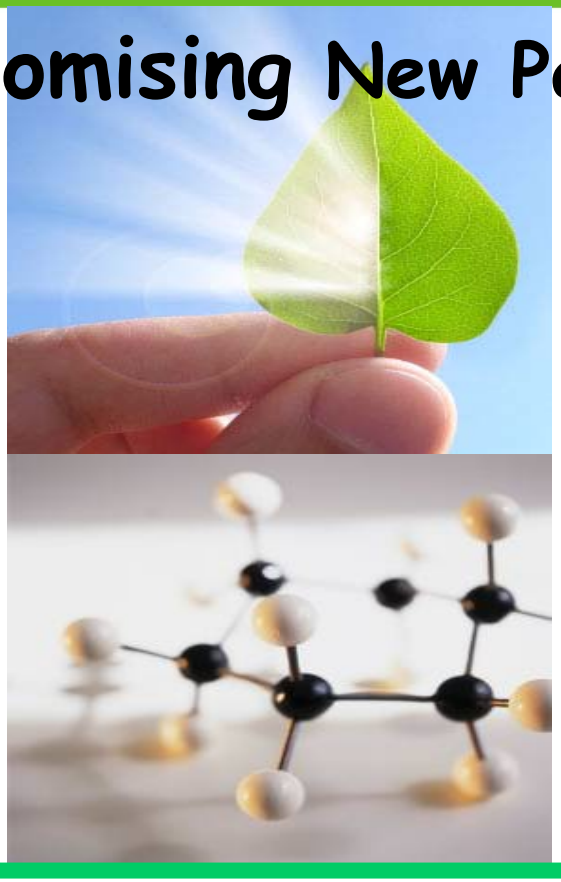
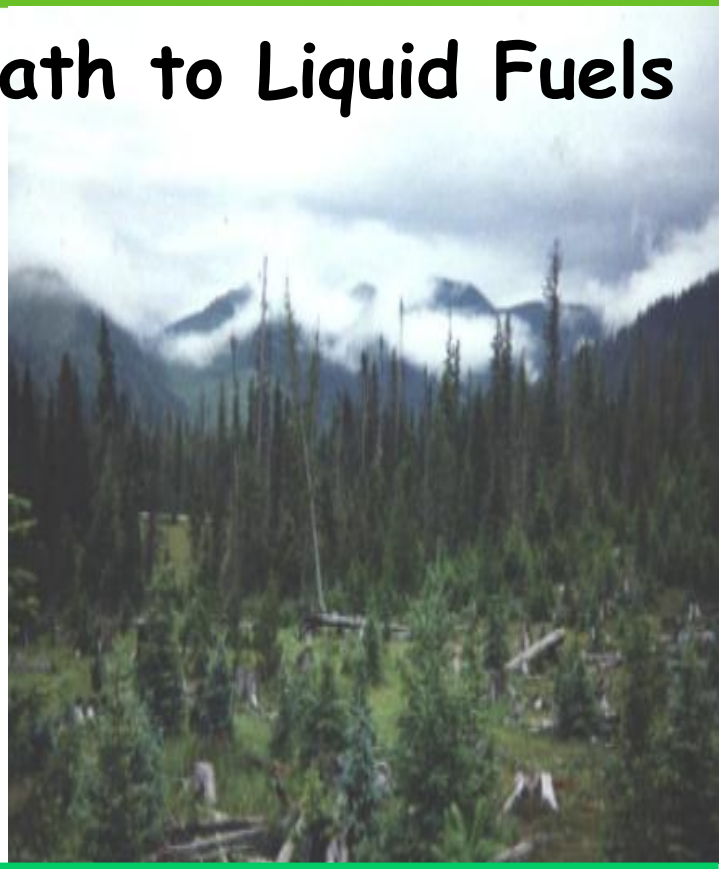
U.S. Department of Energy
Energy Efficiency and Renewable Energy

U.S. Department of Energy
Biomass Program

Pyrolysis – A Promising New Path to Liquid Fuels





The Future of Forest Biomass in Colorado

February 21, 2008 – Colorado State University

John Scahill

DOE Golden Field Office

The Unique Role of Biomass

While the growing need for sustainable electric power can be met by other renewables…

Biomass is the only renewable that can meet our demand for carbon-based liquid fuels and chemicals

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

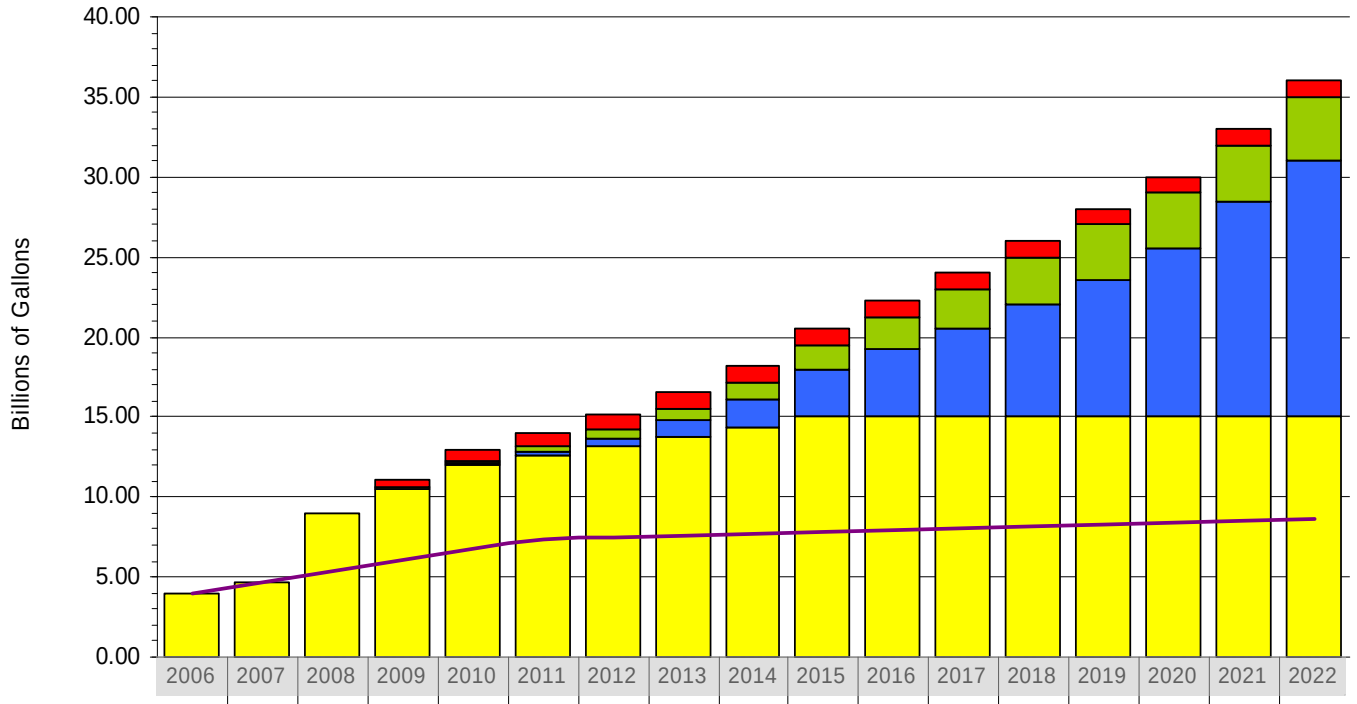
Sec. 942: Incentives to ensure 1 billion gallons of cellulosic biofuel annual production by 2015 (reverse auction)
Title 17: Loan Guarantees

OBP Vision, Mission and Performance Goals

Program Targets

Energy Independence Security Act 2007

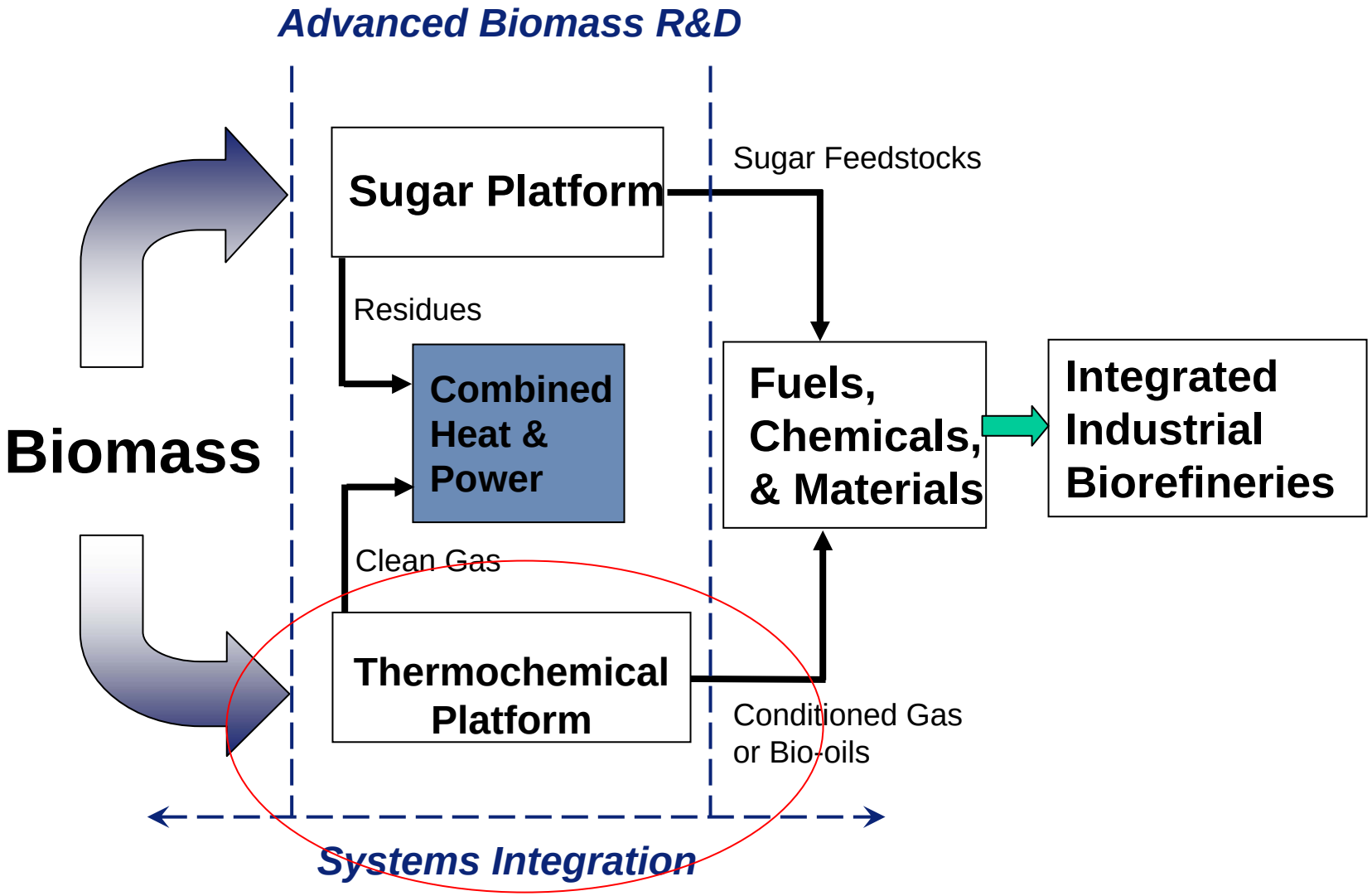
Renewable Fuel Standard (RFS), 2007-2022



	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



Thermochemical Conversion

Basic Definitions

Combustion

- Thermal conversion in the presence of excess oxygen for production of heat

Gasification

- Thermal conversion of organic materials at elevated temperature and reducing conditions to produce primarily permanent gases, with char, water, and condensibles as minor products
- Primary categories are partial oxidation and indirect heating

Pyrolysis

- Thermal conversion (breakdown) of organics in the absence of oxygen
- In the biomass R&D community, this commonly refers to lower temperature thermal processes producing liquids as the primary product

Biomass Constituents

Lignin: 15-25%

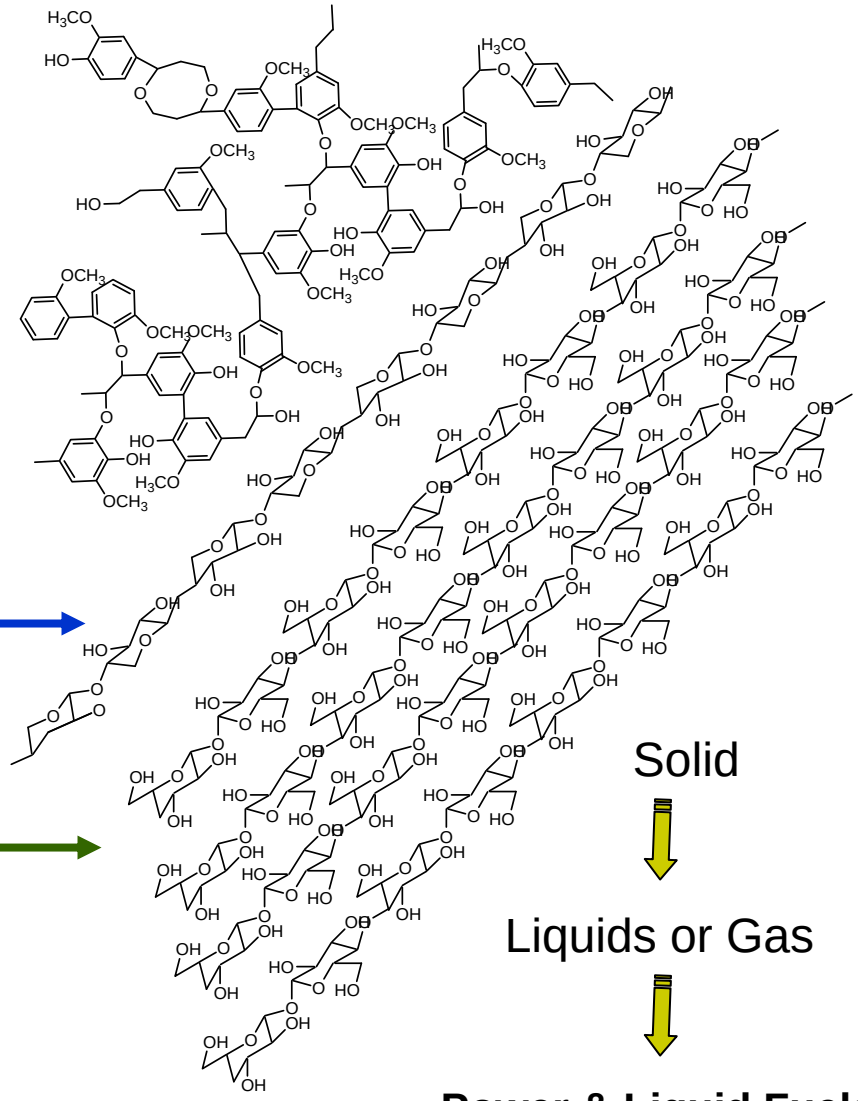
- Complex network of aromatic compounds
- High energy content

Hemicellulose: 23-32%

- Polymer of 5 & 6 carbon sugar

Cellulose: 38-50%

- Polymer of glucose, very good biochemical feedstock

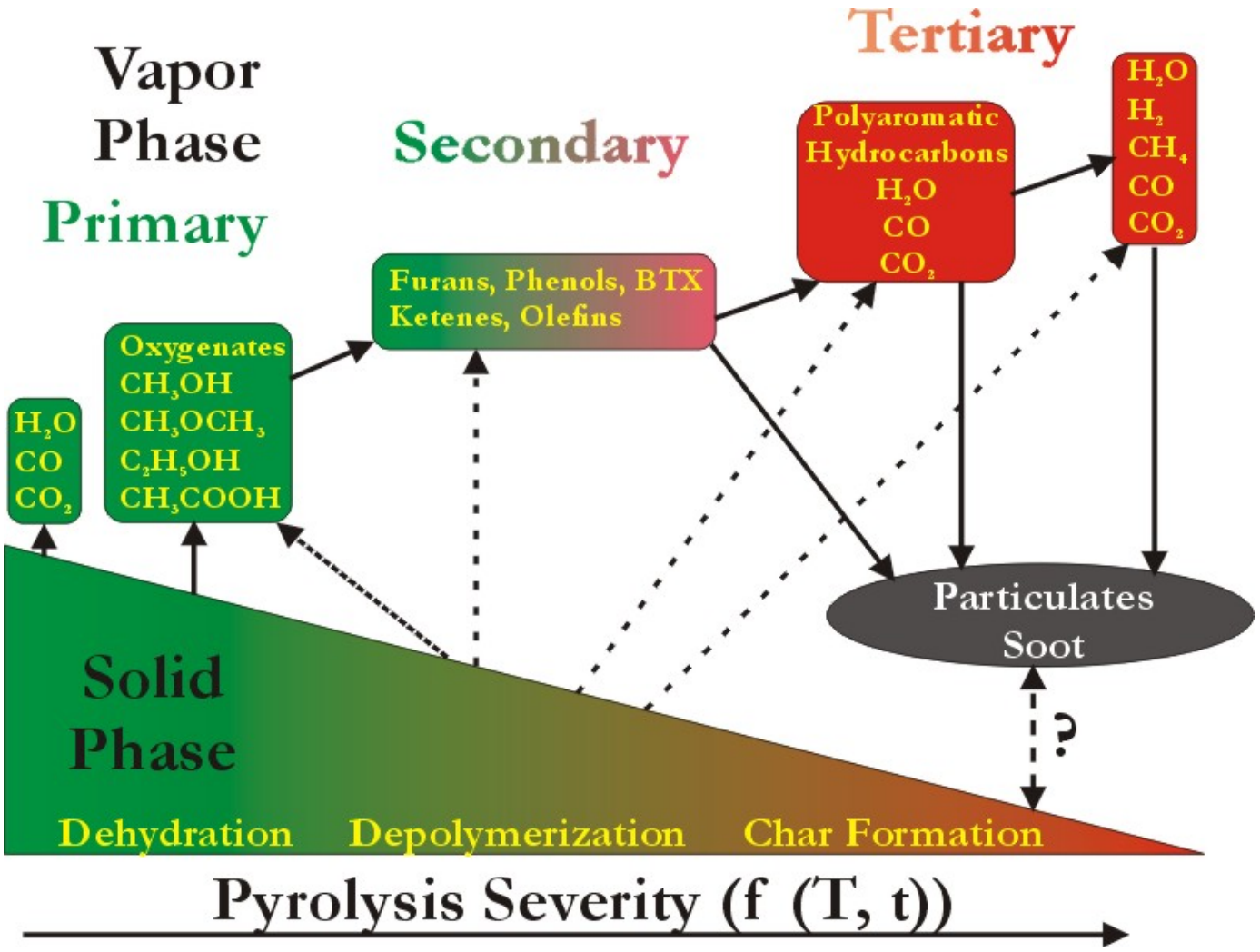


Solid

Liquids or Gas

Power & Liquid Fuels

Thermochemical Pathways



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%)

Fast Pyrolysis Bio-oil

Bio-oil is water miscible and is comprised of many oxygenated organic chemicals.

- **Combustible,**
- **Not miscible with hydrocarbons,**
- **Heating value ~ 17 MJ/kg,**
- **Density ~ 1.2 kg/l,**
- **Acid, pH ~ 2.5,**
- **Pungent odour,**
- **“storage stability” - viscosity increases with time**

Bio-oil Composition

Component	Wt% of Bio-oil
Hydroxyacetaldehyde	5-12
Acetic acid	3-9
Formic acid	1-4
Acetol	3-7
Glyoxal	1-2
Levoglucosan	2-5
Water	15-30
Pyrolytic lignin	15-30

Over 300 individual compounds have been identified in bio-oil

Bio-oil Instability

Bio-oil properties change during storage

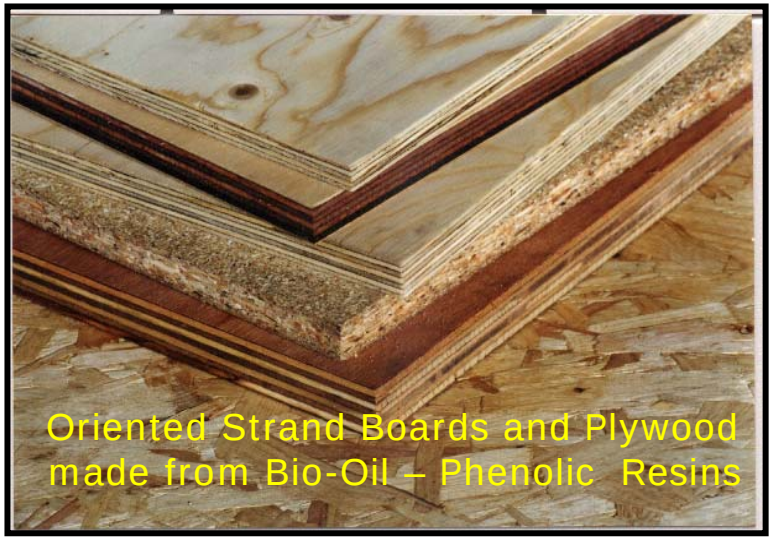
- **Increase in viscosity**

  rate = $2.317 * 10^{13}$ exp(-9659/T) cP/day

  Diebold, J.P.; Czernik, S., *Energy&Fuels* 1997, 11, 1081.
- **Decrease volatility**
- **Phase separation**
- **Formation of gums and deposits**

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

Market Potential for Bio-Oil



Bio-oil Production Cost

Different claims for the cost of production:

Ensyn **$ 14-16 / bbl**

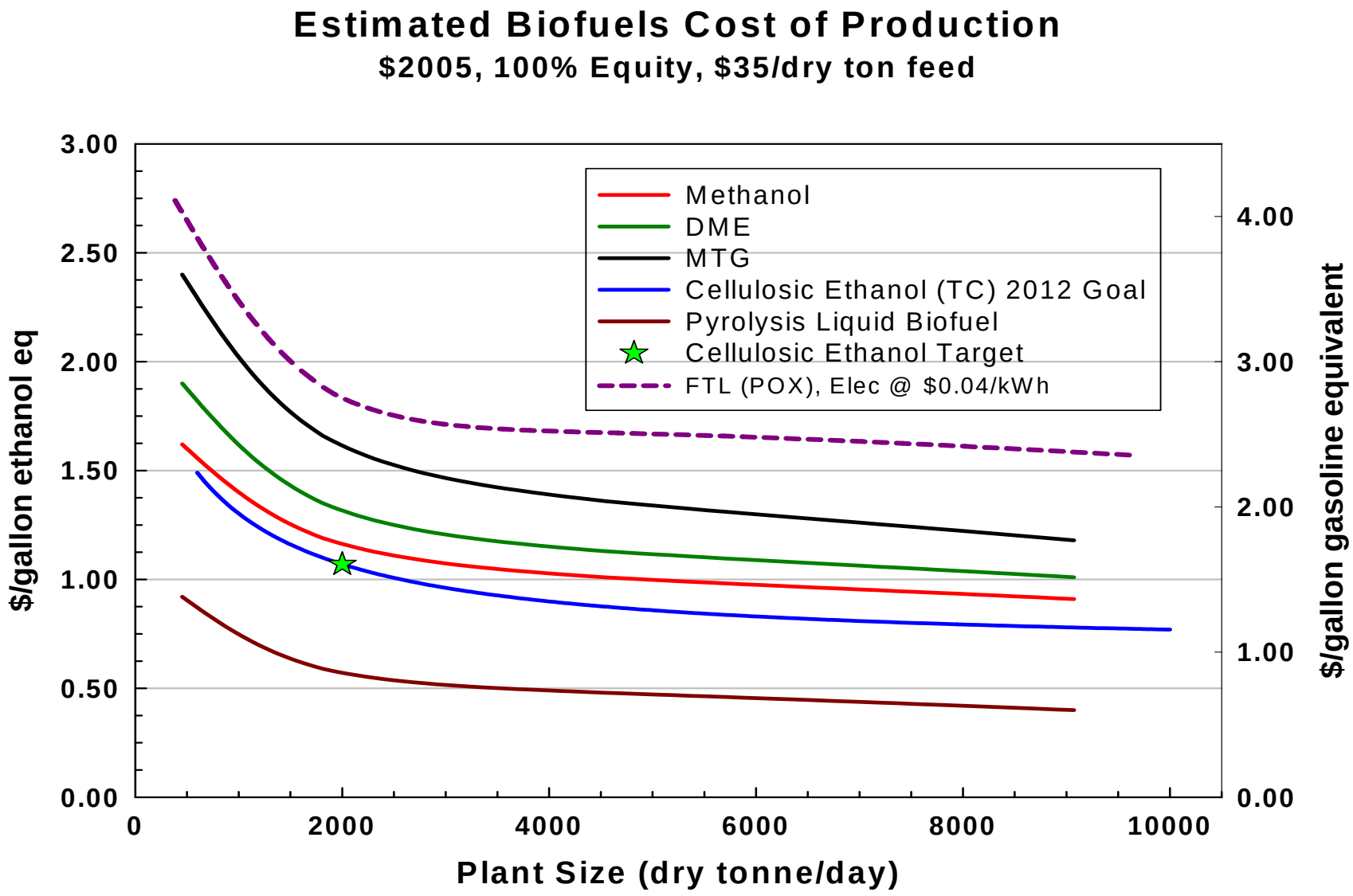
BTG **$ 21 / bbl**

Cost = Wood cost/10 + 8.87 * (Wood throughput)$^{-0.347}$

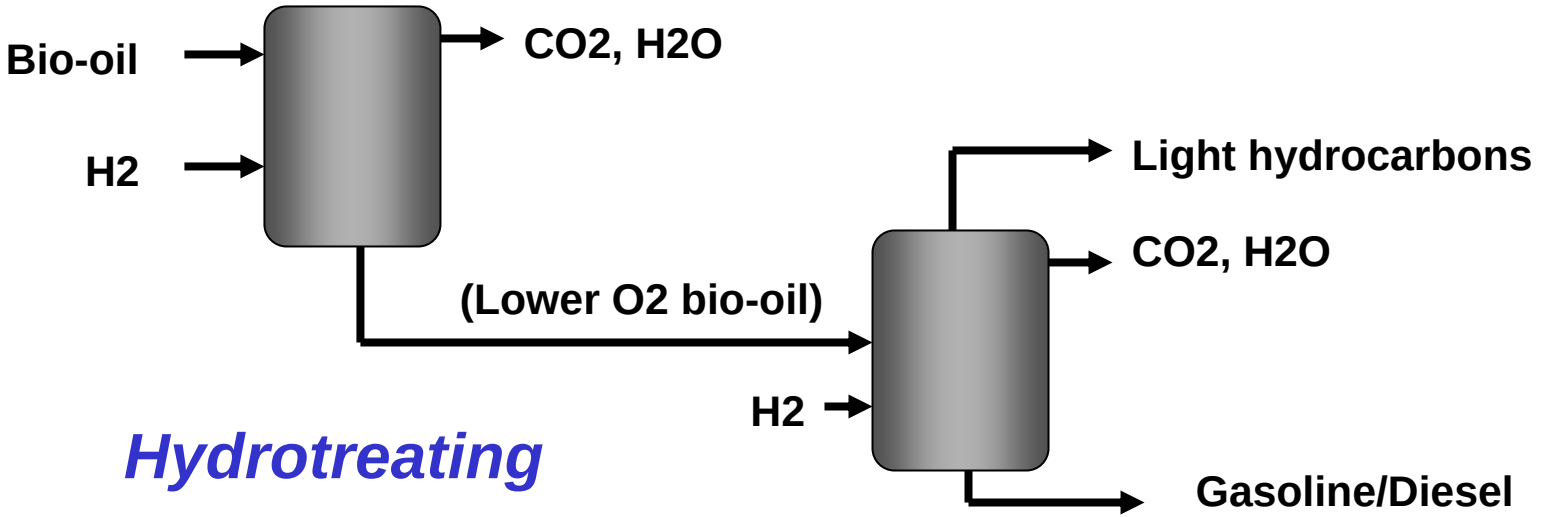
$/GJ **$/dry ton** **dry t/h**

Source: A.V. Bridgwater, A Guide to Fast Pyrolysis of Biomass for Fuels and Chemicals, PyNe Guide 1, www.pyne.co.uk

Bio-oil Cost


Estimated Biofuels Cost of Production
$2005, 100% Equity, $35/dry ton feed
Methanol
DME
MTG
Cellulosic Ethanol (TC) 2012 Goal
Pyrolysis Liquid Biofuel
Cellulosic Ethanol Target
FTL (POX), Elec @ $0.04/kWh
$/gallon ethanol eq
$/gallon gasoline equivalent
Plant Size (dry tonne/day)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4.00
3.00
2.00
1.00
0.00
0
2000
4000
6000
8000
10000

Bio-oil as Refinery Feedstock



Technical Issues

- Improve storage stability
- Lower acid number

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

Bio-oil as Refinery Feedstock

Yields for Hydroprocessed Bio-oil

Feed	***Wgt %***
Bio-oil	100
H2	3-4.5
Products	
Naptha Range	21
Diesel Range	21
CO2, H2O, Light Hydrocarbons	62

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

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	44.2
Iso-Paraffin, wt%	16.7	24.9	
Olefin, wt%	0.6	0.9	4.1
Naphthene, wt%	39.6	55.0	6.9
Aromatic, wt%	9.9	34.6	37.7
Oxygenate, wt%		0.8	

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	2.01	1.80
Production Cost ethanol equivalent $/gal	1.27	1.13
Gal ethanol equivalent / ton	148	126
% carbon recovery	~45	~45

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

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.

Policies May Foster Market Expansion

- Long term access to forest resources on public lands (stewardship contracts)
- Payments to lignocellulosic biomass suppliers for residues and energy crops
- Alternative Fuel Subsidies applied equally to all fuels (incentivise biomass content-not the product fuel)
- Valuation of sequestered carbon

Ramp-up of biofuels production will require innovative and focused policies for infrastructure and biomass feedstocks

Conclusions

Multiple Benefits of Bio-oil to Hydrocarbon Fuel Technology

- **Biomass domestic fuel production can displace significant amounts of petroleum based fuel**
- **Commercial viability appears favorable for the near term (5-10 years)**
- **CO2 sequestration with biomass pyrolysis and char incorporation in soil can potentially be a net negative carbon sink**
- **Terra Preta soil enhancement can potentially improve forest health and agricultural productivity**
- **Emerging industry for domestic jobs in rural economies**
- **Appropriate forest management can benefit long term forest health and minimize fire risk**