Biomass Technologies: Overview and Future Trends

Small Wood 2004

Sacramento, CA

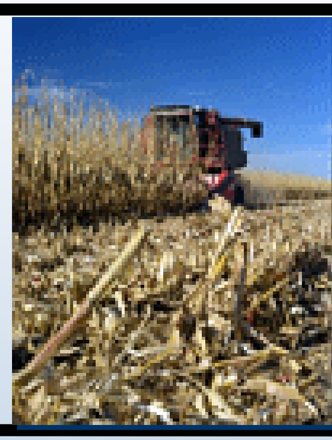
May 20, 2004

John Scahill

Biomass Feedstocks

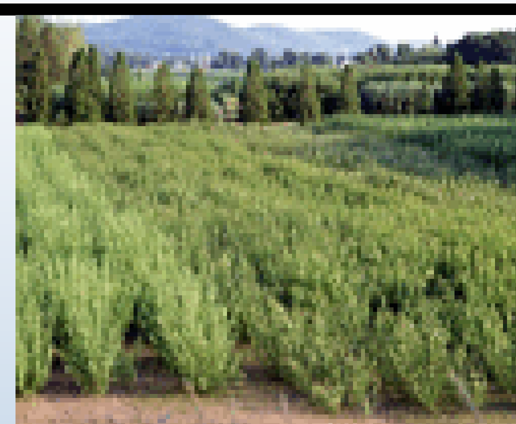
Forest Wood Residues

- Thinning Residues
- Wood chips
- Urban Wood waste
  - pallets
  - crate discards
  - wood yard trimmings



Agricultural Residues

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



Energy Crops

- Hybrid poplar
- Switchgrass
- Willow

Biomass Constituents

Lignin: 15-25%

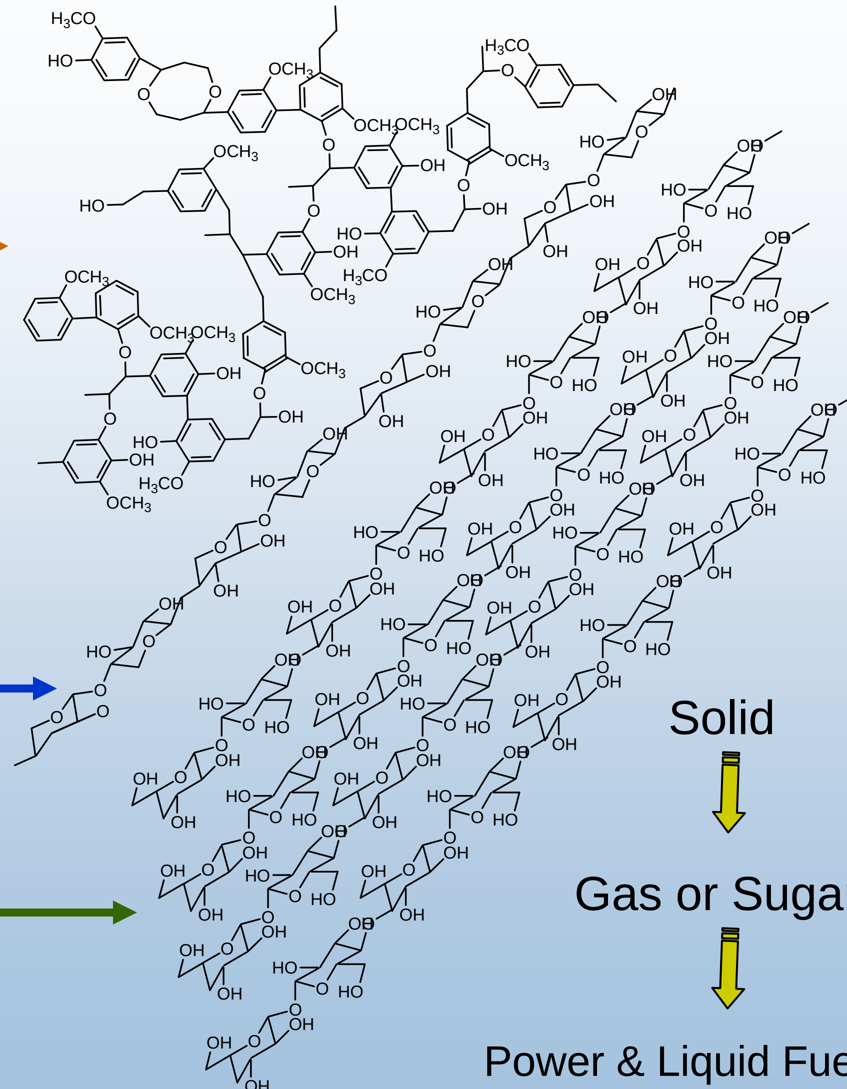
- Complex aromatic structure
- Very high energy content

Hemicellulose: 23-32%

- Polymer of 5 & 6 carbon sugar

Cellulose: 38-50%

- Polymer of glucose, very good biochemical feedstock

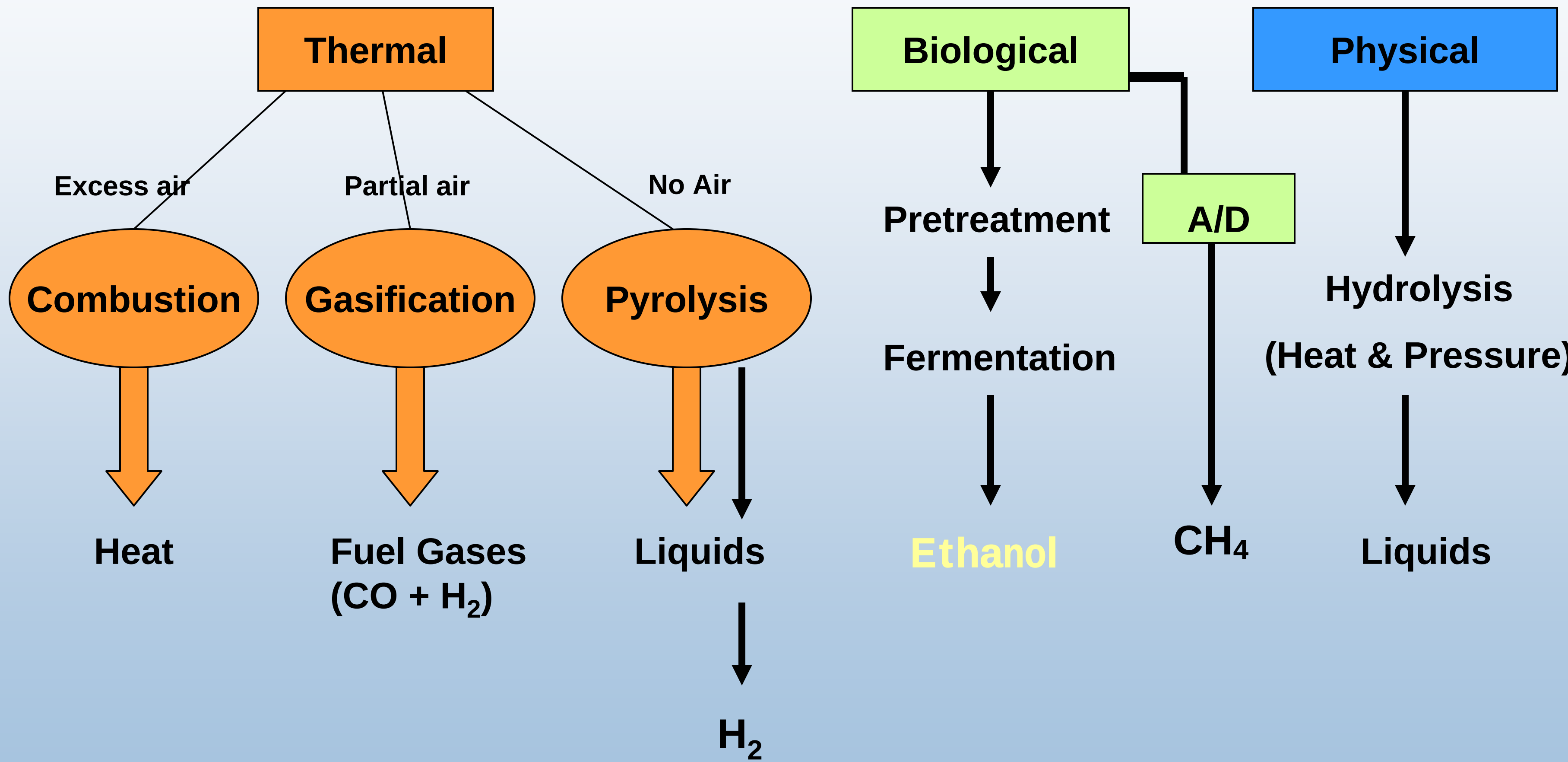


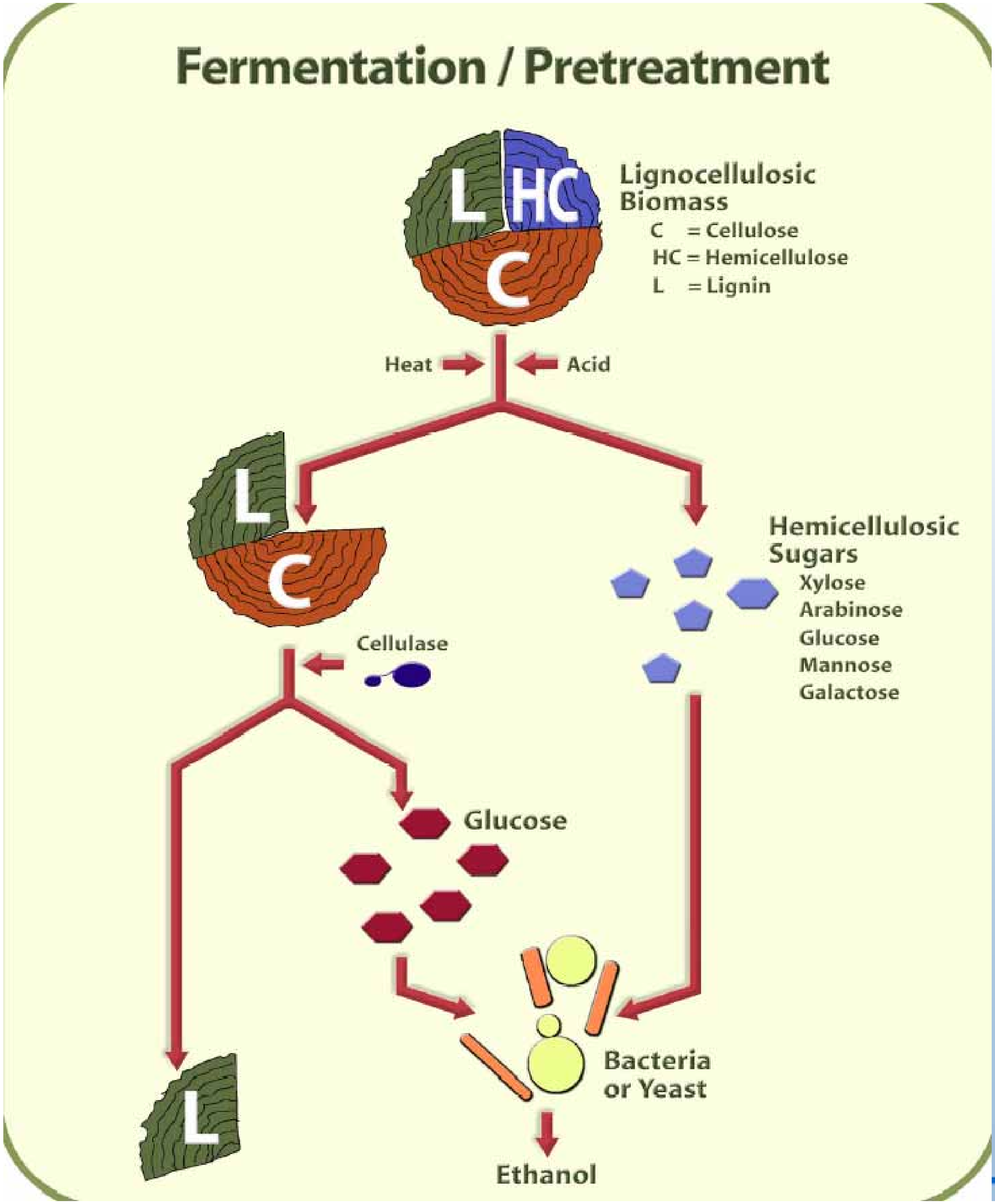
Solid

Gas or Sugars

Power & Liquid Fuels

Biomass Conversion Pathways

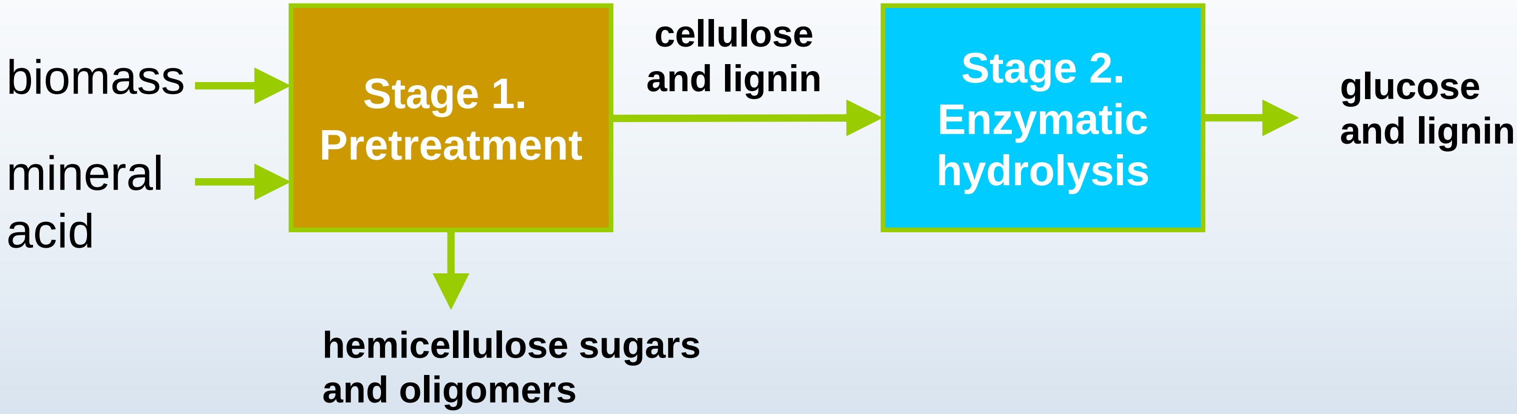




Bio-Chemical Technology Process

effective for converting cellulose- and hemicellulose- into simple sugars

The Biomass Saccharification Process

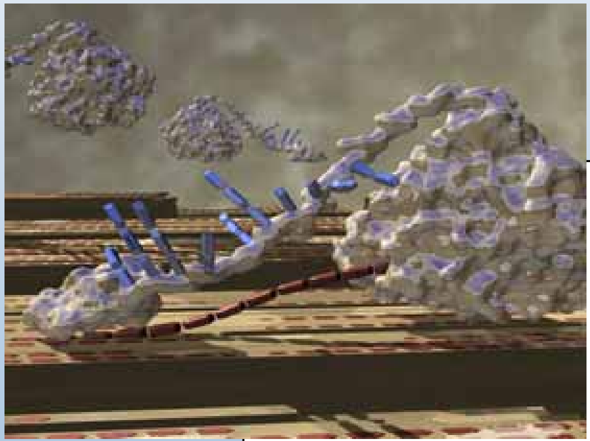


- **Mineral acid gives good hemicellulose sugar yields and high cellulose digestibility**
- **Sulfuric acid usual choice because of low cost**
- **Requires downstream neutralization and conditioning**
- **Typical conditions: 100-200ºC, 50 to 95% moisture, 0-1% H_2SO_4**
- **Some degradation of liberated hemicellulose sugars**
- **Current commercial cellulase enzyme preparations release glucose, cellobiose, and some xylose.**

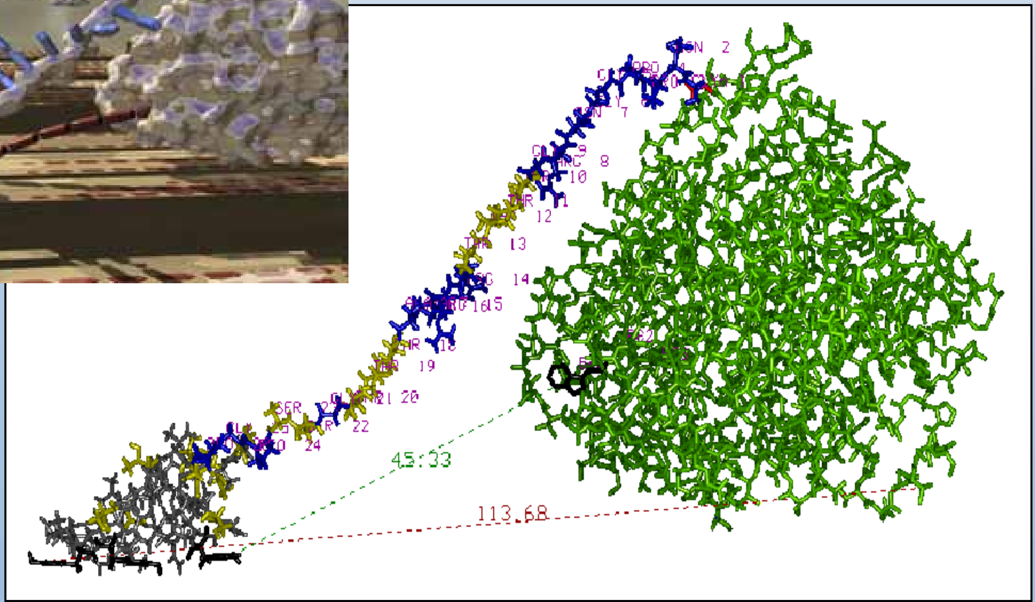
NREL's Enzymatic Hydrolysis Partnerships

3-year Partnerships with Genencor & Novozymes

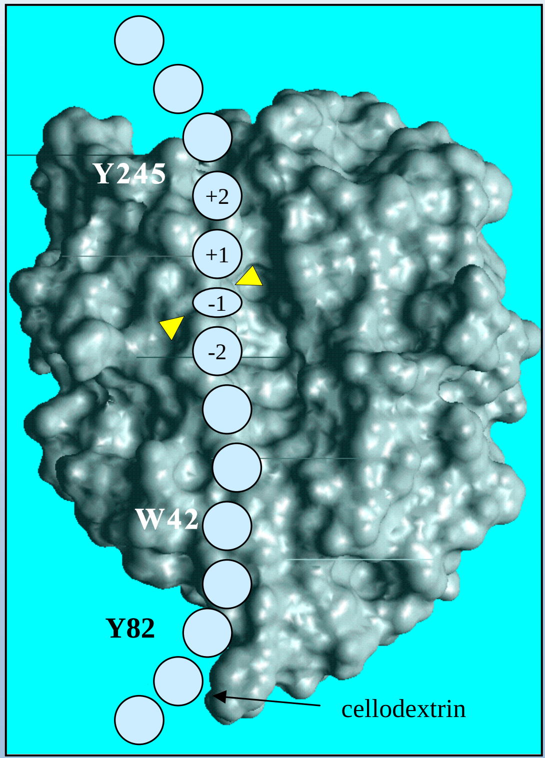
- Enzyme biochemistry and specific activity
- Cellulase - cellulose surface interaction
- Reduce cost of enzyme production ($0.25/gal)
- Reduce risk to investors



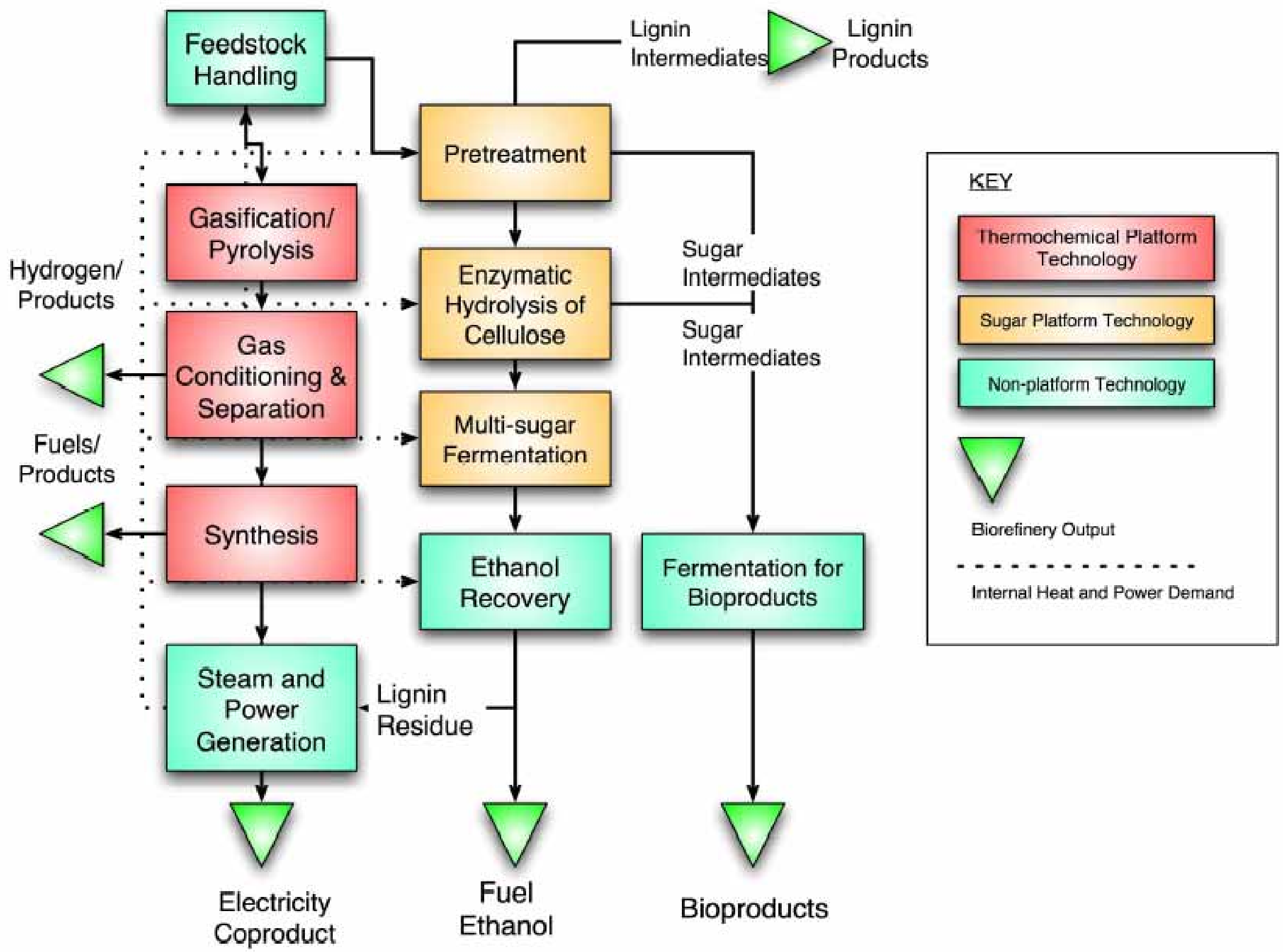
CBH1 from T. reesei



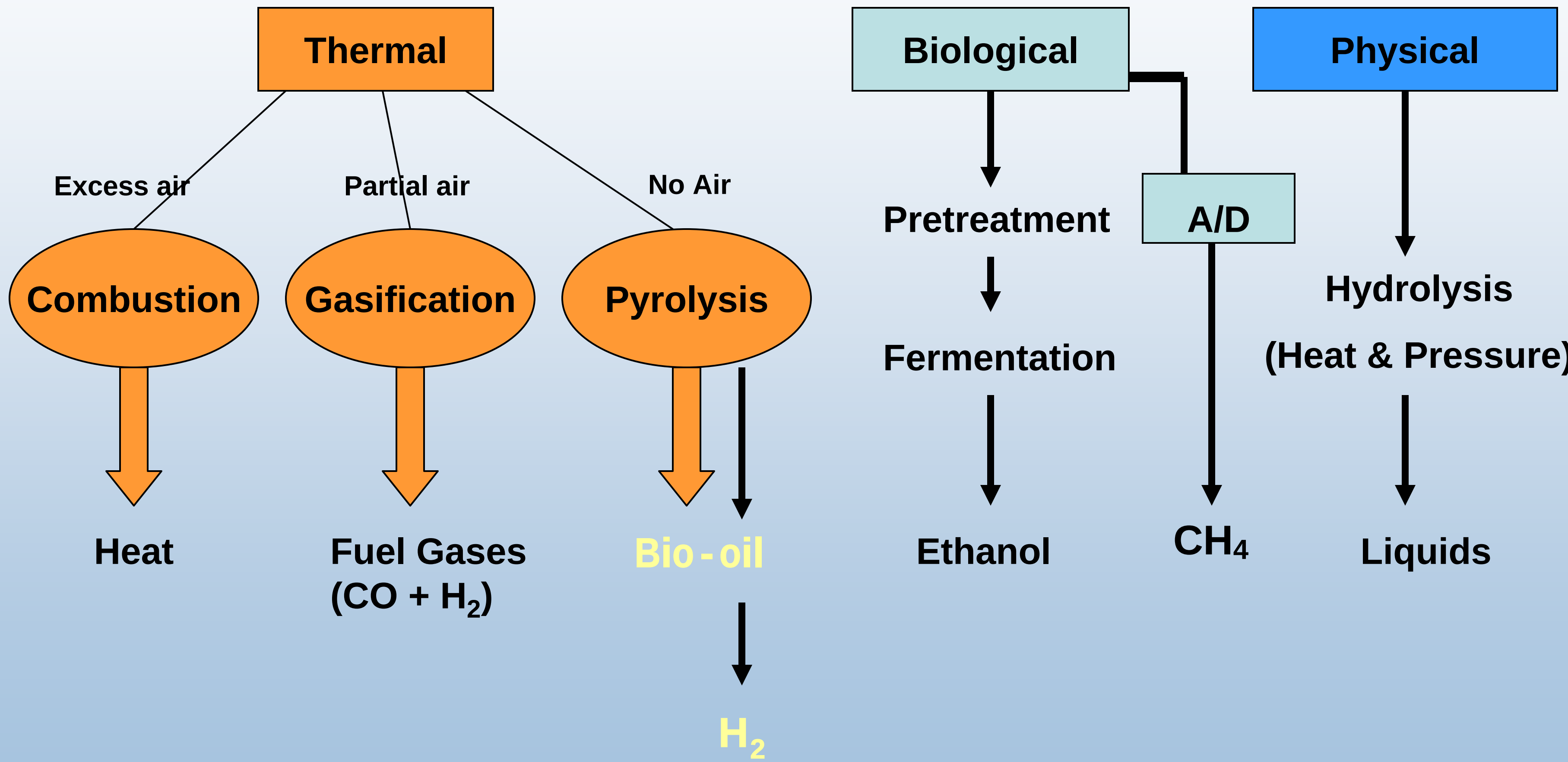
E1 from *A. cellulotiticus*



Schematic of an Integrated Biorefinery

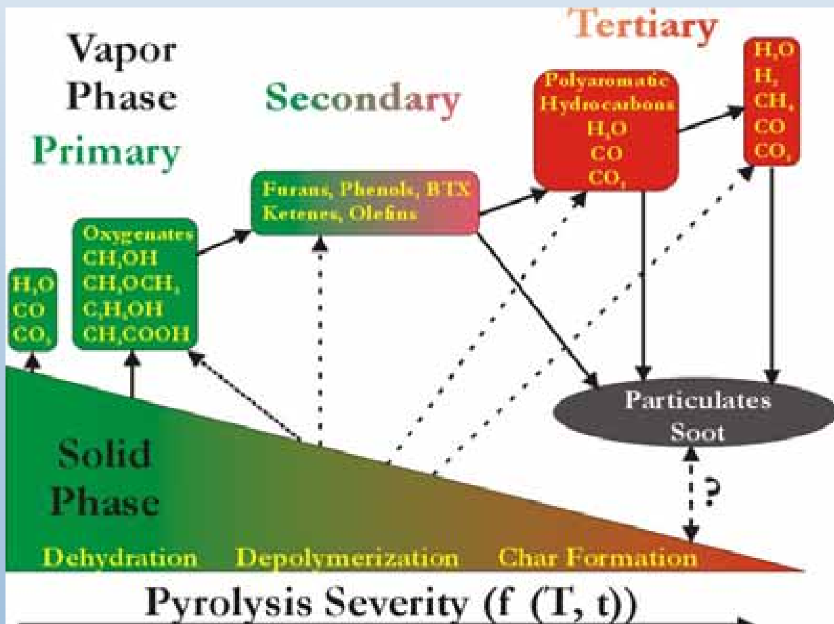


Biomass Conversion Pathways

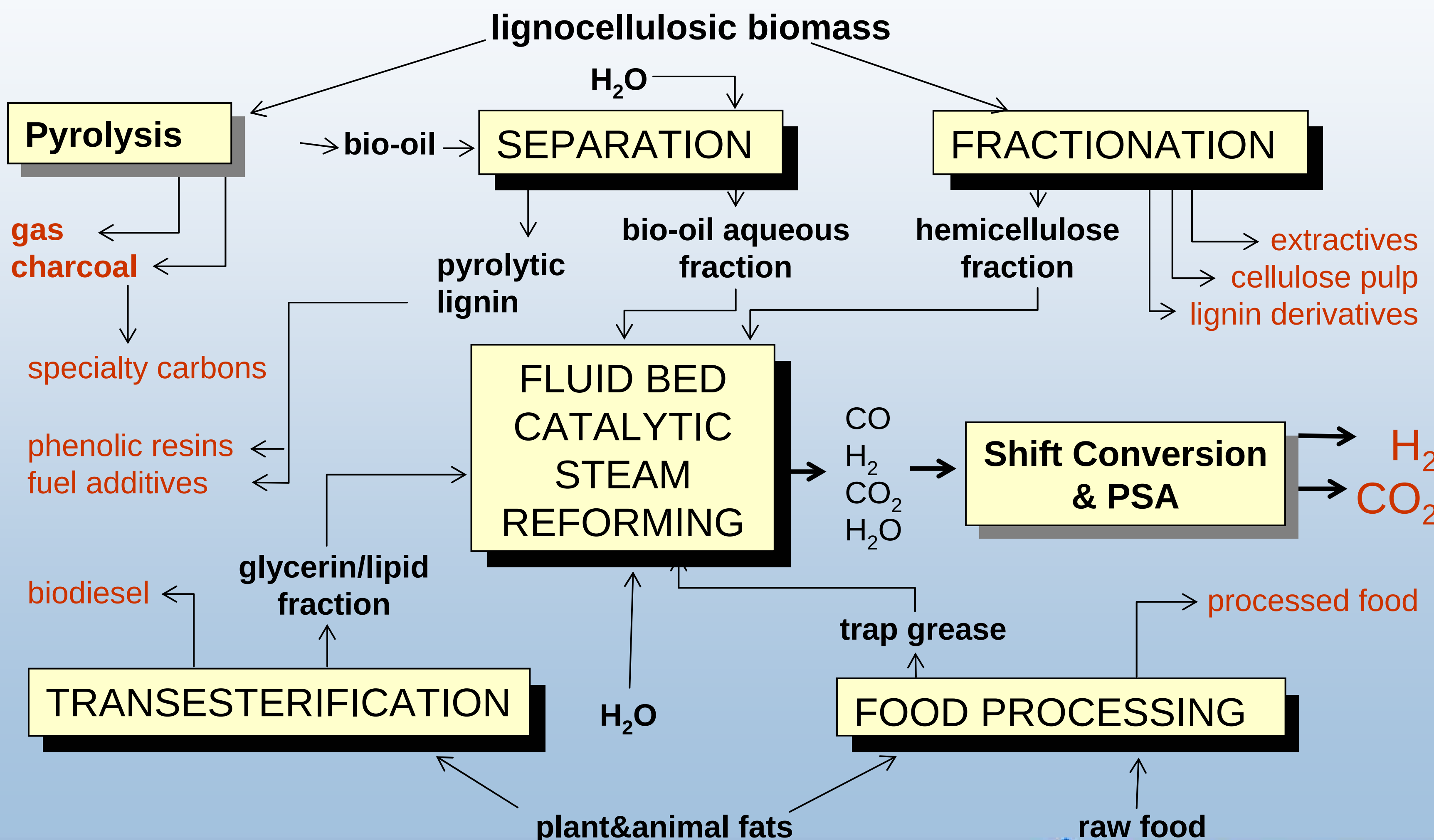


Pyrolysis Technical Requirements

- **Rapid heat transfer in the absence of oxygen**
- **Short residence time at temperature (msec)**
- **Thermal cleavage of macropolymer bonds (lignin, cellulose, hemicellulose)**
- **Liquids (70%), gas (15%), Char (15%)**

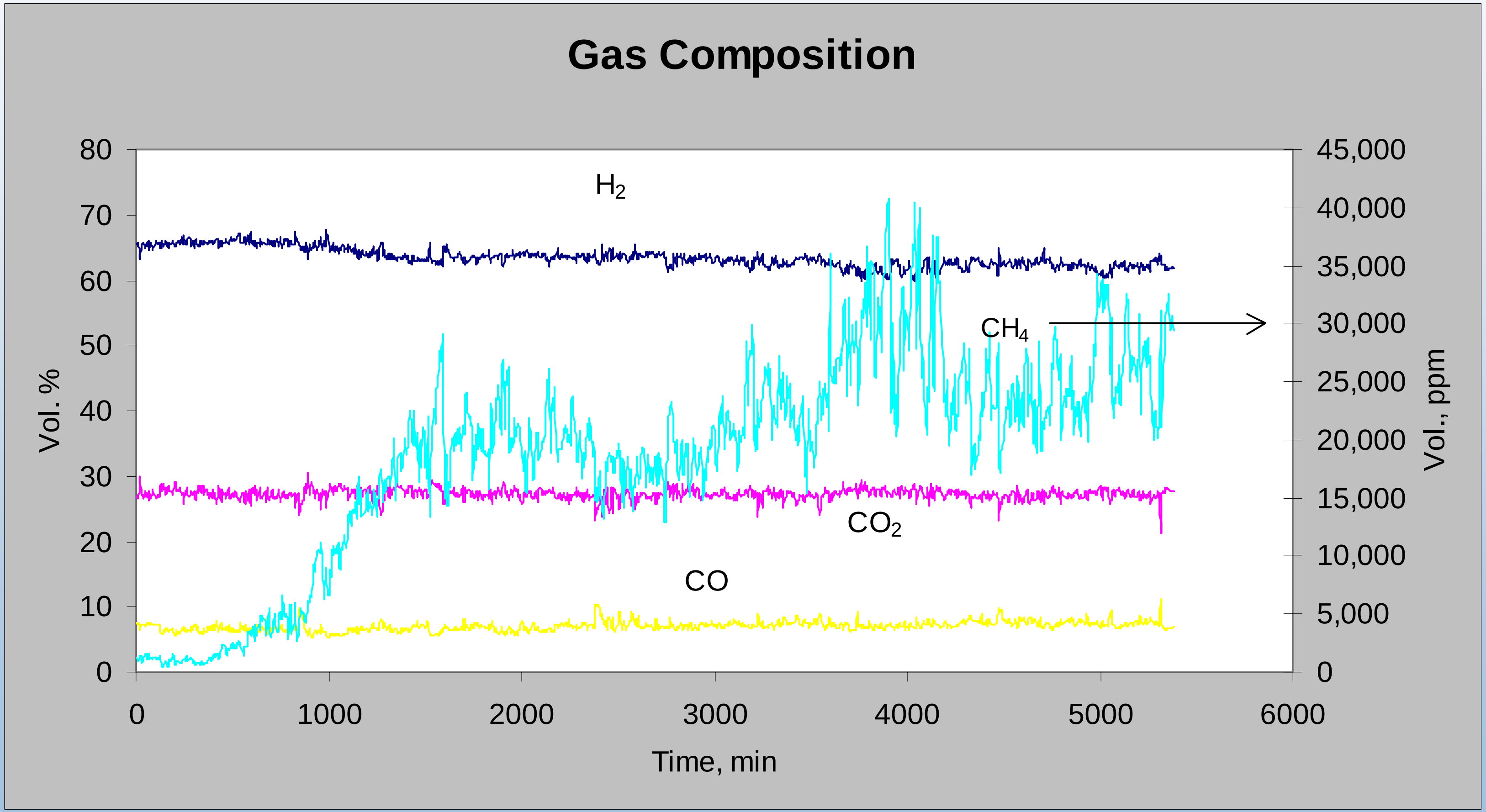


Bio-oil Refinery Approach



NREL National Renewable Energy Laboratory

Bio-Oil Aqueous Fraction Fluidized Bed Reforming

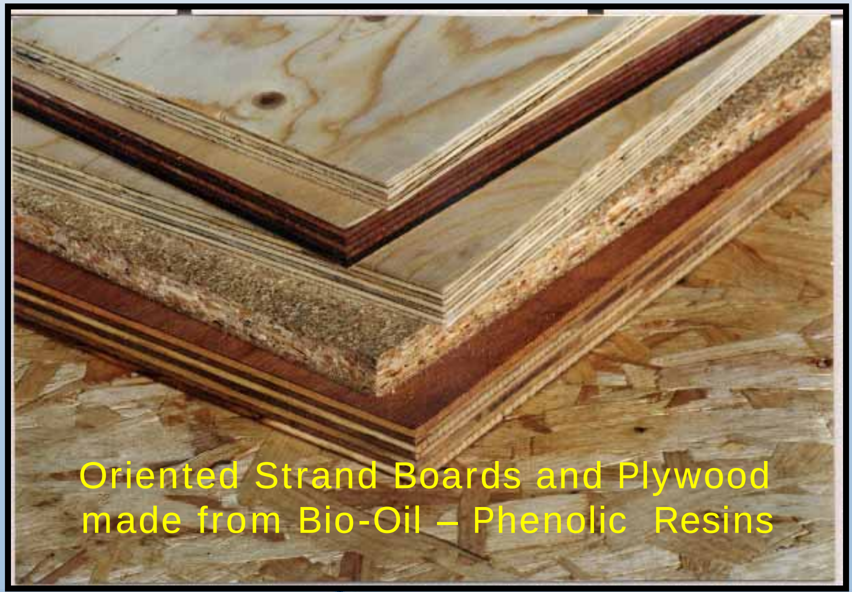


NREL National Renewable Energy Laboratory

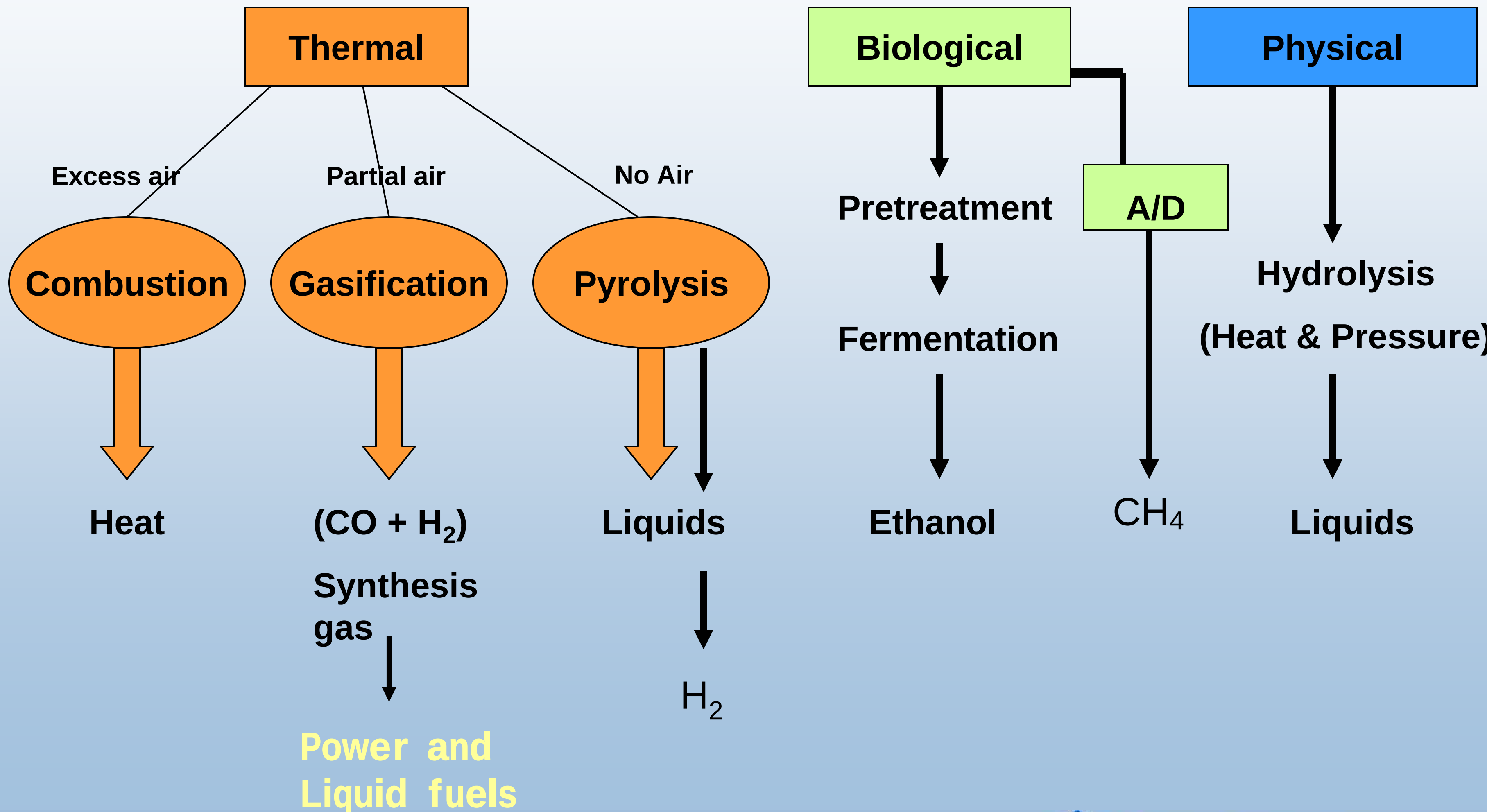
Bio-Oil From Pyrolysis

Potential Markets / Products

- **Liquid boiler fuel substitute**
- **Reform to Hydrogen**
- **Food flavorings / Specialty chemicals**
- **Phenolic replacements**
- **Asphalt binders**

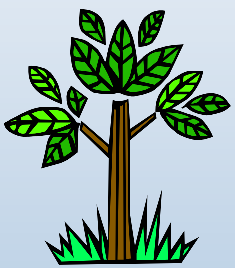


Biomass Conversion Pathways



Gasification

Air (0.3)
O_2 (0.3)
Steam



Heat

Producer Gas (mol%)

CO	24
H_2	13
CH_4	3
CO_2	8
N_2	52

(CO, H_2, CH_4: Fuel Gases)

(tars & particulate)

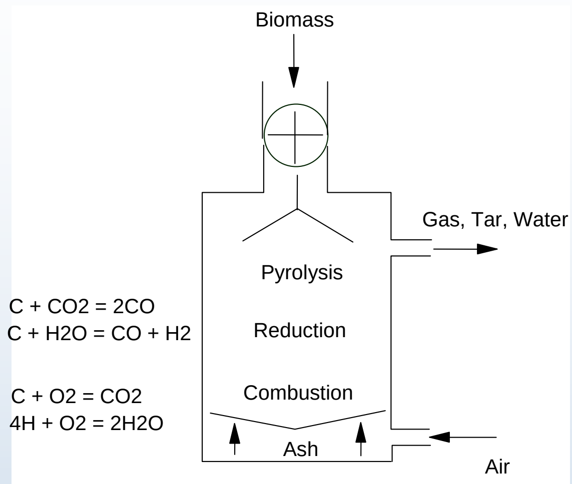
Synthesis Gas (mol%)

CO	39
H_2	20
CH_4	17
C_2H_2	6
CO_2	18
N_2	0

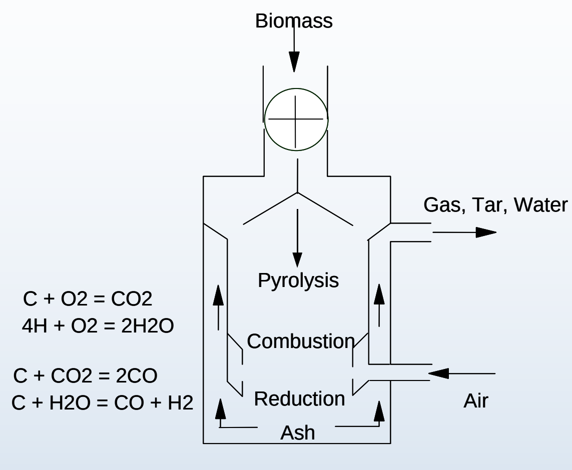
(CO, H_2, CH_4, C_2H_2: Fuel Gases)

(tars & particulate)

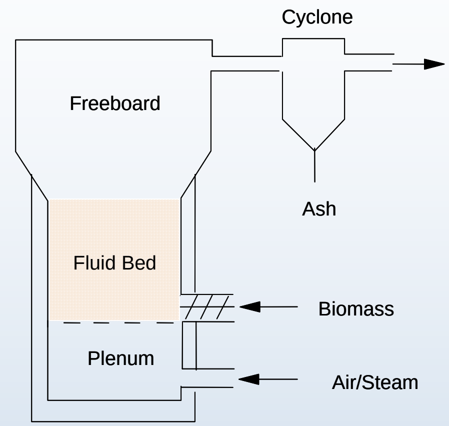
Different Gasifier Designs



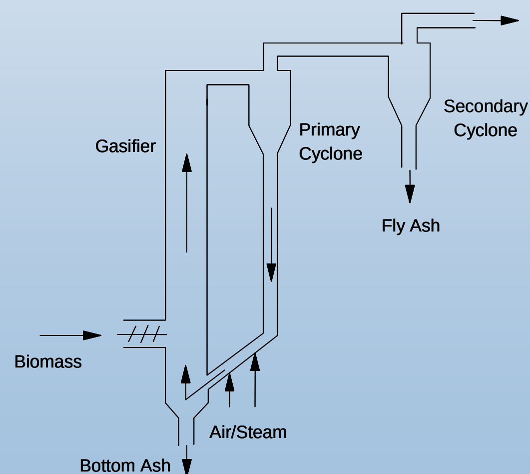
Updraft Gasifier



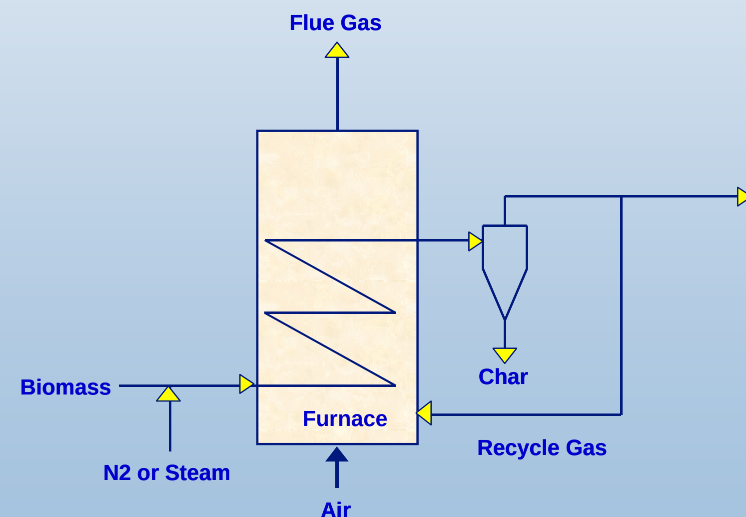
Downdraft Gasifier



Fluid-Bed Gasifier



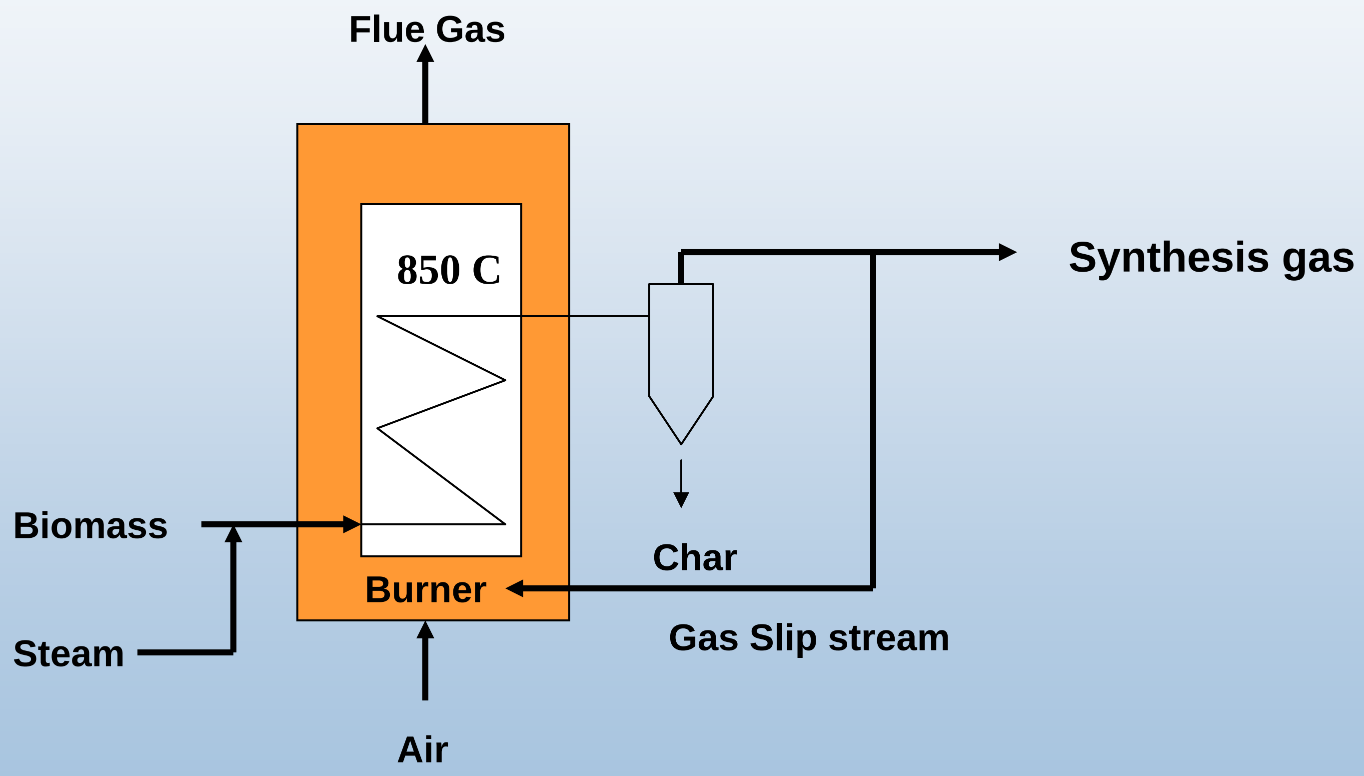
Circulating Fluid-Bed Gasifier



Entrained Flow Gasifier

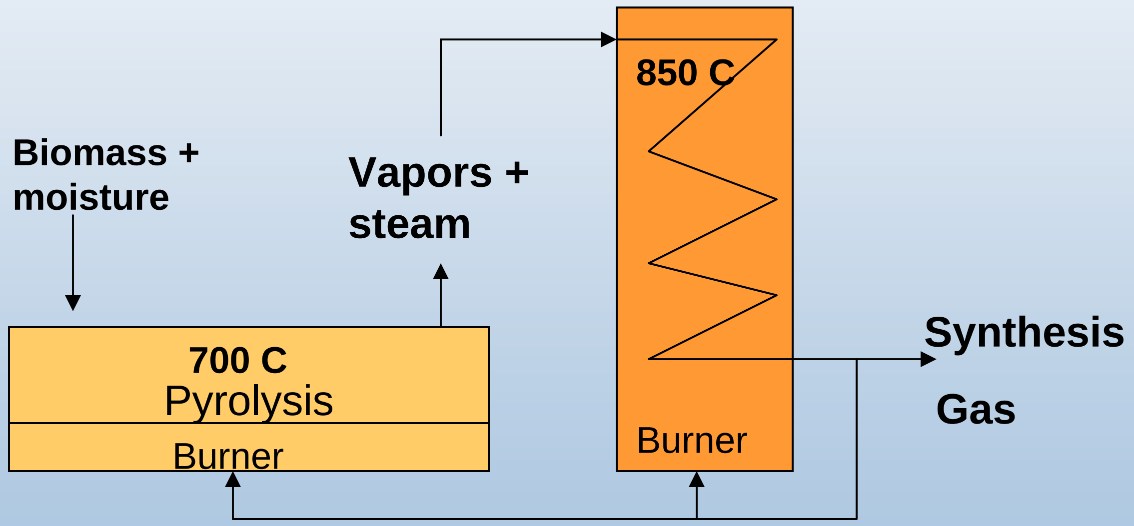
Entrained Flow Gasification

(Steam Reforming)



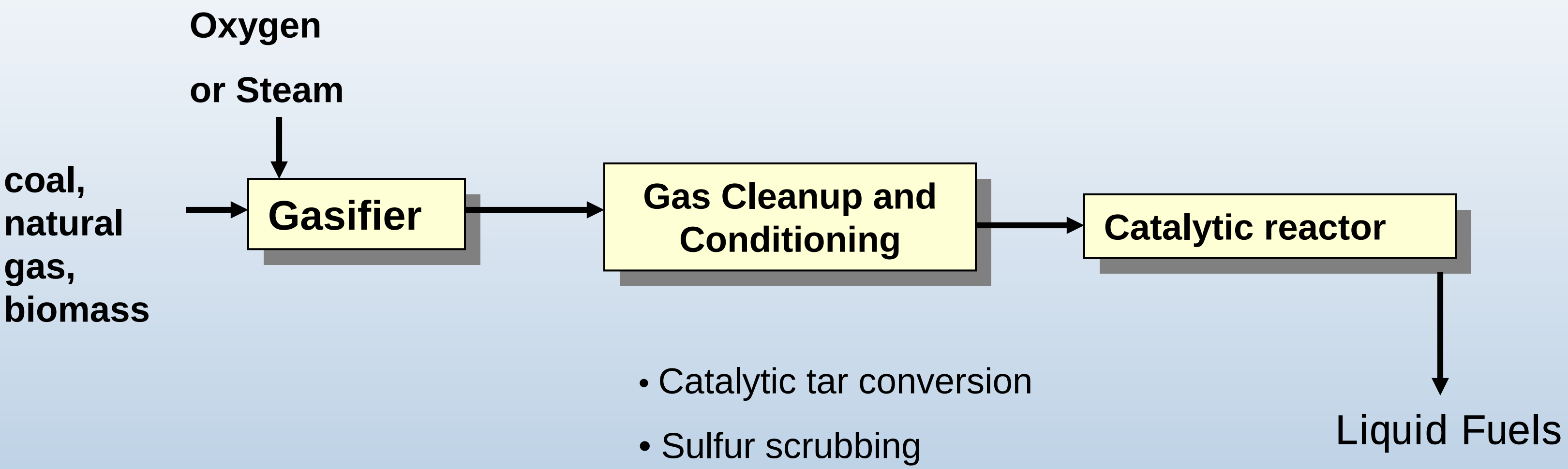
Staged Gasification

Pyrolysis ⇒ Steam Reforming



Carbon Conversion Technologies 2004

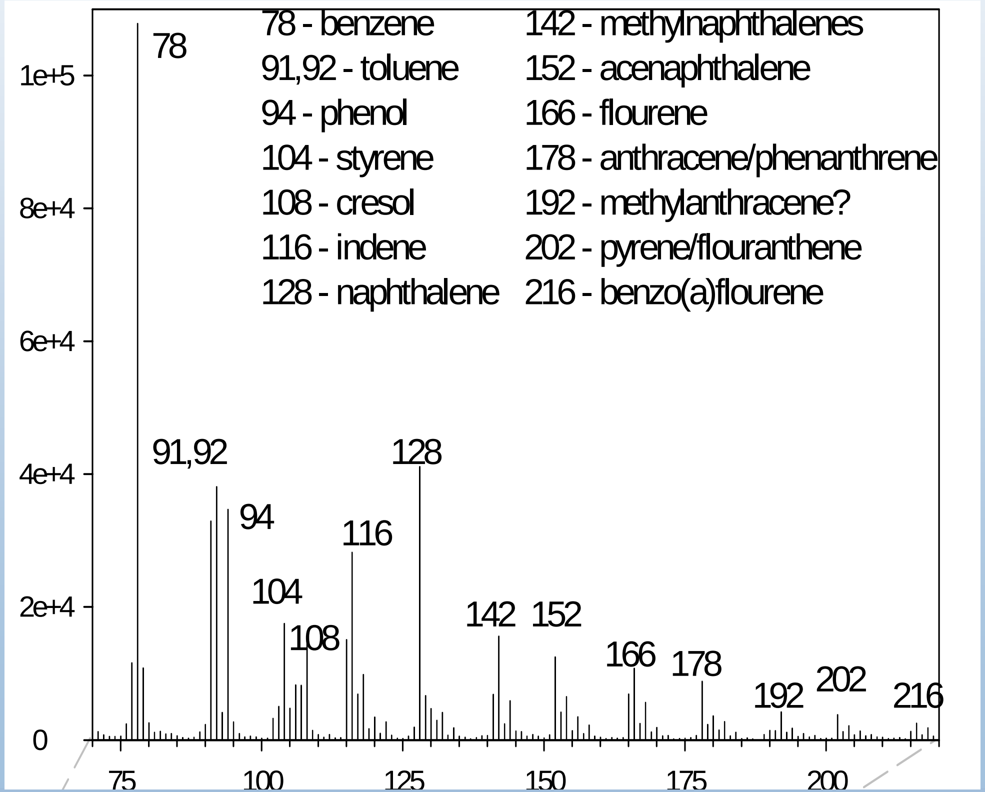
General Process Description
Syngas-to-Liquids

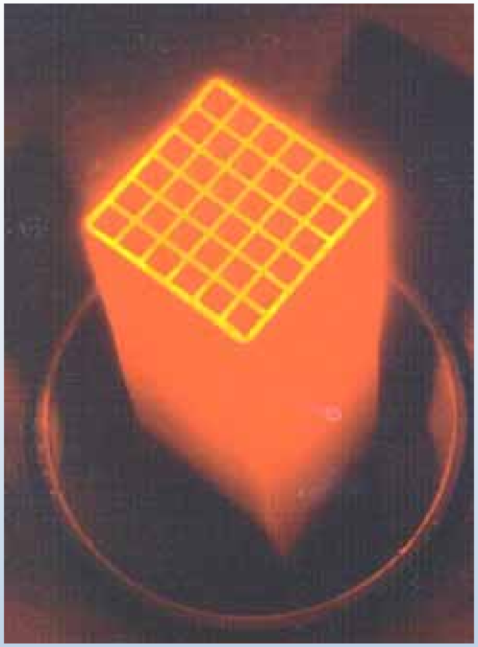


- Catalytic tar conversion
- Sulfur scrubbing
- Shift H2/CO ratio
- Particulate removal
- Wet scrubbing

NREL TCPDU Product Gas Tar Composition

Averaged mass spectrum (TMBMS) of tars from indirect wood gasification





Source: VTT Research Center, Finland

Tars can be reformed to additional H2 + CO

- **Nickel catalysts**
- **850 ° - 900° C**

Syngas Conditioning

Gasification Reactions

$$C + CO_2 \longrightarrow 2\,CO$$ **(Boudouard)**

800° - 850° C

$$CO + H_2O \longrightarrow CO_2 + H_2$$ **(Water gas shift)**

Control of temperature and steam content adjusts H2 / CO ratio in Syngas

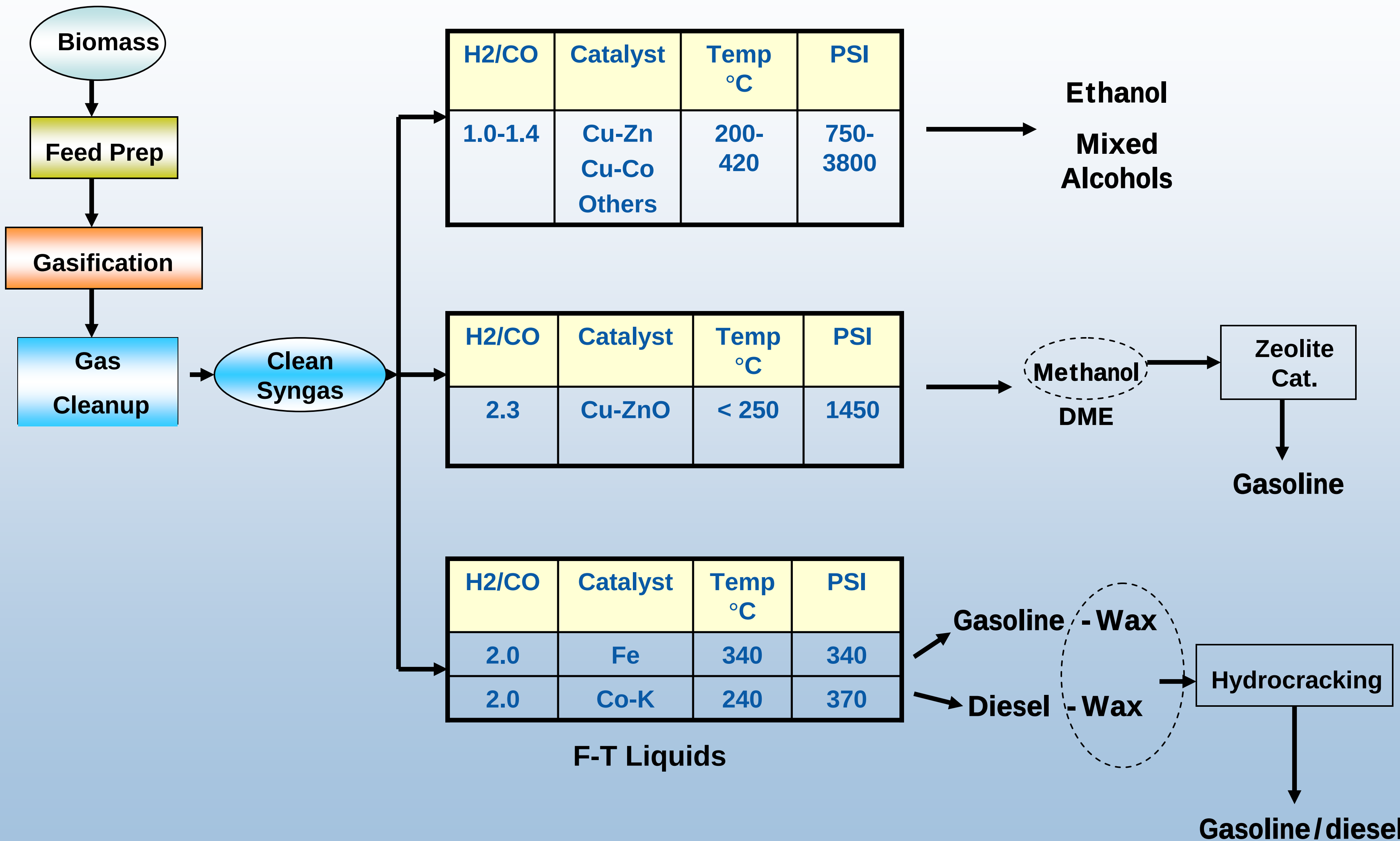
Gas Cleanup Requirements

For Fischer-Tropsch gas-to-liquids

Impurity	Removal level
H_2S, NH_3, HCN	< 1 ppmv
HCl	< 10 ppbv
Soot, dust, ash	Essentially completely
Tars	Below dew point < 1 ppmv

Source: H. Boerrigter et al, October 2002

Syngas to Liquid Fuel Options



H2/CO	Catalyst	Temp °C	PSI
1.0-1.4	Cu-Zn Cu-Co Others	200-420	750-3800

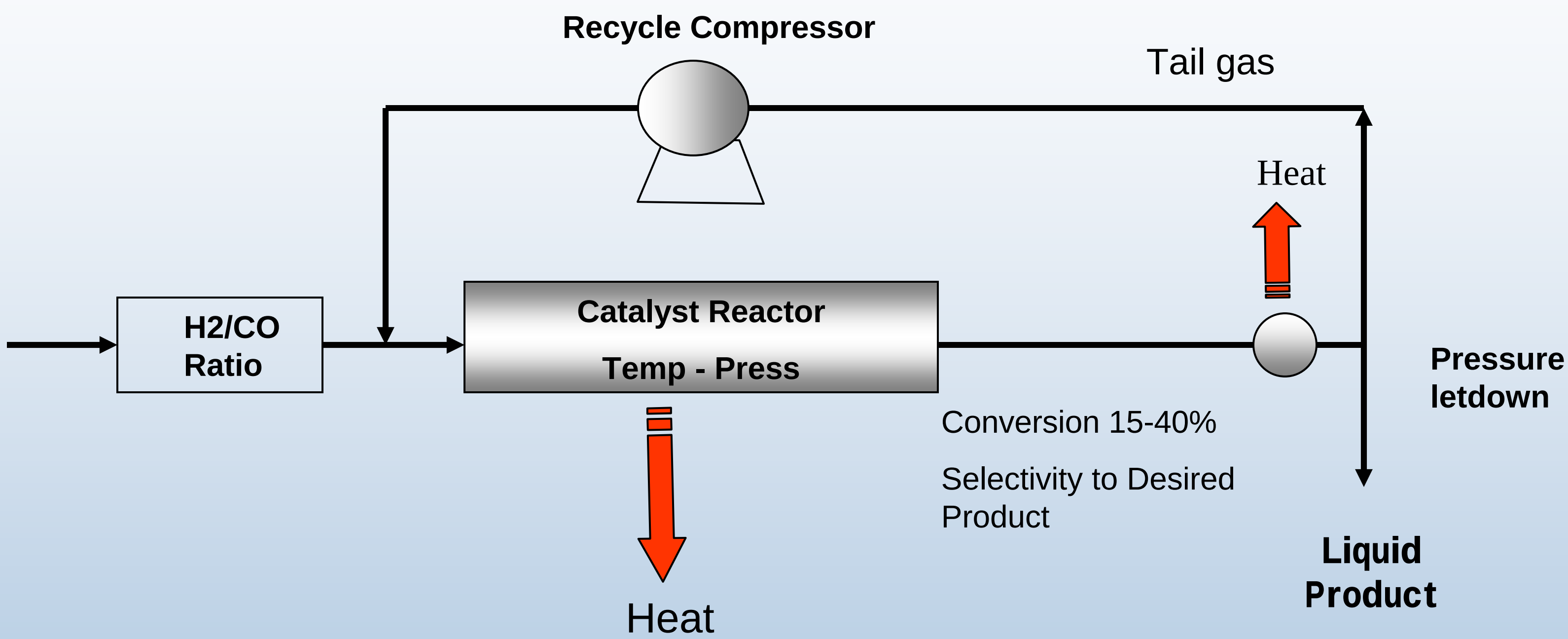
H2/CO	Catalyst	Temp °C	PSI
2.3	Cu-ZnO	< 250	1450

H2/CO	Catalyst	Temp °C	PSI
2.0	Fe	340	340
2.0	Co-K	240	370

F-T Liquids

Source: NREL/TP 510-34929

Gas to Liquids Process Issues



- Syngas Conditioning (cleanup)
- Gas recycle costs
- Heat removal (highly exothermic)

Liquid Fuel Properties

F-T Diesel (high quality)

Cetane	> 70 (conventional 45-50)
Total aromatics	< 3 (vol. %)
Polycyclic aromatics	< 0.01 (mass %)
Sulfur	< 1 (ppm)

Source: www.sasol.com

Mixed Alcohols

Type	Wt%
Methanol	5-30
Ethanol	45-75
Propanol	15
Butanol	5
Pentanol	3
Hexanol & higher	2

Source: Taylor (2002)

Commercial History of Gas-to-Liquids

- SASOL (South Africa) 1955
  - Coal → CH_4 → hydrocarbon fuels/chemicals
- Shell (Malaysia) 1993, 12,000 bbl/day
  - Natural gas → syngas → gasoline
- BP / Davy Process Tech (Alaska) 2002
  - Stranded CH_4 → short chain hydrocarbons
  - Compact, modular design
  - Small barge mounted plants under development
- Syntroleum (Australia) under construction/shakedown

Economic Comparisons

Biomass to F-T Liquids vs. Electricity

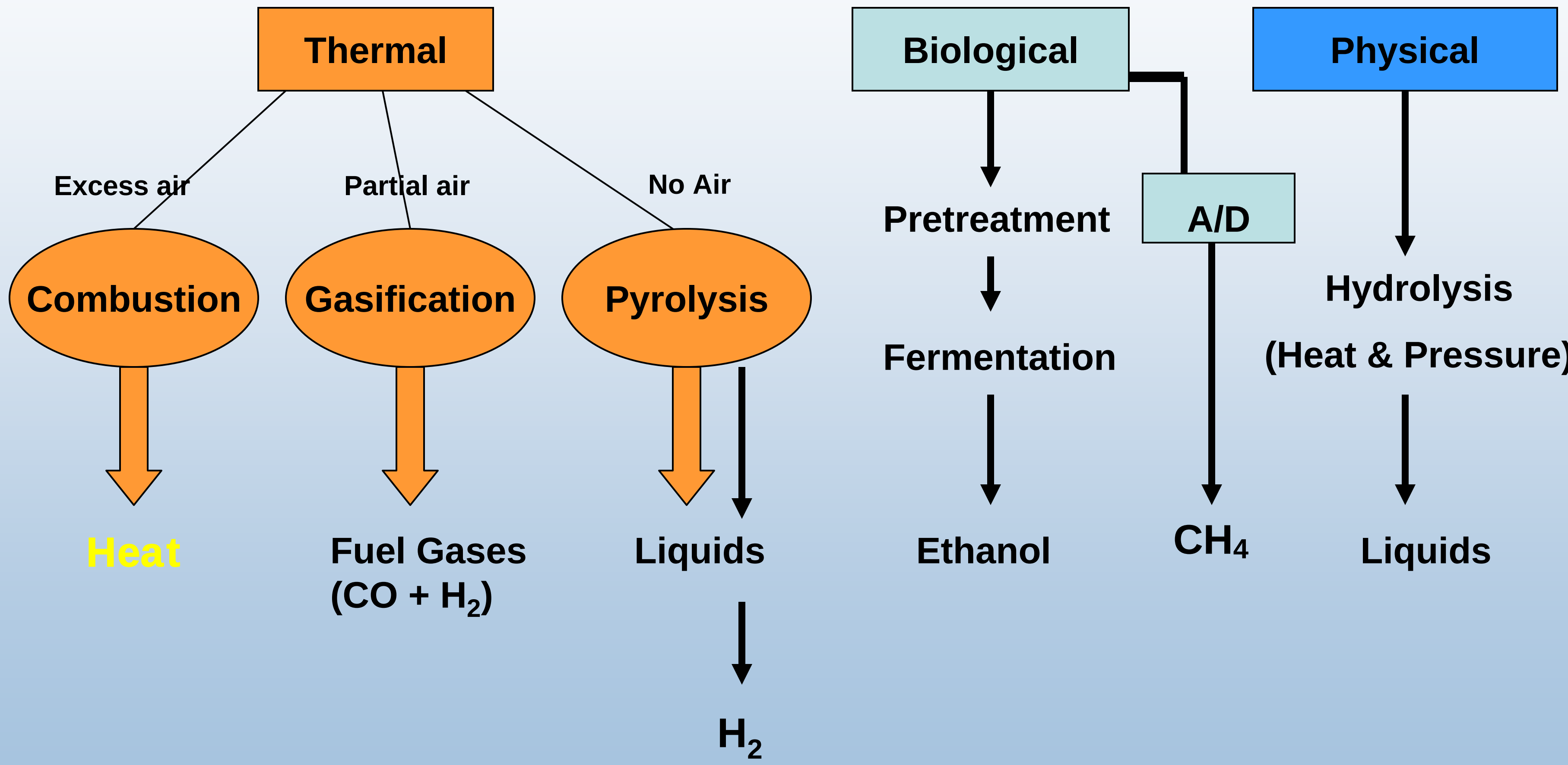
Yield	Value	$/ton biomass
(1) **79.8 gal/ton**	**$1.14+.21=$1.35/gal** (3)(4)	**$108**
(2) **455 kWh/ton** (combustion-steam turbine)	**Purchase agreement $0.02-.04 / kWh**	**$9 - $18**
	Levelized COE $0.07 / kWh (2)	**$32**

Basis:

50 wt% conversion biomass to syngas

1. 10,000 ft3 syngas/bbl syncrude (Hydrocarbon Processing Feb 2003)
2. 455 kWh/g ton biomass, $.07/kWh COE (McNeil Technologies Nov 2003)
3. EIA current diesel production cost (May 9, 2004)
4. EIA estimate of FT diesel premium value - $9/bbl

Biomass Conversion Pathways



Biomass Combustion for Heat

- Increasing interest
  - Industrial parks
  - Multiple buildings (district heating)
- High natural gas costs

Source: BioEnergy Corp.
Nederland, CO

Biomass Power Applications

- Combustion / steam turbine – mature but low efficiency
- Small modular systems - emerging technology
- Gasification combined cycle – under development

Biomass is the only renewable resource that causes problems when it is NOT used!