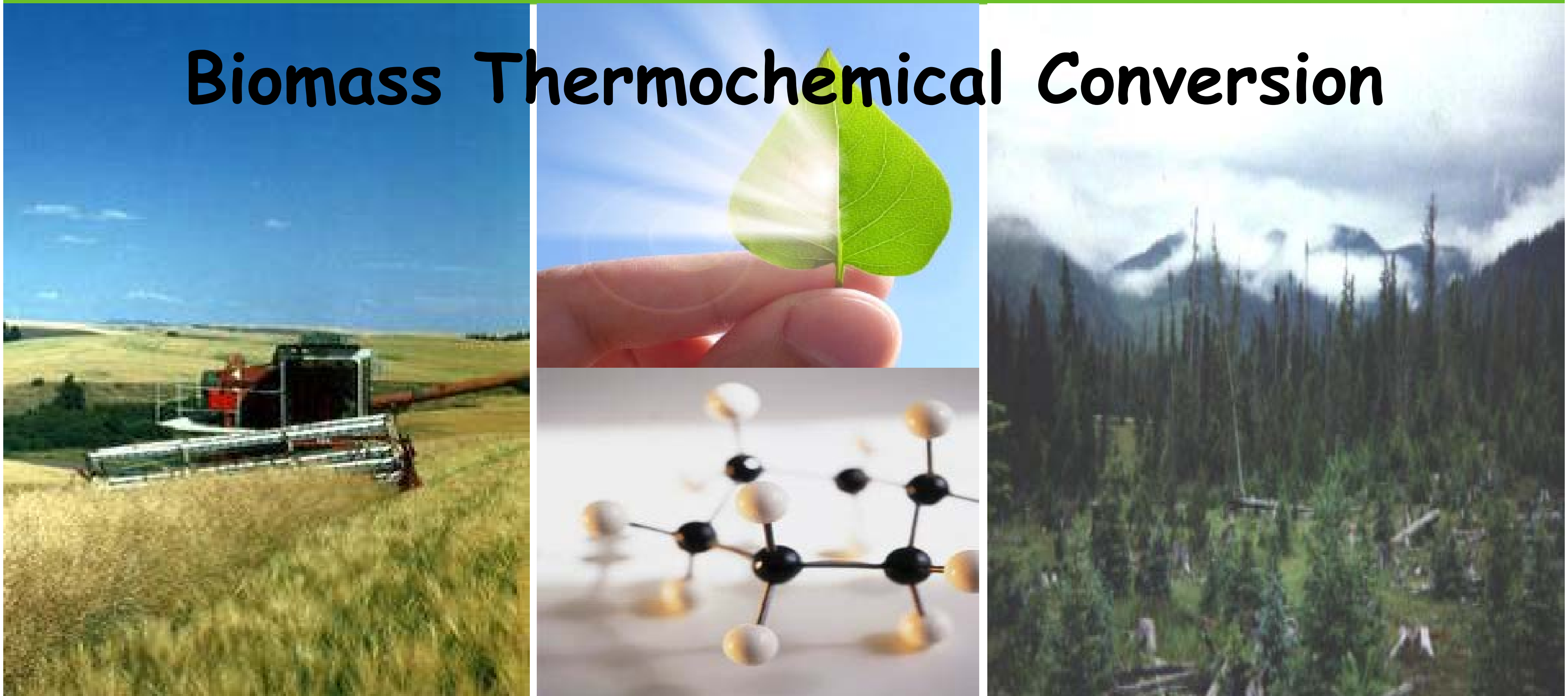
U.S. Department of Energy
Energy Efficiency and Renewable Energy

U.S. Department of Energy
Biomass Program

Biomass Thermochemical Conversion



Biofuels Workshop

2009 Integrated Energy Policy Report

January 13, 2009 – California Energy Commission

John Scahill

DOE Golden Field Office

Office of Biomass Programs - Technology Development Drivers

DOE Strategic Plan (2006)

Theme 1: Energy Security – Promoting America's energy security through reliable, clean, and affordable energy

Theme 3: Scientific Discovery and Innovation – Strengthening U.S. scientific discovery, economic competitiveness, and improving quality of life through innovations in science and technology

↓

EERE Strategic Plan (2002)

Dramatically reduce dependence on foreign oil
Create the new domestic bioindustry

↓

OBP Strategic Goal ('08 Budget)

Develop biorefinery related technologies associated with the different biomass resource pathways to the point that they can compete in terms of cost and performance and are used by the Nation's transportation, chemical, agriculture, forestry, and power industries to meet their respective market objectives.

President's Advanced Energy Initiative (AEI) (2006)

Change the way we fuel our vehicles

Make cellulosic ethanol cost competitive with corn ethanol by 2012

↓

BioFuels Initiative (BFI) (2006)

Make cellulosic ethanol cost competitive by 2012

Replace 30% of transportation fuel supply with biofuels by 2030

President's "20 in 10" Goal (2007 SOU)

Reduce U.S. Gasoline Usage By 20 Percent In The Next Ten Years (by 2017)

↓

Renewable Fuel Standard

35 billion gallons (ethanol basis) of renewable and alternative fuels in 2017.

↓

Biofuel Contribution

Corn Ethanol

Imported Ethanol

Cellulosic Ethanol

Biodiesel

Renewable Diesel

EPAct 2005 Sec. 932. BIOENERGY PROGRAM.

The Secretary shall conduct a program of research, development, demonstration, and commercial application for bioenergy, including-

(1) biopower energy systems;
(2) biofuels;
(3) bioproducts;
(4) integrated biorefineries that may produce biopower, biofuels, and bioproducts;
(5) cross-cutting research and development in feedstocks; and
(6) economic analysis

Includes 'Integrated Biorefinery Demonstration ' (932-d)

↓

Select Other EPAct 2005 Provisions

Sec. 942: Incentives to ensure 1 billion gallons of cellulosic biofuel annual production by 2015 (reverse auction)
Title 17: Loan Guarantees

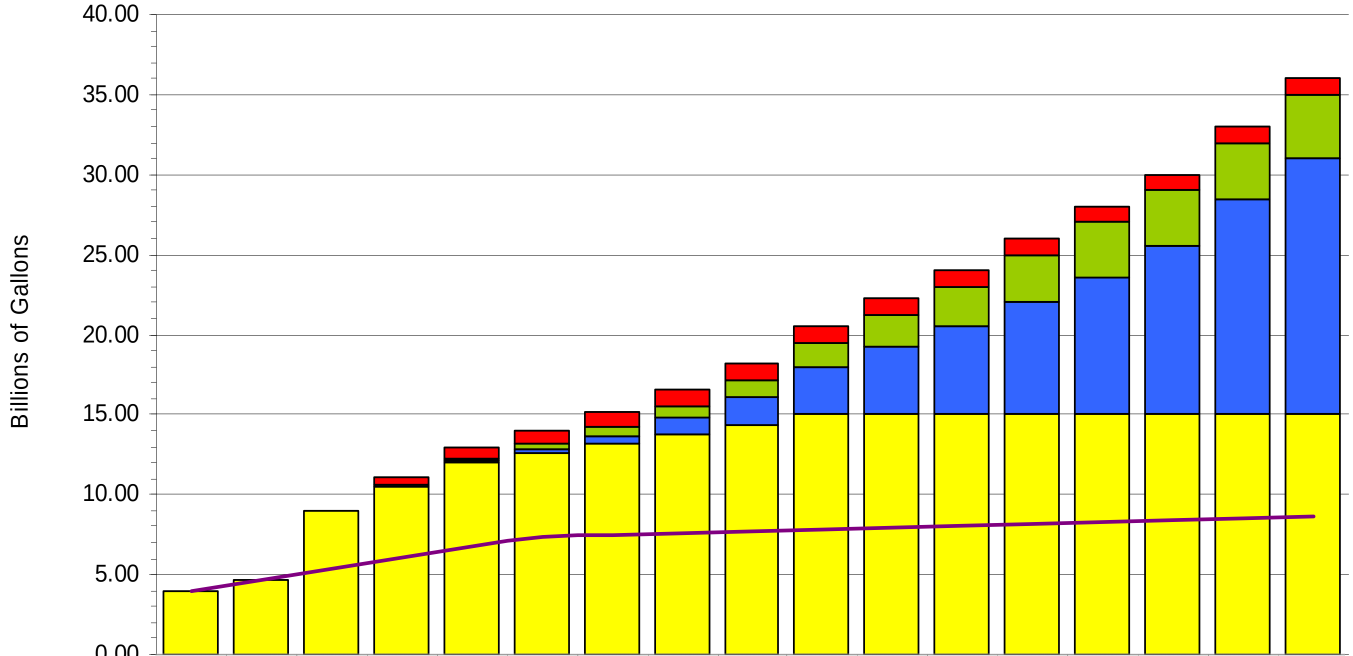
↓

OBP Vision, Mission and Performance Goals

Program Targets

Energy Independence Security Act 2007

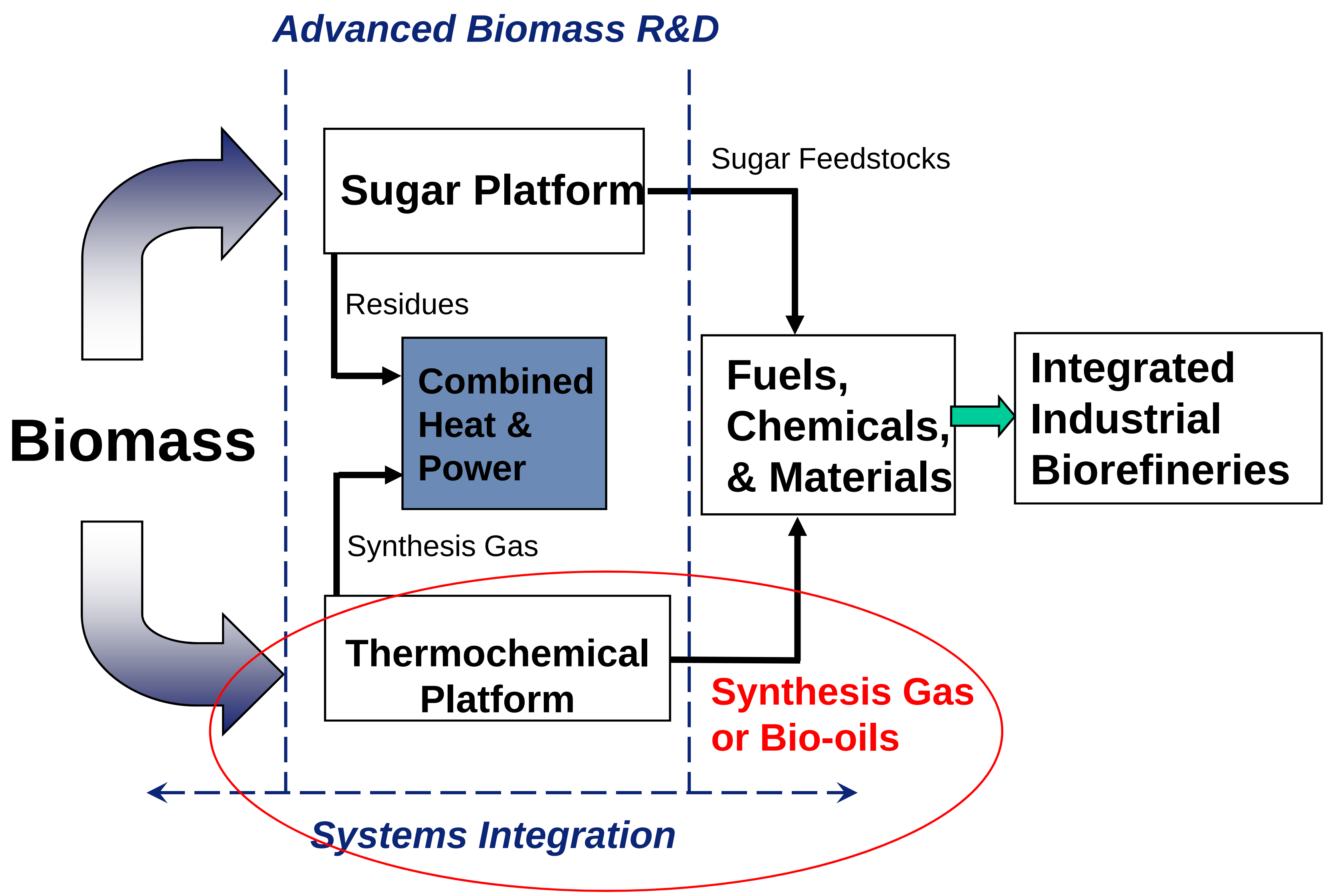
Renewable Fuel Standard (RFS), 2007-2022



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass-based Diesel				0.50	0.65	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Non-celullosic Advanced				0.10	0.20	0.30	0.50	0.75	1.00	1.50	2.00	2.50	3.00	3.50	3.50	3.50	4.00
Celullosic Advanced					0.10	0.25	0.50	1.00	1.75	3.00	4.25	5.50	7.00	8.50	10.50	13.50	16.00
Conventional Biofuels	4.00	4.70	9.00	10.50	12.00	12.60	13.20	13.80	14.40	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Current RFS PL 109-58	4.00	4.70	5.40	6.10	6.80	7.40	7.50	7.60	7.70	7.80	7.90	8.10	8.20	8.30	8.40	8.50	8.60

Source: Hart Energy Consulting, Government Affairs 2007

Research Focus on the Biorefinery



Biomass Constituents

Lignin: 15-25%

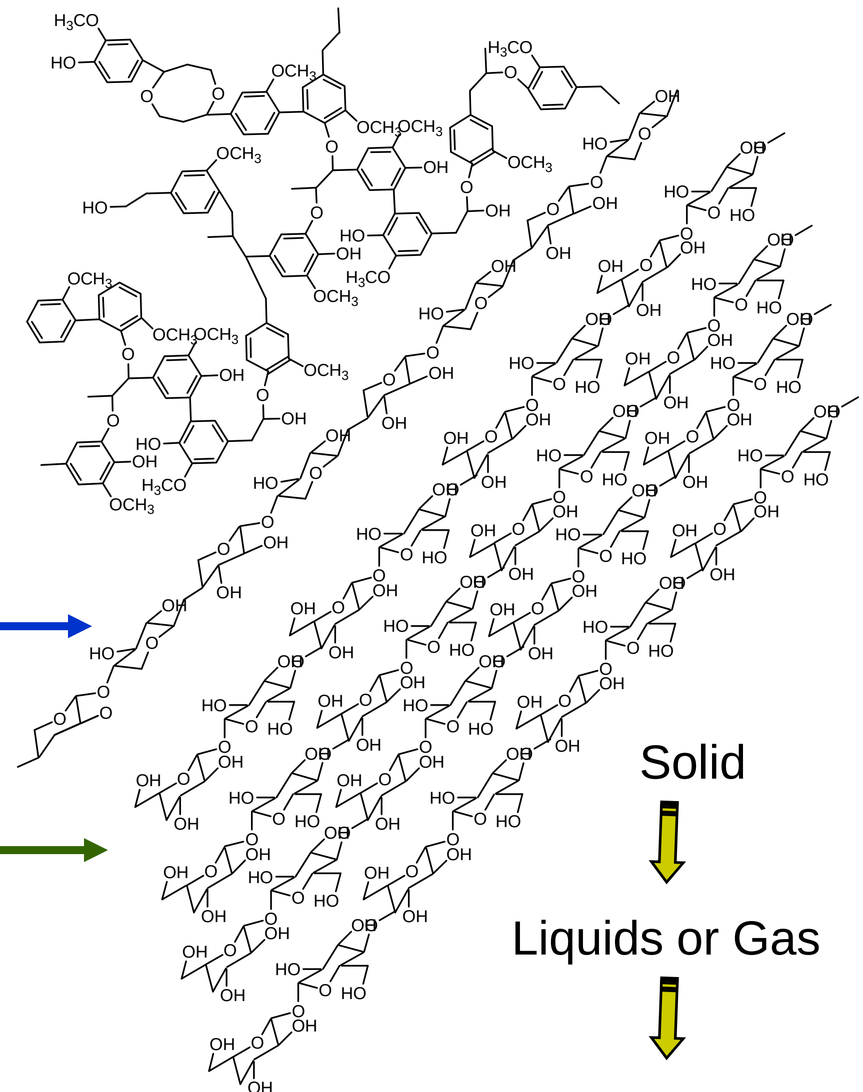
- Complex network of aromatic compounds
- High energy content

Hemicellulose: 23-32%

- Polymer of 5 & 6 carbon sugar

Cellulose: 38-50%

- Polymer of glucose, very good biochemical feedstock

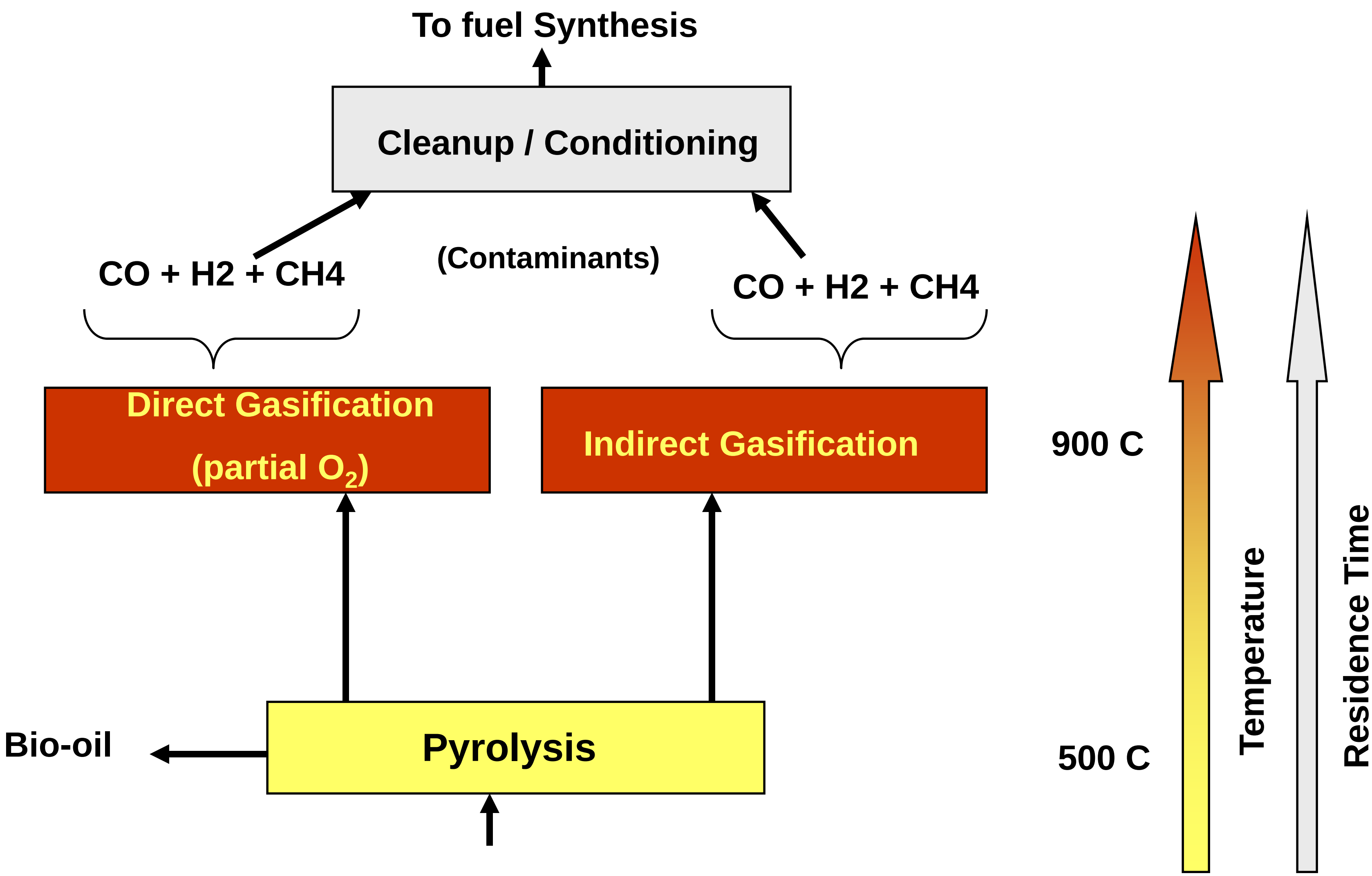


Solid

Liquids or Gas

Liquid Fuels

Thermochemical Platform



Thermal Conversion Pathway

Gasification Development

Biomass gasification has a relatively long history of commercial development

53 ton/day- Gussing Austria

195 ton/day

Freiberg Germany

100 ton/day plant in Hawaii using bagasse

50 ton/day Burlington VT

Synthesis Gas Cleanup

Cost effective gas cleanup remains as the key technical challenge for biomass gasification

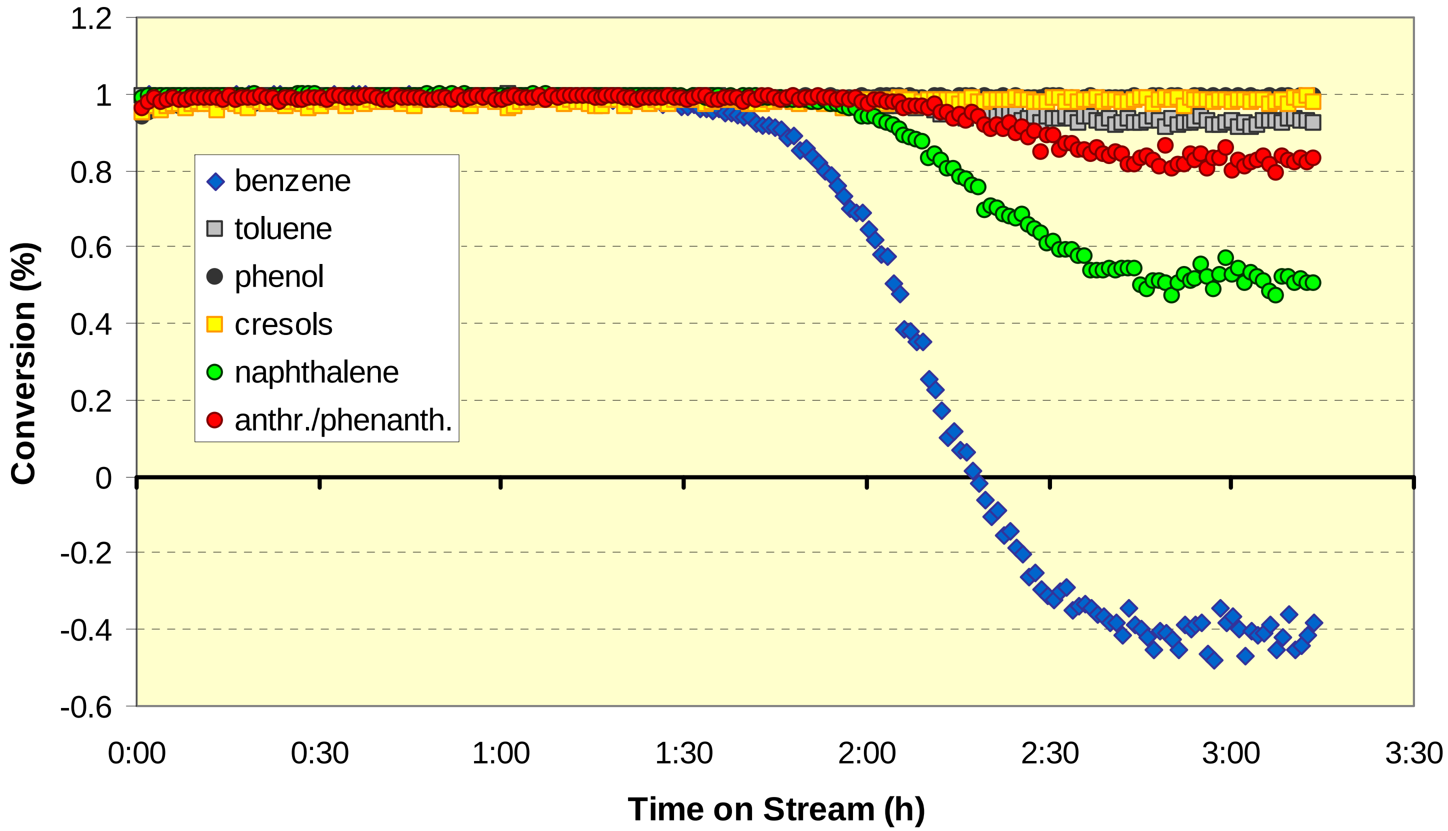
- Rectisol or Selexol commercial processes but only economic at large scale (coal gasification)
- Office of Biomass Program is pursuing catalytic reforming/destruction of tars and other contaminants for biomass scale plants
  - 2004 DOE/USDA joint solicitation topic ($4.4 MM)
  - 2007 DOE solicitation ($9 MM)
  - On going National Lab development

Fuel Synthesis Gas Cleanup Requirements

Process	Contaminant	Level	Source/comments
Fischer-Tropsch Synthesis	Sulfur	0.2 ppm 1 ppmv 60 ppb	Dry, 1981 Boerrigter, et al, 2002 Turk, et al, 2001
	Halides	10 ppb	Boerrigter, et al, 2002
	Nitrogen	10 ppmv NH_3 0.2 ppmv NO_x 10 ppb HCN	Turk, et al, 2001
Methanol Synthesis	Sulfur (not COS)	<0.5 ppmv (<0.1 ppmv preferred)	Kung, 1992
	Halides	0.001 ppmv	Twigg and Spencer 2001
	Fe and Ni	0.005 ppmv	Kung, 1992
LPMeOH Synthesis	Sulfur (including OCS)	0.1 ppmv	Novem (2002)
	Total halides	0.01 ppmv	
	Acetylene	5 ppmv	
	Total unsaturates	300 ppmv	
	NH_3	10 ppmv	
	HCN	0.01 ppmv	
	Fe and Ni	0.01 ppmv	
Ammonia Synthesis	H_2O	200 ppm	Revsible
	CO	200 ppm	Revsible
	CO_2	100 ppm	Revsible
	O_2	100 ppm	Revsible
	Sulfur (H_2S)	0.1 ppm	Irrevsible
	Chlorine	0.1 ppm	Irrevsible
	As, P, Sb	---	Irrevsible
Ethanol Synthesis	Very little work has been published on the effects of syngas impurities		
Higher Alcohol Synthesis	- modified FT catalysts are the same as those for FT catalyst - modified methanol synthesis catalysts are the same as those for meOH catatysts		
Oxosynthesis	Strong acids, HCN, organosulfur, H_2S, COS, O_2, and dienes (Bahrmann and Bach 2000)		
Isosynthesis	Thoria catalysts are not poisoned by sulfur and have high resistance to other poisons as well		
Steam Methane Reforming	<0.5 ppm for reformer catalyst life of 3 years		

NREL Tar Reforming Catalyst Development

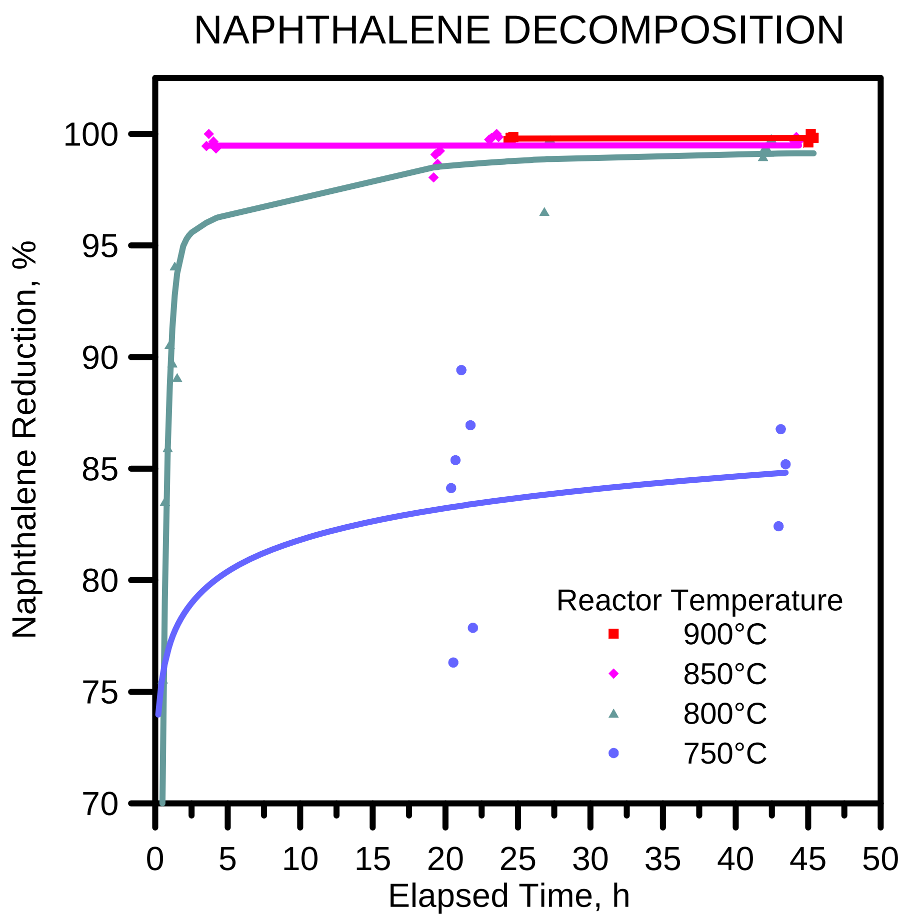
Goal: Improve effective on-stream time and regenerability of nickel based tar reforming catalysts



GTI Engineered Catalysts

sintered Ni-olivine catalyst

- **Use thermal impregnation techniques to manufacture**
- **When catalysts based on the olivine structure attrit, they would expose fresh, catalytically-active surfaces**
- **Catalytic metals may constantly *replenish* themselves at a solid-gas interface.**



GTI Engineered Catalysts

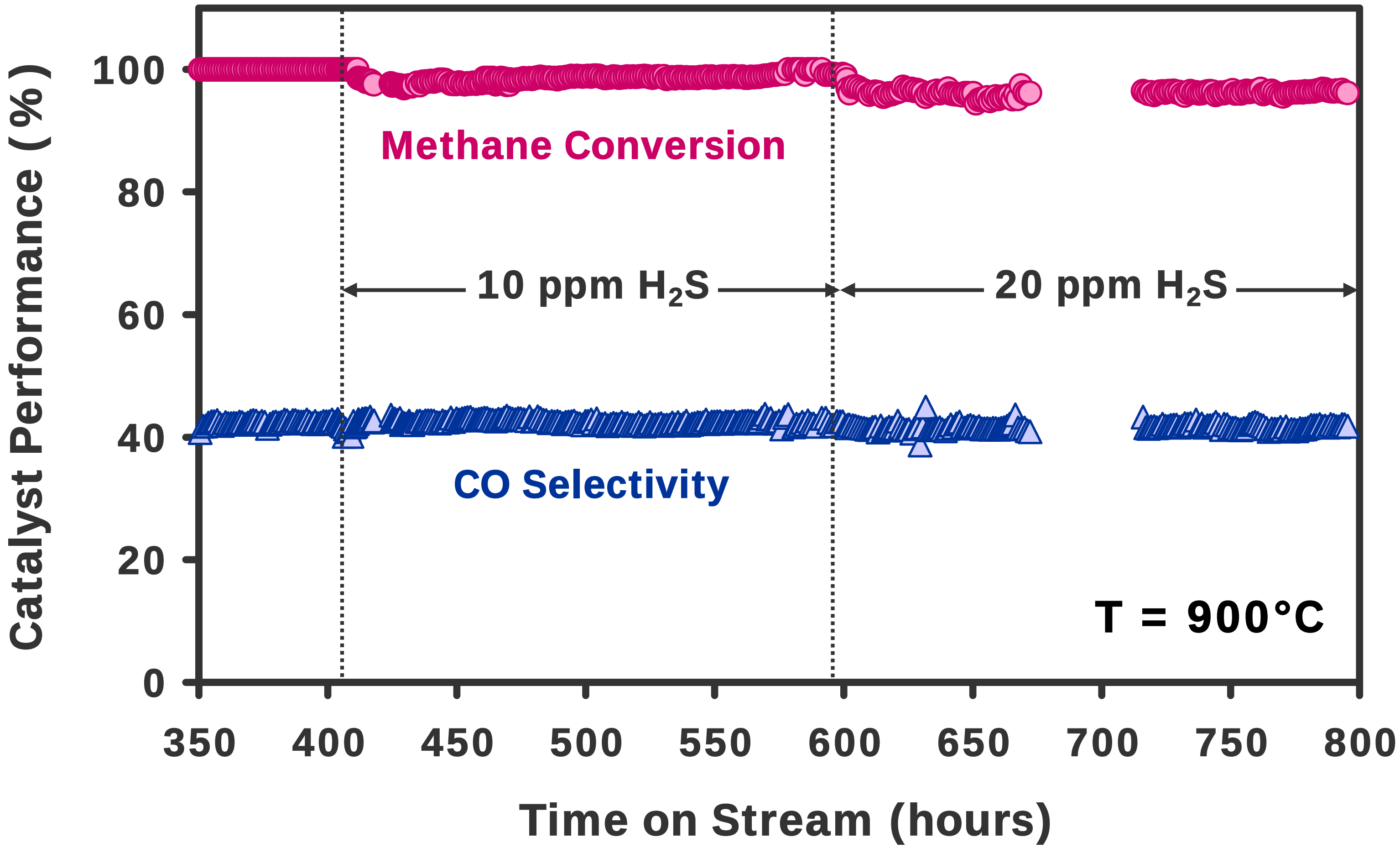
Glass-ceramic material containing 15% nickel oxide

(a) (b) (c)

(a) shows the base material, as an amorphous glass, (b) shows the material after ceramming (heat treatment) to create a microcrystalline glass-ceramic, (c) shows the glass-ceramic after reduction under hydrogen to create Ni metal on exposed surfaces.

GTI Engineered Catalysts

$Ni_xMg_{2-x}SiO_4$ – H_2S Sensitivity*



*3.7% H_2, 7.6% CH_4, 8.6% CO, 13.9% CO_2, 42.1% He, 0.40% C_2H_6, 0.40% C_2H_4, 23.4% H_2O

Synthesis Gas Cleanup

2007 synthesis gas cleanup validation solicitation - $9 MM

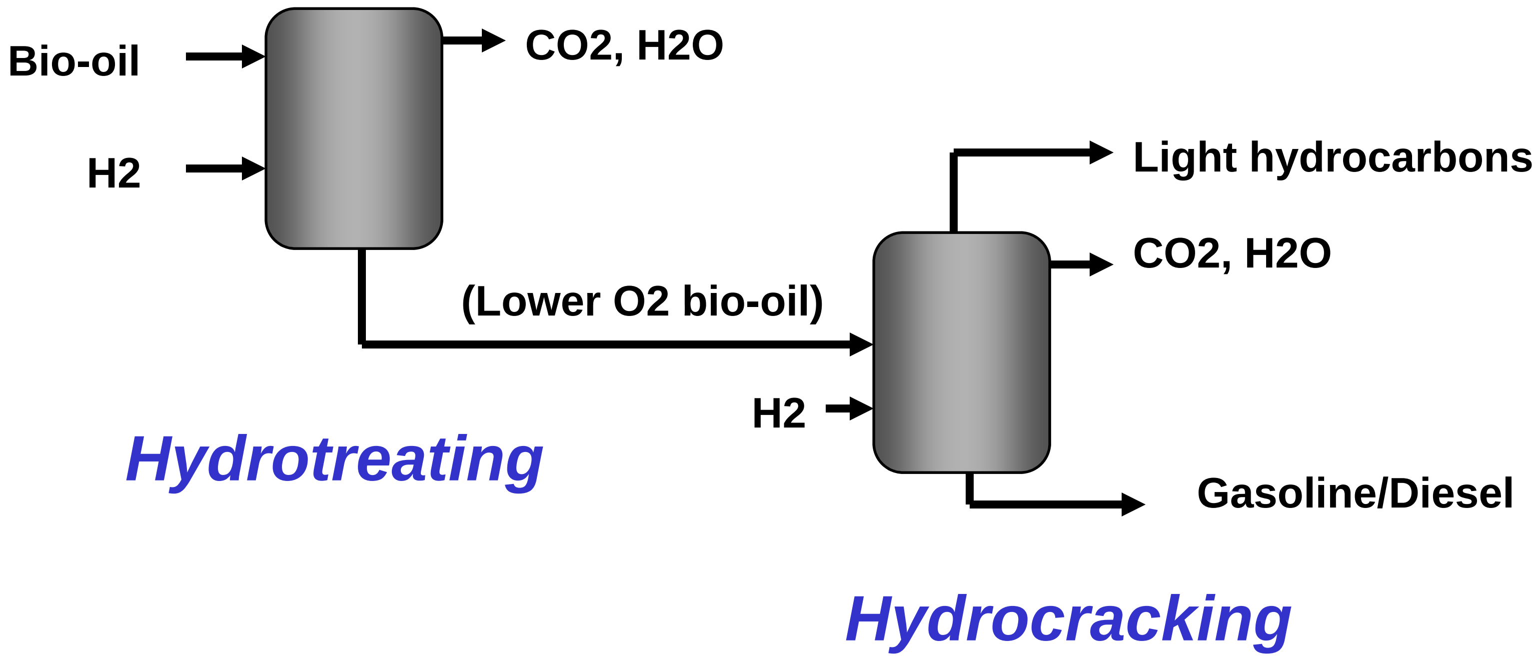
Five projects selected

- Demonstrate cleanup technology to low ppm or ppb level at 20 kg/hr scale with biomass generated syngas
- Validate data at stage gate review
- Couple fuels synthesis to gas cleanup process
- Demonstrate integrated fuel synthesis production for 500 hours
- Evaluate catalyst durability and develop technoeconomic assessment

Fast Pyrolysis Technical Requirements

- Rapid heat transfer in the absence of oxygen
- Short residence time at temperature (msec)
- Rapid thermal quenching of vapor products
- Products = Gas (15%), Char (15%), Liquids (70%)

Bio-oil as Refinery Feedstock



Can leverage existing petroleum refinery investments and infrastructure

Source: Historical Developments in Hydroprocessing Bio-oils, Energy & Fuels May 2007, 21, 1793-1815

Bio-oil as Refinery Feedstock

Hydroprocessed Bio-oil Product Composition

Hydroprocessed bio-oil (from mixed wood)			***Gasoline***
	Min	***Max***	***Typical***
Paraffin, wt%	5.2	9.5	9
Iso-Paraffin, wt%	16.7	24.9	35
Olefin, wt%	0.6	0.9	4
Naphthene, wt%	39.6	55.0	7
Aromatic, wt%	9.9	34.6	38
Oxygenate, wt%		0.8	7

Source: UOP Presentation to National Petroleum Refiners Association, February 2008

Bio-oil as Refinery Feedstock

Bio-oil Hydrocarbon Product Cost Estimates

	From Wood	From Corn Stover
Production Cost $/gal	2.50	2.82
Production Cost ethanol equivalent $/gal	1.55	1.74
Gal ethanol equivalent / ton	120	87
% carbon recovery	~44	~36

Source: DOE EERE Fact Sheet, August 2008

Bio-oil Instability

Bio-oil properties can change during storage

- Increase in viscosity
- Decrease volatility
- Phase separation
- Formation of gums and deposits

Instability is caused by chemical reactions occurring between certain compounds leading to molecular growth

Pyrolysis Technical Issues

- **Bio-oil Stability tied to:**
  - **Acidity (low acid number)**
  - **Char content in bio-oil**
  - **O_2 content of bio-oil**

Recent $7 MM DOE solicitation intended to address stability issue

Terra Preta (Dark Earth)

Addition of ***char*** *to soil* →

Terra Preta Soil

"Normal" Soil

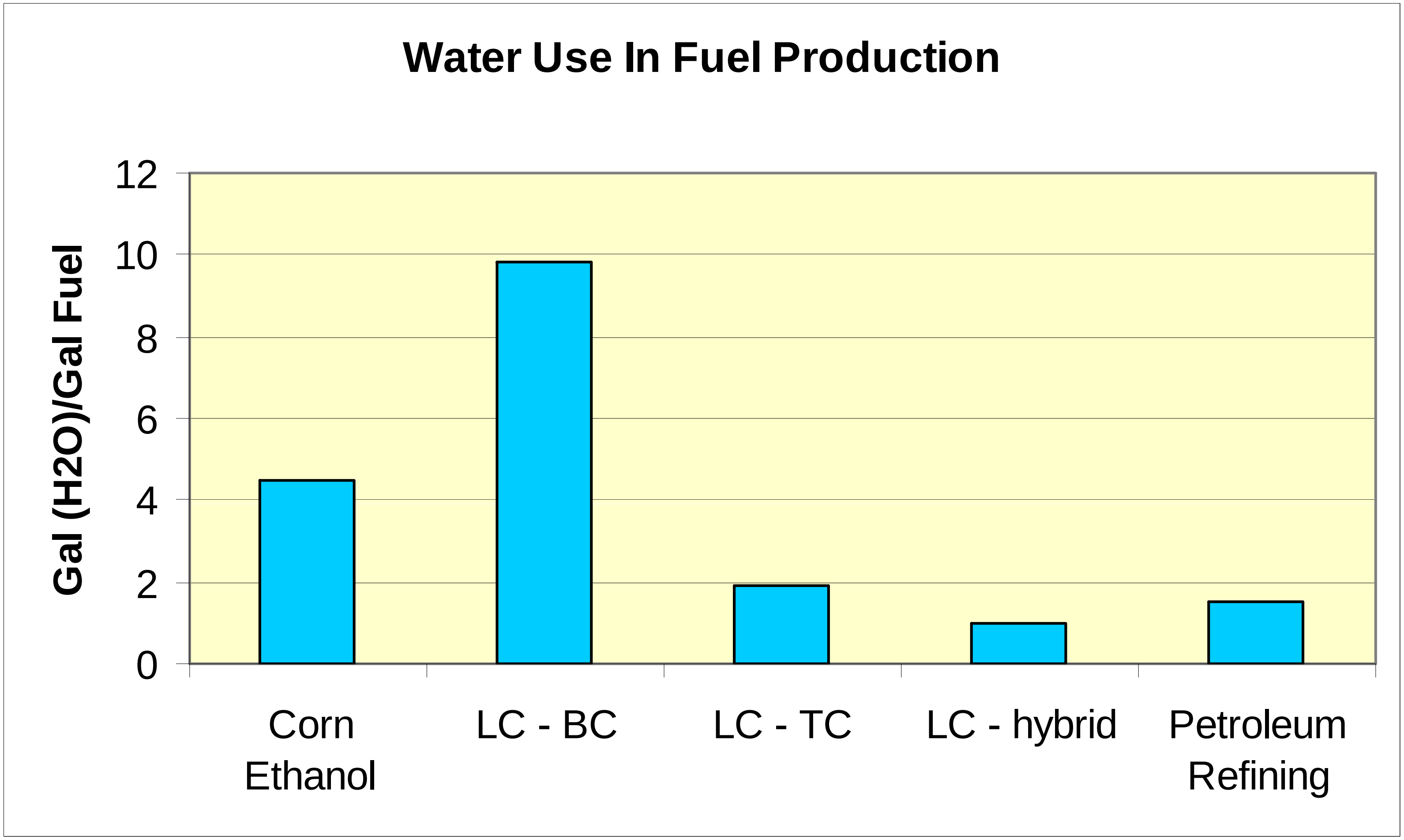
- Observed in ancient Amazoian soils
- Bio-char is highly stable in soil and can persist thousands of years.
- Enhanced nutrient retention mechanism (water retention, microbial & fungus habitat, minerals)
- May offer potential for significant carbon sequestration (~3 tons CO2/ton char)
- Positive effects inconclusive in some geographical regions (needs further study)

Source:2007 Grossman J.M., Farmers' understanding of soil processes. Low External Input and Sustainable Agriculture (LEISA). Issue title: "Ecological Processes at Work" 22(4):24.

Commercial Scale Biorefineries

- DOE support for 932 projects
  - -Abengoa $76MM
  - -Blue Fire $40 MM
  - -POET $80 MM
  - -Range Fuels $76 MM
- Commissioning to begin in 2010
- Collapse of financial markets will slow progress

Water Use in Fuel Production



Source: “Consumptive Water Use in the Production of Bioethanol and Petroleum Gasoline” Argonne National Lab, Dec 2008

Conclusions

Multiple Benefits of Biomass Thermal Conversion to Hydrocarbon Fuel Technologies

- **Biomass domestic fuel production can displace significant amounts of petroleum based fuel (~1/3)**
- **Commercial viability appears favorable for the near term (5-10 years)**
- **CO_2 sequestration with biomass pyrolysis and char incorporation in soil can potentially be a net <u>negative</u> carbon sink**
- **Terra Preta soil enhancement can potentially improve forest health and agricultural productivity**
- **Emerging industry for domestic jobs in rural economies**