Issues and Options for the Forest Biorefinery

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Yes, Everyone is working on Biofuels

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Why Forest Bioenergy in the US?

- Reduce dependence on Imported Oil
- Reduce green house gas emissions
- Rural or local economic development
- Improve the competitiveness of the Forest Products industry
- Improve forest health and/or reduce risk and impacts of fire

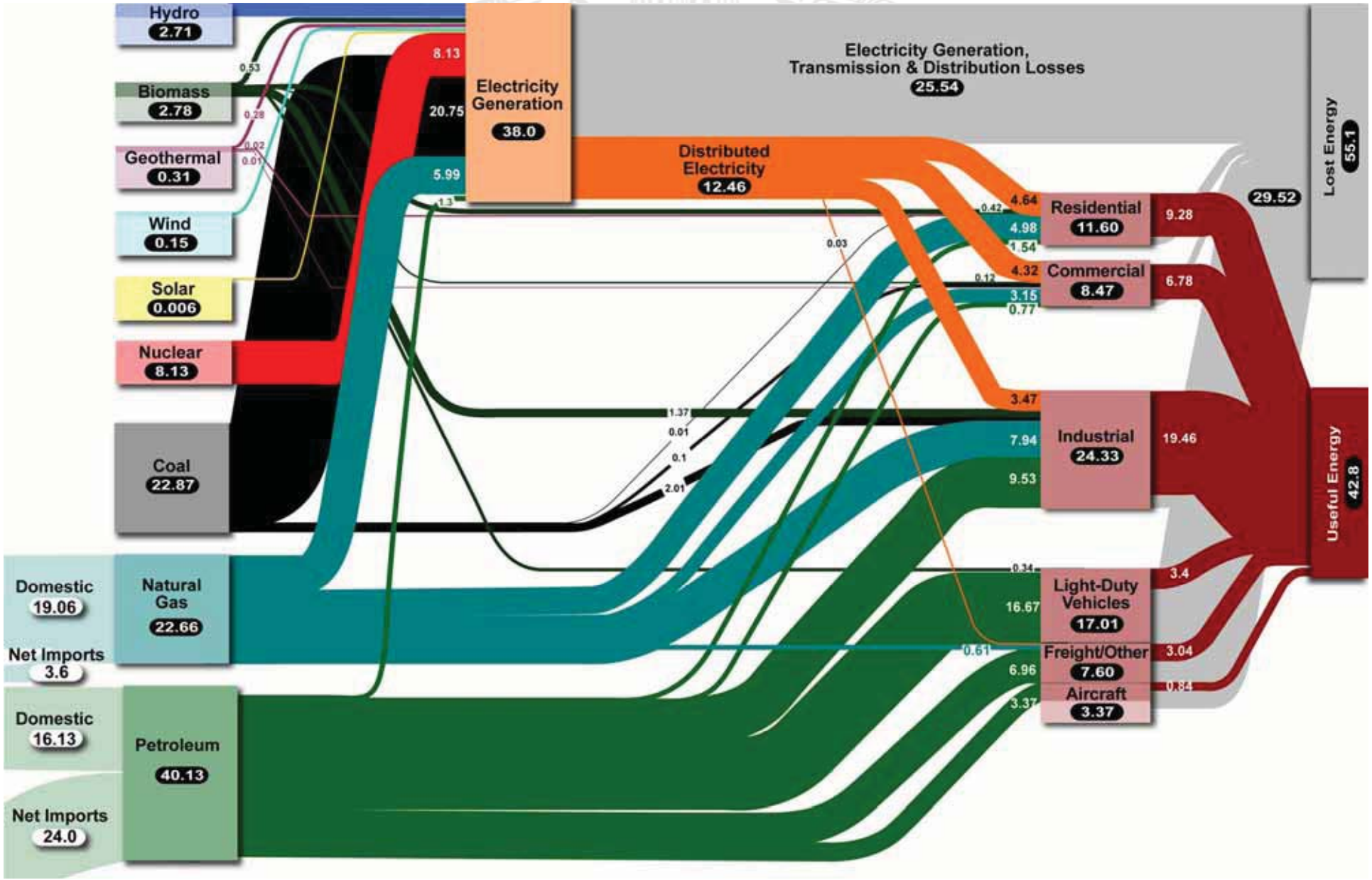
Current approaches can not achieve all 5

A Partial List of Current Biofuels Projects in the US

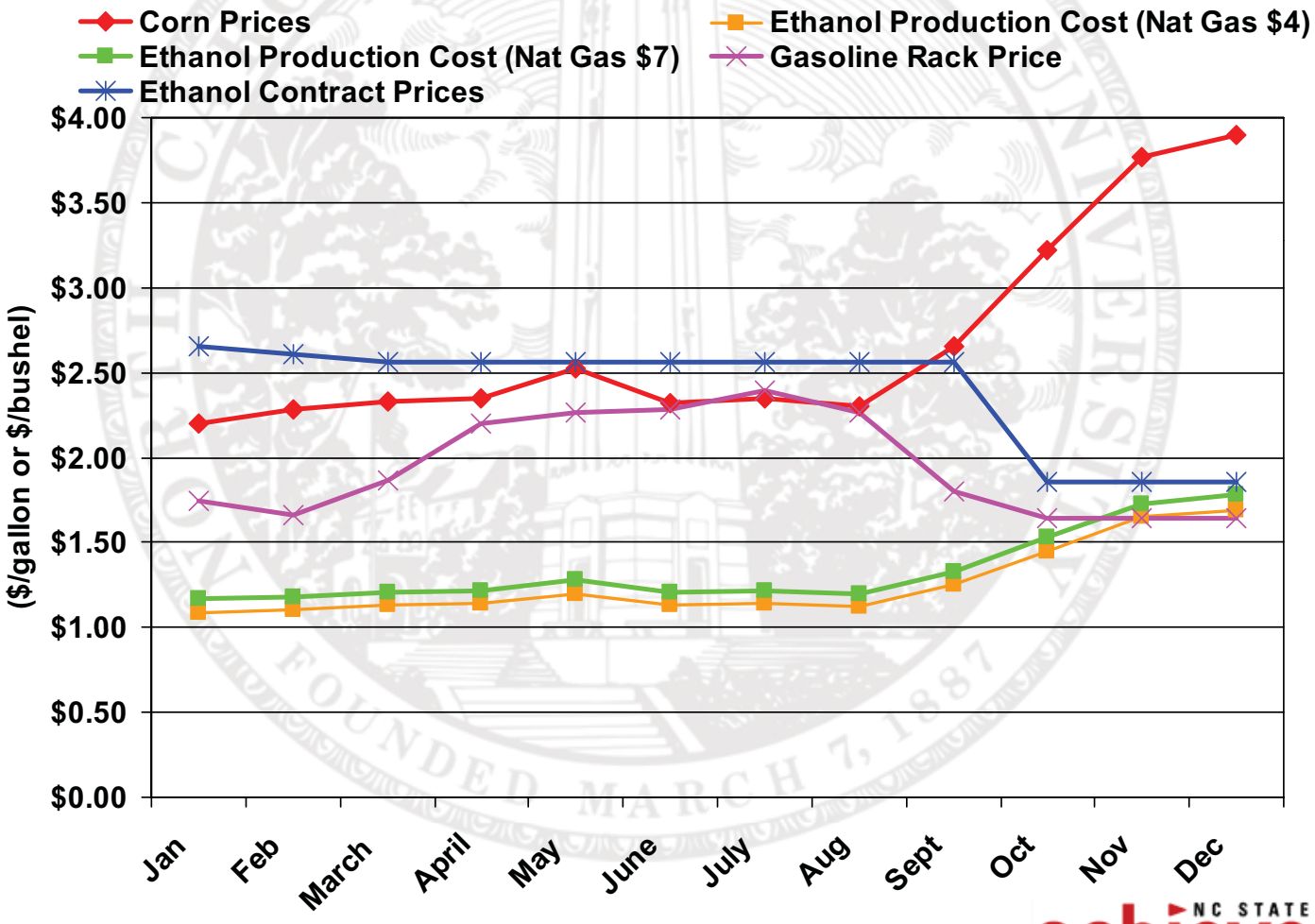
More than $2.5 billion in real projects have been announced, but NONE are actually making fuels from lignocellulosic biomass.

- DOE and Private Companies– $1.2 billion for six ethanol demo. projects at the 700 tpd scale
- DOE - $375 million for 3 Genomes to Life Centers to "Break the Barriers to Cellulosic Ethanol"
- BP – $500 million to look at fundamentals barriers, to UC Berkeley and Univ. of Illinois
- DOE - $300 million in 7 "small" scale (70 tpd) demo projects
- Individual States – 10-15 states working on initiatives, research, pilot plants, that range between $5 and 60 million

US Energy Flows



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



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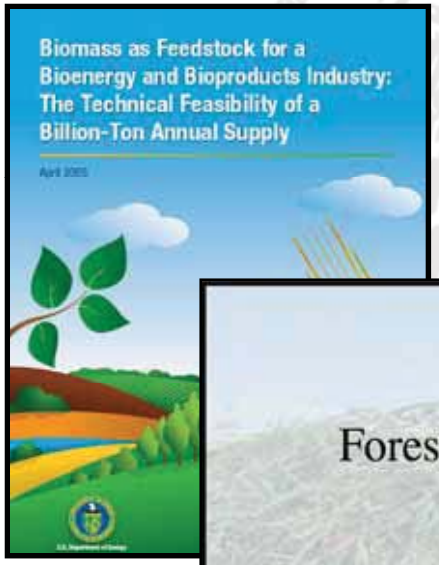
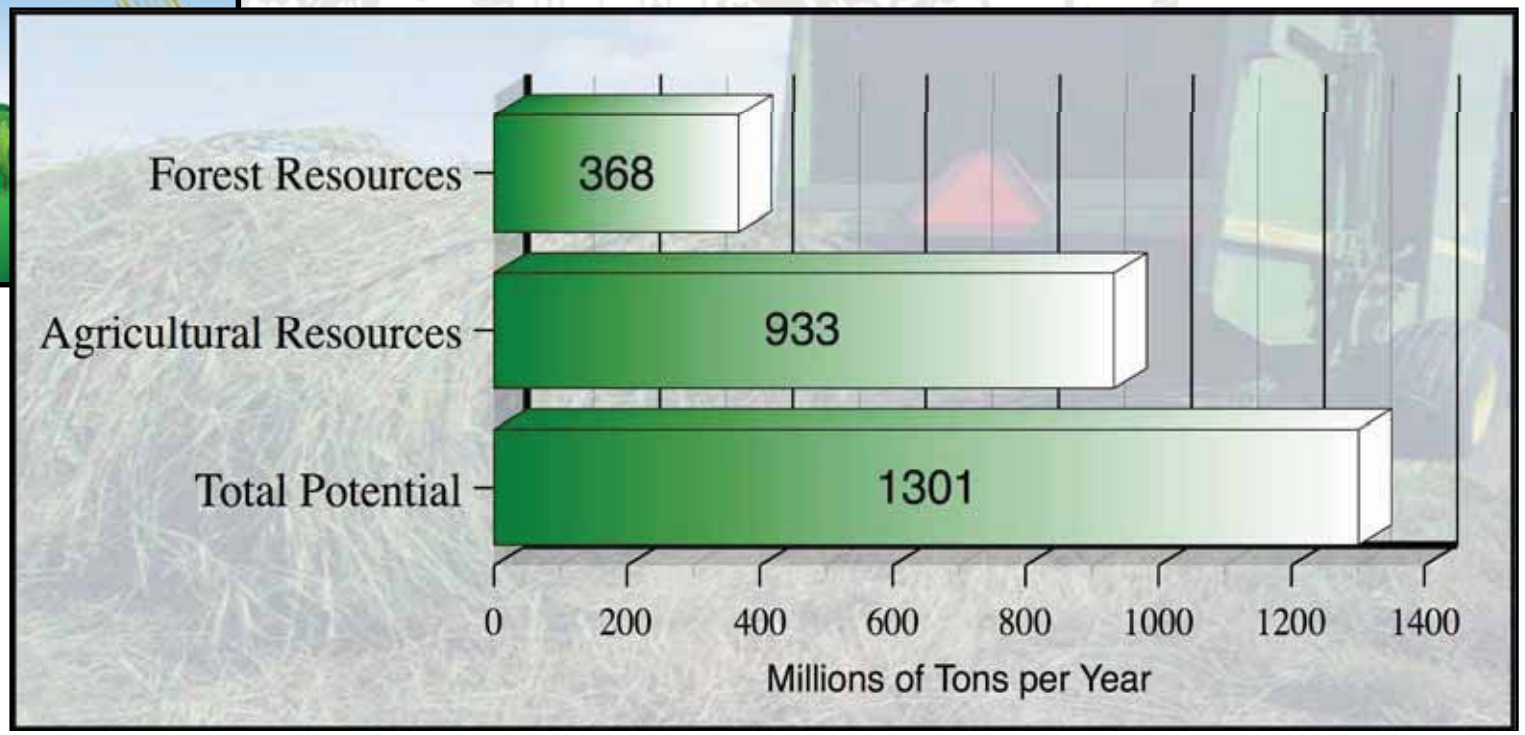
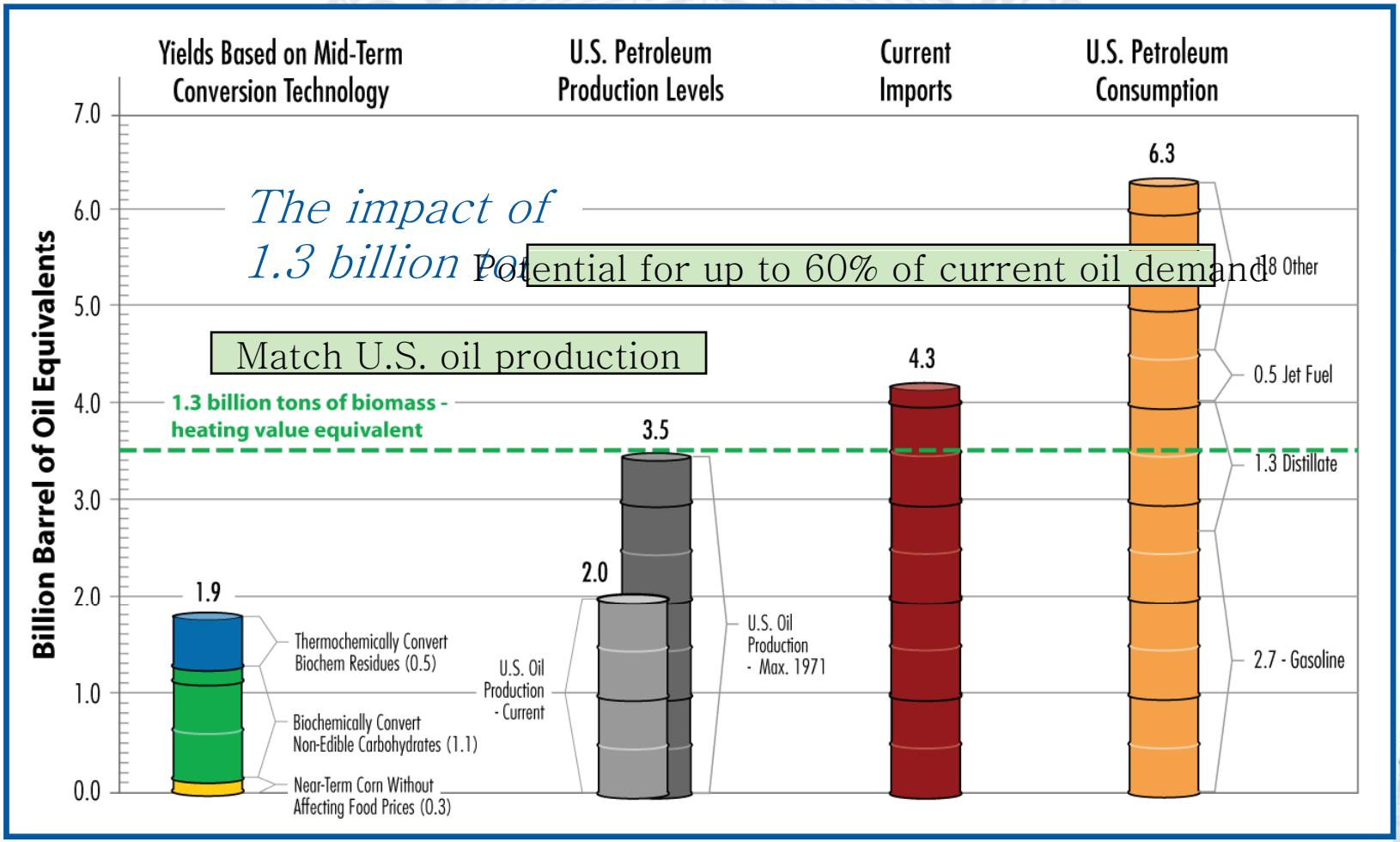
U.S. Biomass Resource Assessment



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



Potential for Impact of 1.3 Billion Tons of Biomass Converted into Liquid Fuels



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Biomass Composition

Lignin: 15-25%

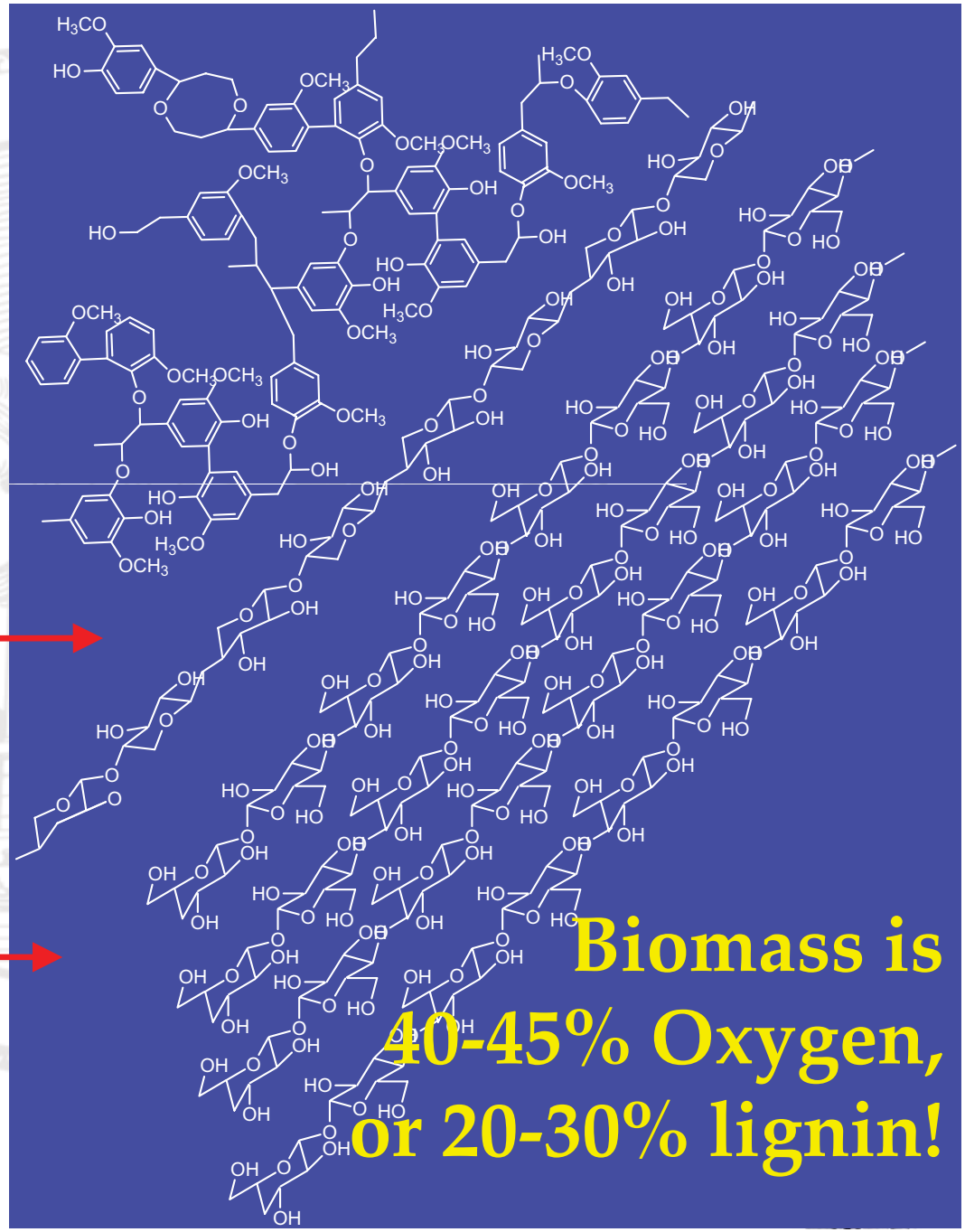
- Complex aromatic structure
- Very high energy content
- Resists biochemical conversion

Hemicelluloses: 23-32%

- Xylose is the 2nd most abundant sugar in biosphere
- Polymer of 5- and 6-carbon sugars, marginal biochemical feed

Cellulose: 38-50%

- Most abundant form of carbon in biosphere
- Polymer of glucose, good biochemical feedstock

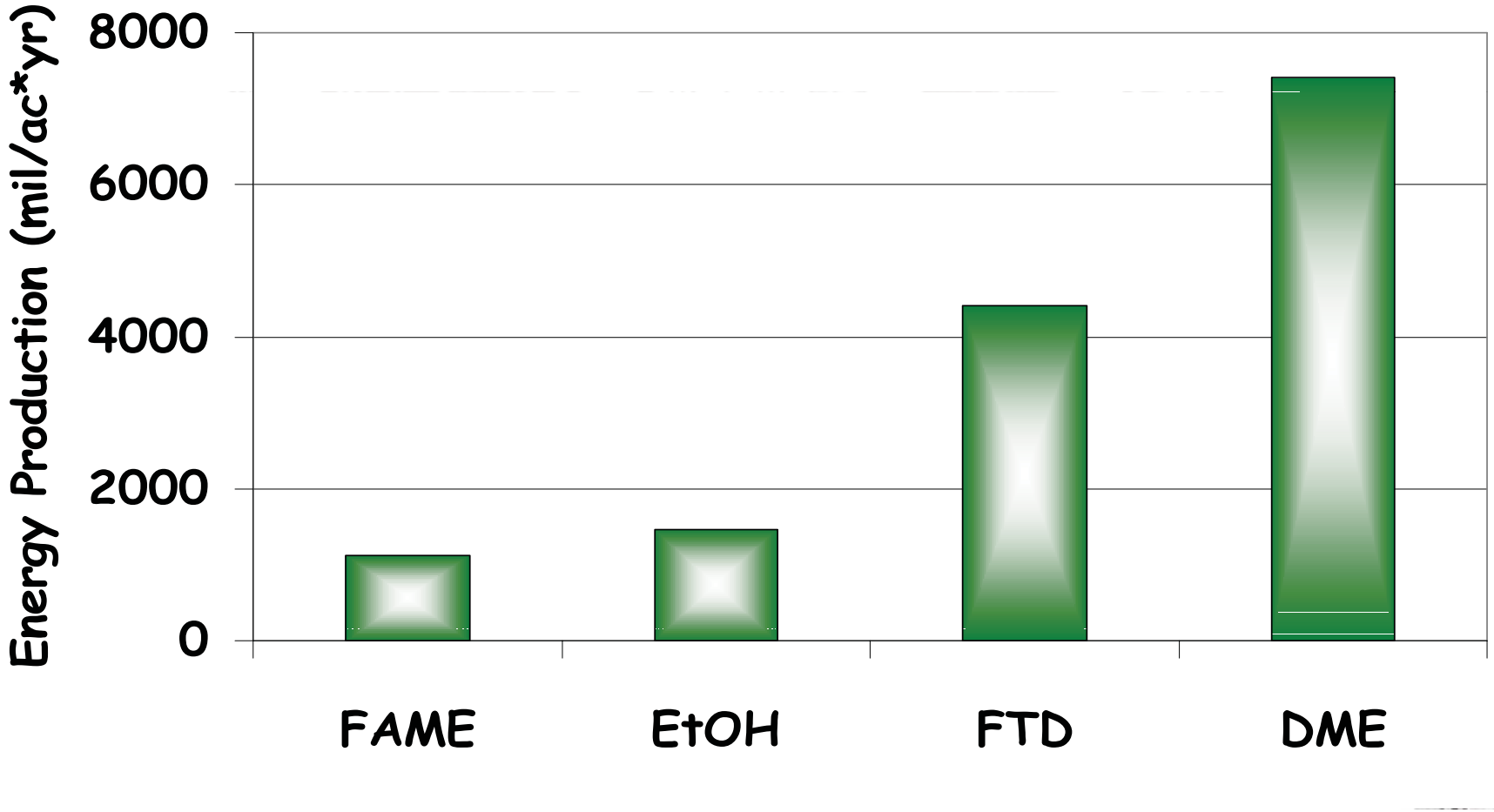


Biomass is 40-45% Oxygen, or 20-30% lignin!

Composition Matters -
at the beginning and at the end of the year

- 20-30% lignin can not be used to produce ethanol; 50% of the sugars are converted to CO_2
- 40-45% oxygen can not be convert to FTL via gasification; there is potential for making ethanol via gasification, but using current technology yields are low.
- Ag. residues will begin to change “rot” over the 9 months period between harvesting and conversion. Only sugars can be fermented, gasification more robust

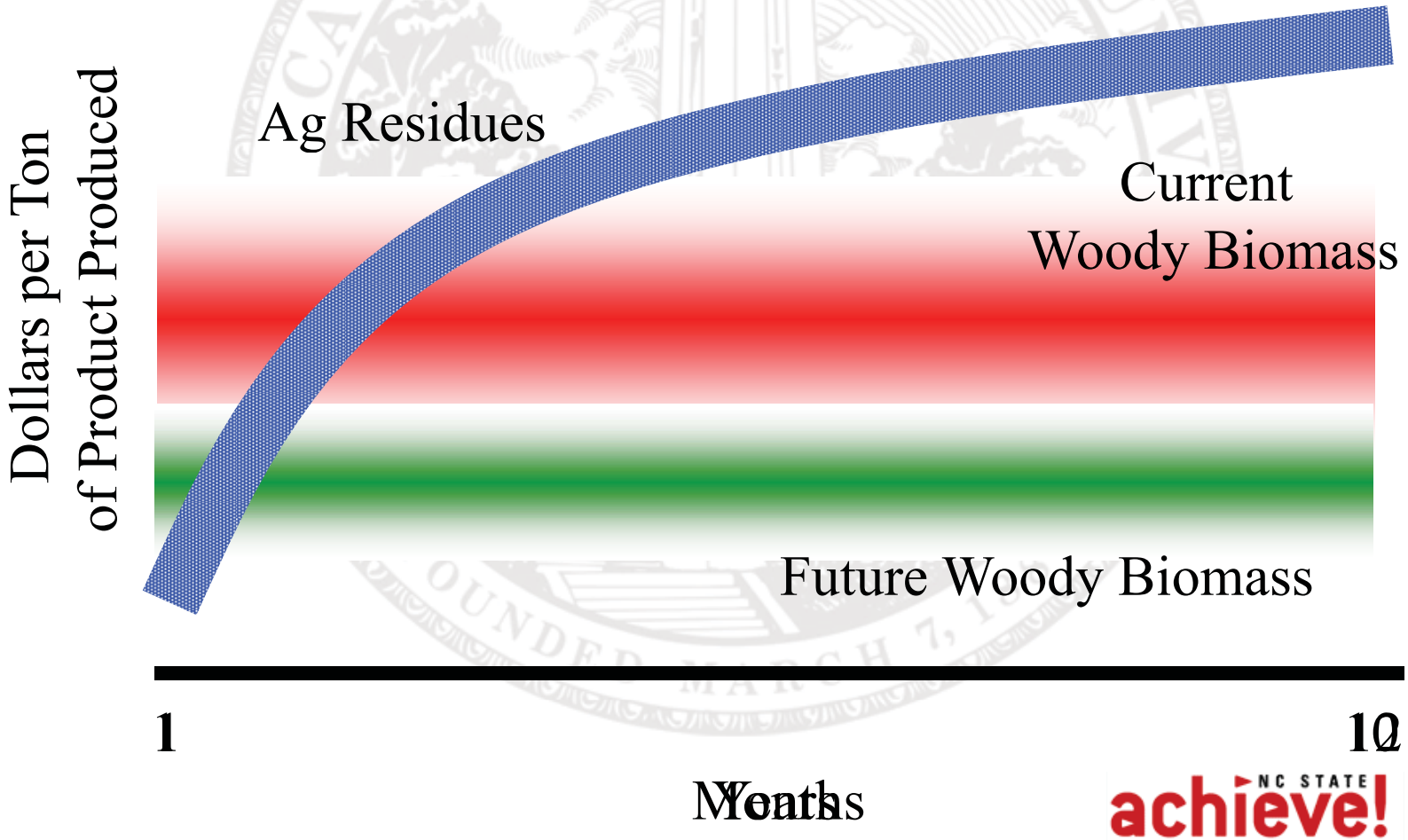
LCA and process models are need to make sound economic and policy decisions



Sustainable Biomass Sources

- There is abundant data on the composition of biomass feedstocks, and their growth rates under "optimal or enhanced" conditions, but must understand production on lower productivity land.
- Feedstock composition must be integrated with engineering process models and technoeconomic analysis tools to evaluate the impact of biomass composition on production cost biofuels.
- Sustainable feedstock production must include carbon, water, wildlife and goals of rural landowners.

Cost of Feedstocks?
(what is the real question?)



Primary Conversion Routes

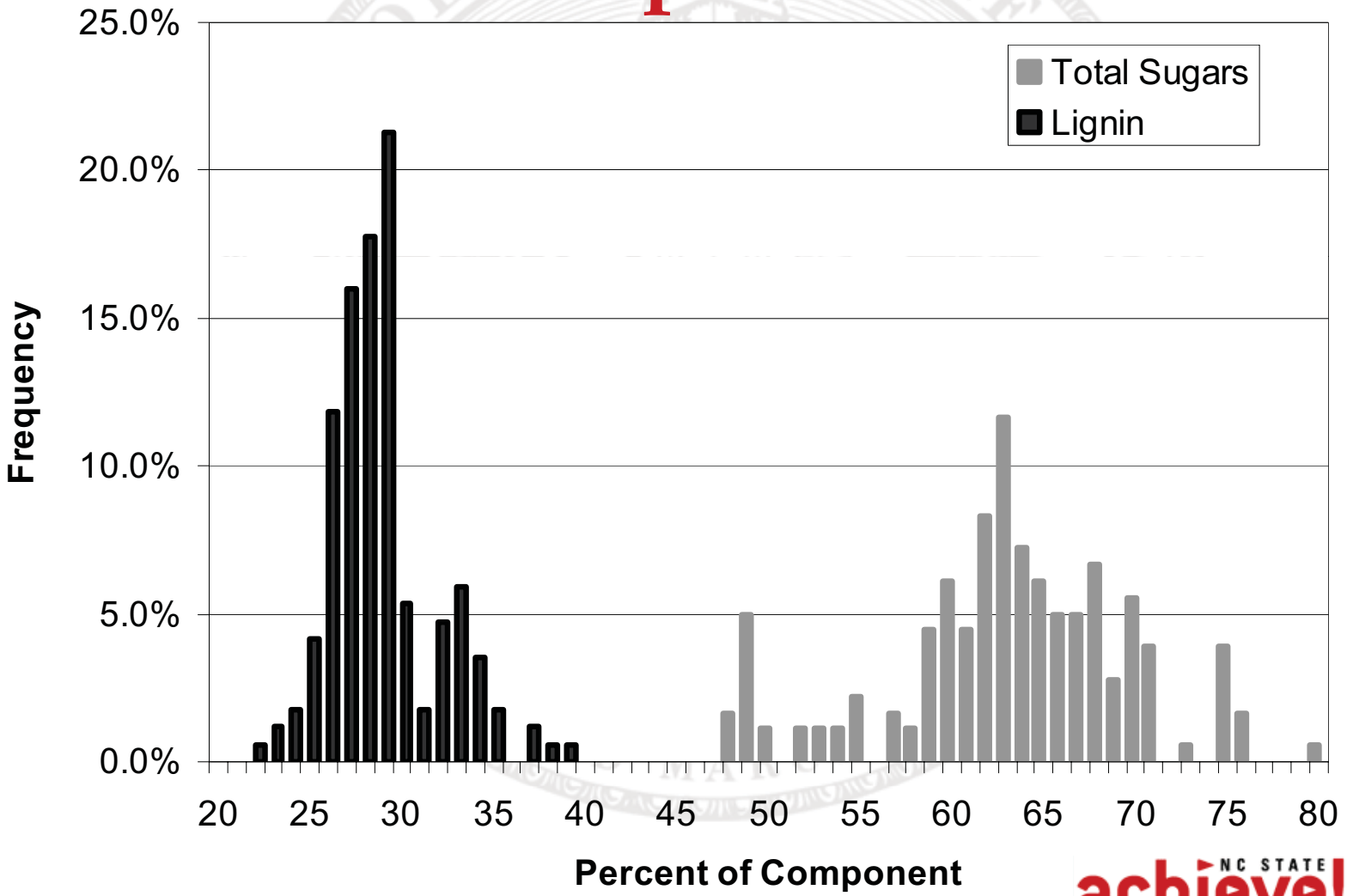
Transformation through Intermediates (sugars)

"Biochemical conversion"

Gasification (reduction to CO, H_2) and Pyrolysis

"Thermochemical conversion"

Variation of Woody Biomass Composition



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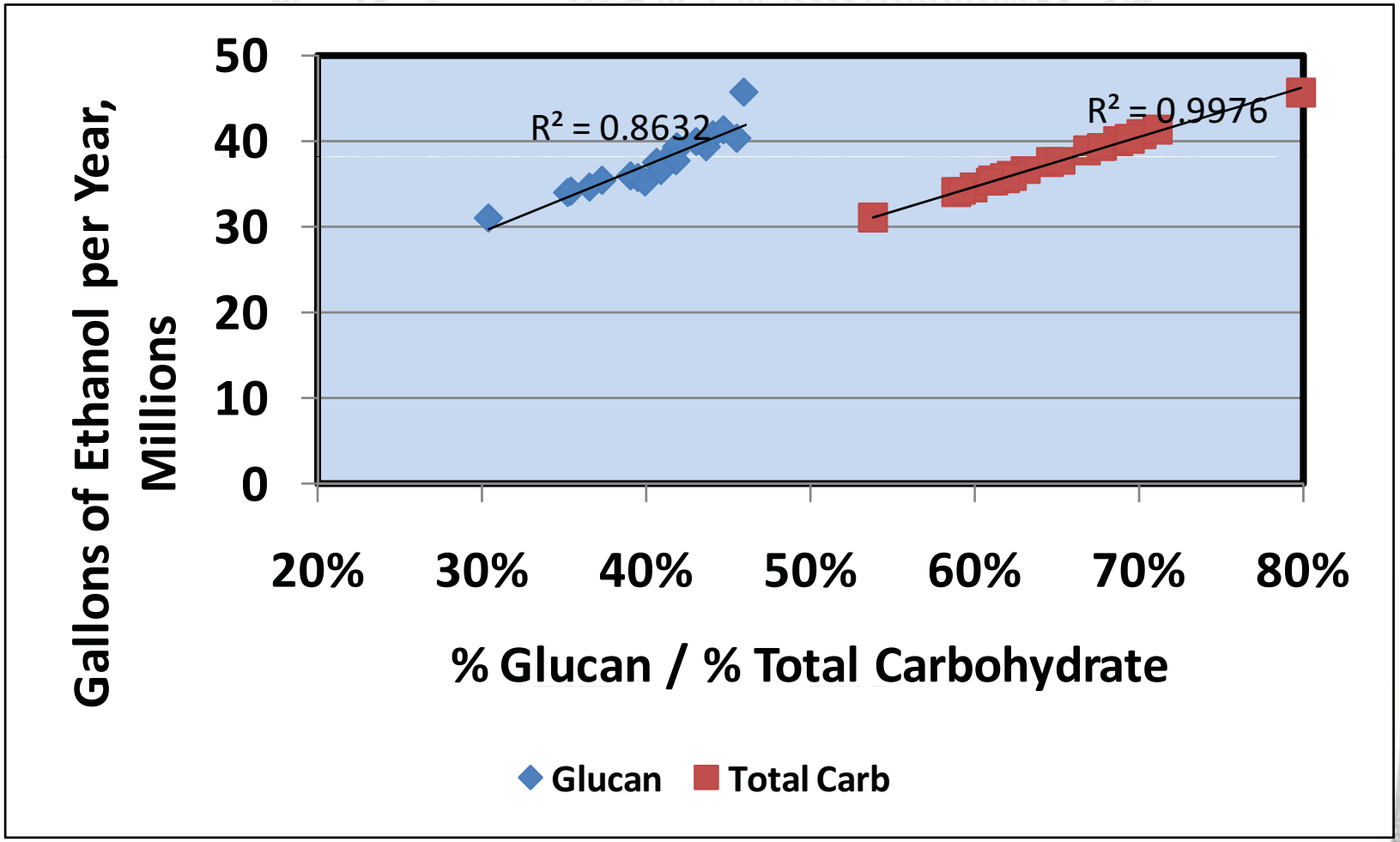
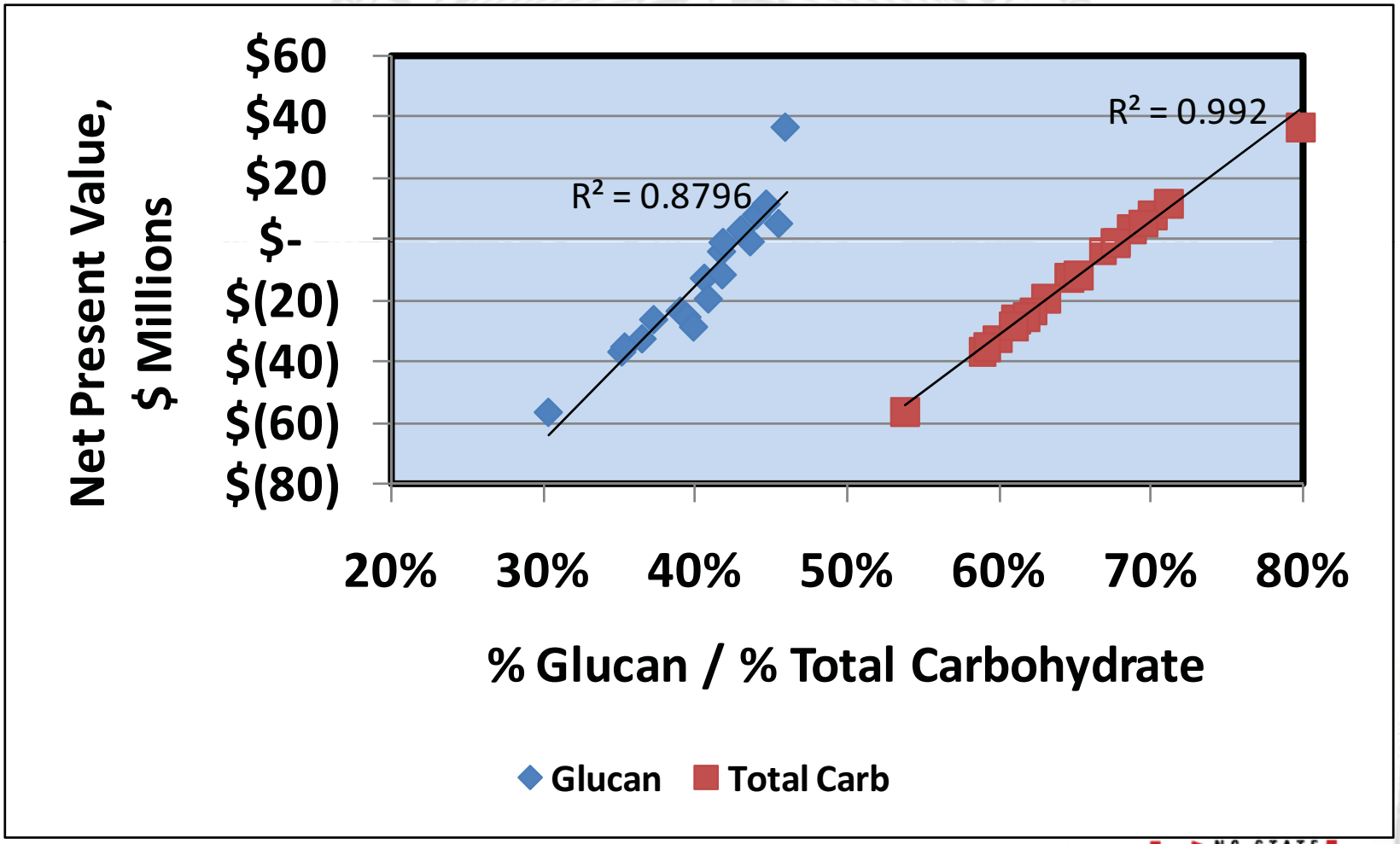
Ethanol Production as Function of Carbohydrate Content

(~ 15 Million Gallons per Year difference in production volume)

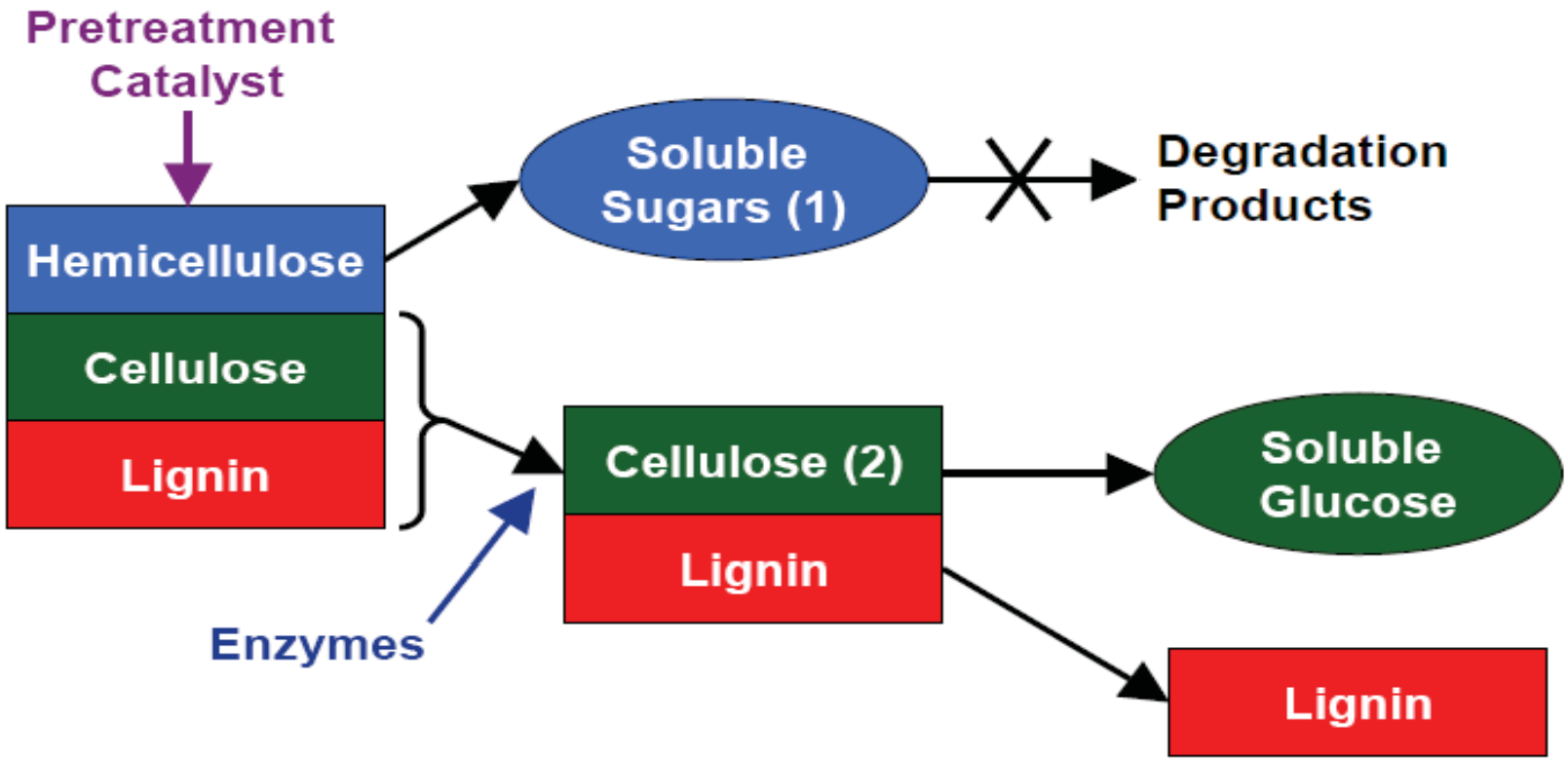


NPV as Function of Carbohydrate Content

(~$93 Million difference in NPV over range of sugar content)



Biomass Fractionation in Pretreatment



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

Technical Barriers to Total Conversion

- Feedstock Variation
- Feedstock Quality
- Feedstock Cost

Enzyme Production

- Enzyme Cost

Pretreatment → Conditioning → Enzymatic Hydrolysis → Co-fermentation of C5 & C6 Sugars → Product Recovery → Products

Product Recovery → Residue Processing → By-products

- Xylose Yield
- Xylose Degradation
- Solids Loading
- Reactor Costs

- Sugar Losses

- Glucose Yield
- Solids Loading (titer)

- Ethanol Yields
- Ethanol Concentration
- Rate
- Hydrolyzate Toxicity

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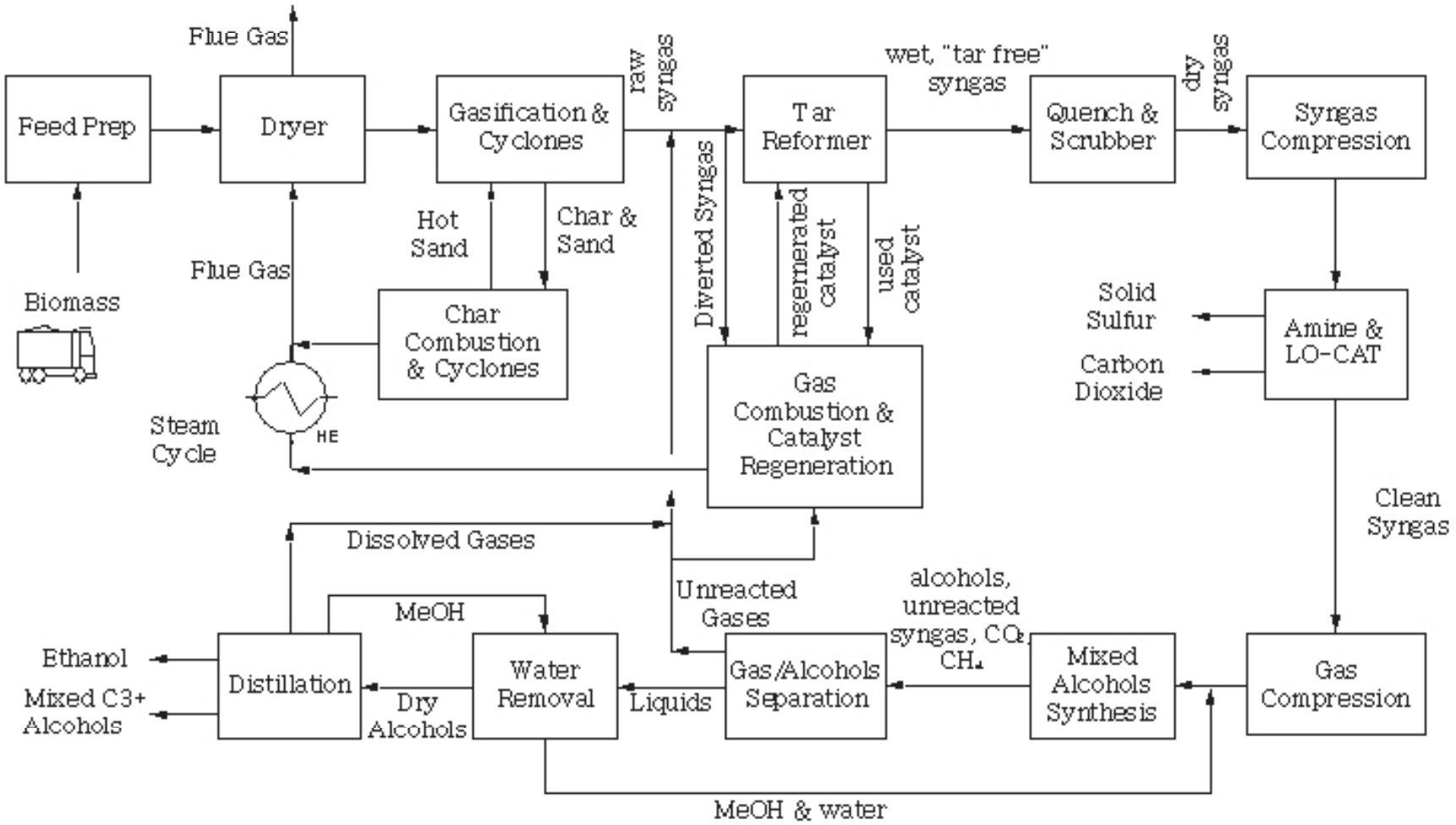
Conversion of Biomass

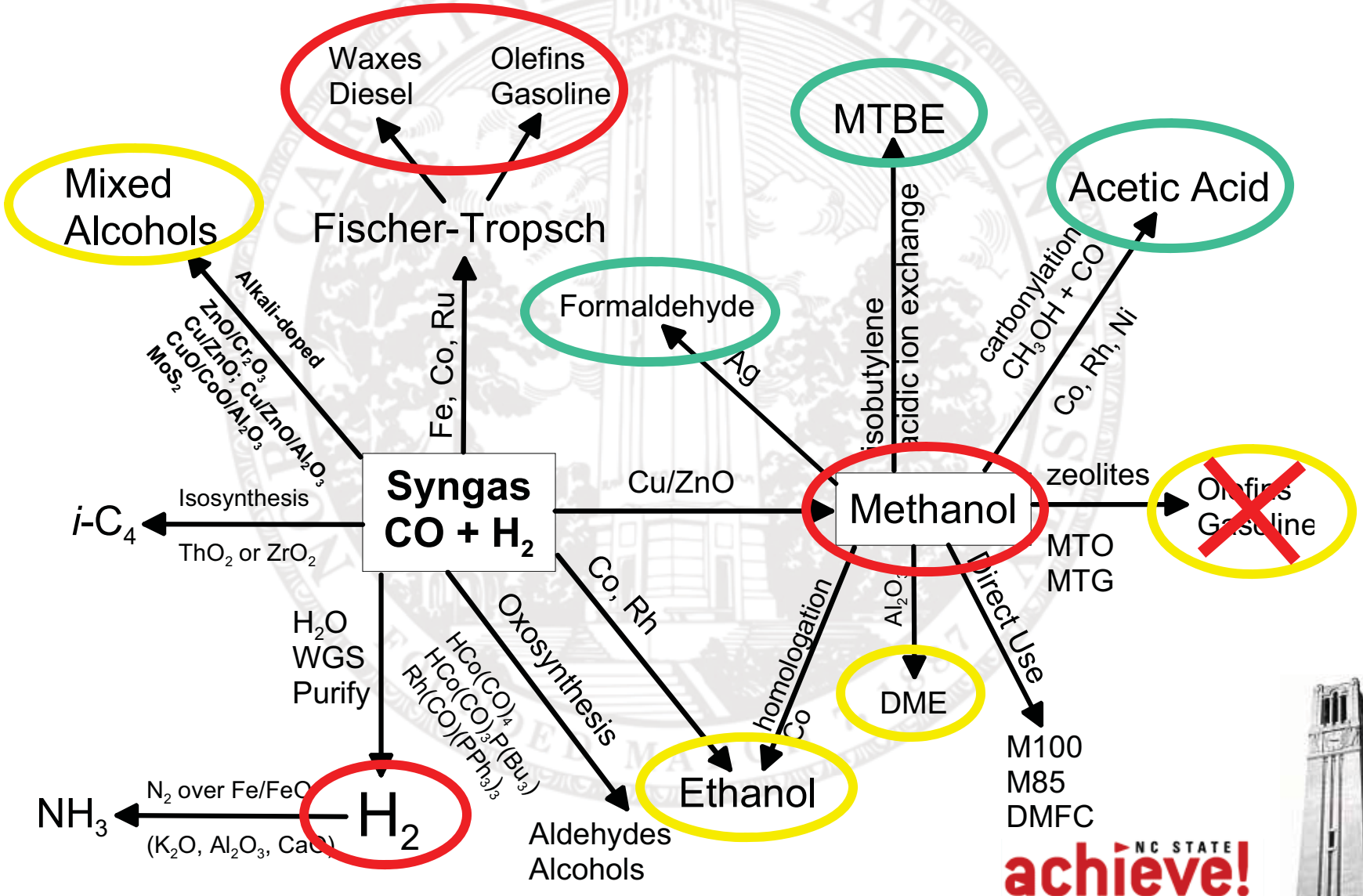
Biomass Gasification



Coal Gasification Plant

Eastman Chemicals, Kingsport TN

Products from Syngas



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Miracles - Sugar Fermentation
New Facility

- Improved enzymes; higher efficiency, lower cost
- Fermentation of mixed sugars; C-6 vs. C-5 simultaneously or sequentially
- Consistent feedstock quality/product yields
- Capital costs of $200-300 million

Miracles – Wood Sugars
"Repurposed" mill

- Improved enzymes; higher efficiency, lower cost, but potential for recycle with clear pulp

- Fermentation of mixed sugars; C-6 vs. C-5 simultaneously or sequentially

- Consistent wood feedstock

- Lower capital costs; $100 million ??

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Miracles - Biomass Gasification

- Similar coal and natural gas systems are 50-150 times larger on a Btu basis

- Several successful woody biomass systems in service, limited materials issues

- Much less sensitive to biomass feedstock quality

- Tar removal/destruction to provide clean syngas (catalysts), several options for process integration

- Scale and capital are major issues to get reasonable economics

Wood Feedstocks Focus

ALICO, Inc. investors/participants include: Bioengineering Resources, Inc. of Fayetteville, Arkansas; Washington Group International of Boise, Idaho; GeoSyntec Consultants of Boca Raton, Florida; BG Katz Companies/JAKS, LLC of Parkland, Florida; and Emmaus Foundation, Inc.

DOE - $76 million; Private – $114 million

The proposed plant will be in LaBelle, Florida. Using **gasification and catalysts** technology the plant will produce 20.9 million gallons of ethanol a year and 6,255 kilowatts of electric power, as well as 8.8 tons of hydrogen and 50 tons of ammonia per day. For feedstock, the plant will use 770 tons per day of yard, wood, and vegetative wastes and eventually energy cane.

Target – 75 gal/ton; plus ammonia, hydrogen and power

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Small Scale Projects at NCSU

VPP (similar to Red Shield) – target - extraction of hemis, production of EtOH and pulp; challenges - small plants, fermentation of mixed sugars, pulp quality

VPC – target – extraction of hemis, production of EtOH and power; challenges – CHP have lower value, fermentation of mixed sugars (larger plants)

Repurposing Pulp Mills – WERC (Project Ponderosa), target - redeploy assets of closed pulp mill, challenges – requires cellulase enzymes (cleaner sugar fermentation, larger plants)

Paper Sludge to Ethanol – target – produce ethanol from paper sludge; challenges – requires cellulase enzymes (very low cost feedstock, clean sugars)

Torrefaction for Energy Densification – target – reduce transportation costs, increase energy density to "coal"; challenges – energy balance, throughput

Summary

- We already know how to sustainably produce and collect woody biomass on the large scale.
- Wood biomass is a “safe”, reliable feedstock on an annual and multi-year basis.
- Collection and storage of Ag residues will be a significant challenge
- There will be a series of transitional projects to reduce capital and technology risks (OPM). Smaller plants 100-500 tpd will be sited near current operating plants
- Large scale deployment (more than 20 plants) will require 3-5 years of operating experience/Government support/100 dollar oil, in some combination
- GE plants have tremendous potential for lowering production and manufacturing costs, but we need to consider the social and political issues that limit deployment.

Questions?

Mixed Waste Focus

BlueFire Ethanol, Inc. investors/participants include: Waste Management, Inc.; JGC Corporation; MECS Inc.; NAES; and PetroDiamond.

DOE - $40 million; Private - $60 million

The proposed plant will be in Southern California. The plant will use **strong acid hydrolysis and fermentation**, and will be sited on an existing landfill and produce about 90 million gallons of ethanol a year. It will use sorted green waste and wood waste from landfills.

Target - 63 gal/ton

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Agricultural Waste Focus

Broin Companies (now POET) participants include: E. I. du Pont de Nemours and Company; Novozymes North America, Inc.; and DOE's National Renewable Energy Laboratory.

DOE - $80 million; Private – $120 million

The plant is in Emmetsburg, Iowa. The plant will use **enzyme hydrolysis and fermentation** to 35 million gallons of ethanol per year. For feedstock in the production of cellulosic ethanol, the plant expects to use 842 tons per day of corn fiber, cobs, and stalks.

Target – 83 gal/ton

Agricultural Waste Focus

Iogen Biorefinery Partners, LLC investors/partners include: Iogen Corporation; Goldman Sachs; and The Royal Dutch/Shell Group.

DOE - $80 million; Private – $120 million

The proposed plant will be built in Shelley, Idaho, near Idaho Falls. The plant will use **enzyme hydrolysis and fermentation** to produce 250 million annual gallons. The plant will use 700 tons per day of agricultural residues including wheat straw, barley straw, corn stover, or switchgrassas feedstocks.

Target - 71 gal/ton

Agricultural Waste Focus

Abengoa Bioenergy Biomass investors/participants include: Abengoa Bioenergy R&D, Inc.; Abengoa Engineering and Construction, LLC; Antares Corp.; and Taylor Engineering

(DOE - $76 million; Private – $110 million.

The proposed plant will be located in the state of Kansas. The plant will use **gasification** to produce 11.4 million gallons of ethanol annually and enough energy to power the facility, with any excess energy being used to power the adjacent corn dry grind mill. The plant will use 700 tons per day of corn stover, wheat straw, milo stubble, switchgrass, and other feedstocks.

Target – 79 gal/ton

Wood Feedstocks Focus

Range Fuels investors/participants include: Merrick and Company; PRAJ Industries Ltd.; Western Research Institute; Georgia Forestry Commission; Yeomans Wood and Timber; Truetlen County Development Authority; BioConversion Technology; Khosla Ventures; CH2MHill; Gillis Ag and Timber.

DOE - $76 million; private - $150 million

The proposed plant will be constructed in Soperton, Georgia. The plant will use **gasification and catalysts** to produce about 40 million gallons of ethanol per year and 9 million gallons per year of methanol. As feedstock, the plant will use 1,200 tons per day of wood residues and wood based energy crops.

Target – 113 gal/ton

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A Partial List of Current Biofuels Projects in the US

More than $2.5 billion in real projects have been announced, but NONE are actually making fuels from lignocellulosic biomass.

- $300 million in 9 “small” scale (70 tpd) demo projects
  - New Page - Woody Gasification
  - Flambeau River - Woody Gasification
  - Red Shield – Hemicellulose extraction, ethanol
  - Lignol – Fractionation, ethanol and CHP

Wood Feedstocks Focus

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DOE - $76 million; private - $150 million

The proposed plant will be constructed in Soperton, Georgia. The plant will use gasification and catalysts to produce about 40 million gallons of ethanol per year and 9 million gallons per year of methanol. As feedstock, the plant will use 1,200 tons per day of wood residues and wood based energy crops.

Status - Moving dirt

Wood Feedstocks

New Page, Thermo Recovery International, EFT, Inc. Oak Ridge National Lab., Clean Tech Partners

DOE - $30 million; private - $170 million

The plant will be constructed in Falls Park, WI. Uses gasification and catalysts to convert 1000 tpd of wood wastes (mostly bark) and produces about 15 million gallons of crude FT liquids. May be expanded with 1200 tpd within 50 miles. Tail gases will also be used in lime kiln.

Wood Feedstocks

Flambeau River Paper, Thermo Recovery International, Clean Tech Partners

DOE - $30 million; private - $53 million

The plant will be constructed in Park Falls, WI. Uses gasification and catalysts to convert 1000 tpd of wood wastes (mostly bark) and produces about 15 million gallons of crude FT liquids. Tail gases will also be used for CHP.

Wood Feedstocks

Red Shield Pulp and Chemicals, Univ. Maine, American Process, Waldron Engineering and Construction, Andritz, Xethanol, Lenzing,

DOE - $30 million; private - $106 million

The plant will be constructed in Old Town, Maine. Uses pre-extraction of hemicelluloses to produce fermentable sugars and "chemical" pulp. Pre-extraction in a two vessel series. Requires mixed sugar fermentation.

Wood Feedstocks

Lignol, Suncor Oil

DOE - $30 million; private - $70 million

The plant will be constructed in Commerce City (Denver), CO. Uses softwood residues and **organic solvent fractionation** to create "reactive" cellulose and hemicellulose stream for **fermentation**. Lignin isolated for chemicals or CHP. Integrated into a oils refinery and can deliver E10 directly to customers.