The Integrated Biomass Supply Systems (IBSS) Partnership:
Technology and Supply Systems for Integrated Production of Advanced Biofuels in the Southeastern US

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NC STATE UNIVERSITY 125 YEARS

IBSS Executive Team

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NCSU IBSS Process Metrics and Modeling Team

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Forest Biomaterials – Skills for Integrated Approaches

Outline

- US National view and goals
- IBSS approach and partners
- Effects of biomass feedstocks on tar formation
- Supply chain and process modeling allow for high resolution financial and life cycle analysis
- Conclusions

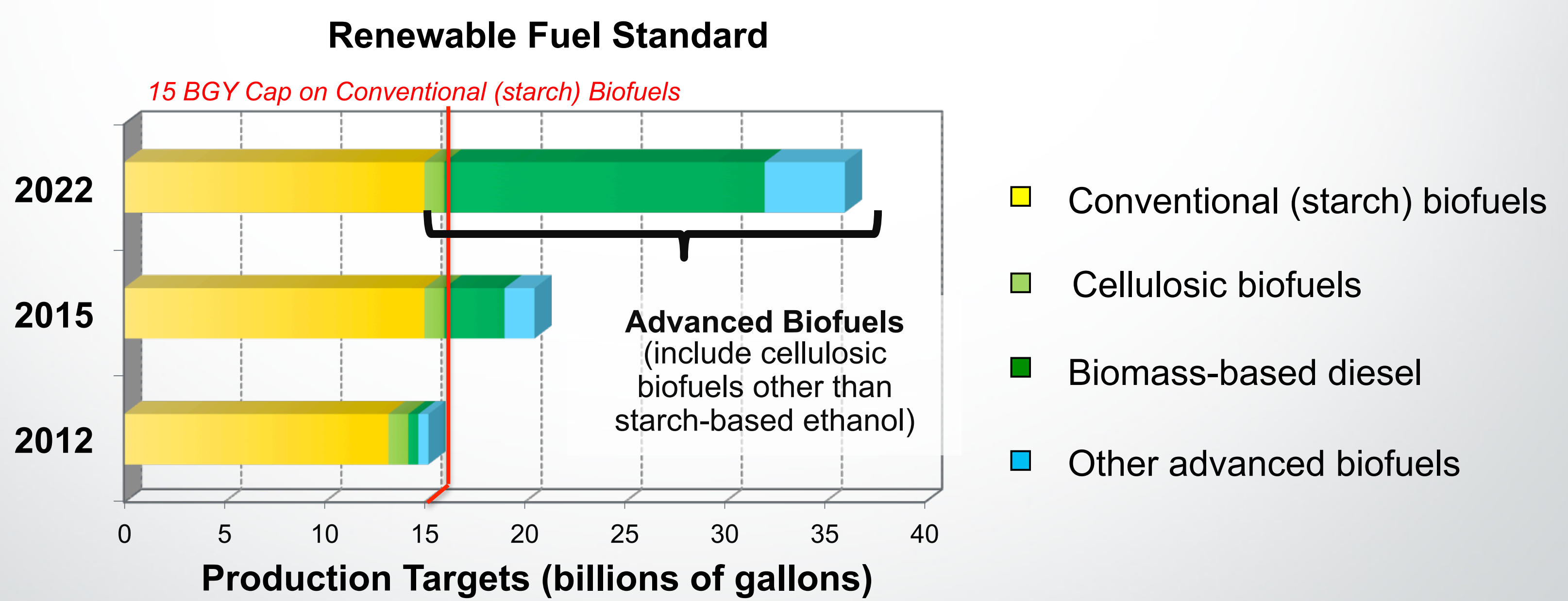
DOE focus on fuels, not power (oil vs. coal and natural gas, or other renewables)

EISA 2007 set aggressive goals:

- Reduce the nation's dependence on foreign sources of energy
- Reduce GHG emissions from the transportation sector
- Move renewable fuels into the marketplace

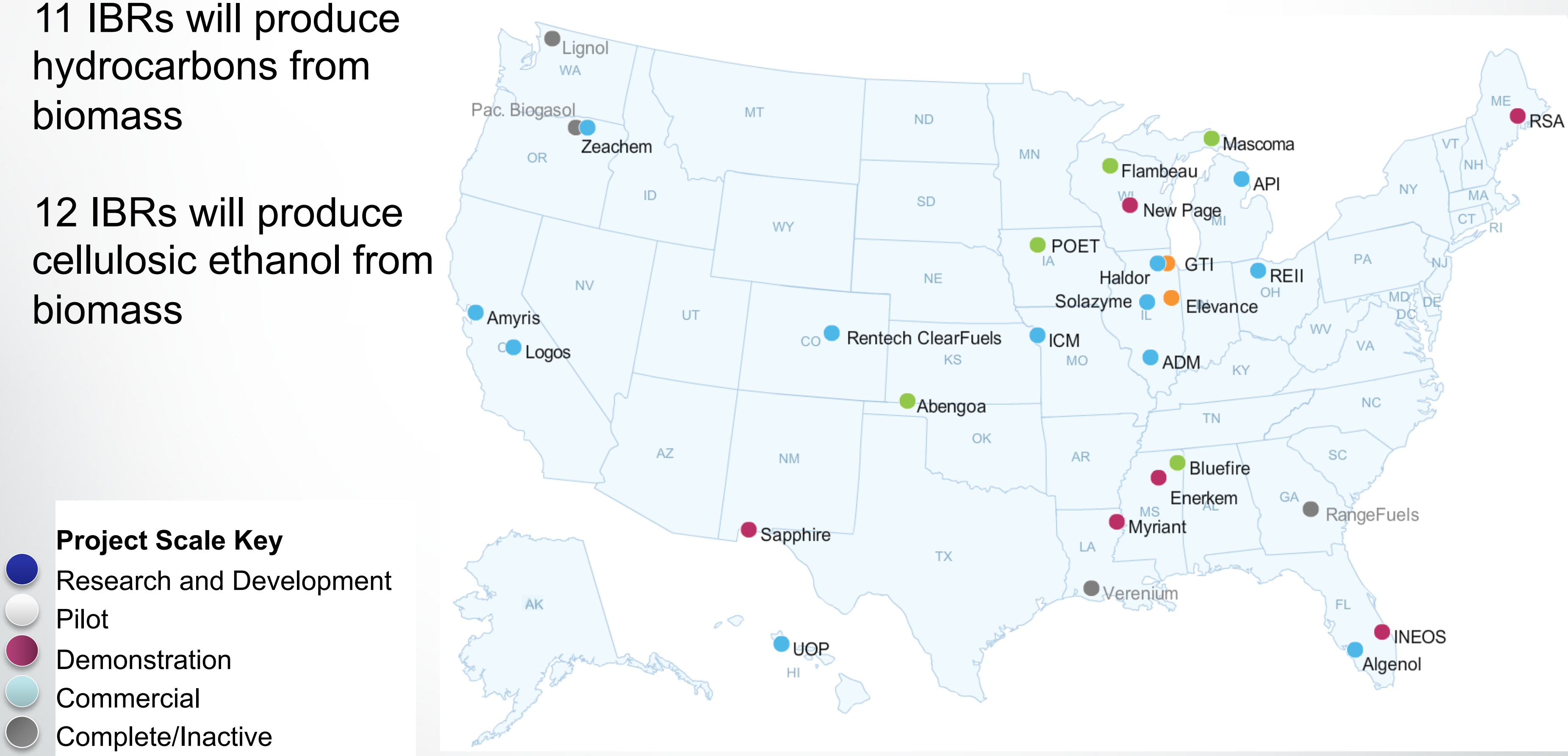
Established production volumes for the Renewable Fuel Standard Program (RFS), increasing the supply of renewable fuels to 36 billion gallons by 2022

Focuses on developing advanced biofuels to support meeting the RFS



Integrated Biorefinery Projects

- 11 IBRs will produce hydrocarbons from biomass
- 12 IBRs will produce cellulosic ethanol from biomass



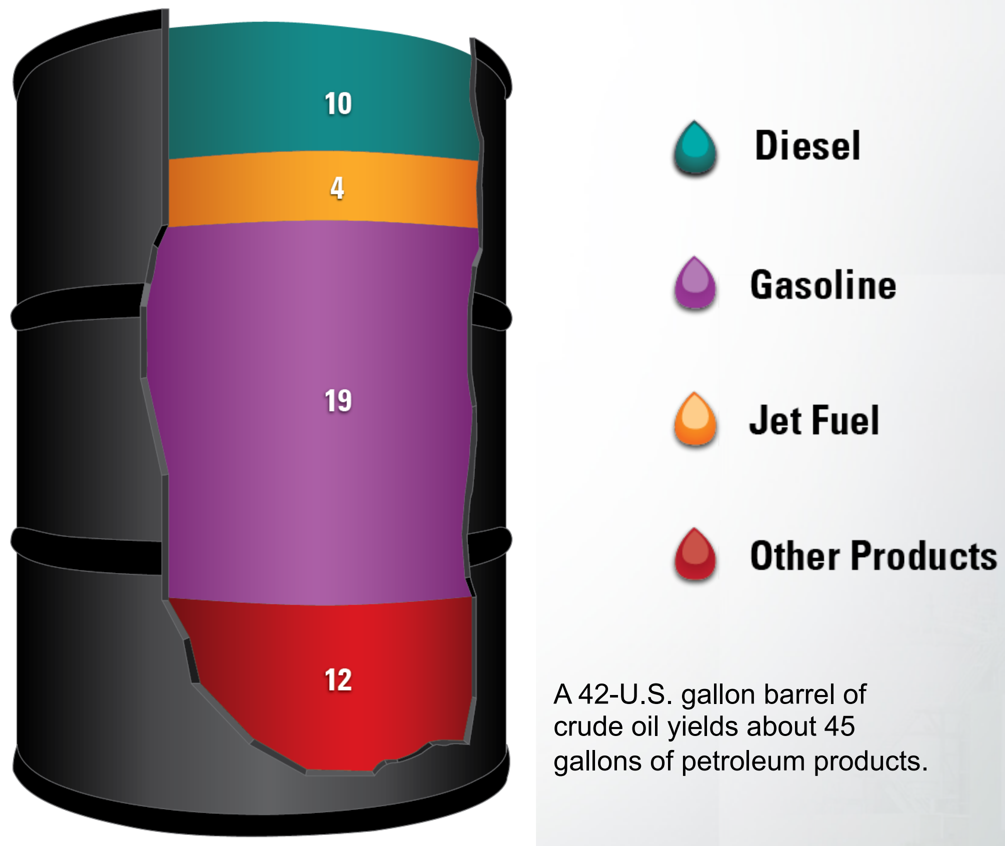
For more information visit: http://www.eere.energy.gov/biomass/integrated_biorefineries.html

DOE focus has expanded to 'replacing the whole barrel'

Greater focus needed on RDD&D for a range of technologies to displace the *entire* barrel of petroleum crude

- U.S. spends more about $1B each day on crude oil imports*
- Only about 40% of a barrel of crude oil is used to produce gasoline
- Cellulosic ethanol can only displace gasoline fraction
- Reducing dependence on oil requires replacing diesel, jet, heavy distillates, and a range of other chemicals and products

Products Made from a Barrel of Crude Oil (Gallons) in 2010



A 42-U.S. gallon barrel of crude oil yields about 45 gallons of petroleum products.

Source: Energy Information Administration

*American Petroleum Institute

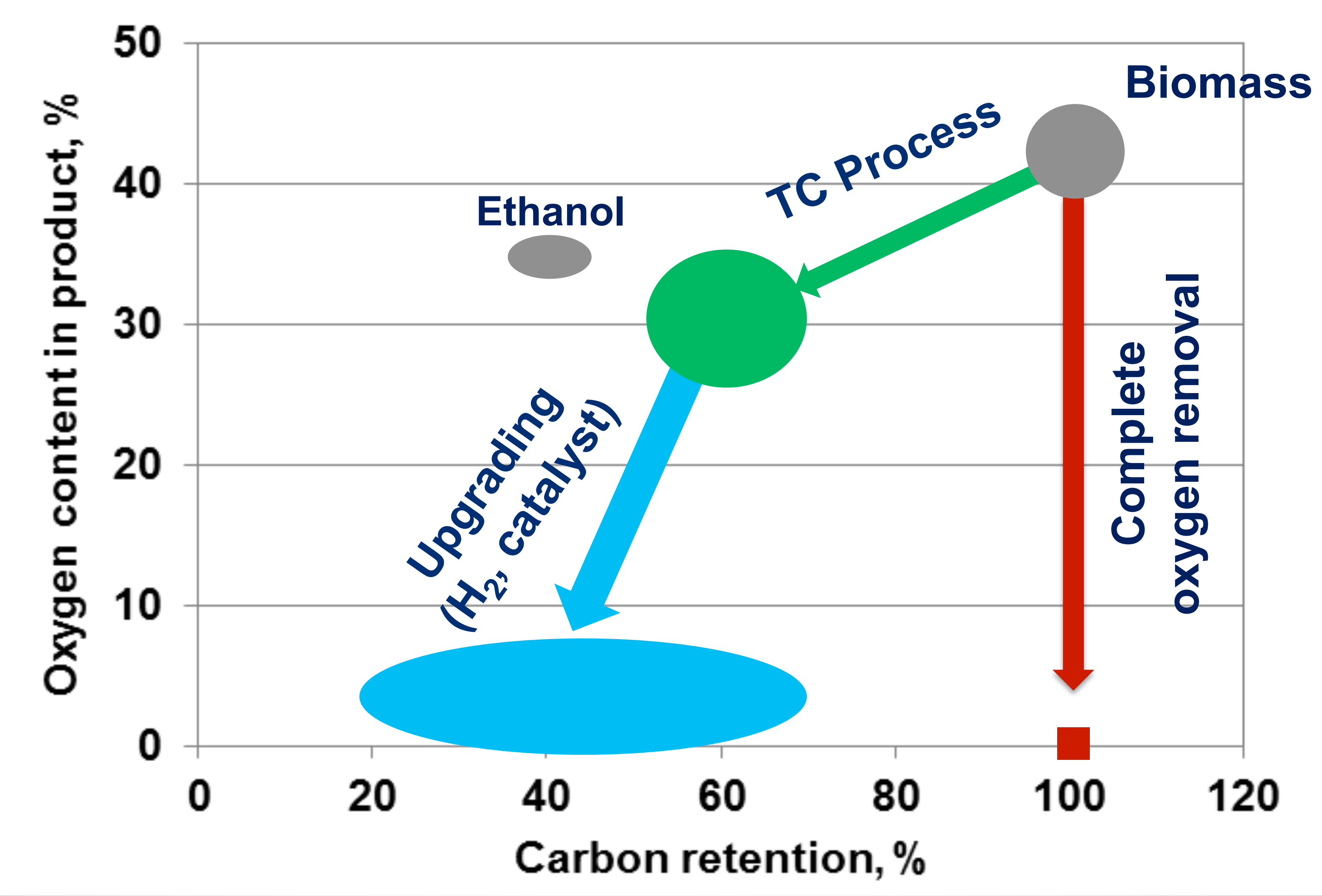
Biomass and TC Processes

- TC processes can use biomass from a wide variety of sources
- Sasol has been making hydrocarbons from coal derived syngas for 40 years
- All methanol and ammonia, and many other chemicals are made from natural gas derived syngas

- Biomass is 40% oxygen, and you buy biomass by the ton ($/ton), so you are buying oxygen
- Ethanol is 33% oxygen and is solid by volume/caloric value (selling oxygen)
- Hydrocarbons (gasoline, diesel, jet, etc.) has no oxygen

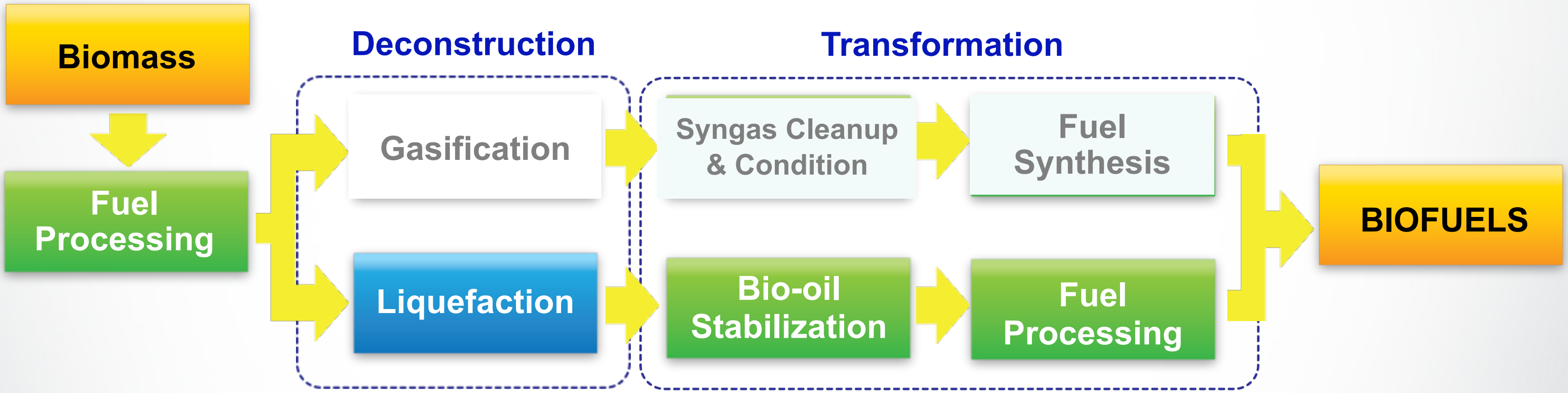
- The oxygen is lost as H_2O or CO_2
- Carbon is required for the hydrocarbon product, minimize CO_2
- Hydrogen, made from natural gas or reformed biomass, is required to remove H_2O

TC processes to remove oxygen



Thermochemical Conversion Platform

RDD&D projects are improving the thermochemical conversion of cellulosic biomass into biofuels such as gasoline, diesel, and jet fuel.



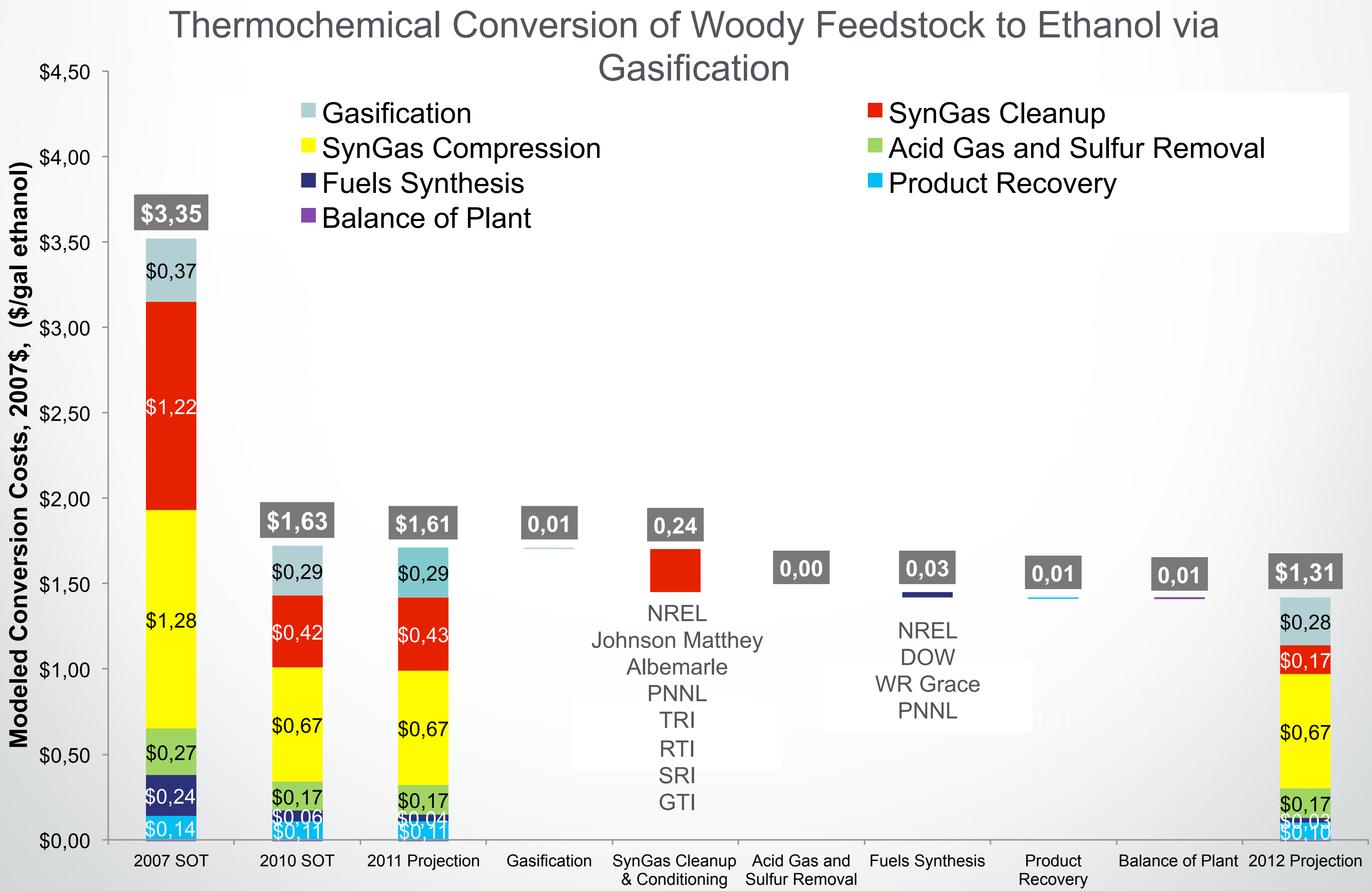
Deconstruction

- Ground and dried biomass is **heated** in reactors to produce gas, solid, and liquid intermediates
- process temperature determines proportions

Transformation

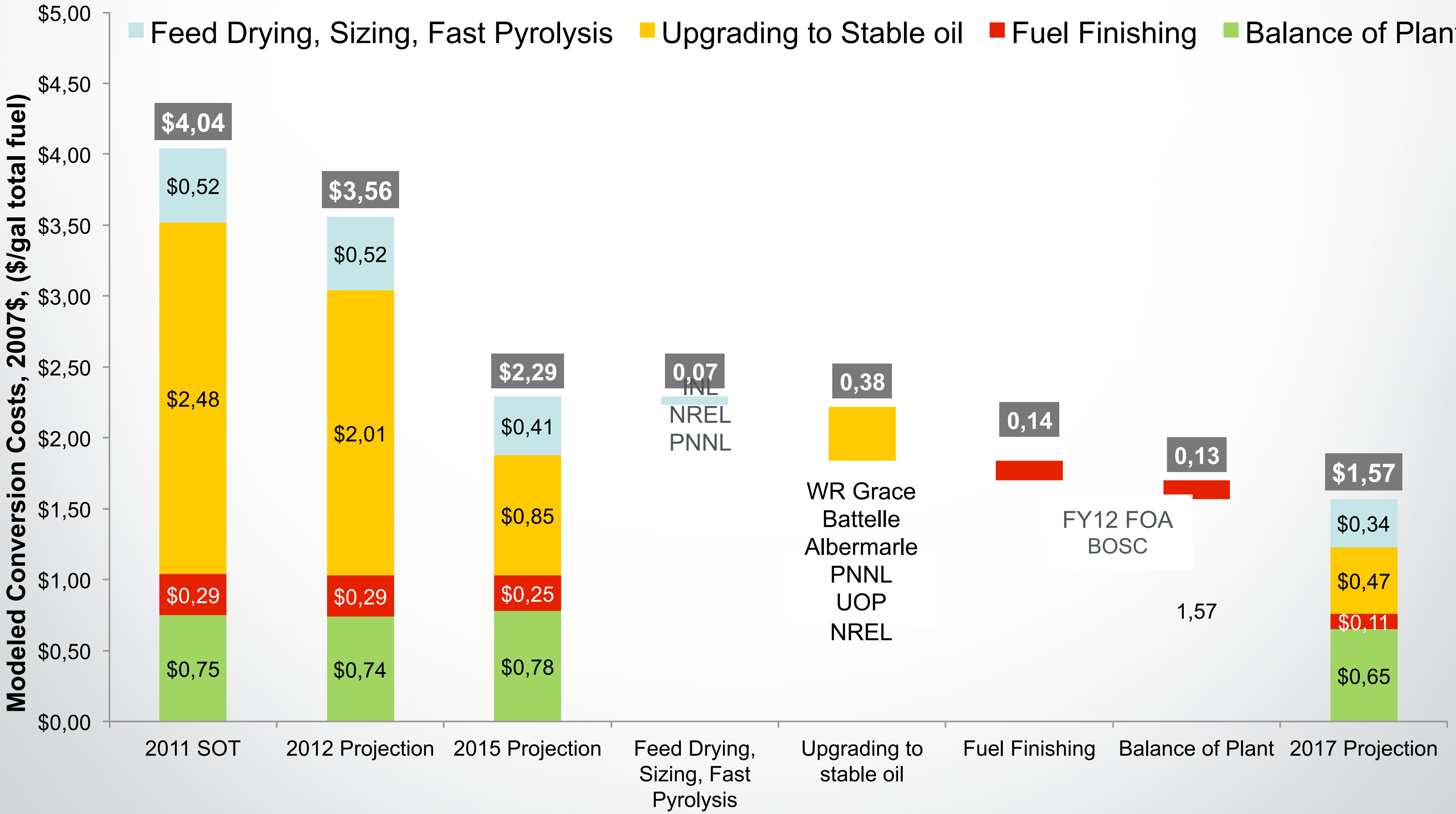
- Synthesis gas is cleaned (inorganics and CO_2 removal) and conditioned (tar reforming) and converted into biofuels and chemicals
- Bio-oils are stabilized and upgraded (O_2 removal) to produce biofuels and chemicals

Gasification to EtOH Cost Curves



Fast Pyrolysis to Hydrocarbons Costs Curves

Thermochemical Conversion of Woody Feedstocks to Hydrocarbons via Fast Pyrolysis



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The IBSS Partnership:

Progress Toward the Southeast's Advanced Biofuels Industry

USDA ArborGen AUBURN UNIVERSITY ceres The University of Georgia NC STATE UNIVERSITY

IBSS works to address the complete integration from <u>the land to the fuel use</u>, and <u>financial and social acceptance</u>

$15 mil, 5 yrs

- Biofuels production is complex (if this was easy it would be done)
- Biofuels requires an allocation of very large land areas, and the ‘permission’ from landowners and communities
- The cost and quality of the biomass are important for both Biochem. and Thermochem. processes.

The IBSS Partnership's Footprint

The Partners

- ArborGen
- Auburn University
- Ceres (not shown, Thousand Oaks, CA)
- NC State University
- University of Georgia
- University of Tennessee

The Collaborators

- Fort Valley State University
- Tuskegee University
- Alabama A&M University
- Tennessee State University
- Oak Ridge National Laboratory
- USFS-Southern Research Station
- Louisiana-Pacific Corp, Nashville, TN
- Rentech, Inc. (not shown, Commerce City, CO)
- DuPont/Genera Energy, Vonore, TN

The Focal Points (Research)

- Louisiana-Pacific, Roxboro, NC
- Genera Energy, Inc., Vonore, TN

The Field Trials

IBSS Rentech Hydrocarbon Partner

- 20 tpd biomass gasifier now operational (500 hours)
- Harvested, preprocessed, and shipped SR biomass
  - Hybrid poplar (20 dry tons)
  - Loblolly pine (60 dry tons)
- Addressed material handling issues
  - Size reduction approach
  - Moisture content
  - Particle flow
- Bio-syngas to FT reactor

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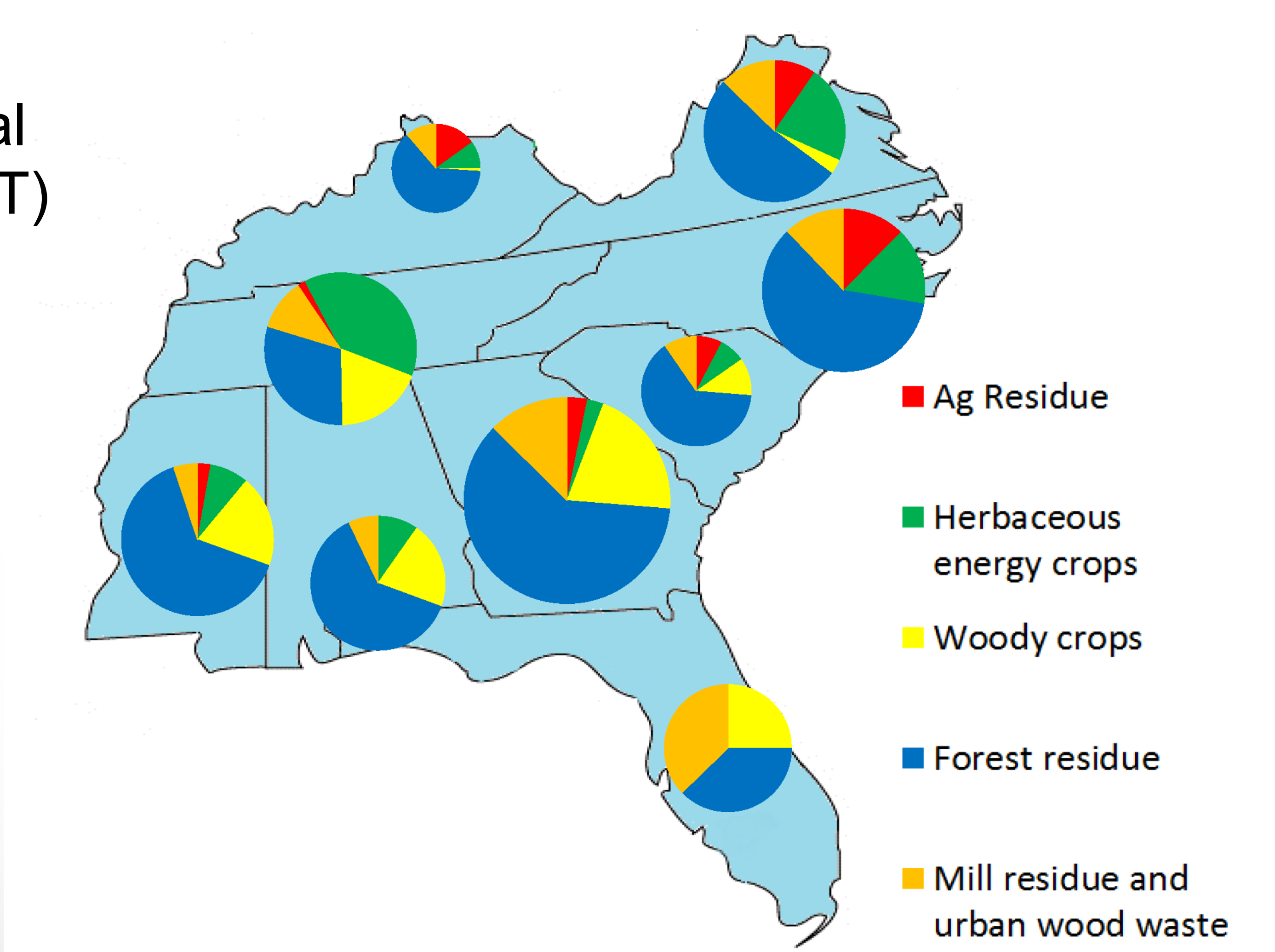
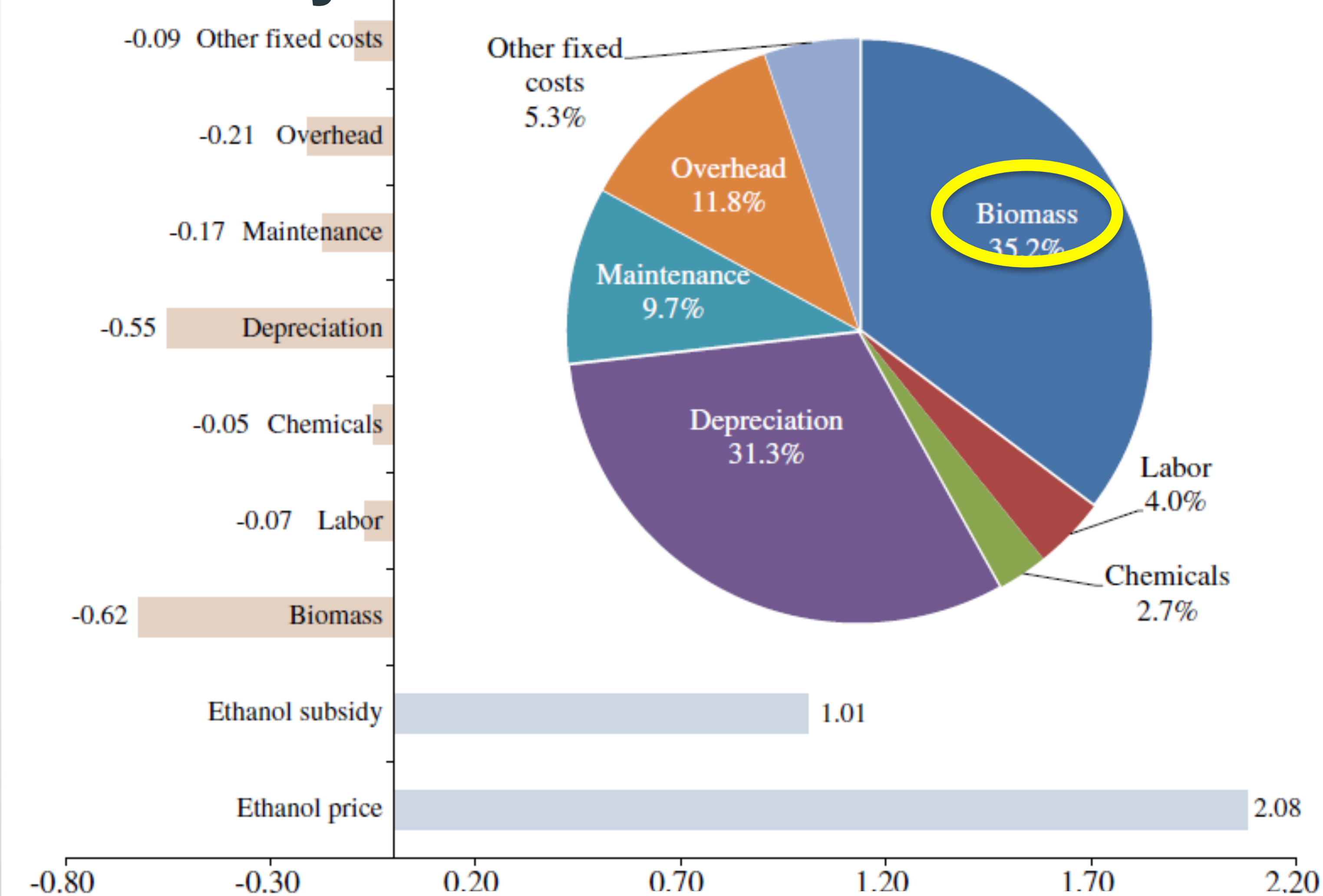
The IBSS partnership footprint

State	Potential (mil. ODT)
GA	10.3
NC	8.6
TN	8.4
MS	8.3
VA	7.5
AL	7.1
FL	6.7
SC	5.1
KY	4.6

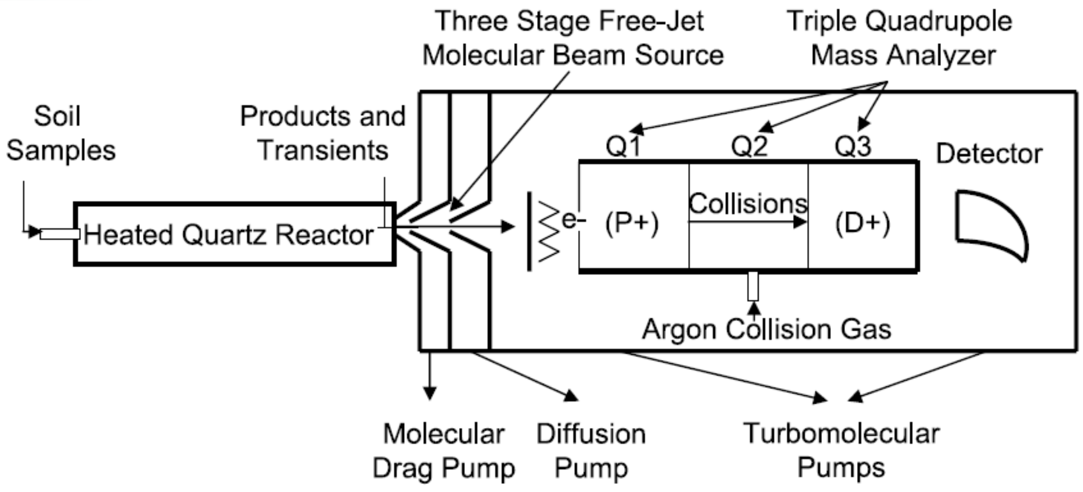


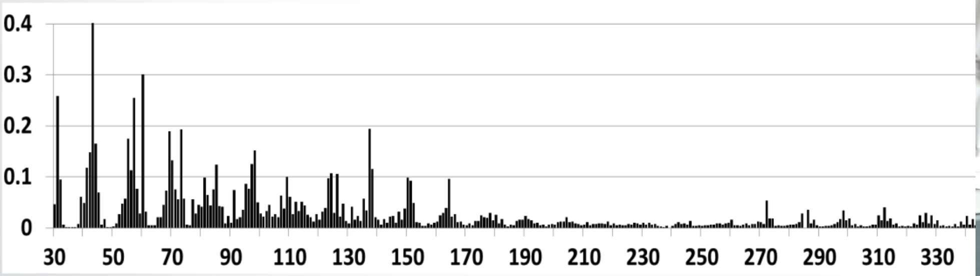
Whole System Costs



Cost and Revenue (US$ per gallon ethanol)

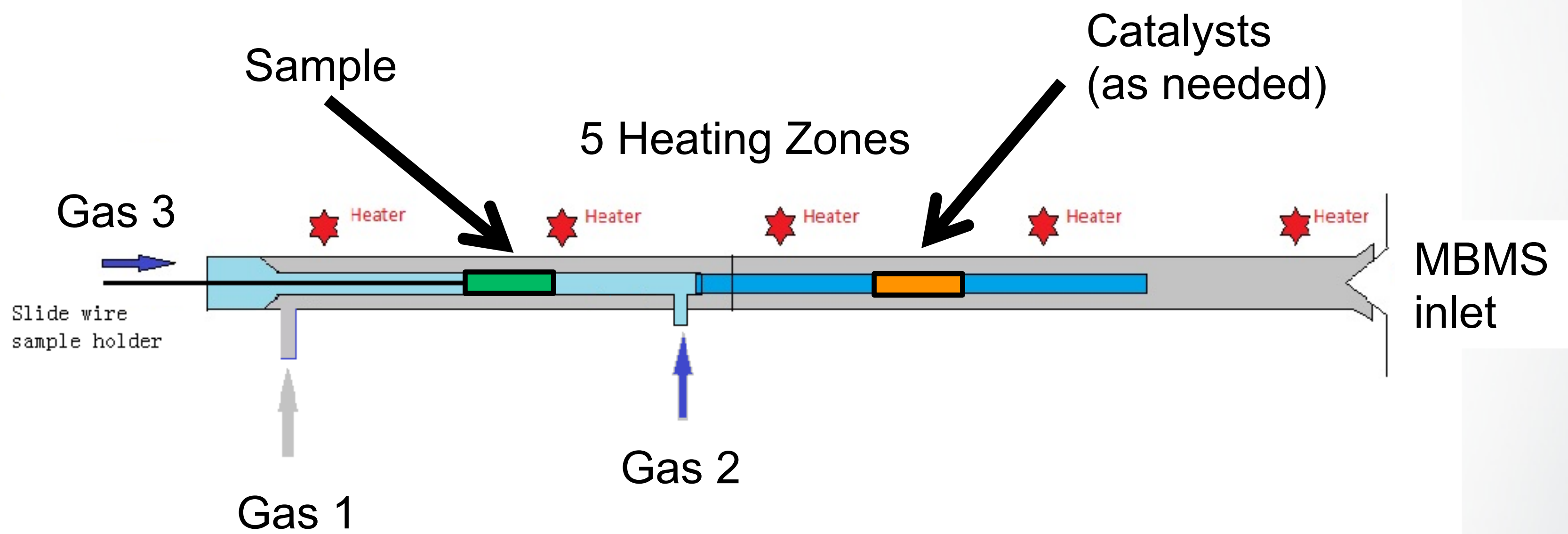
Py-MBMS screening





Raw MBMS spectra

Py-MBMS - furnance design



Set up to run

1) as an high-throughput analytical tool with autosampler, 3 min per sample
2) as a 'minigasifier', screen reactor conditions, catalysts

Set up

Oven temperature: 550 – 950^{o}C

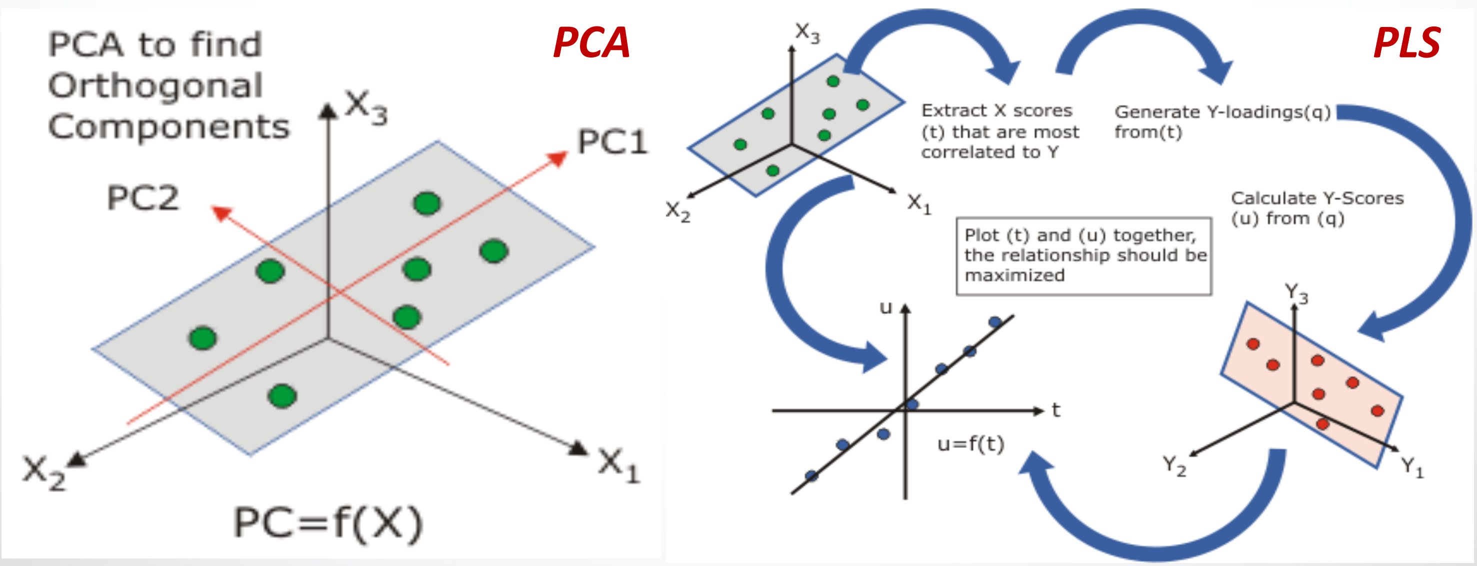
Gas 1: Steam
Gas 2: Oxygen
Gas 3: Helium

MBMS: scan range: 10-600 amz

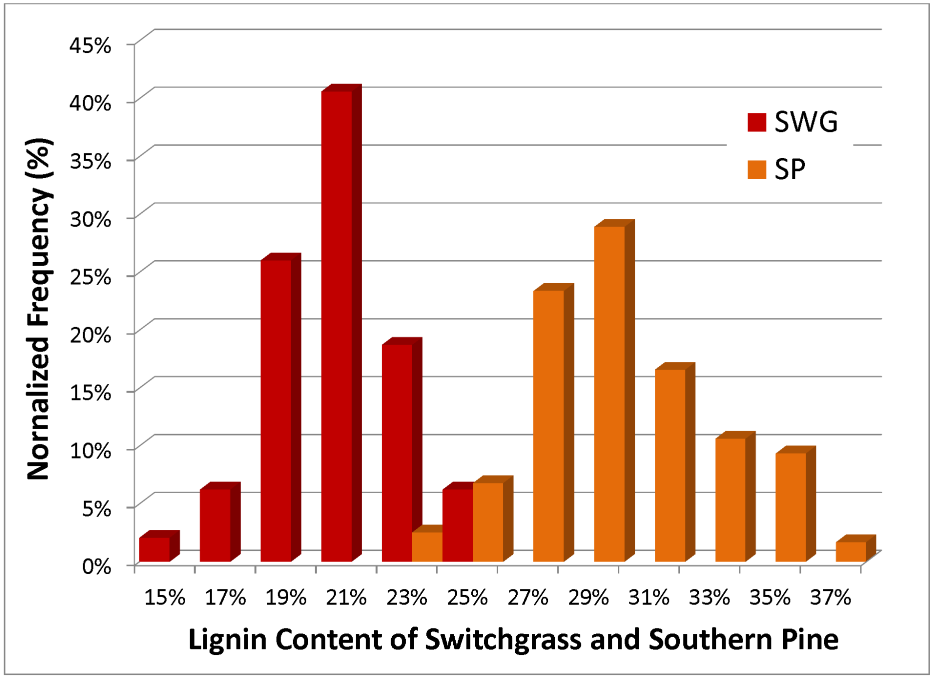
Complex patterns – Multivariate Tools

- *PCA* : reduction and redefinition of original variables
  → A smaller number of latent variables (PC)
  - *Interpret similarities or differences between samples with sample groupings*

- *PLS* : modeling of both the X- and Y-matrices
  → Latent variables in X (Py-MBMS spectra, factor) and latent variables in Y (characteristics)
  - *Describe the relationship between the two groups of variables or to predict new values*



Variations between species



- Biomass samples evaluated using py-MBMS include: 1) 400 pine samples, 2) 200 eucalyptus, 3) 100 poplar, and 4) 100 switchgrass
- TC processes, i.e., higher BTU content is desired, but Tars are a major cost barrier, and the source of tars are unclear

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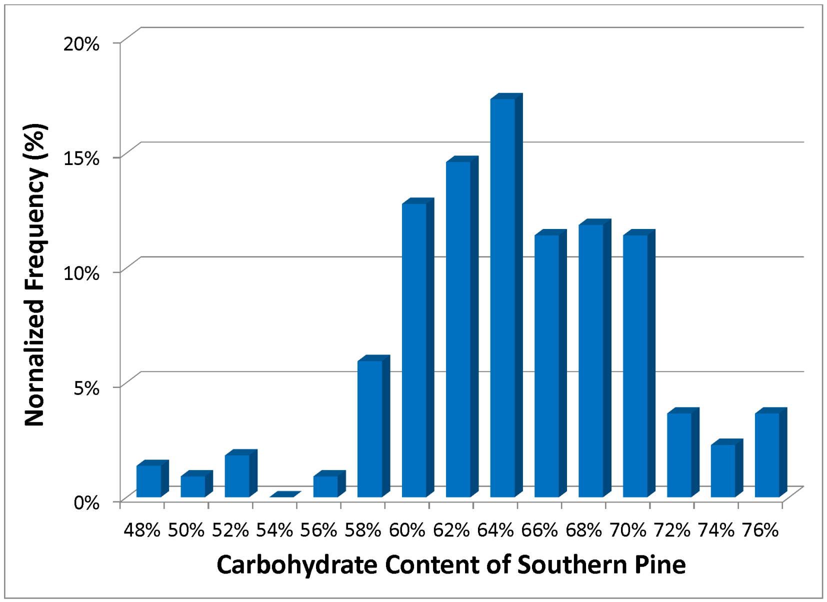
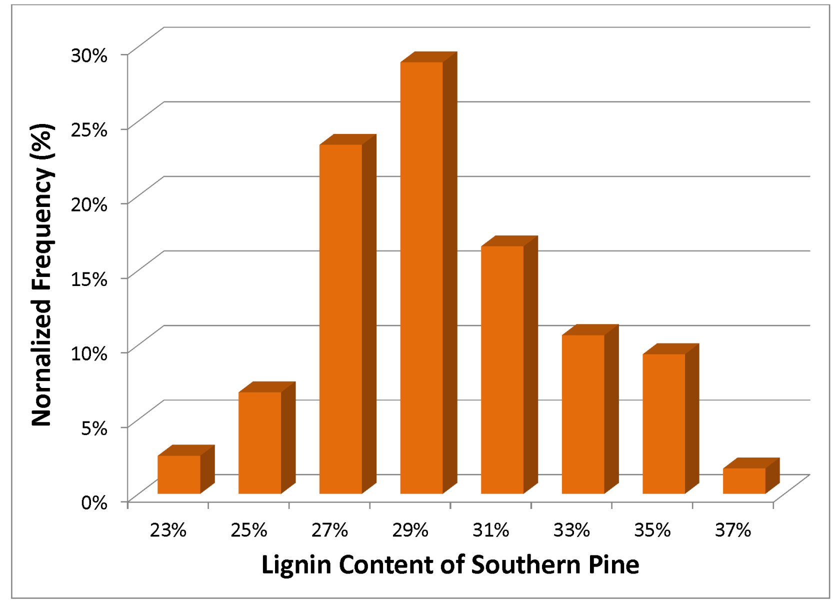
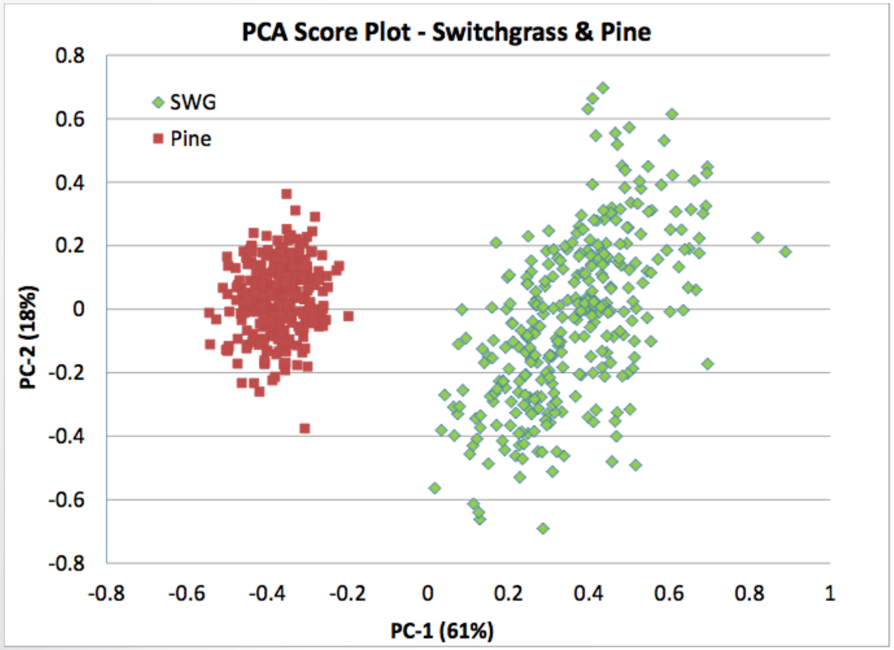
Variations within species – Southern Pine

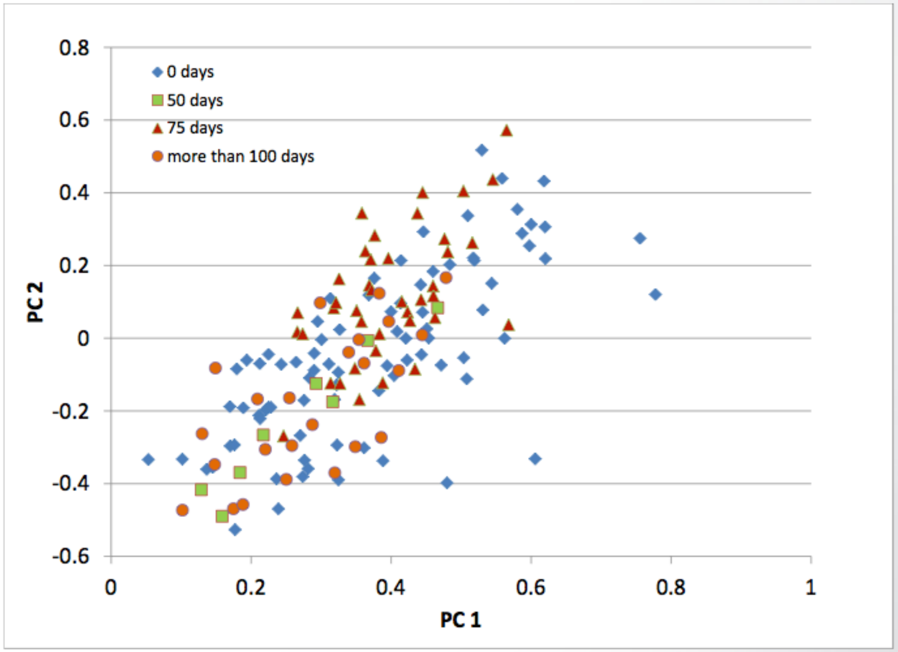




- Costs, composition and consistency are all key for a commercial operation
- Looking at the effects of genetics and site (ash could have a major impacts on tars)

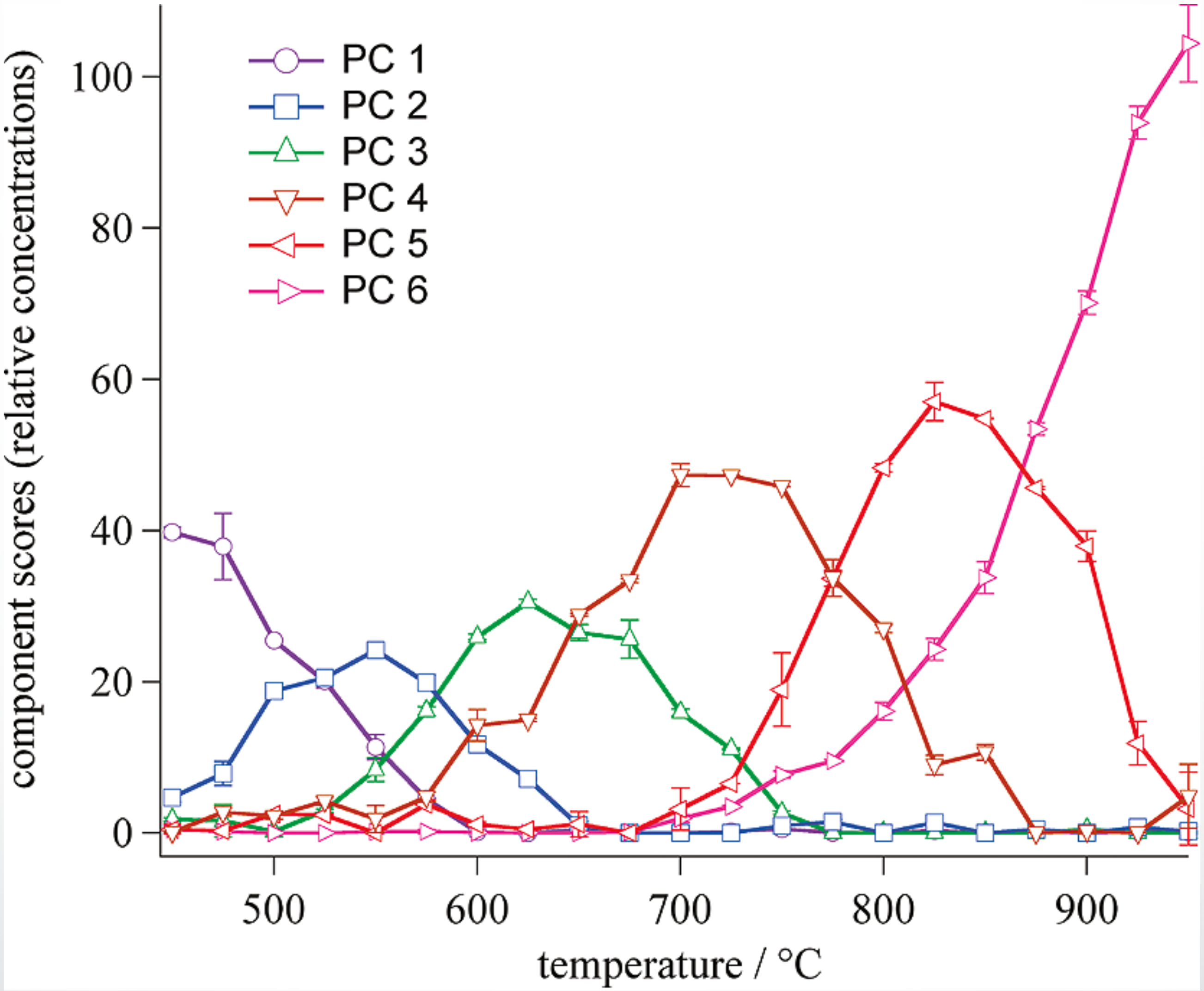
Tar variations within and between species





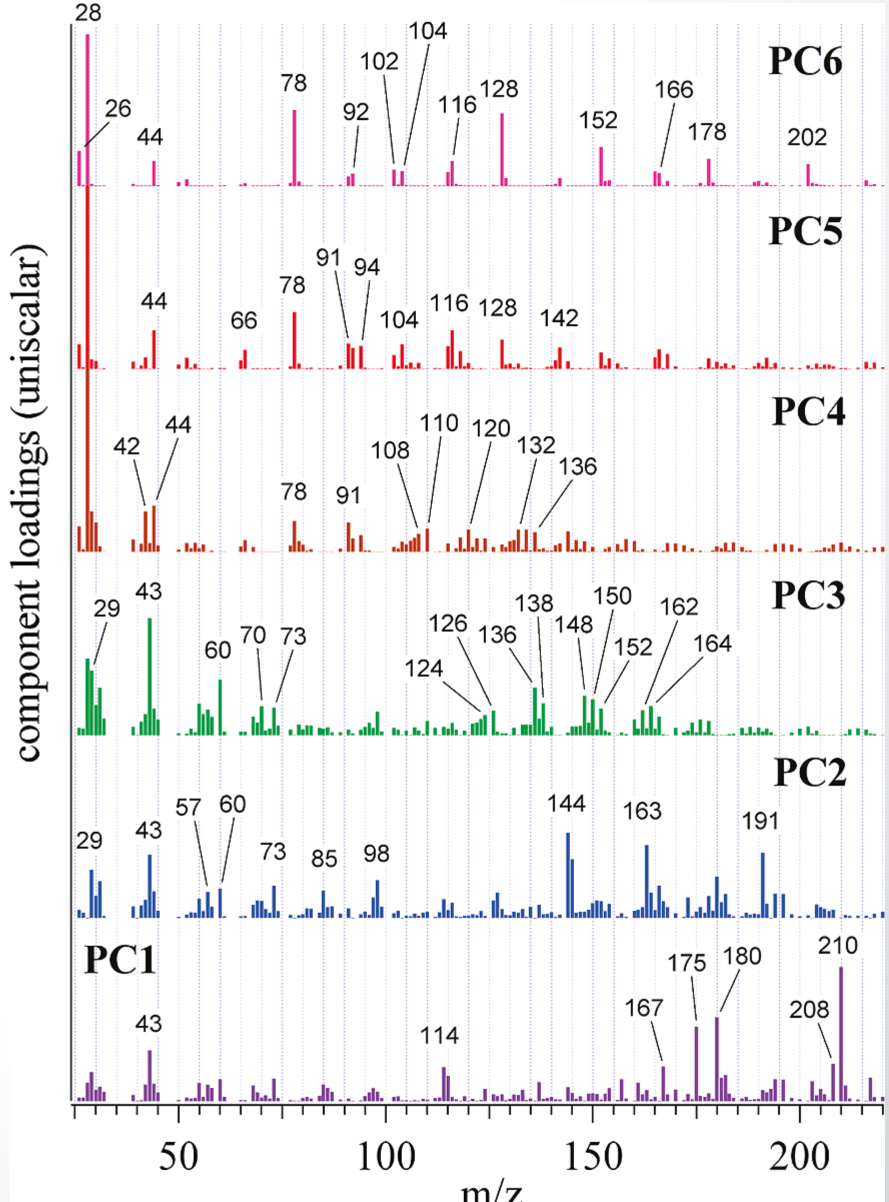
- Tar formation different between species
- Tar formation highly varied within Switchgrass
- Switchgrass tars are not related to storage

Time-resolved profiles



Biomass/Tars - time resolved MBMS

- PC 1 – extractives, simple fragments
- PC 2 – Hemicelluloses
- PC 3 – Primary Lignin
- PC 4 – Lignin fragments (demethoxylated)
- PC 5 – Cellulose fragments
- PC 6 – Tart formation



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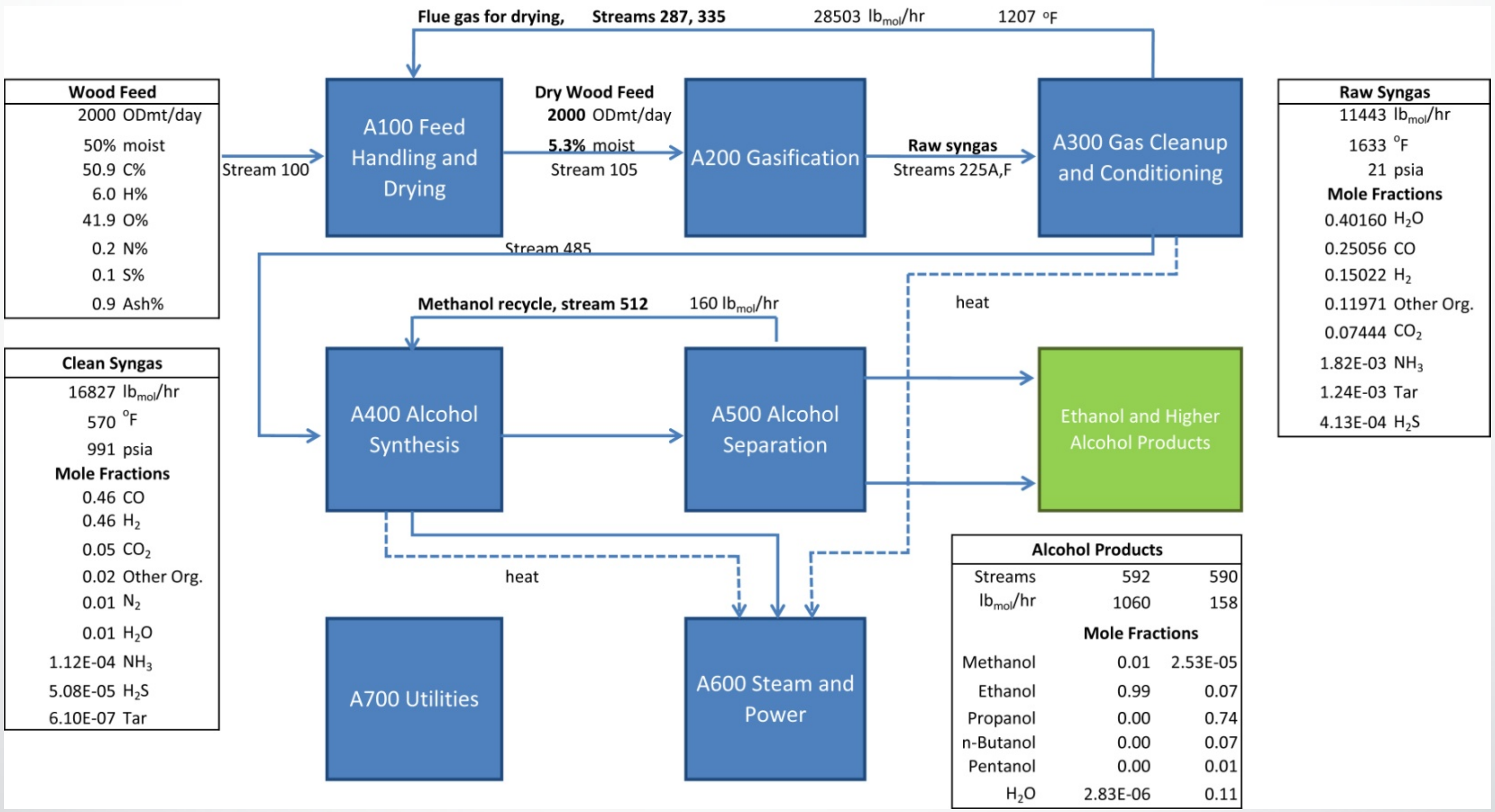
Effective modeling requires consideration of the INTEGRATED SYSTEM

- Two major systems 1) biomass production/supply chain, 2) fuel production; fuel utilization will become more important as production increases
- Biomass production is complex, components that **scale** with land, with annual production, and with composition
  - Land – cost of land, planting and harvesting, chemicals, (water)
  - Production – tons per acre, transportation, percent of land needed
  - Composition – % carbohydrate, value added chemicals
- Fuel production – larger scale is ALWAYS better, but typical engineering calculations for scale, different conversion processes have different cost curves ($ of capital/gal of fuel)

- Both the financial and Life Cycle analyses require consideration of the integrated system

Biofuels production system

NREL Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass Model



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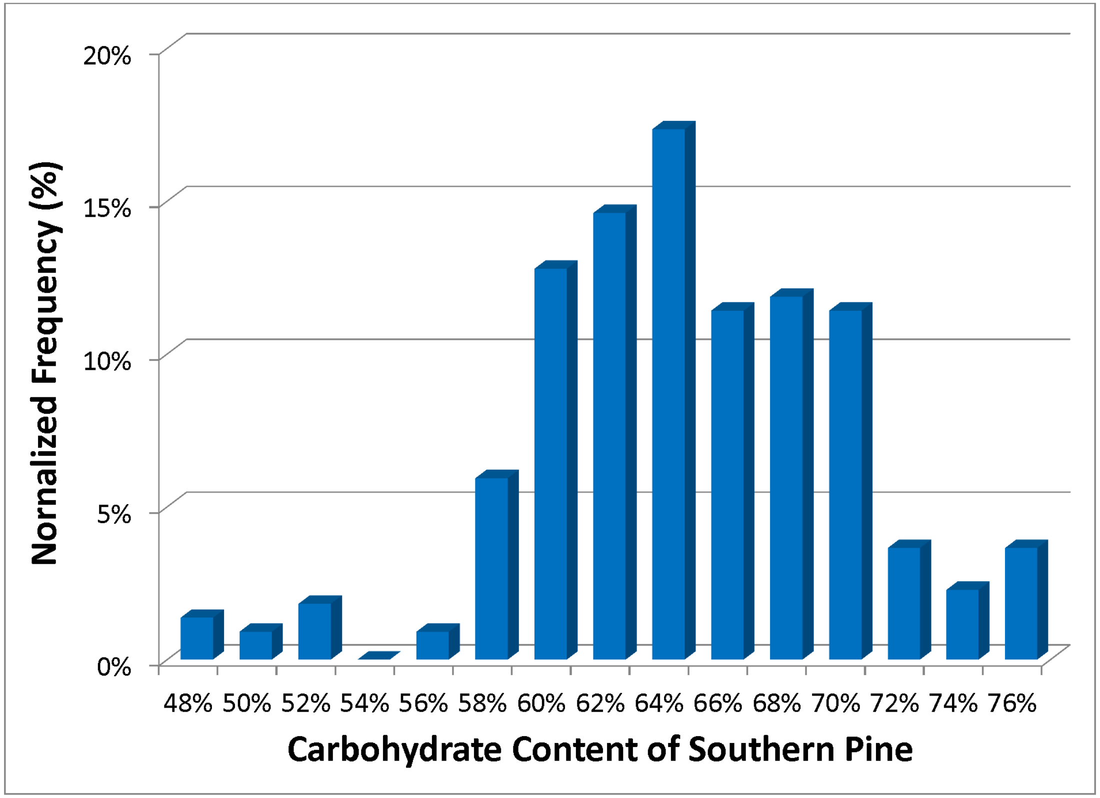
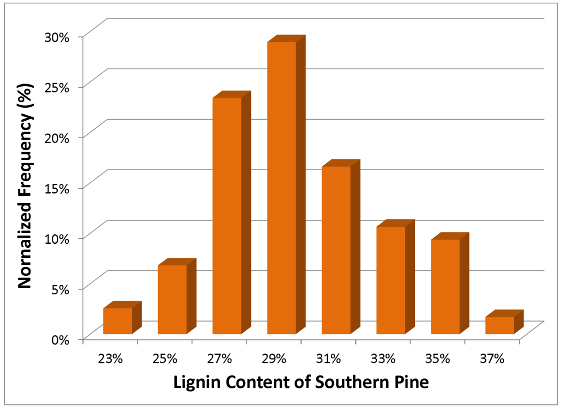
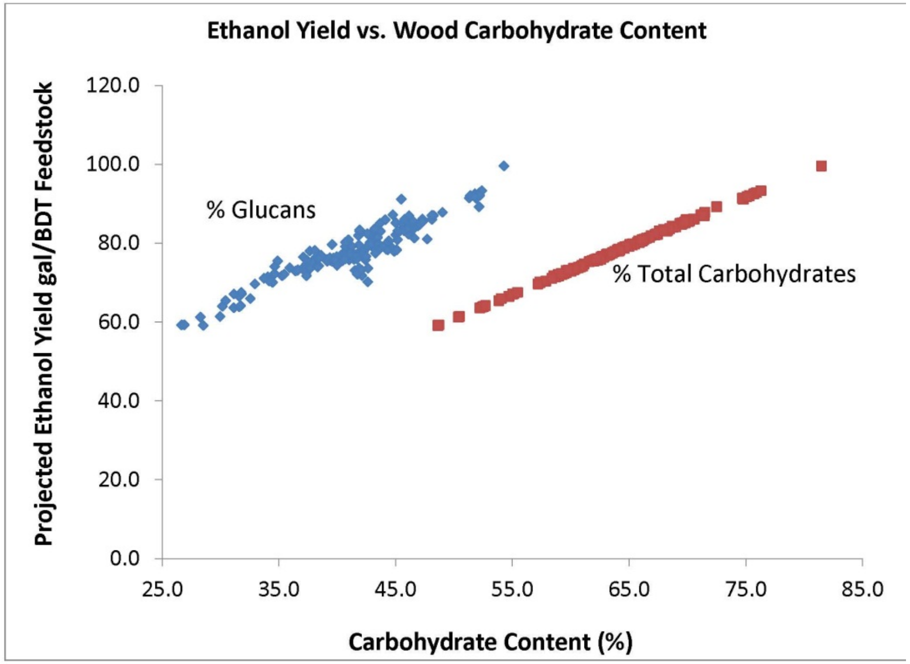
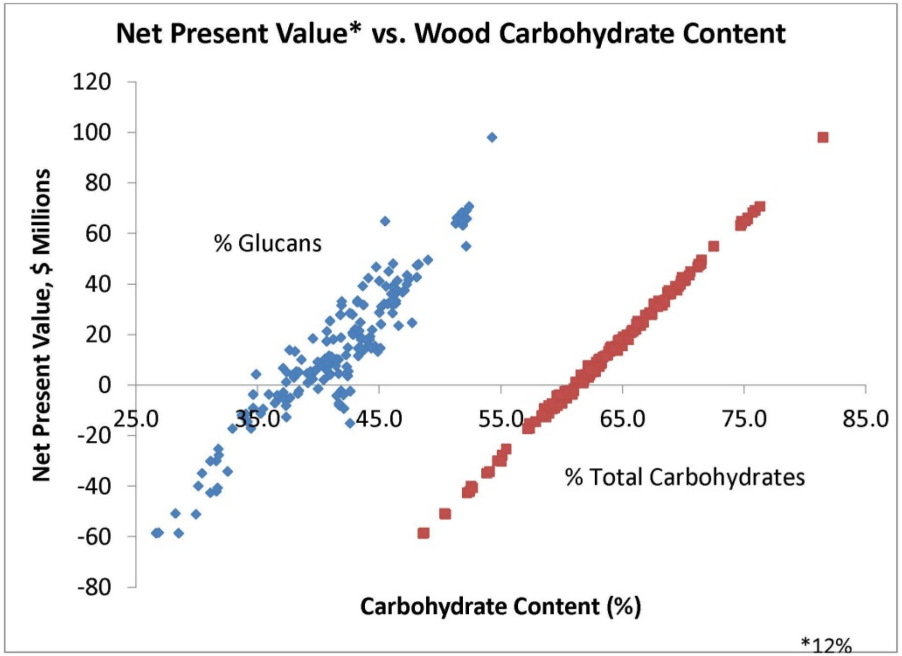




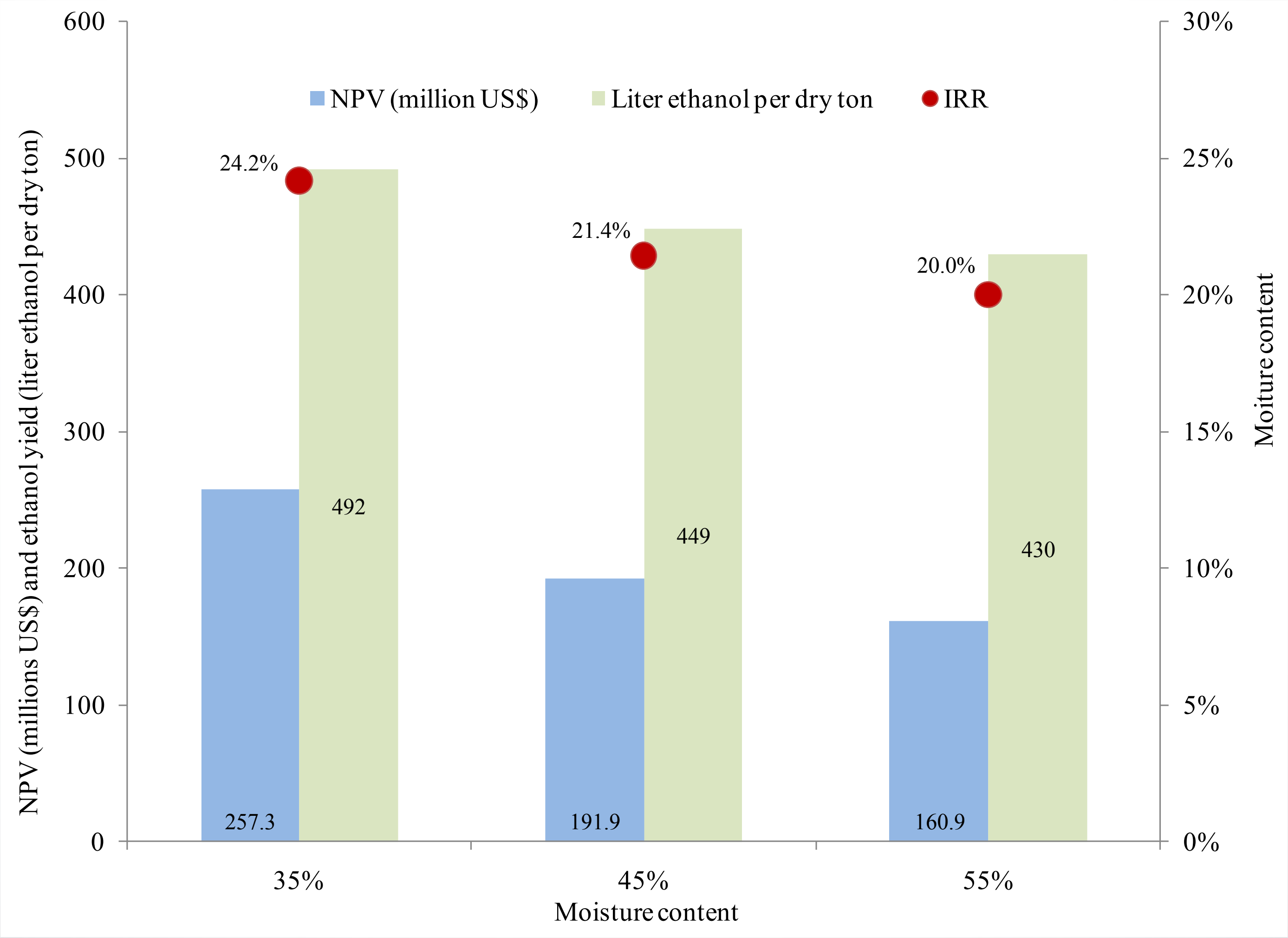
- Costs, composition and consistency are all key for a commercial operation – fuel; process heat

Effects of composition on financial return (BC)





Moisture content is a unique issue for TC



Biomass production systems

Biorefinery

- Dilute acid
- Thermochem
- GL
- ZeaChem

- Plant location
- Complete financial analysis

Freight

- $/BDT

Storage

- $/BDT
- Sugar/Biomass loss

Integrated Supply and Financial Models

- Land available to grow biomass?
- What are the strategies for conversion of land use?
- Whole tree chemical composition?

Harvesting

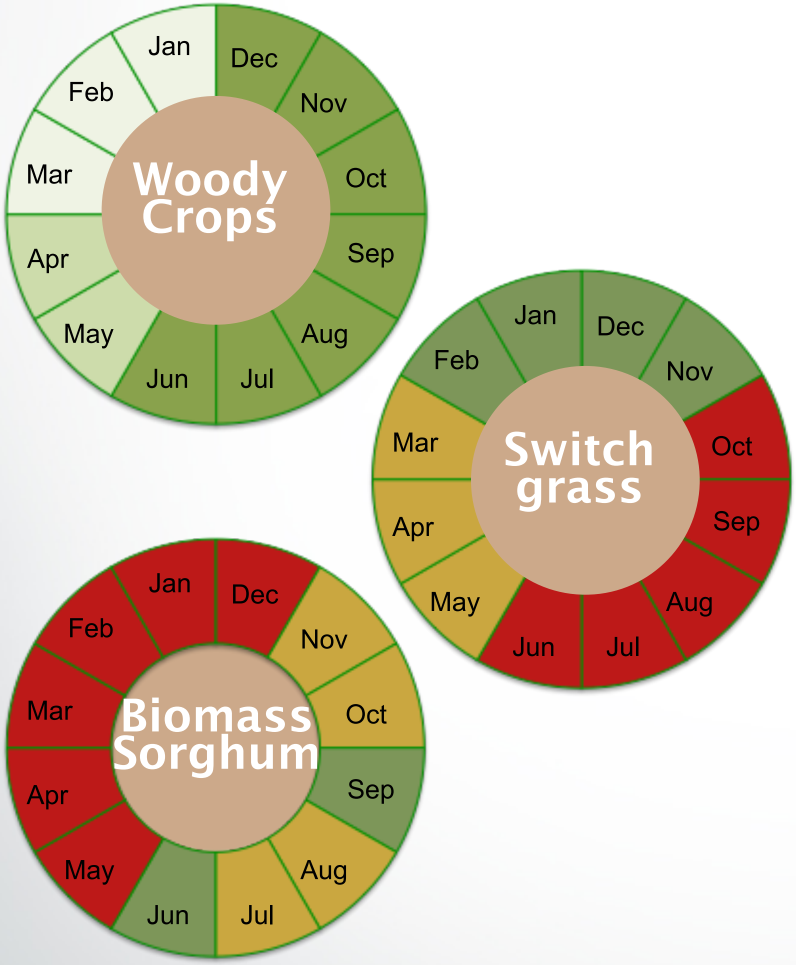
- Biometrics
- $/acre; $/BDT
- Ton Carbohydrate/acre

Biomass production/supply chain

Description	Loblolly Pine	Eucalyptus	Unmanaged Hardwood	Switchgrass	Sweet Sorghum	Forest Residues
Productivity (dry tonne ha^{-1} $year^{-1}$)	12.80	13.50	2.24	13.50	11.77	0.76
Rotation length (years)	12	4	50	n/a	n/a	n/a
Harvesting window	Year round	Year round	Year round	Three months	Three months	Year round
Moisture content	45%	45%	45%	16%	74%	45%
Delivery form	Logs	Logs	Logs	Square bales	Cane	Chips
Establishment cost ($/ha)	637	552	0.0	181	416	n/a
Maintenance cost ($/ha)	62.4 [1]	62.4 [1]	0.0	85.3 [2]	n/a	n/a

1 = Second year of plantation; 2 = Maintenance cost per year, year 2 through 10

The Value of Integrated Supply



- Reduce risk of supply chain disruptions
  - Weather extremes
  - Insects/disease
- Minimize or eliminate storage costs with ‘just in time’ delivery
- Optimize biomass quality and process performance
- Maximize biomass yield
- Increase environmental benefits
- Meet landowner goals

Biomass production/supply chain – details

		Loblolly Pine			Eucalyptus			Unmanaged Hardwood			Forest Residues			Switchgrass			Sweet Sorghum		
	Productivity level	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Fuel Use		Liter per dry ton			Liter per dry ton			Liter per dry ton			Liter per dry ton			Liter per dry ton			Liter per dry ton		
	Fuel consumption, collection	-	-	-	-	-	-	-	-	-	0.05	0.04	0.03	-	-	-	-	-	-
	Plantation establishment and maintenance, diesel	0.86	0.65	0.52	2.47	1.85	1.48	-	-	-	0.61	0.45	0.36	-	-	-	-	-	-
	Plantation establishment and maintenance, gasoline	0.04	0.03	0.03	0.12	0.09	0.07	-	-	-	8.0	6.0	4.8	3.93	2.95	2.36	-	-	-
	Harvesting, diesel	10.1	7.58	6.06	10.1	7.58	6.06	10.1	7.6	6.1	-	-	-	6.02	4.51	3.61	4.13	3.1	2.48
	Storage													0.6	0.6	0.6	0.84	0.84	0.84
Transport		Dry ton*km			Dry ton*km			Dry ton*km			Dry ton*km			Dry ton*km			Dry ton*km		
	Transportation forest to facility	79	69	62	78	67	60	219	190	170	327	283	253	-	-	-			
	Transportation farm to storage	-	-	-	-	-	-	-	-	-	-	-	-	51	44	39	175	152	136
	Transportation storage to facility	-	-	-	-	-	-	-	-	-	-	-	-	9.5	9.5	9.5	31	31	31
Chemical Use	Fertilizer	kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton		
	UREA	2.1	1.6	1.3	2.9	2.2	1.7	-	-	-	0.13	0.1	0.08	-	-	-			
	Phosphorus	-	-	-	-	-	-	-	-	-	-	-	-	1.6	1.2	0.96	3.43	2.57	2.06
	Potassium	-	-	-	-	-	-	-	-	-	-	-	-	15.83	11.88	9.5	1.7	1.27	1.02
	Lime	-	-	-	-	-	-	-	-	-	-	-	-	62.28	46.71	37.37	-	-	-
	Nitrogen	-	-	-	-	-	-	-	-	-	-	-	-	8.47	6.36	5.08	-	-	-
	Herbicide	kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton			kg per Dry Ton		
	General herbicide, glyphosate	0.03	0.01	0.01	0.08	0.04	0.03	-	-	-	0.002	0.001	0.001	-	-	-	-	-	-
	Pursuit	-	-	-	-	-	-	-	-	-	-	-	-	2.36	1.77	1.41	-	-	-
	MSO	-	-	-	-	-	-	-	-	-	-	-	-	3.31	2.48	1.99	-	-	-
	2,4	-	-	-	-	-	-	-	-	-	-	-	-	1.14	0.85	0.68	-	-	-
	Alzarine 90 DF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.19	0.14	0.11
	Dipel ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	0.15	0.12

Note: 453,592 BD metric tonnes /year, 10% covered area

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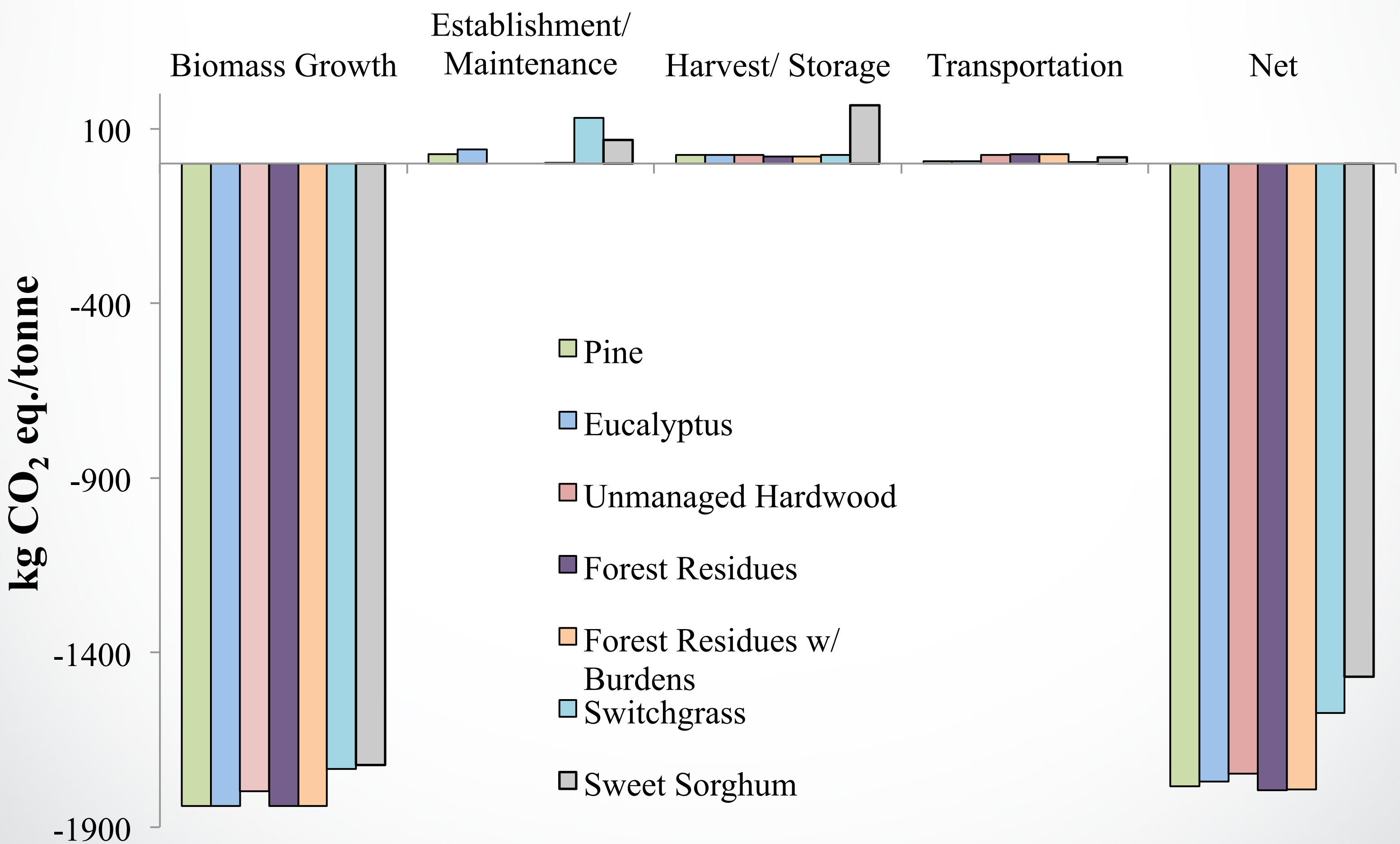
GHG emissions from biomass production



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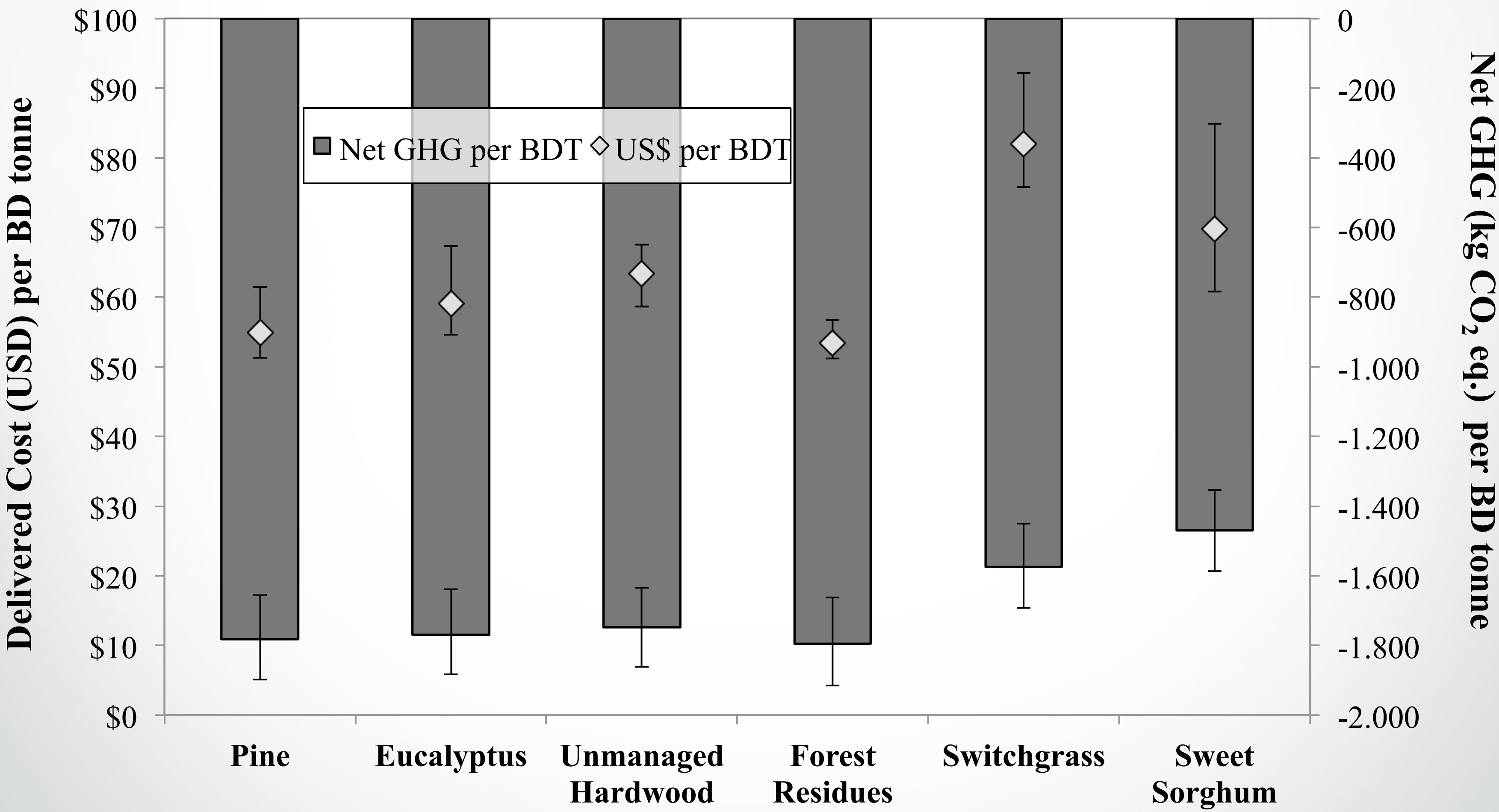
Biomass production/supply chain



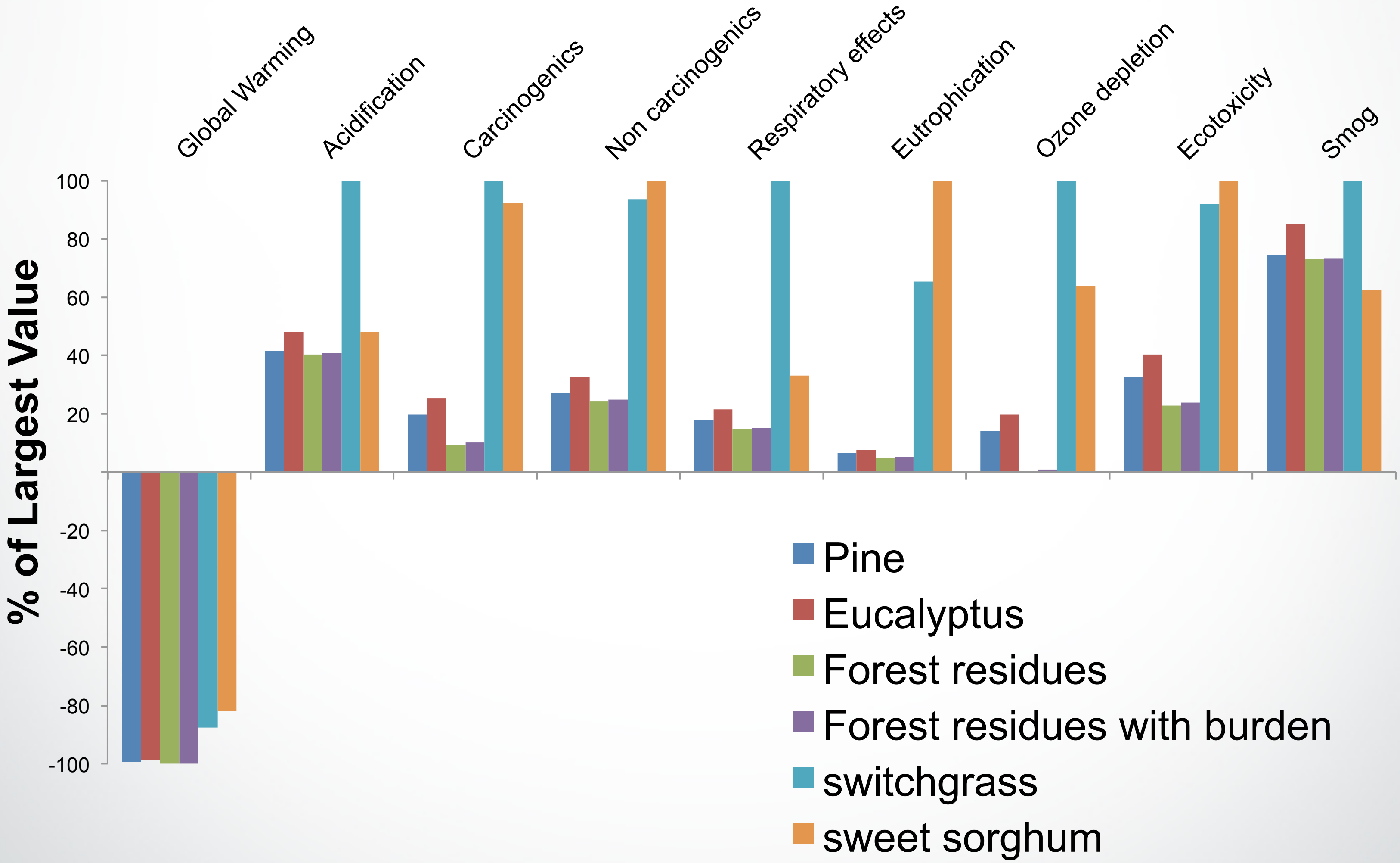
TRACI – Impact assessment methods

HUGE NUMBER OF BACKGROUND ASSUMPTIONS

- Global warming
- Acidification
- Carcinogenics
- Non Carcinogenics
- Respiratory effects
- Eutrophication
- Ozone depletion
- Ecotoxicity
- Smog

Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI)

TRACI results for biomass production



Conclusions

- Need to understand the context for your work
  - we are not running out of oil (cheap oil - yes)
  - we have to use marginal lands
  - biofuels will be expensive, what is the policy driver
- Have to understand the process and scale issues, some systems are inherently difficult to scale down, with others the composition or energy density may offer opportunity
- Biomass source and composition matters for both BC and TC
- Tar formation include primary and terairy reaction systems, and the process plays a role
- For any financial or Life Cycle analysis the entire system must be defined, and the details are very important
- LCA includes 'objective' (if imprecise) criteria and 'subjective' (very imprecise) criteria, and opens the door to a great deal of conflicting outputs
- First generation of cellulosic plants will require unique co-location or market drivers

Thank you!

Gracias!

Danke schoen!

Merci!