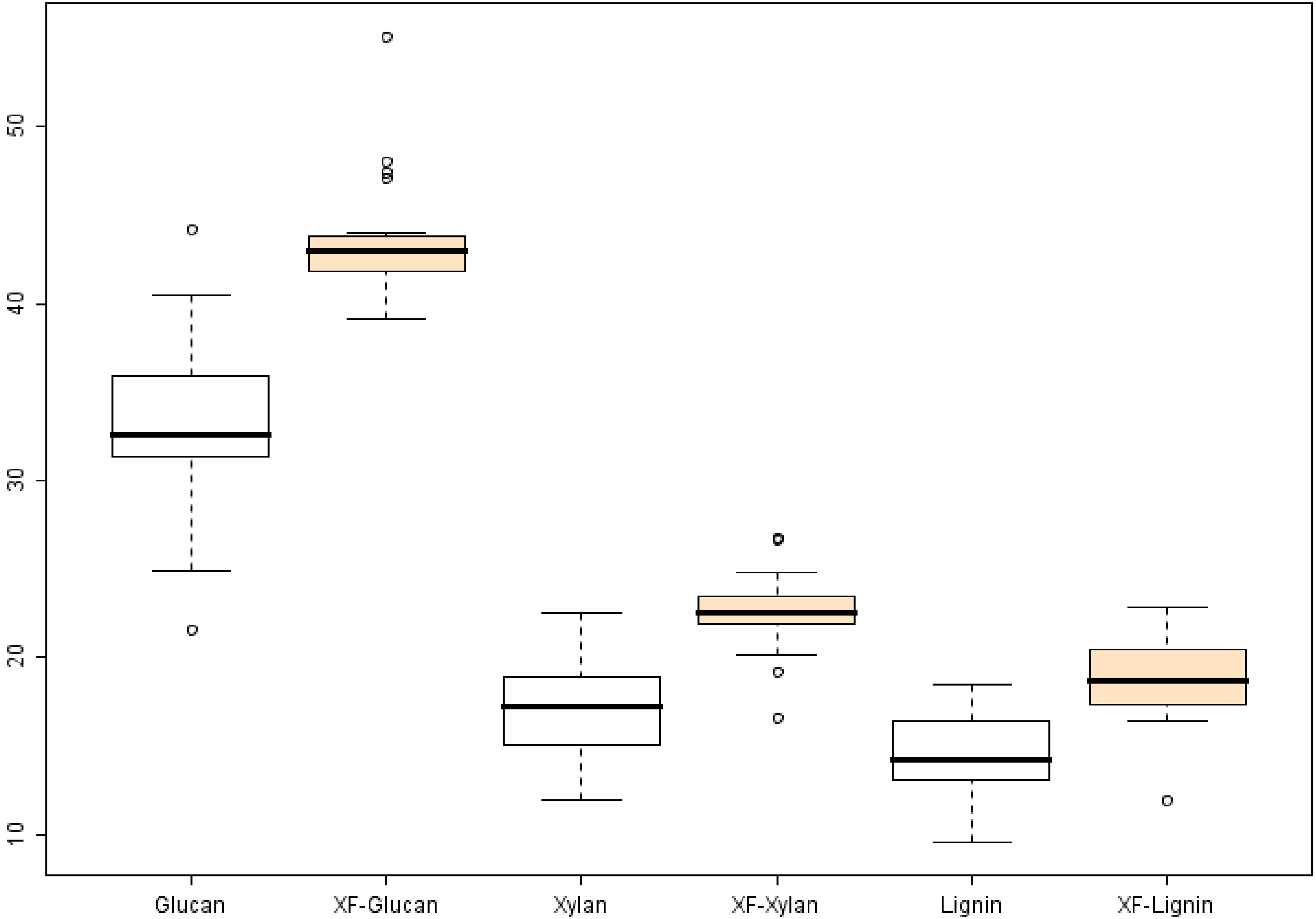
	Glucan	Xylan	Lignin	Sucrose	Extractives	Structurals
min	21.6	11.9	9.5	0.1	14.3	51.7
mean	32.8	17.3	14.2	5.5	24.3	72.7
max	44.2	22.5	18.4	21.3	44.8	86.0
range	22.6	10.6	8.9	21.2	30.5	34.2



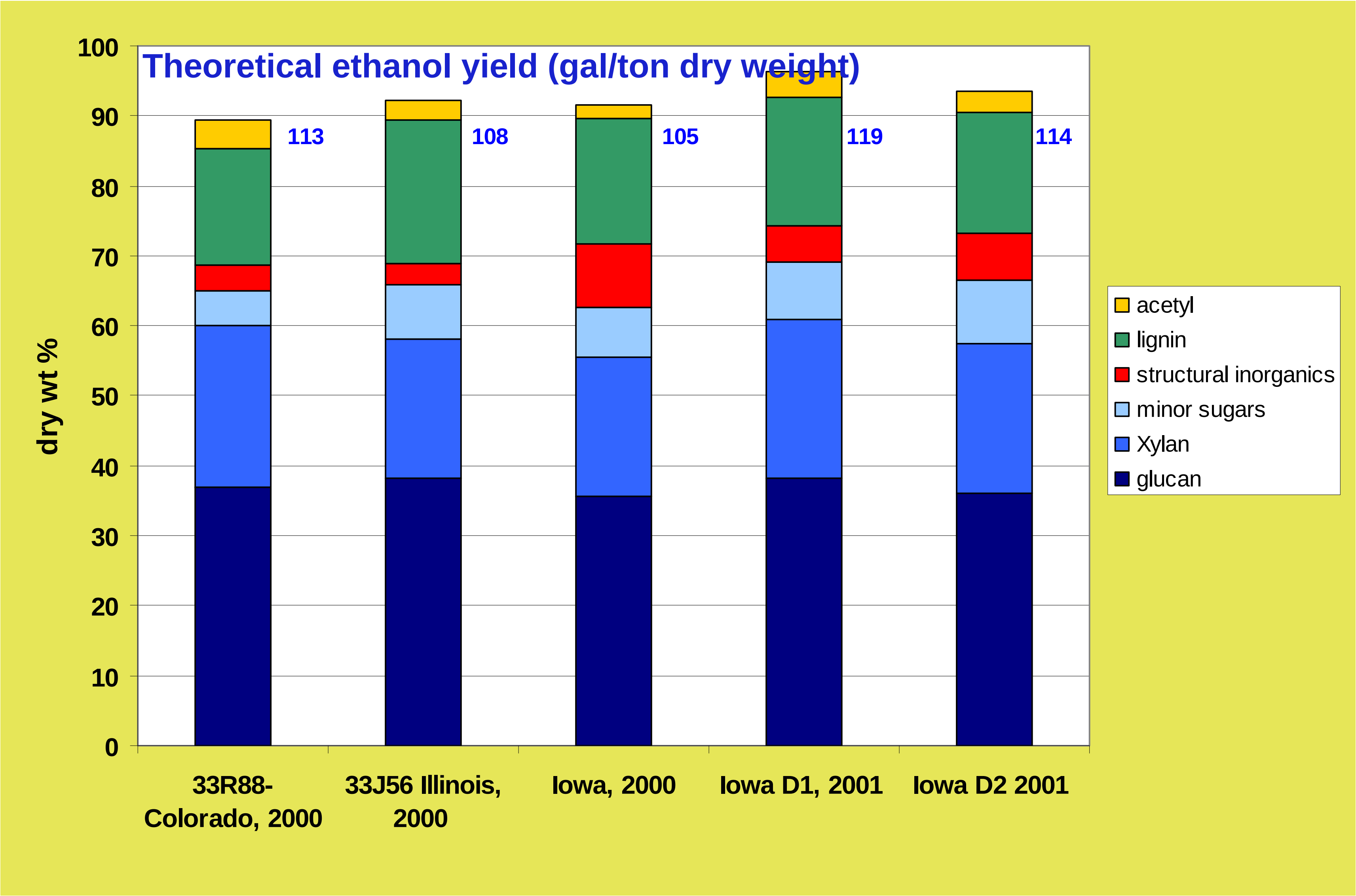
Initial Sorghum Compositional Data (cont.)



Less Variability on Extractives-Free Basis



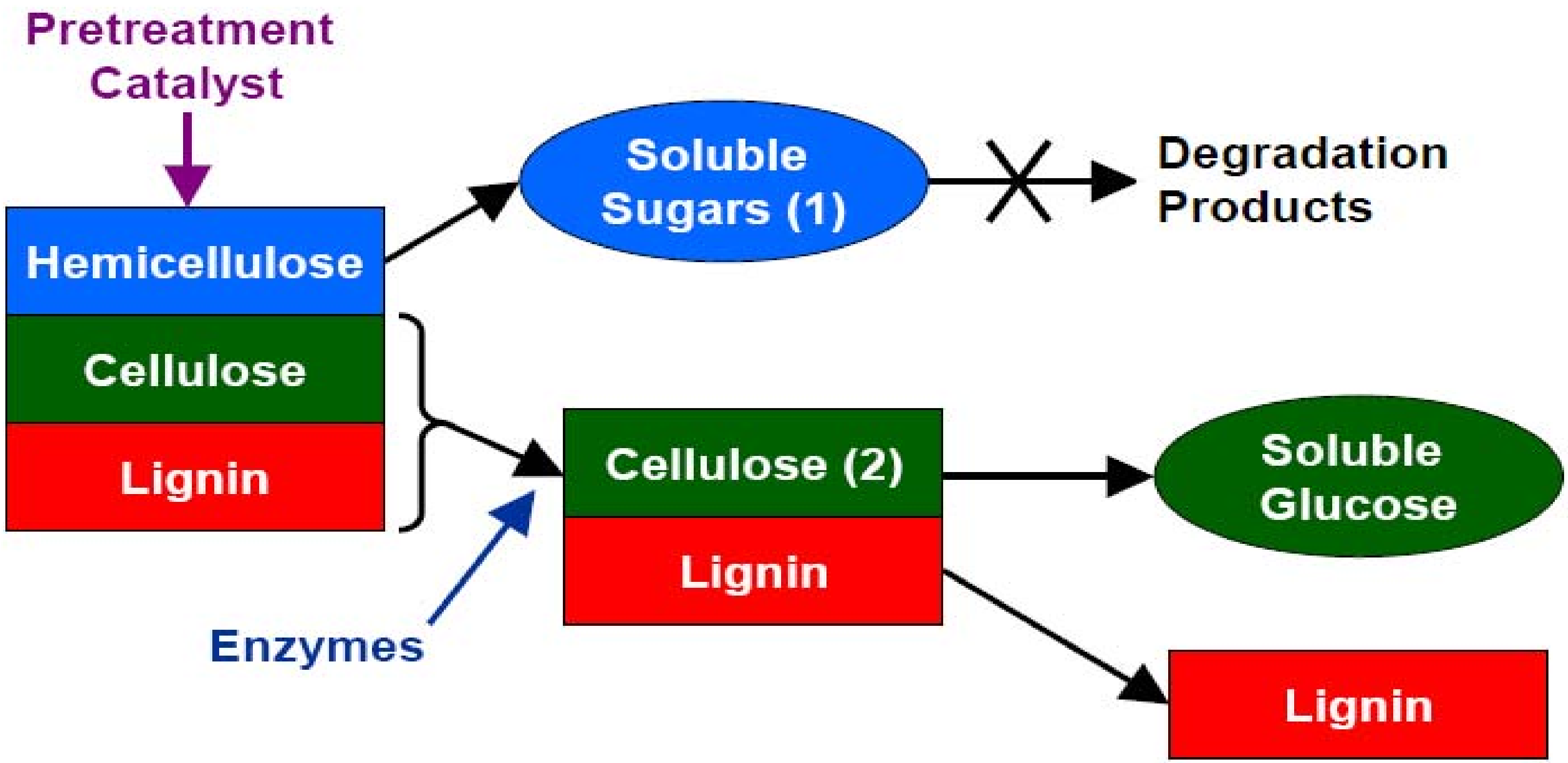
Variability Within a Feedstock (Corn stover)



Status of Research & Development

Biochemical Route to Lignocellulosic Ethanol and Other Transportation Fuels

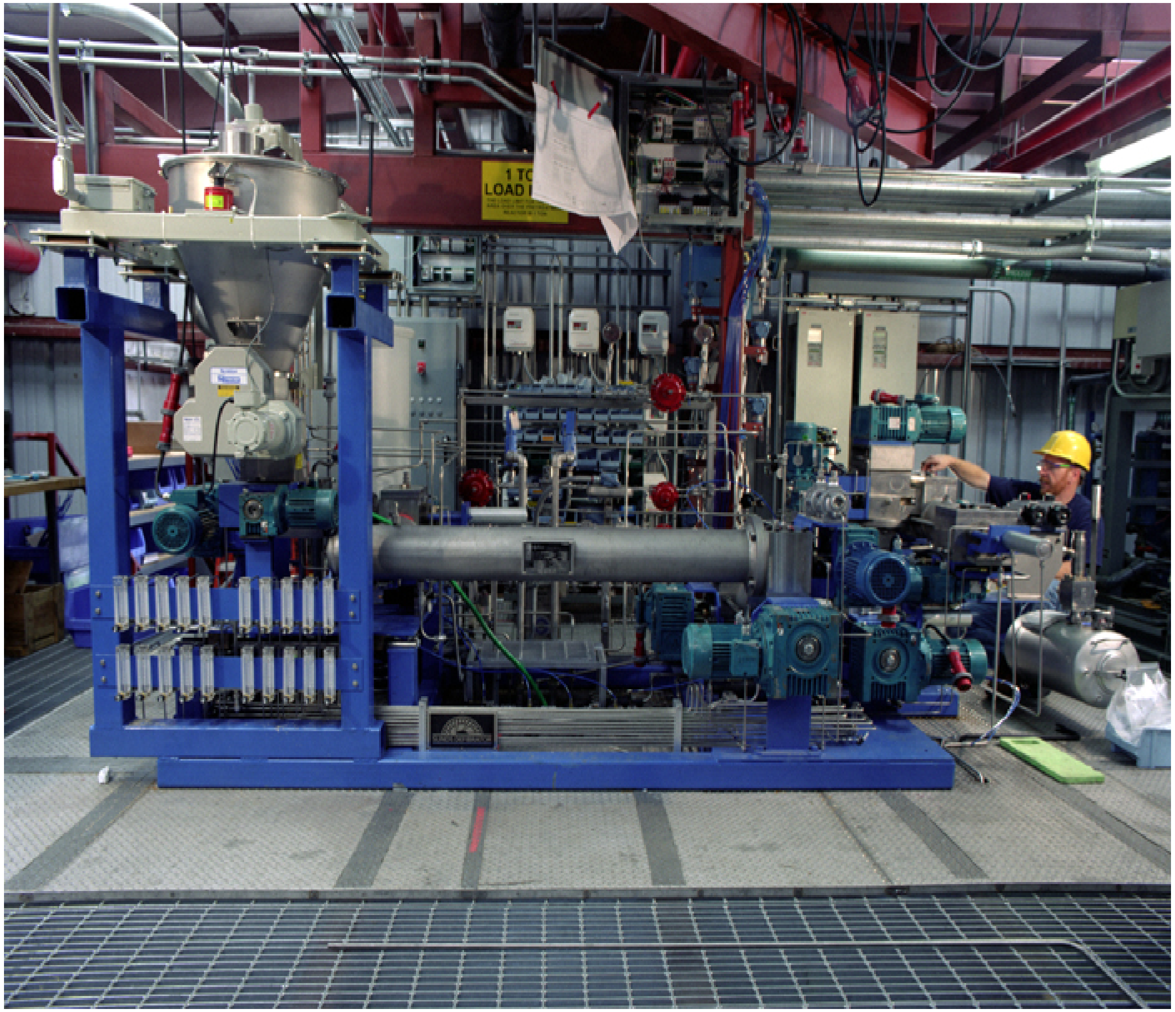
Biomass Fractionation in Pretreatment



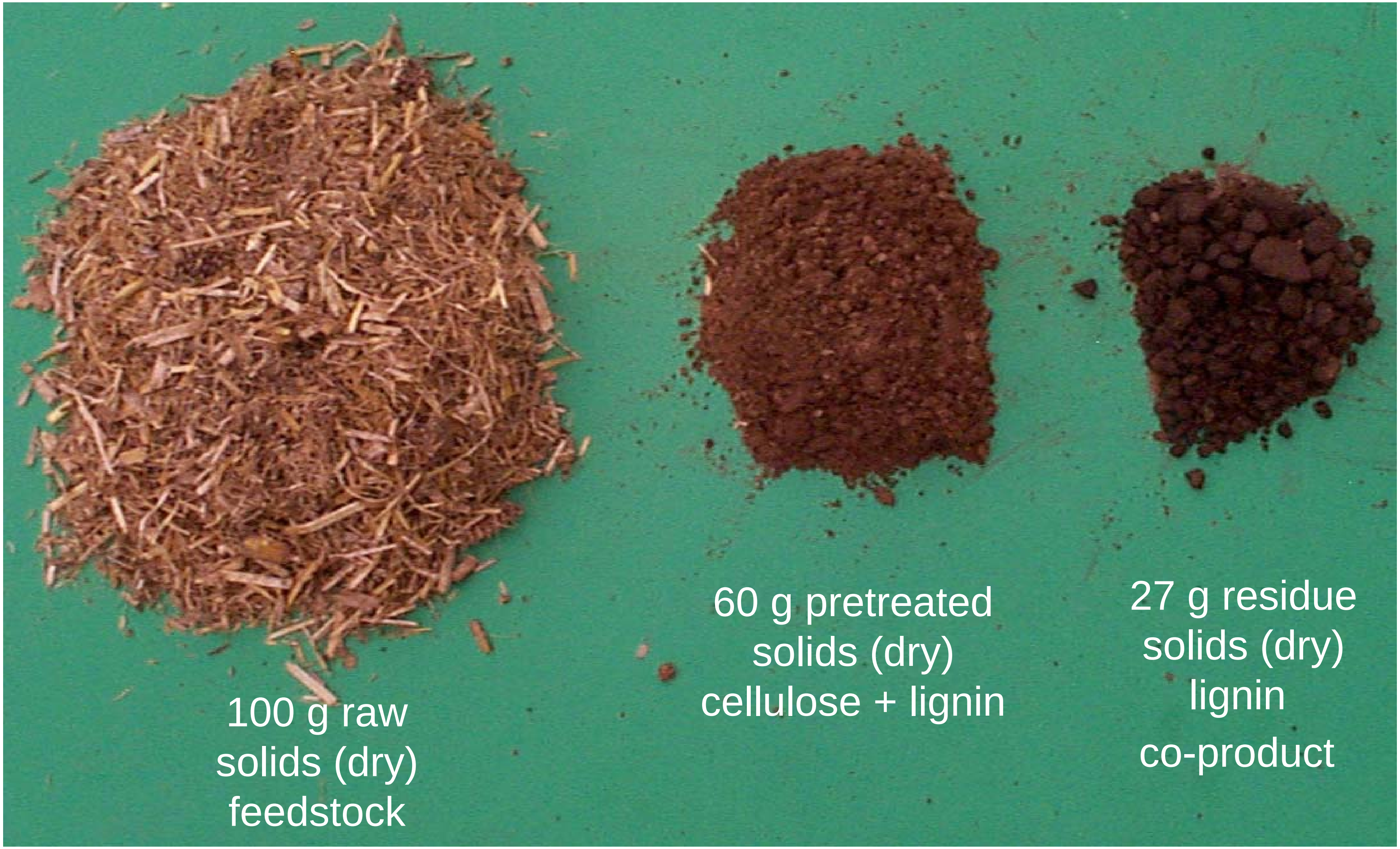
1. All xylose, mannose, arabinose, galactose and portion of glucose released
2. Cellulose is highly digestible by enzymes

Pretreatment

- Converts hemicellulose to fermentable sugars
- Makes cellulose susceptible to enzymatic hydrolysis



Conversion of Biomass



Enzymatic Hydrolysis Research

NREL worked with *Genencor* and *Novozymes* for 4 years

- Focusing on enzyme biochemistry, cost, and specific activity
- Investigating the interaction of biomass pretreatment and enzymatic hydrolysis

Result

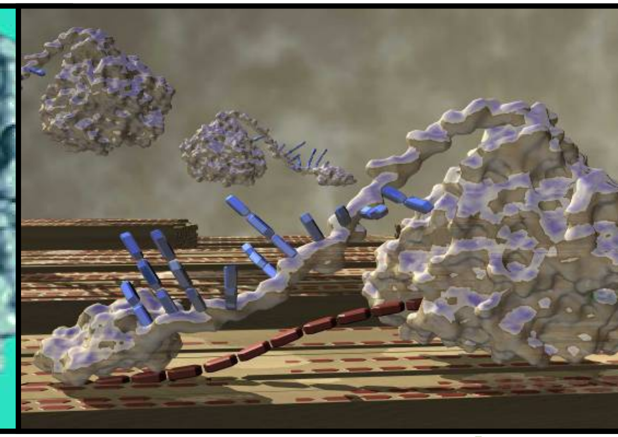
- 20-fold reduction in cost contributions of enzymes

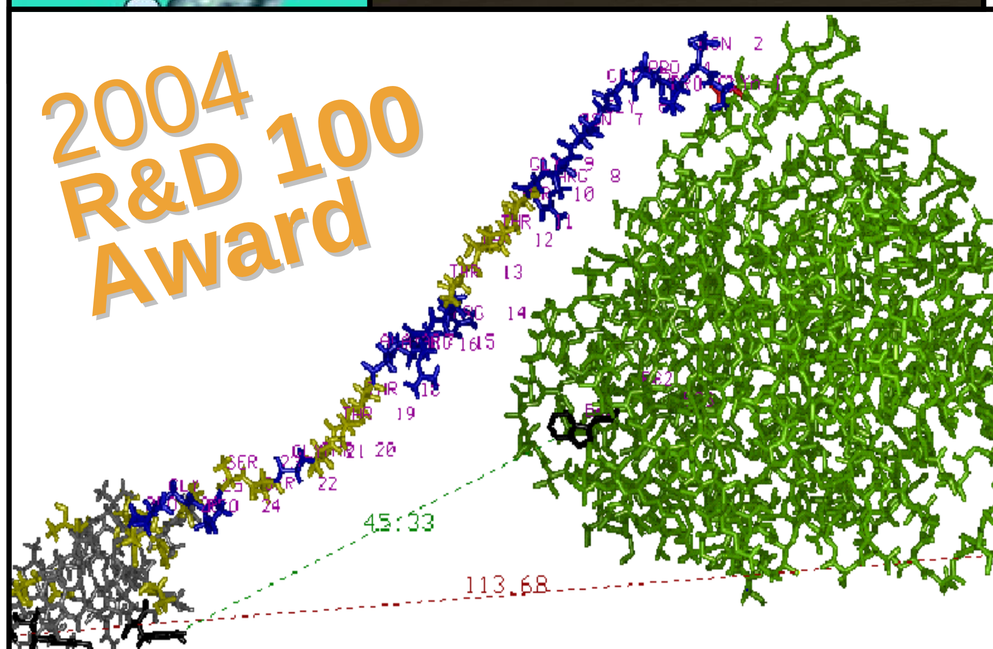
  ($/gal ethanol)

$40 million R&D effort cost-shared by the Office of the Biomass Program and the enzyme manufacturers

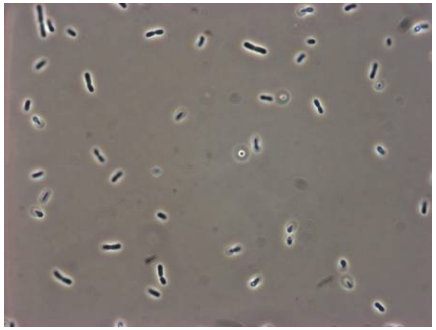
E1 from *A. cellulotiticus*

CBH1 from *T. reesei*





Fermentation



Development of *Zymomonas*

Introduced xylose utilization - 1994

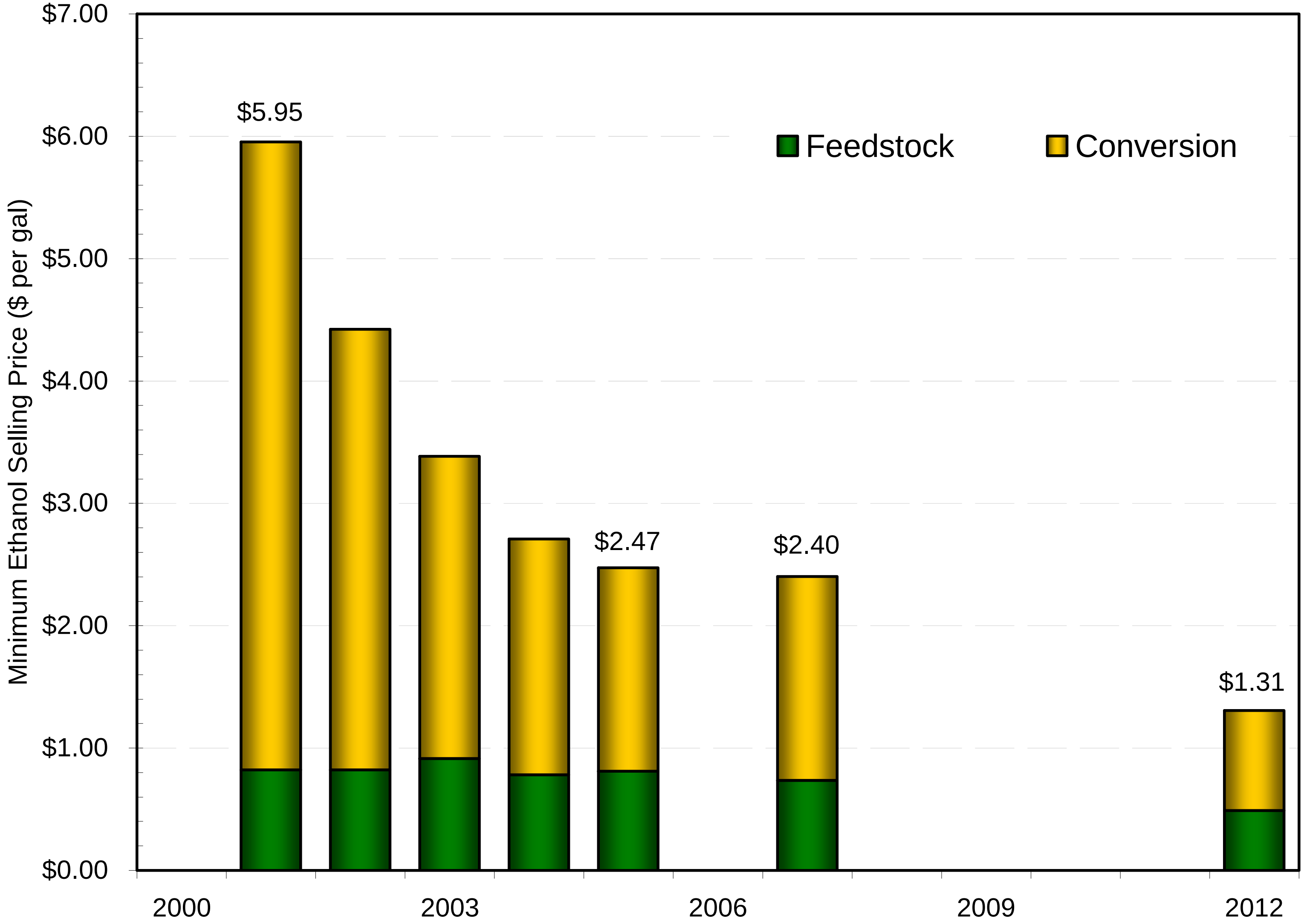
Introduced arabinose utilization - 1995

Combined pentose utilization - 1997

Stabilization by integration - 1999

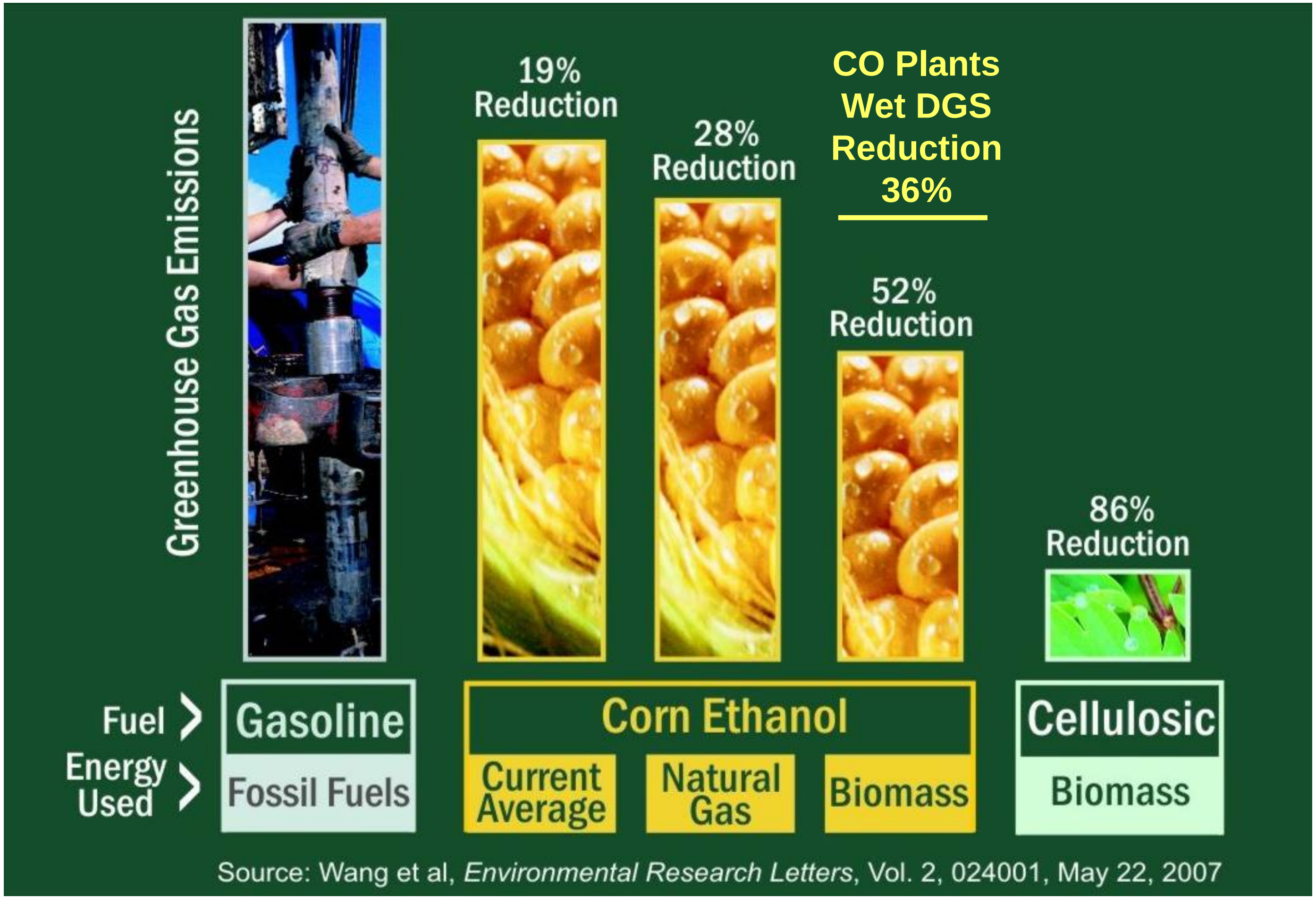
Further Development in CRADA with DuPont
2002-2007

Tracking Research Progress



GHG Impacts – Need to determine for Sorghum

Relative Emissions Impacts



Greenhouse gas emissions of fuels vary by feedstock and by type of energy used for processing.

Thank you for the opportunity.