Current and Potential Energy Products from Biomass

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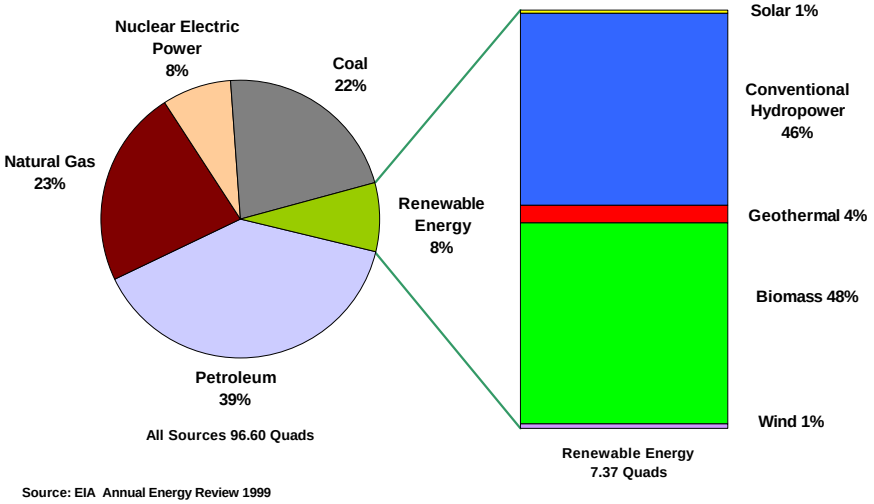
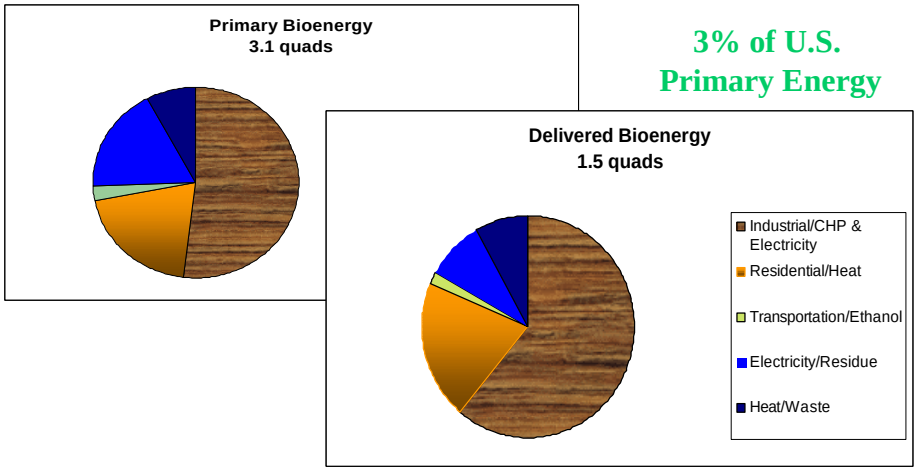
U.S. Primary Energy Consumption, 1999



Source: EIA Annual Energy Review 1999

U.S. Bioenergy 2000



3% of U.S. Primary Energy

Biomass Feedstocks

Forest products / residues

- Sawdust
- Wood chips
- Wood waste
  - pallets
  - crate discards
  - wood yard trimmings

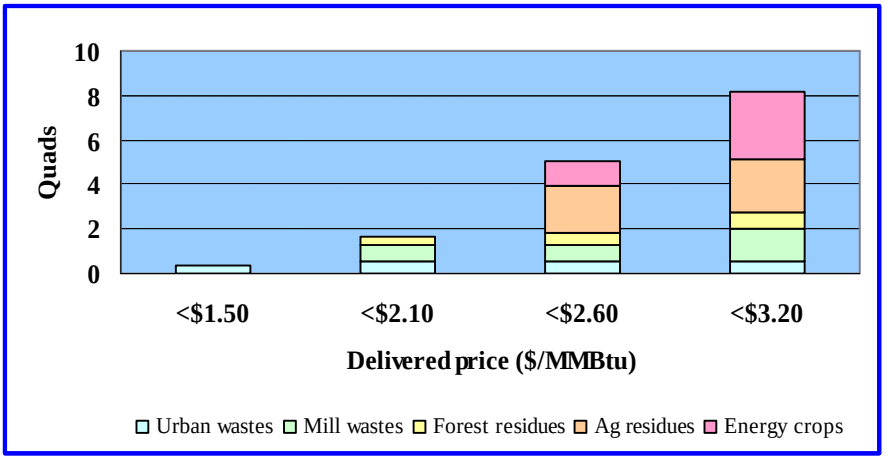
Agricultural residues

- Corn stover
- Rice hulls
- Sugarcane bagasse
- Animal biosolids

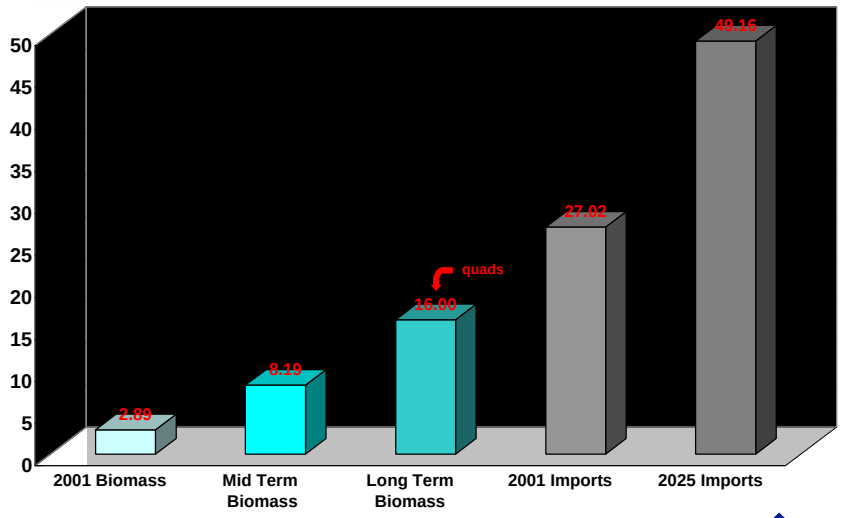
Dedicated energy crops

- Hybrid poplar
- Switchgrass
- Willow

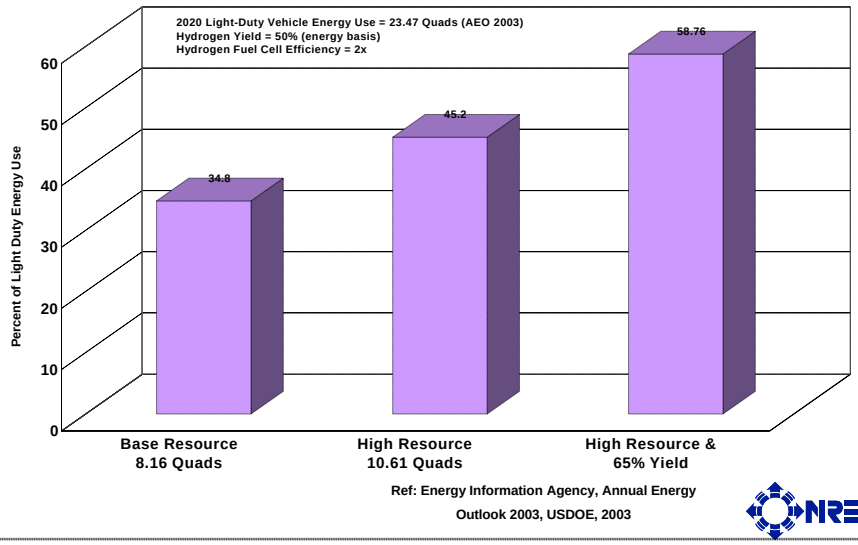
Potential Midterm U.S. Biomass Supply



Biomass Potential Relative to Petroleum and Natural Gas Imports



Potential Penetration of Hydrogen From Biomass in the Light-Duty Vehicle Market



Ref: Energy Information Agency, Annual Energy Outlook 2003, USDOE, 2003

Fuels, Chemicals, Materials, Heat and Power from Biomass

Biomass Feedstock

– Trees
– Forest Residues
– Grasses
– Agricultural Crops
– Agricultural Residues
– Animal Wastes
– Municipal Solid Waste

Conversion Processes

- Gasification
- Combustion and Cofiring
- Pyrolysis
- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation
- Other

USES

Fuels:
Ethanol
Renewable Diesel

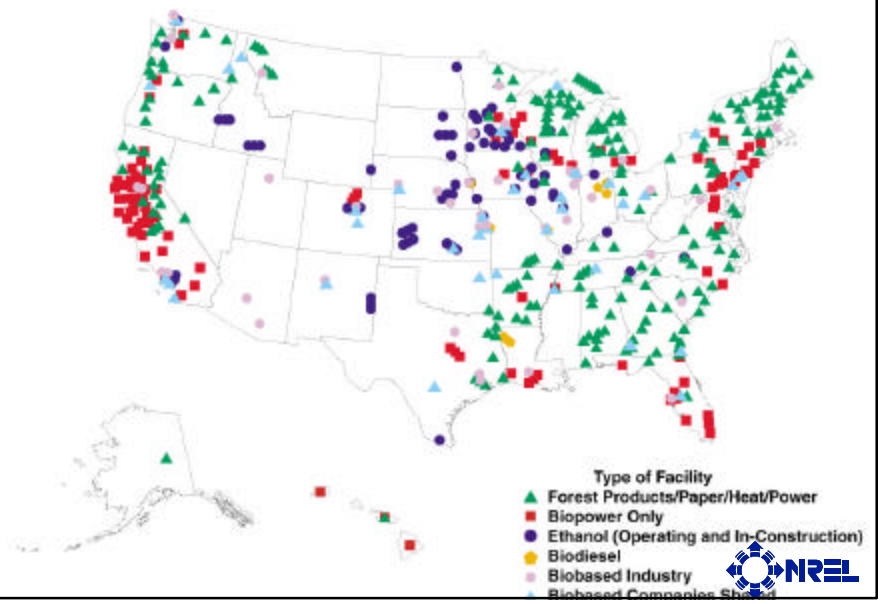
Electricity

Heat

Chemicals
– Plastics
– Solvents
– Pharmaceuticals
– Chemical Intermediates
– Phenolics
– Adhesives
– Furfural
– Fatty acids
– Acetic Acid
– Carbon black
– Paints
– Dyes, Pigments, and Ink
– Detergents
– Etc.

Food and Feed

Bioenergy and Biobased Products Facilities



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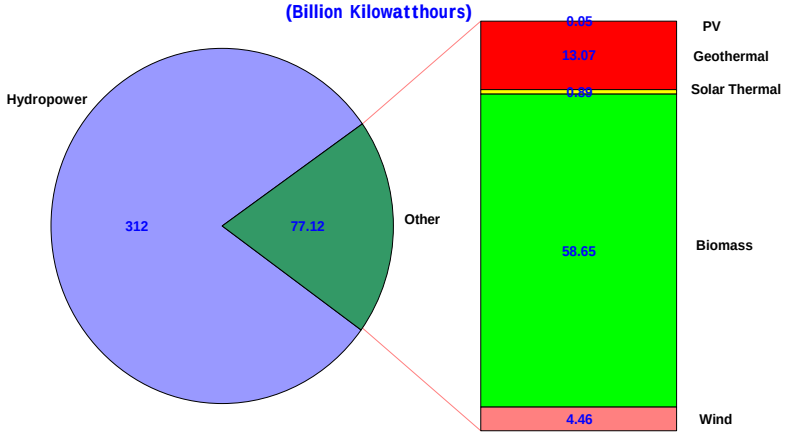
1999 Renewable Electricity Generation

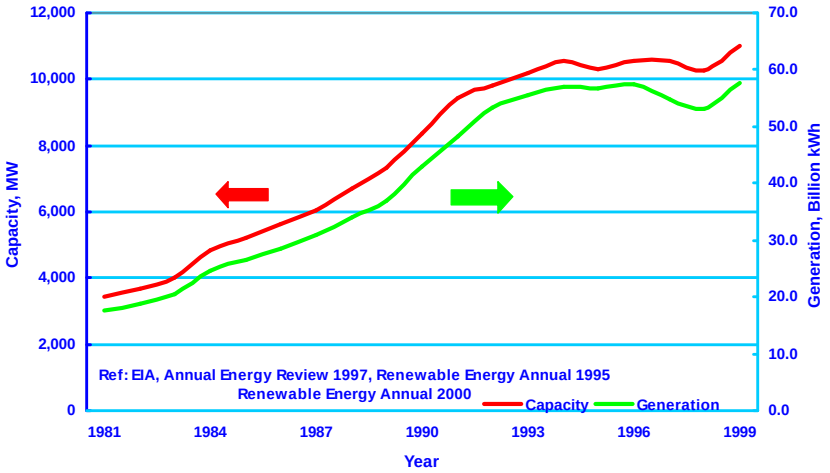
(Billion Kilowatthours)



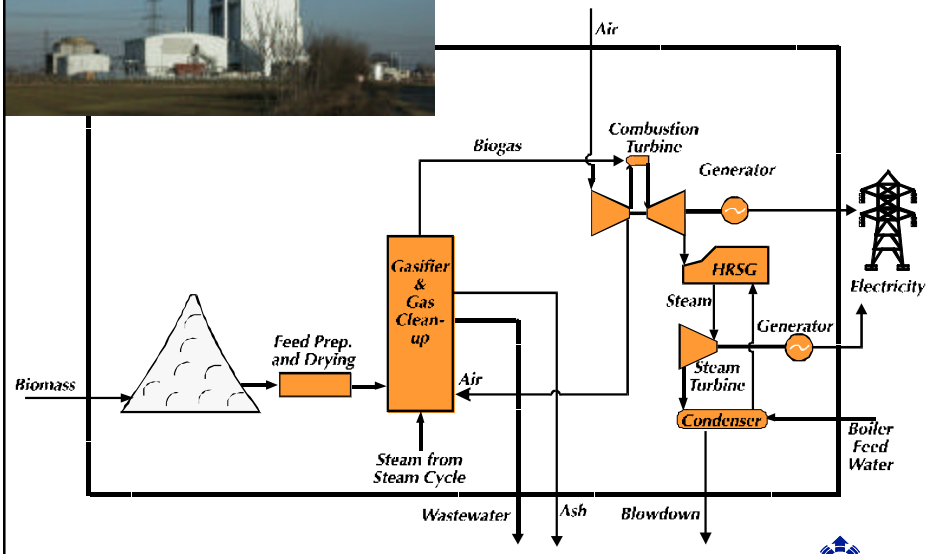
Source: DOE EIA Annual Energy Outlook 2001

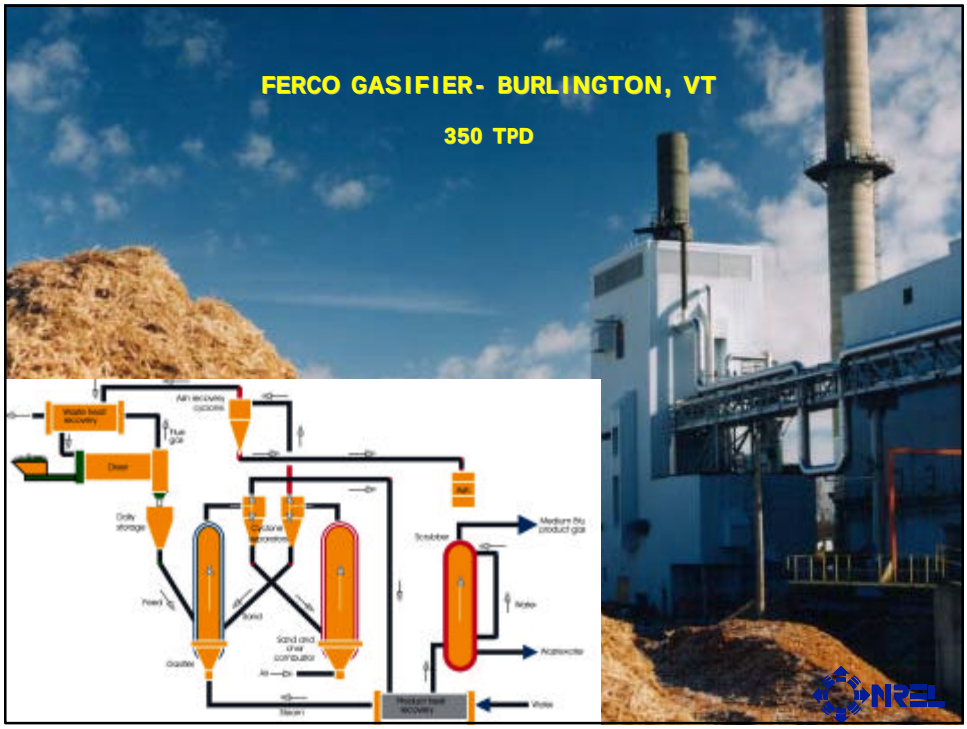
NREL

Bioenergy Electricity Generation, 1981 - 1999



Biorefinery Utilities Applications





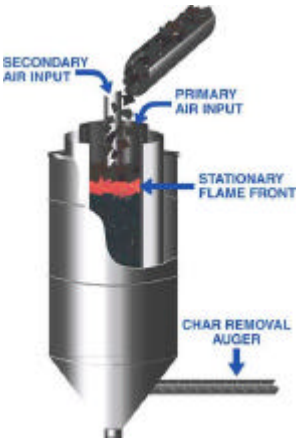
Combustion Systems

Automated bin feeding system

Wood heated greenhouse

Source: Tim Maker – Biomass Energy Resource Center

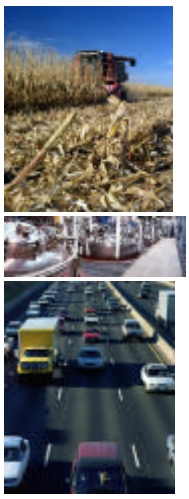
Community Power Corporation's
BioMax 15 Modular Biopower System



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

Ethanol from Biomass



Existing Industry:

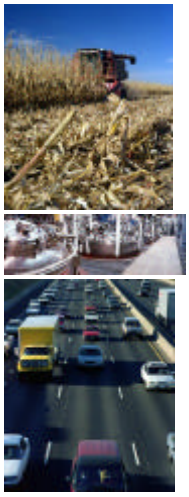
•~2 Billion gallons/year from starch containing grains

Near Term:

•Convert structural carbohydrates in corn fiber products to ethanol (increasing existing industry capacity by 10-15%)

•Pioneer plants using 0 or negative cost feedstocks

Ethanol from Biomass (cont.)



Mid-term:

• Ethanol from lignocellulosic agricultural residues (e.g.. corn stover)

- •$1.07/gal by 2010
- • Competitive with starch-based ethanol

Long term:

• Production Cost $0.70/gal by 2025

- • Competitive with Gasoline on BTU Basis (Crude at $25/barrel)

Biodiesel

Capacity: 80 Million gallons/year
Potential: 5% of U.S. Diesel Market

Griffin Industries, USA and
Bruck Industries, Austria

NREL

Production Cost per Gallon Biodiesel

3 mil gal/yr plant, 80% glycerin. Total cost at plant gate.
Does not include transportation and handling.

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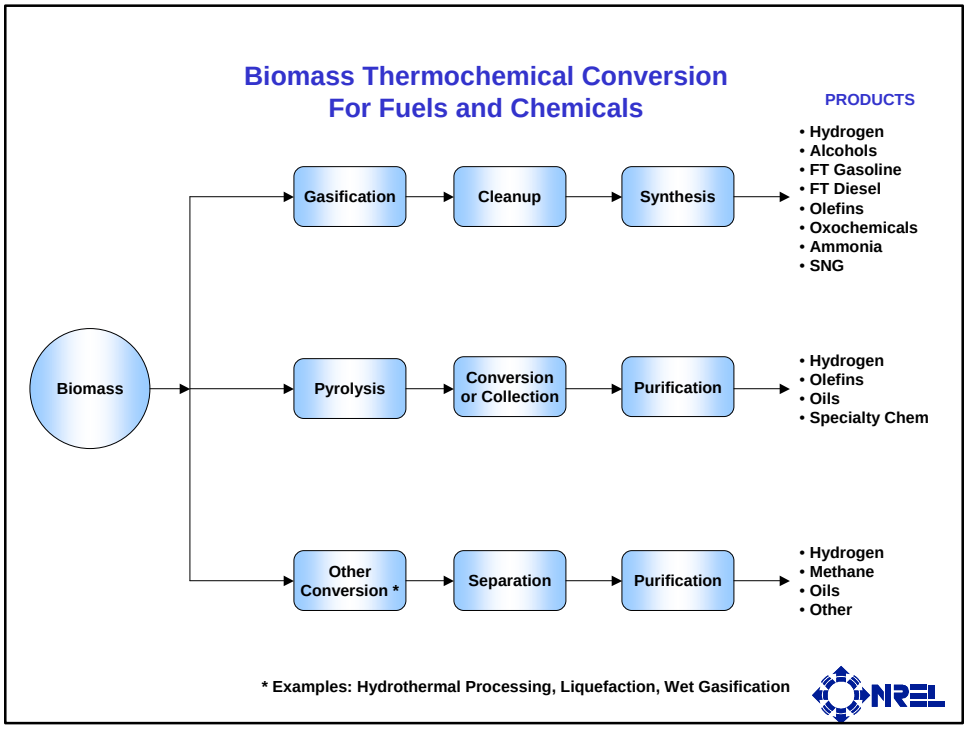
Biomass Thermochemical Conversion
For Fuels and Chemicals
PRODUCTS
Biomass
Gasification
Cleanup
Synthesis
• Hydrogen
• Alcohols
• FT Gasoline
• FT Diesel
• Olefins
• Oxochemicals
• Ammonia
• SNG
Pyrolysis
Conversion or Collection
Purification
• Hydrogen
• Olefins
• Oils
• Specialty Chem
Other Conversion *
Separation
Purification
• Hydrogen
• Methane
• Oils
• Other
* Examples: Hydrothermal Processing, Liquefaction, Wet Gasification
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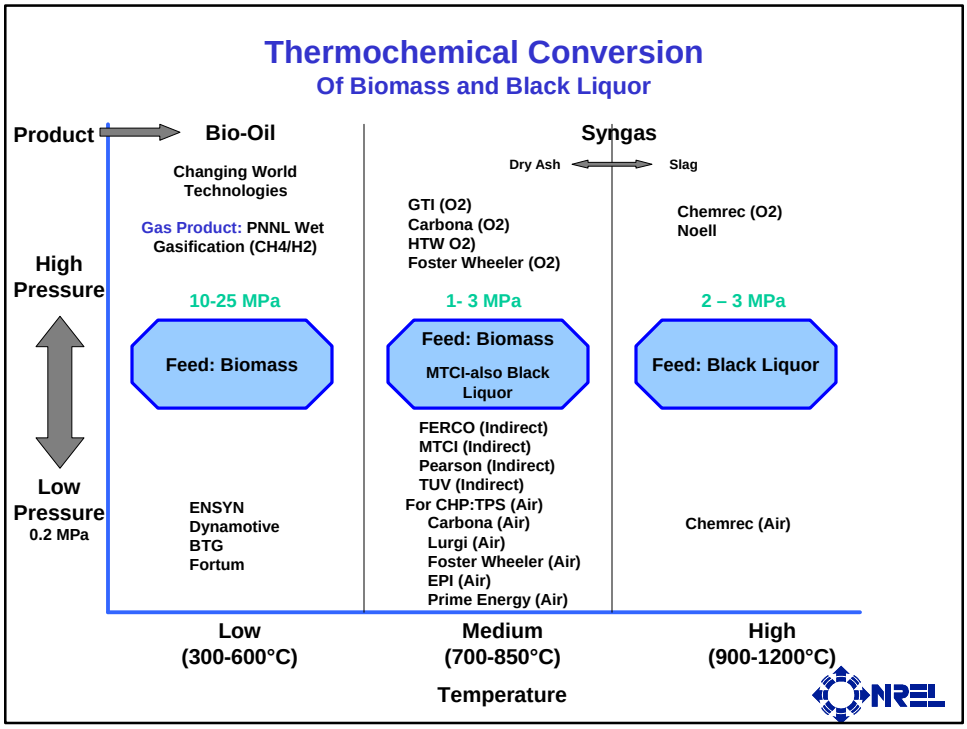
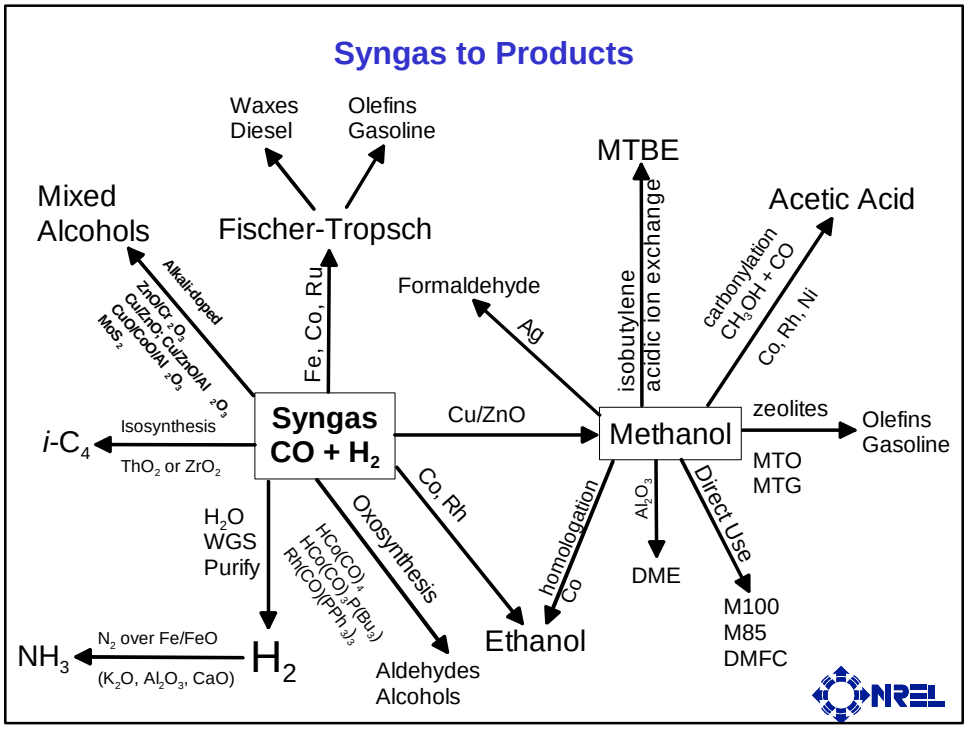
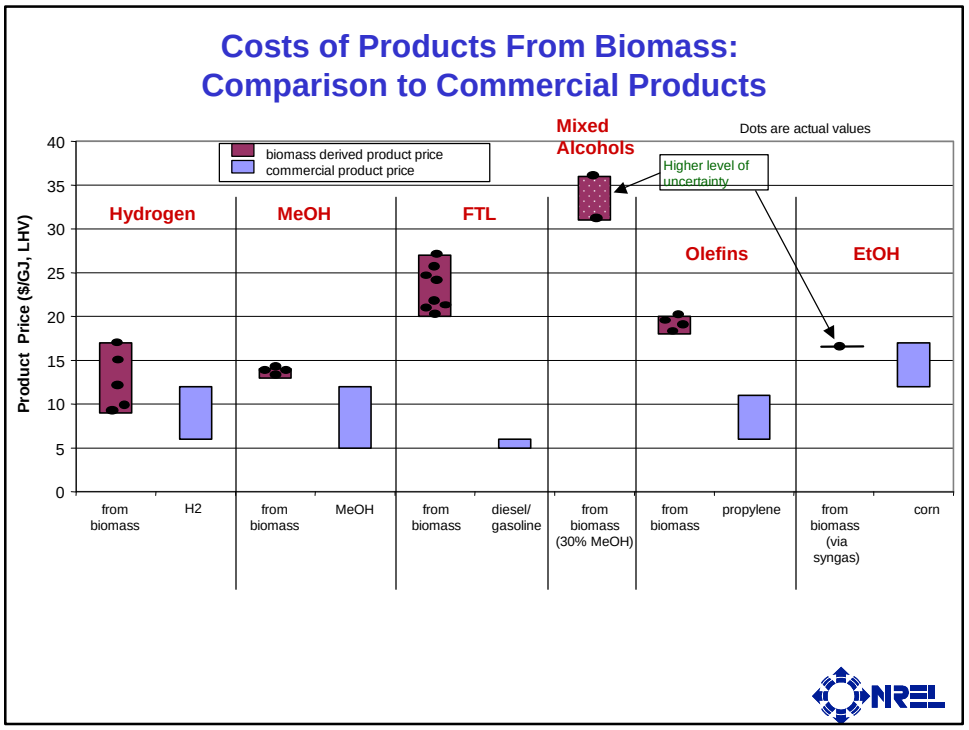

Thermochemical Conversion
Of Biomass and Black Liquor
Product
Bio-Oil
Changing World Technologies
Gas Product: PNNL Wet Gasification (CH4/H2)
10-25 MPa
Feed: Biomass
ENSYN
Dynamotive
BTG
Fortum
Syngas
Dry Ash
Slag
GTI (O2)
Carbona (O2)
HTW O2)
Foster Wheeler (O2)
1- 3 MPa
Feed: Biomass
MTCI-also Black Liquor
FERCO (Indirect)
MTCI (Indirect)
Pearson (Indirect)
TUV (Indirect)
For CHP:TPS (Air)
Carbona (Air)
Lurgi (Air)
Foster Wheeler (Air)
EPI (Air)
Prime Energy (Air)
Chemrec (O2)
Noell
2 – 3 MPa
Feed: Black Liquor
Chemrec (Air)
High Pressure
Low Pressure
0.2 MPa
Low (300-600°C)
Medium (700-850°C)
High (900-1200°C)
Temperature
NREL


Syngas to Products
Waxes
Diesel
Olefins
Gasoline
Mixed
Alcohols
Fischer-Tropsch
MTBE
Acetic Acid
Alkali-doped
ZnO/Cr2O3
Cu/ZnO; Cu/ZnO/Al2O3
CuO/CoO/Al2O3
MoS2
Fe, Co, Ru
Formaldehyde
Ag
isobutylene
acidic ion exchange
carbonylation
CH3OH + CO
Co, Rh, Ni
Isosynthesis
i-C4
ThO2 or ZrO2
Syngas
CO + H2
Cu/ZnO
Methanol
zeolites
Olefins
Gasoline
MTO
MTG
H2O
WGS
Purify
Co, Rh
Oxosynthesis
HCo(CO)4
HCo(CO)3P(Bu3)
Rh(CO)(PPh3)3
homologation
Co
Al2O3
DME
Direct Use
M100
M85
DMFC
N2 over Fe/FeO
(K2O, Al2O3, CaO)
NH3
H2
Ethanol
Aldehydes
Alcohols
NREL


Costs of Products From Biomass:
Comparison to Commercial Products
Dots are actual values
biomass derived product price
commercial product price
Mixed Alcohols
Higher level of uncertainty
Hydrogen
MeOH
FTL
Olefins
EtOH
Product Price ($/GJ, LHV)
40
35
30
25
20
15
10
5
0
from biomass
H2
from biomass
MeOH
from biomass
diesel/ gasoline
from biomass (30% MeOH)
from biomass
propylene
from biomass (via syngas)
corn
NREL

Bioenergy Cycle