Biomass Gasification

Presented by
Dr. Richard L. Bain, Principal Research Supervisor, Biorefinery Analysis
Biorefinery Analysis and Exploratory Research Group
National Bioenergy Center

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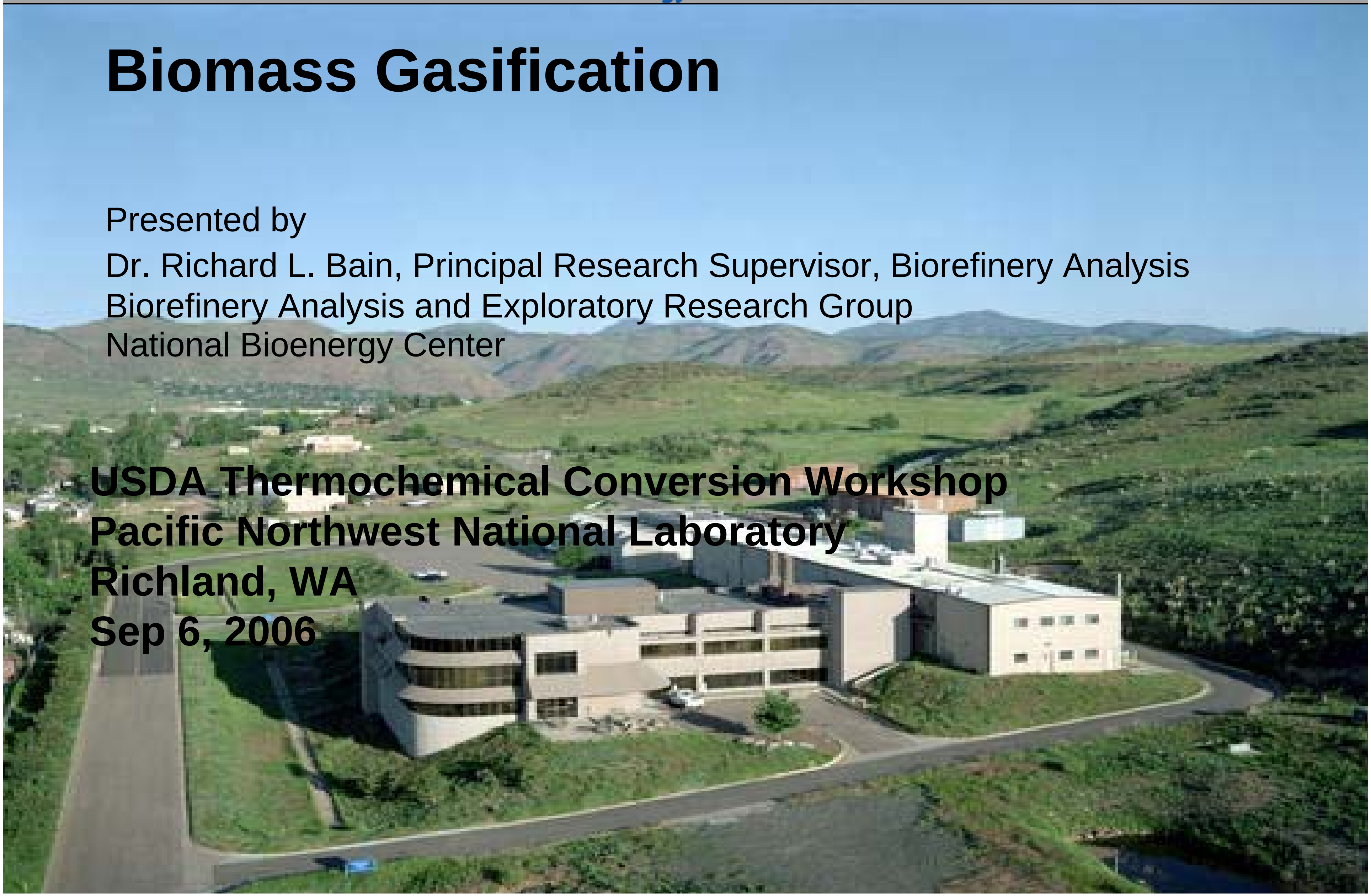

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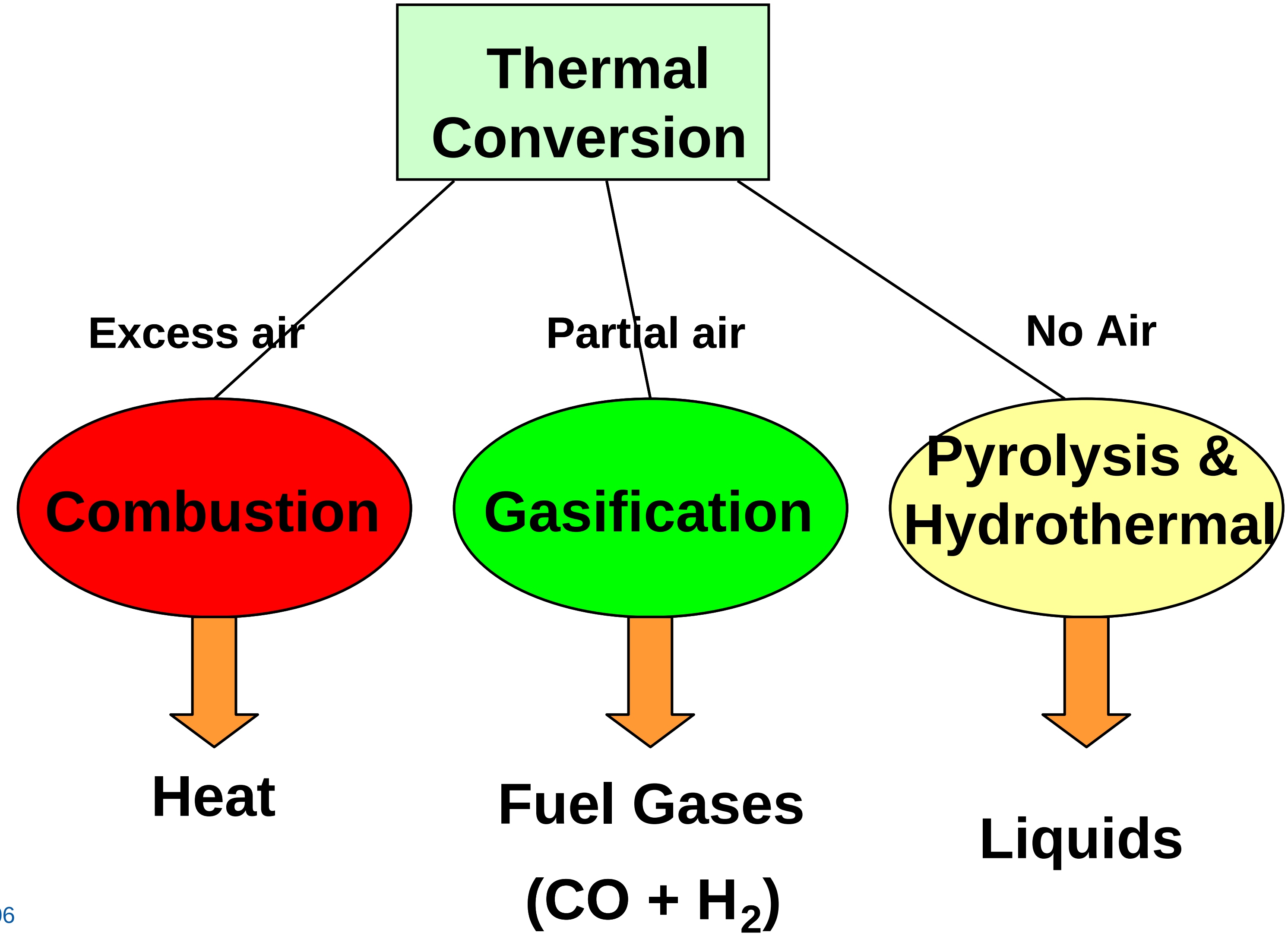
Presentation Outline

- Definitions
- Biomass Properties
- Biomass Gasifiers
- Combined Heat and Power
- Transportation Fuels

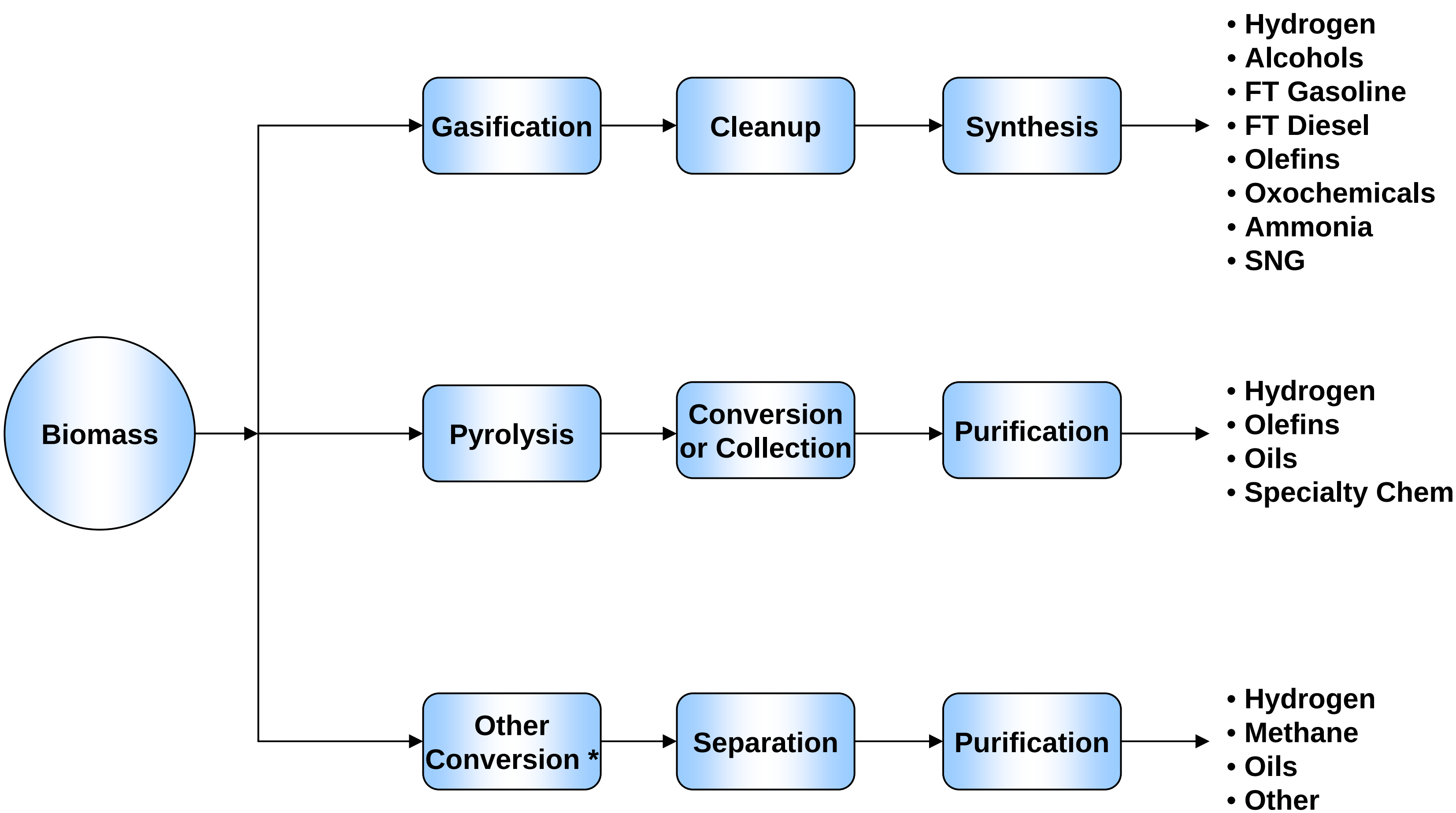
There are a number of reasons for considering gasification based processes

- **Gasification can handle a wide range of biomass feedstocks, ranging from woody residues to agricultural residues to dedicated crops without major changes in the basic process. A system can be designed to handle a variety of feeds**
- **Gasification is applicable across a wide-range of sizes, e.g., farm, village, small industry or town, to large-scale industrial**
- **The thermal efficiency of gasification based processes can be high**
  - **CHP – up to 90%**
  - **1st generation fuels processes – up to 60%**
- **Fuels and chemicals synthesis processes from syngas are already commercial**
- **Gasification-based CHP can maximize the renewable character of existing and proposed ethanol projects.**

The primary conversion routes give different types of products



Fungible fuels & chemicals are major products. New classes of products (e.g., oxygenated oils) require market development



*** Examples: Hydrothermal Processing, Liquefaction, Wet Gasification**

Combustion, pyrolysis, and gasification are the primary types of thermochemical conversion processes

Combustion is defined as

- Thermal conversion of organic matter with an oxidant (normally oxygen) to produce primarily carbon dioxide and water
- The oxidant is in stoichiometric excess, i.e., complete oxidation

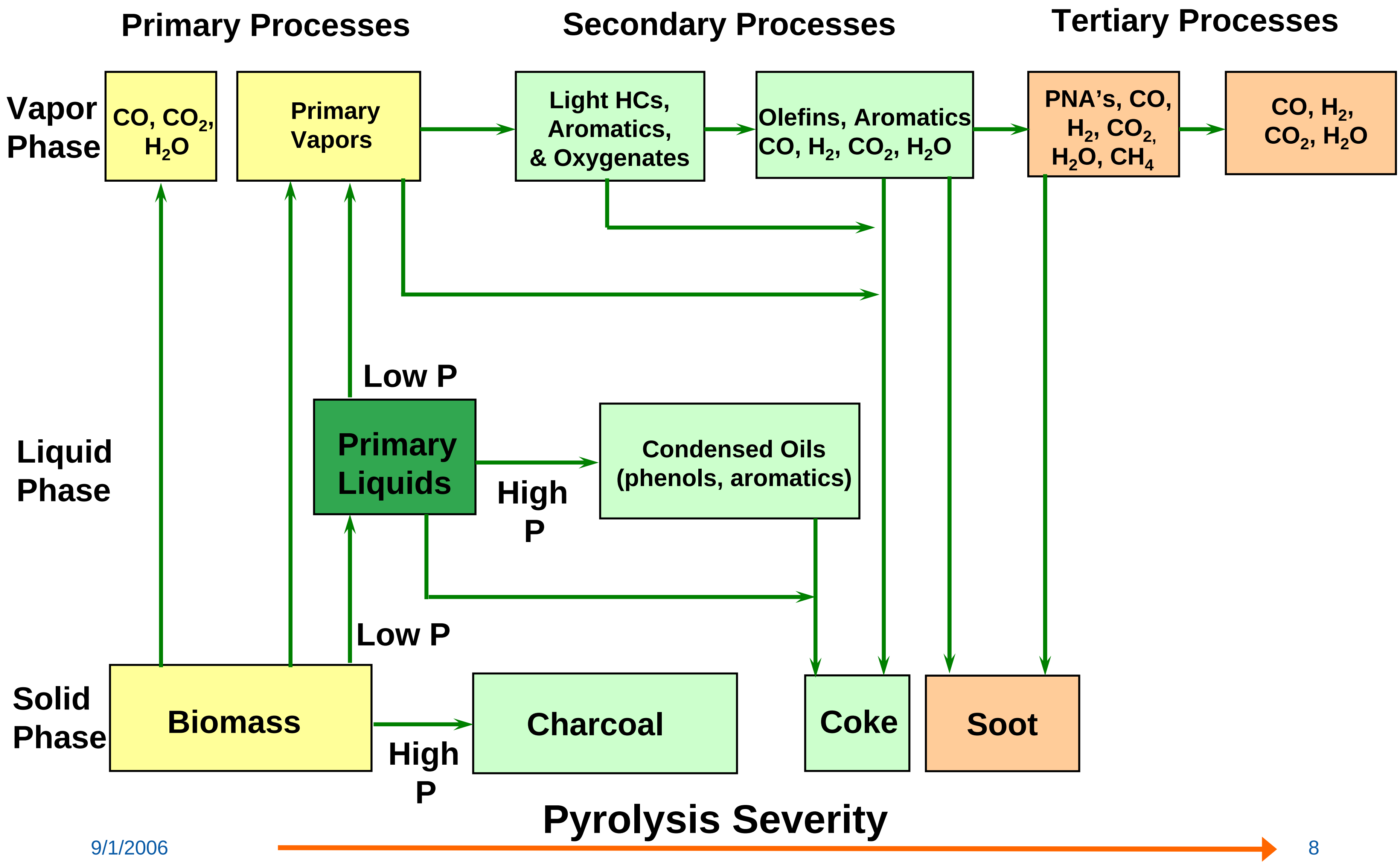
Pyrolysis is defined as

- Thermal conversion (destruction) of organics in the absence of oxygen
- In the biomass community, this commonly refers to lower temperature thermal processes producing liquids as the primary product
- Possibility of chemical and food byproducts

Gasification is defined as

- 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 (steam gasification)

Gasification involves primary, secondary, and tertiary reactions



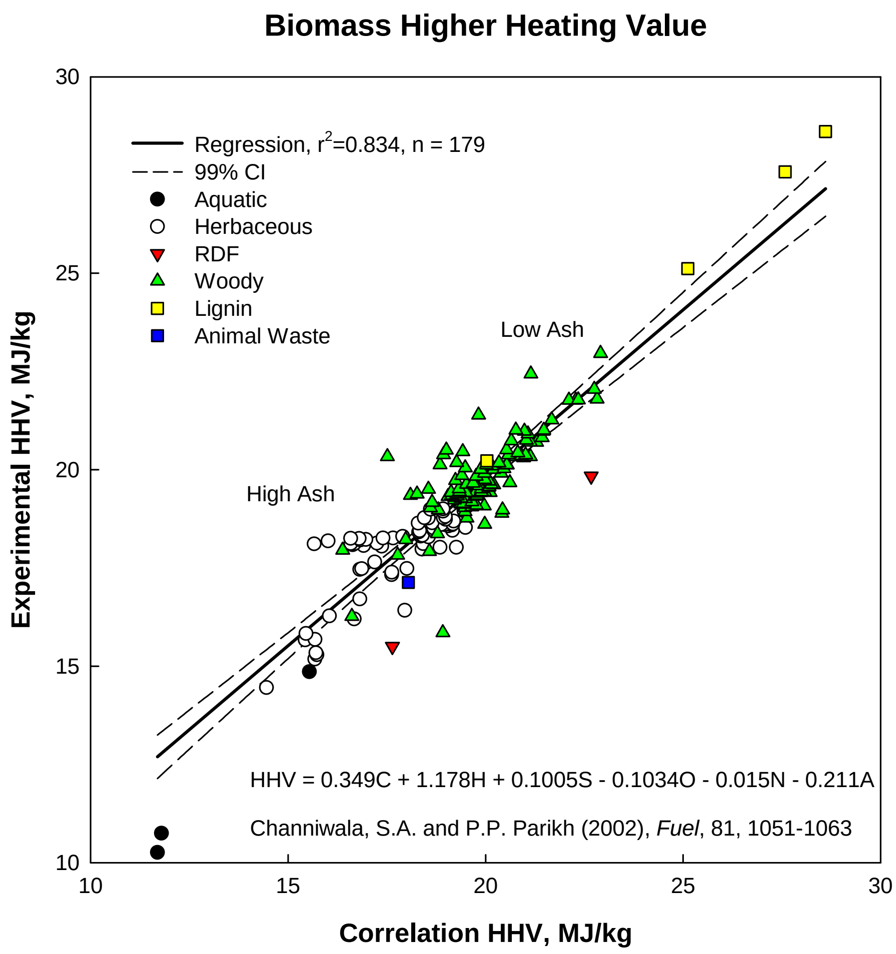
To understand thermochemical conversion we need to know the physical and thermal properties that influence thermal behavior

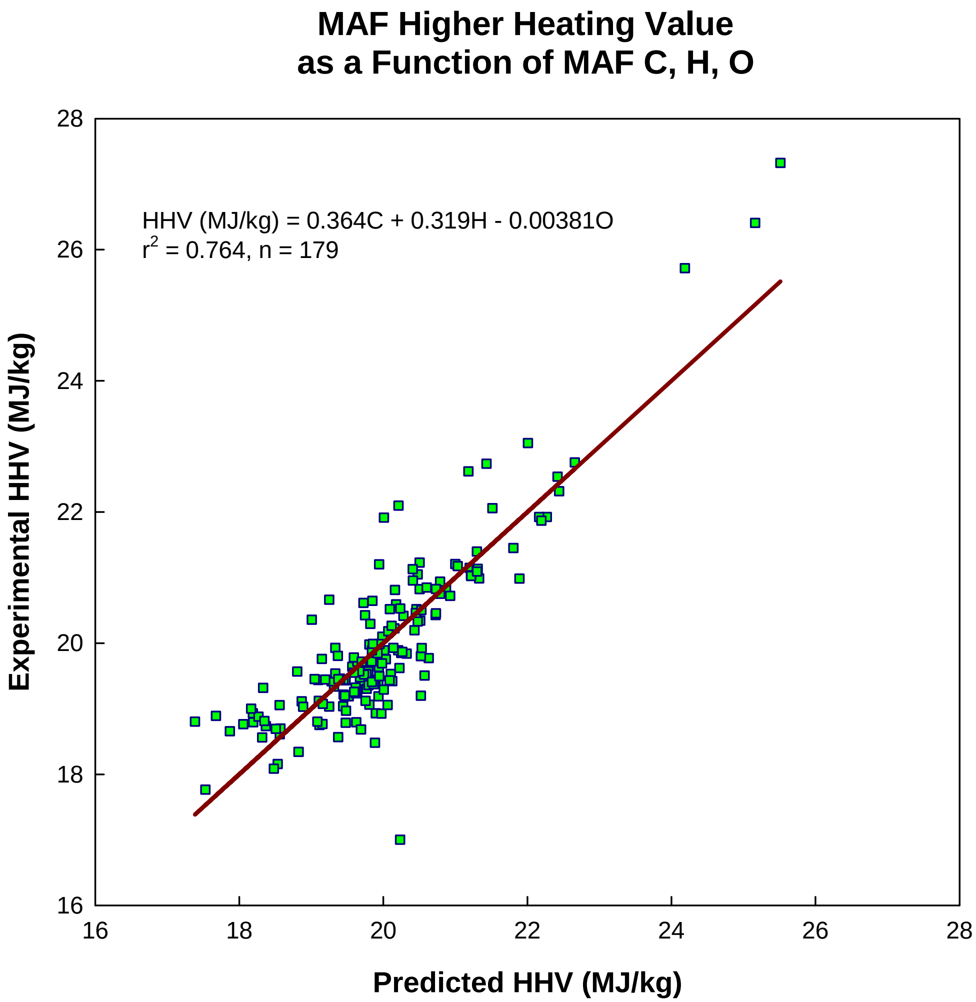
The basic properties for the comparison of thermal behavior are proximate and ultimate analyses

Representative Biomass & Black Liquor Compositions

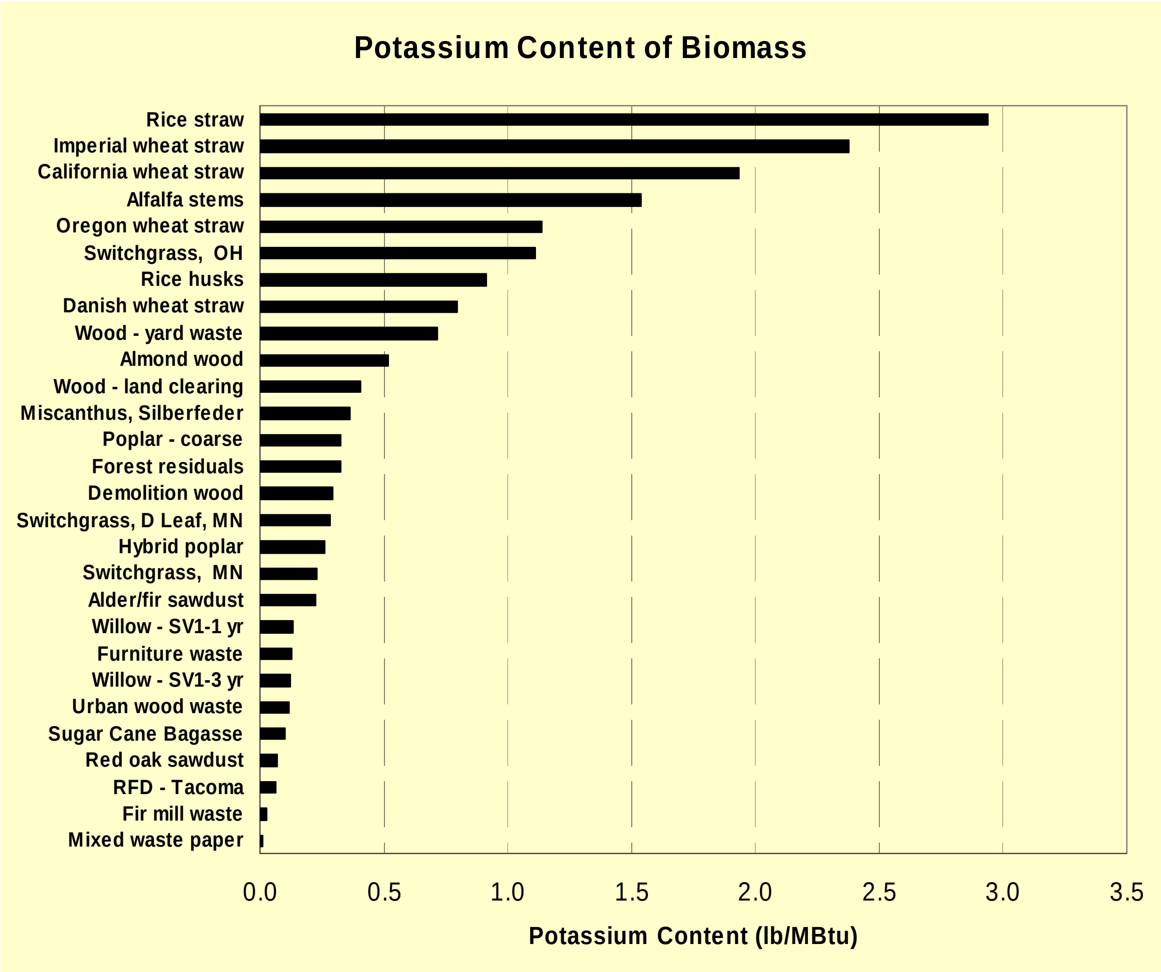
	Poplar	Corn Stover	Chicken Litter	Black Liquor
Proximate (wt% as received)				
Ash	1.16	4.75	18.65	52.01
Volatile Matter	81.99	75.96	58.21	35.26
Fixed Carbon	13.05	13.23	11.53	6.11
Moisture	4.80	6.06	11.61	9.61
HHV, Dry (Btu/lb)	8382	7782	6310	4971
Ultimate, wt% as received				
Carbon	47.05	43.98	32.00	32.12
Hydrogen	5.71	5.39	5.48	2.85
Nitrogen	0.22	0.62	6.64	0.24
Sulfur	0.05	0.10	0.96	4.79
Oxygen (by diff)	41.01	39.10	34.45	0.71
Chlorine	<0.01	0.25	1.14	0.07
Ash	1.16	4.75	19.33	51.91
Elemental Ash Analysis, wt% of fuel as received				
Si	0.05	1.20	0.82	<0.01
Fe	---	---	0.25	0.05
Al	0.02	0.05	0.14	<0.01
Na	0.02	0.01	0.77	8.65
K	0.04	1.08	2.72	0.82
Ca	0.39	0.29	2.79	0.05
Mg	0.08	0.18	0.87	<0.01
P	0.08	0.18	1.59	<0.01
As (ppm)			14	

The heating value is important in estimating process efficiency



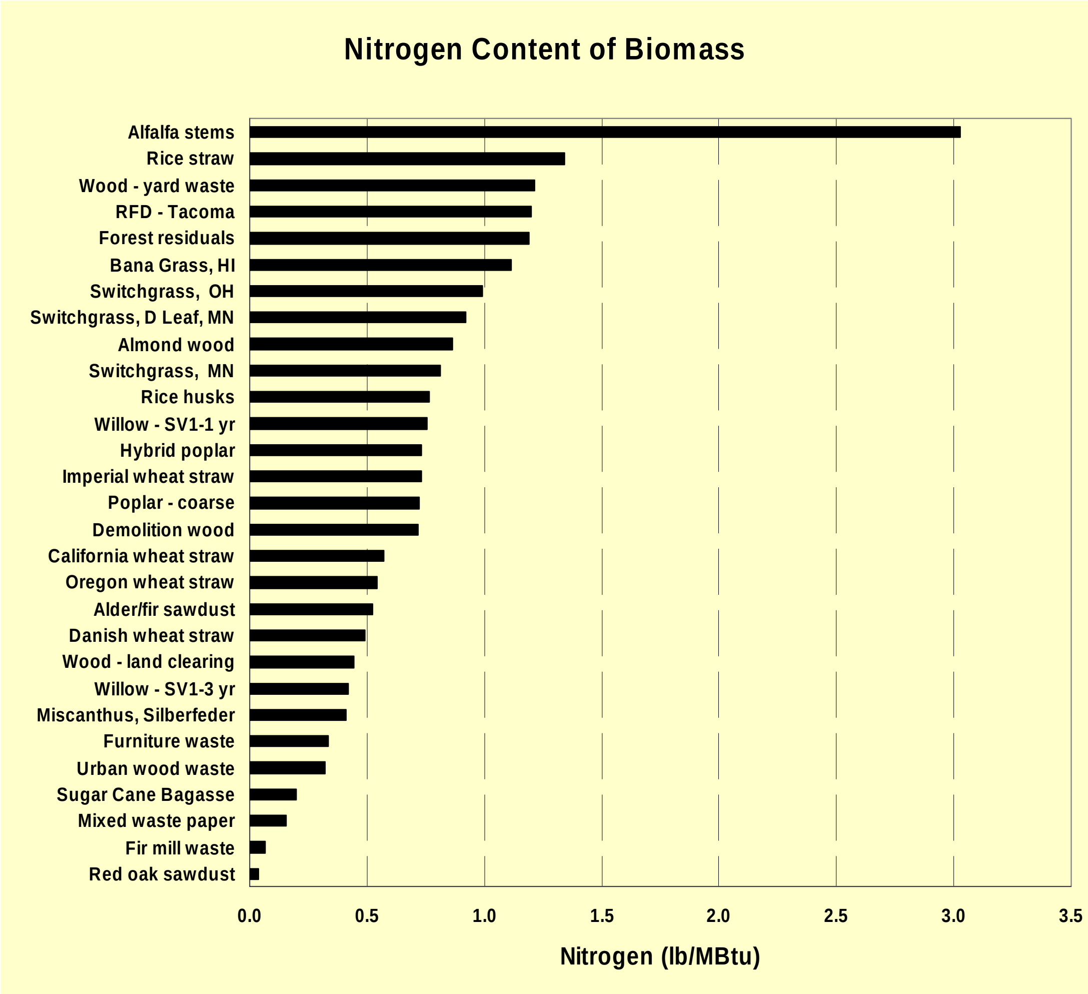


Potassium content influences slagging, fouling, and pyrolysis oil properties



Bain, R. L.; Amos, W. P.; Downing, M.; Perlack, R. L. (2003). Biopower Technical Assessment: State of the Industry and the Technology. 277 pp.; NREL Report No. TP-510-33123

Nitrogen is important in determining the need for NOx emission mitigation strategies



Bain, R. L.; Amos, W. P.; Downing, M.; Perlack, R. L. (2003). Biopower Technical Assessment: State of the Industry and the Technology. 277 pp.; NREL Report No. TP-510-33123

Gasification has a long history of development and use

Murdoch (1792) coal distillation

London gas lights 1802

Blau gas – Fontana 1780

1900s Colonial power

MeOH 1913 BASF

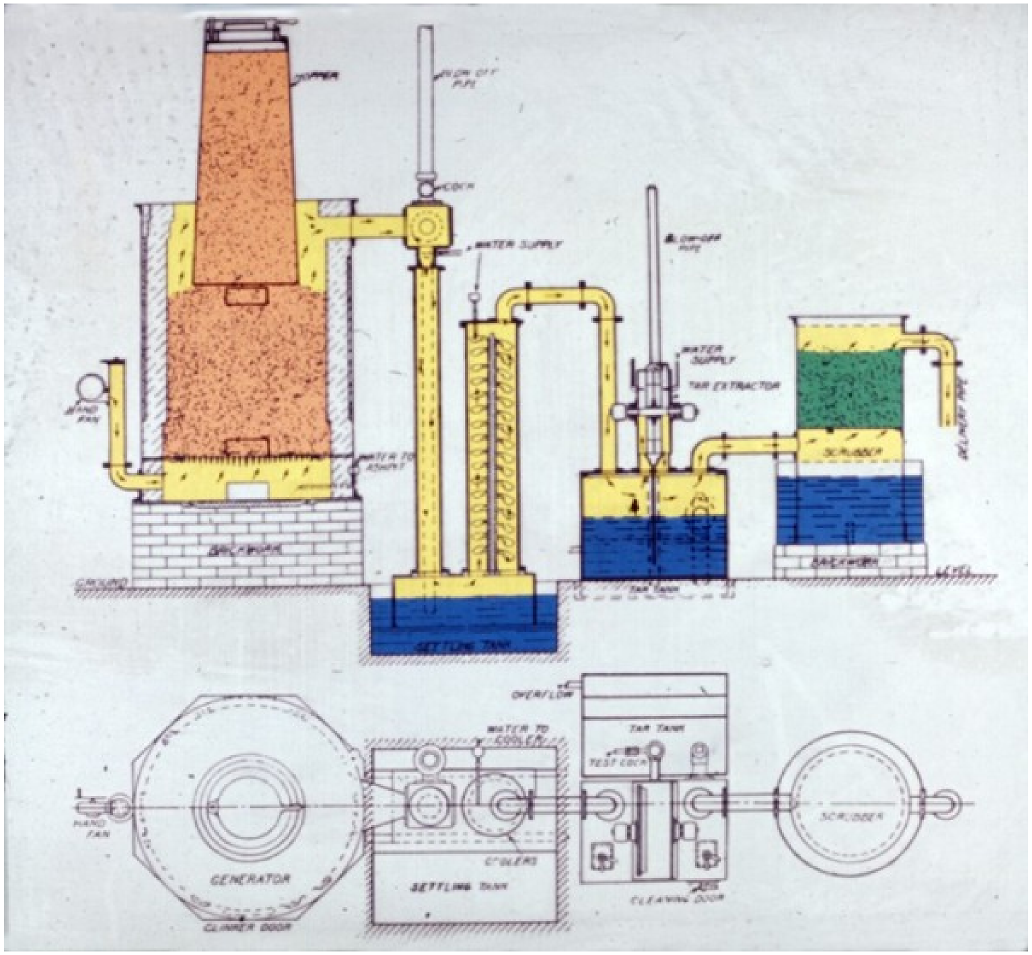
Fischer Tropsch 1920s

Vehicle Gazogens WWII

SASOL 1955 - Present

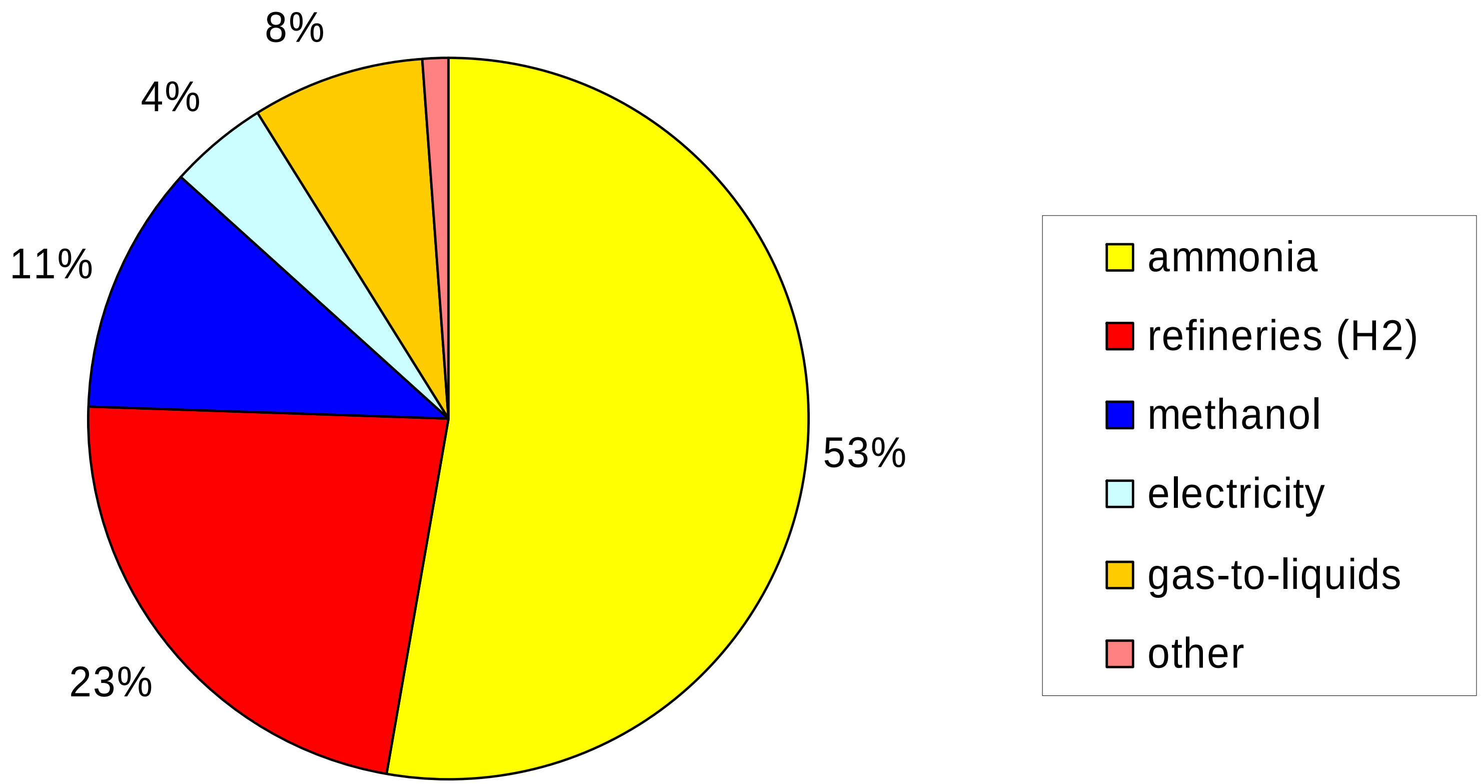
GTL 1995 – Present

Hydrogen – Future?



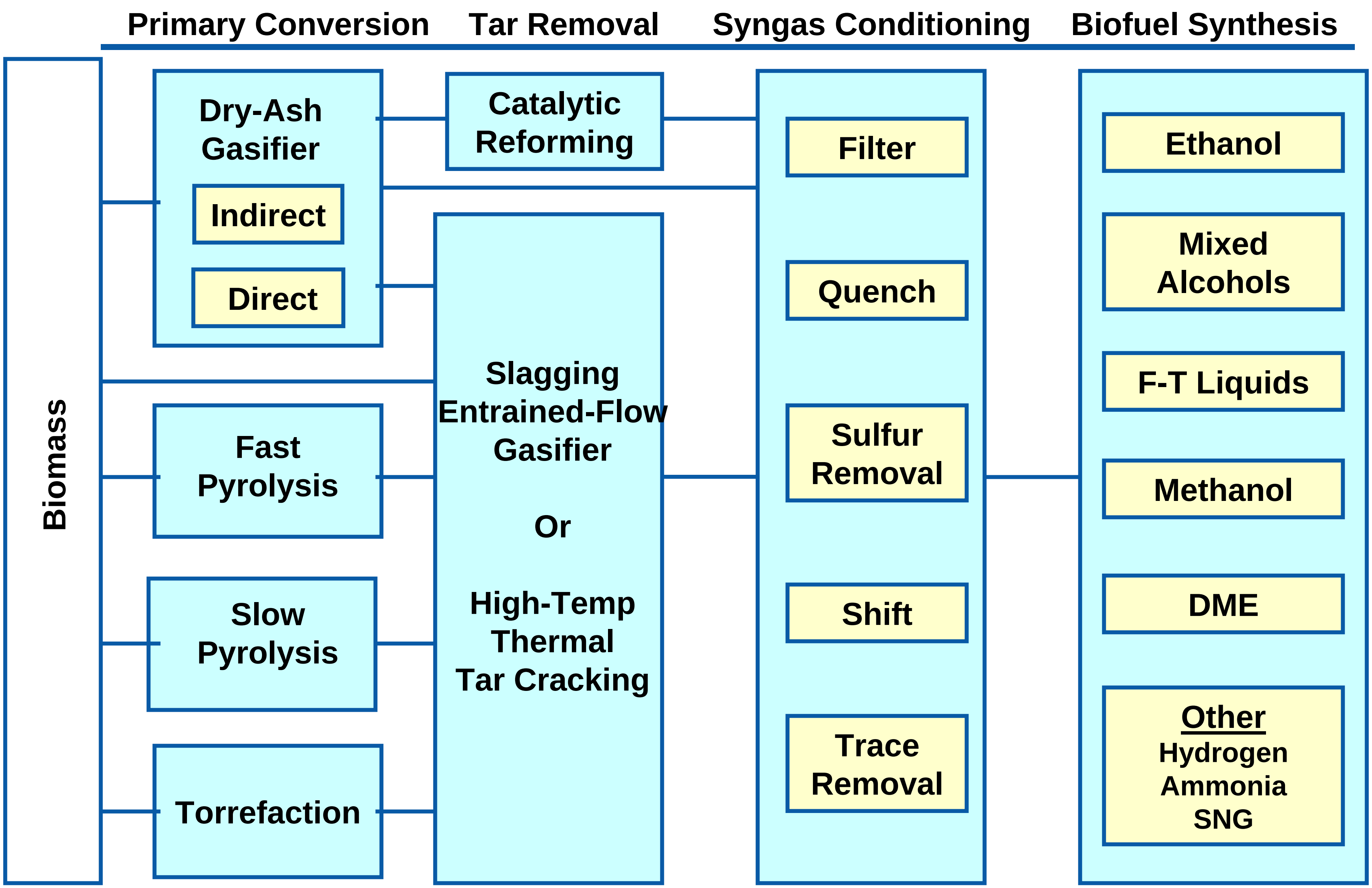
Circa 1898

The world syngas market is approximately 6 EJ/yr



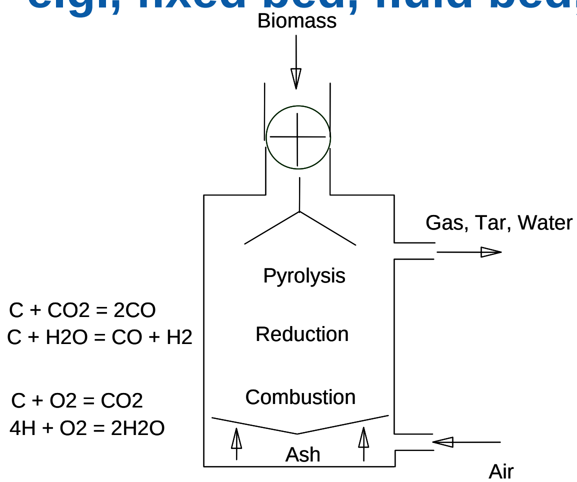
A. van der Drift, R. van Ree, H. Boerrigter and K. Hemmes: *Bio-syngas: key intermediate for large scale production of green fuels and chemicals*. In: The 2nd World Conference on Biomass for Energy, Industry, and Climate Protection, 10-14 May 2004, Rome, Italy, pp. 2155-2157 (2004).

There are a number of gasification pathways

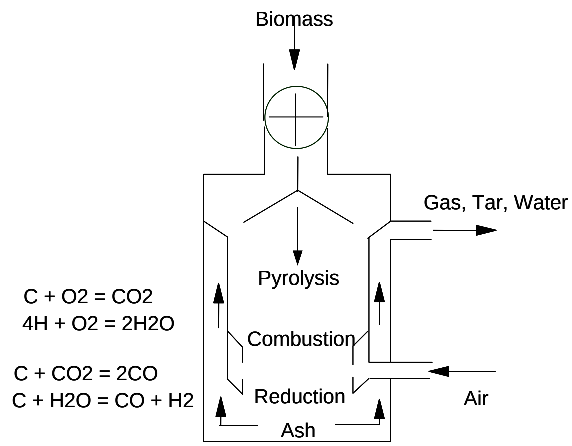


Source: ECN (2006), ECN-C-06-001

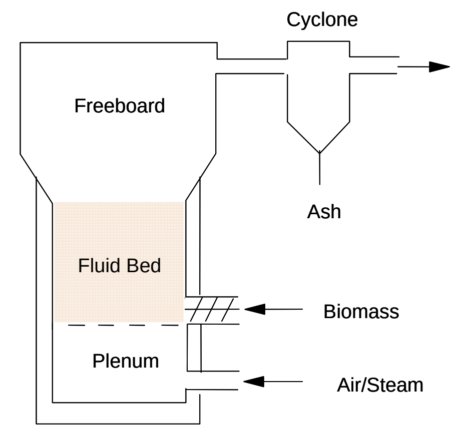
There are a number of types of biomass gasifiers – e.g., fixed bed, fluid bed, and entrained flow



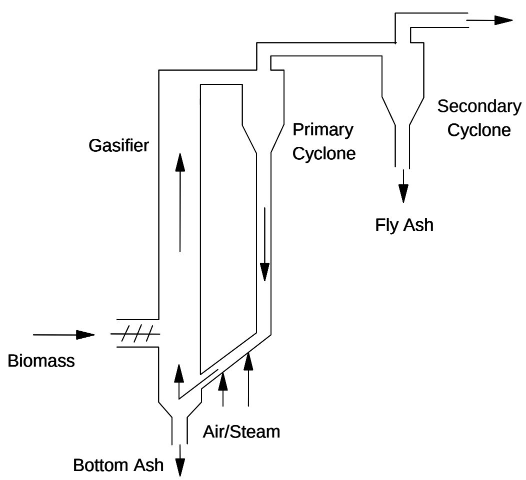
Updraft Gasifier



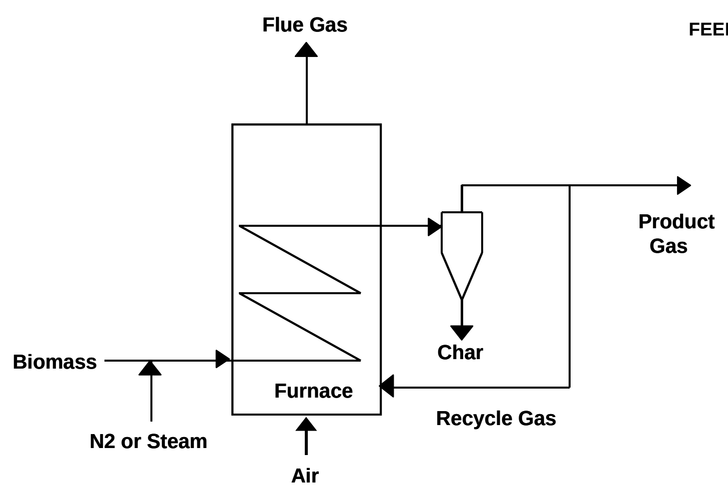
Downdraft Gasifier



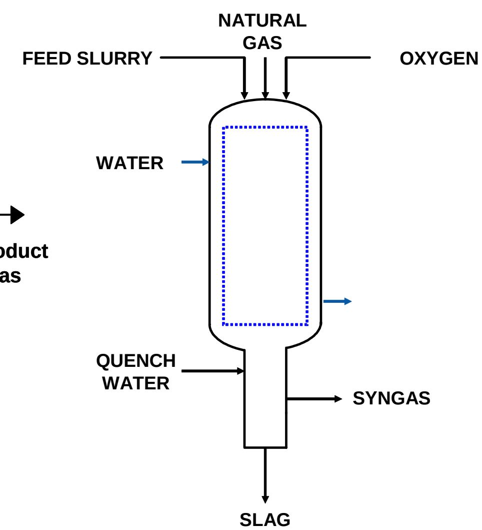
Fluid-Bed Gasifier



Circulating Fluid-Bed Gasifier



Entrained Flow Gasifier



Entrained-Flow
Slagging Gasifier

Each gasifier has advantages and disadvantages

Gasifier	Advantages	Disadvantages
Updraft	Mature for heat Small scale applications Can handle high moisture No carbon in ash	Feed size limits High tar yields Scale limitations Producer gas Slagging potential
Downdraft	Small scale applications Low particulates Low tar	Feed size limits Scale limitations Producer gas Moisture sensitive
Fluid Bed	Large scale applications Feed characteristics Direct/indirect heating Can produce syngas	Medium tar yield Higher particle loading
Circulating Fluid Bed	Large scale applications Feed characteristics Can produce syngas	Medium tar yield Higher particle loading
Entrained Flow	Can be scaled Potential for low tar Potential for low CH4 Can produce syngas	Large amount of carrier gas Higher particle loading Potentially high S/C Particle size limits

Efficient biomass gasifiers exploit the unique characteristics of biomass

Characteristic		*Implications*
Fibrous material	→	**Feeding systems:** ▪ Particle size limitations, pressurized operation more difficult
High reactivity ▪ High volatiles content ▪ High char reactivity	→	**Gasifier design** ▪ Allows gasification without pure oxygen
Raw syngas composition ▪ Tars ▪ Sulfur ▪ Alkali, ammonia, others	→	**Gas cleanup** ▪ More tar, water soluble ▪ Low sulfur (except BL) ▪ Must be considered
Scale of Operation	→	**Limits economies of scale**

A large number of companies are involved in biomass thermal conversion

	Low (300-600°C)	Medium (700-850°C)	High (900-1200°C)
Product	Bio-Oil	Syngas (Dry Ash ↔ Slag)	
High Pressure	Changing World Technologies Gas Product: PNNL Wet Gasification (CH_4/H_2)	GTI (O2) Carbona (O2) HTW O2) Foster Wheeler (O2)	Chemrec (O2) Future Energy (Siemens) Choren – 2 stage
	10-25 MPa	1- 3 MPa	2 – 3 MPa
	Feed: Biomass	Feed: Biomass MTCI-also Black Liquor	Feed: Black Liquor
Low Pressure 0.2 MPa	ENSYN Dynamotive BTG Fortum	FERCO (Indirect) MTCI (Indirect) Pearson (Indirect) TUV (Indirect) For CHP:TPS (Air) Carbona (Air) Lurgi (Air) Foster Wheeler (Air) EPI (Air) Primenergy (Air) Community Power Frontline	Chemrec (Air)

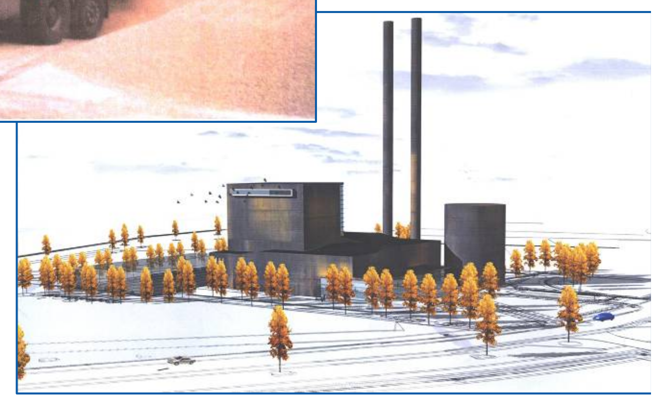
Gas compositions vary according to gasifier type

Gasifier	FERCO	Carbona	Princeton Model	IGT
Type	Indirect CFB	Air FB	Indirect FB	PFB
Agent	steam	air	steam	O2/steam
Bed Material	olivine	sand	none	alumina
Feed	wood chips	wood pellets	black liquor	wood chips
Gas Composition				
H_2	26.2	21.7	29.4	19.1
CO	38.2	23.8	39.2	11.1
CO_2	15.1	9.4	13.1	28.9
N_2	2	41.6	0.2	27.8
CH_4	14.9	0.08	13.0	11.2
C_2+	4	0.6	4.4	2.0
GCV, MJ/Nm^3	16.3	5.4	17.2	9.2

Typical gas heating values vary from 15% to 40% of natural gas heating value

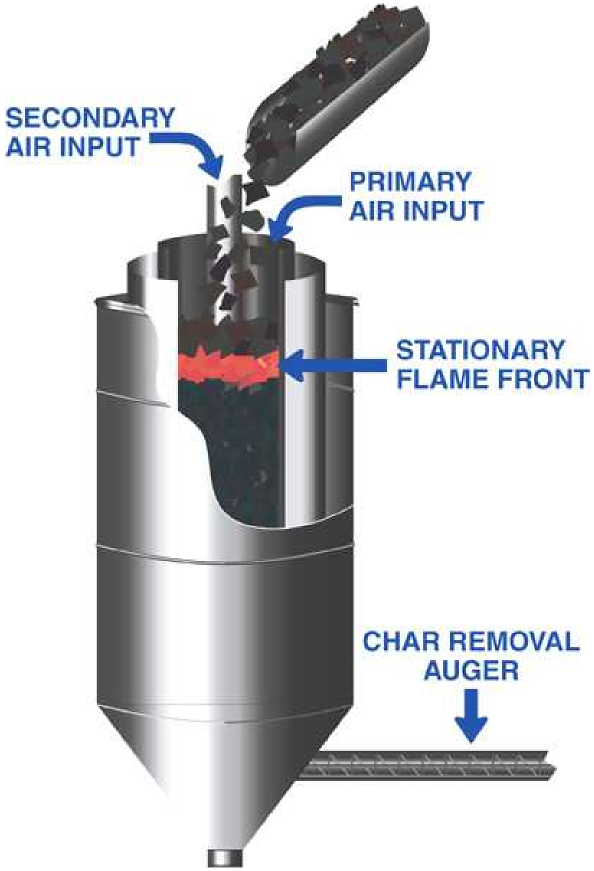
Gasifier	Inlet Gas	Product Gas Type	Product Gas HHV MJ/Nm^3
Partial Oxidation	Air	Producer Gas	5-7
Partial Oxidation	Oxygen	Synthesis Gas	10
Indirect	Steam	Synthesis Gas	15
		Natural Gas	38
		Methane	41

Small and medium size combined heat and power is a good opportunity for biomass

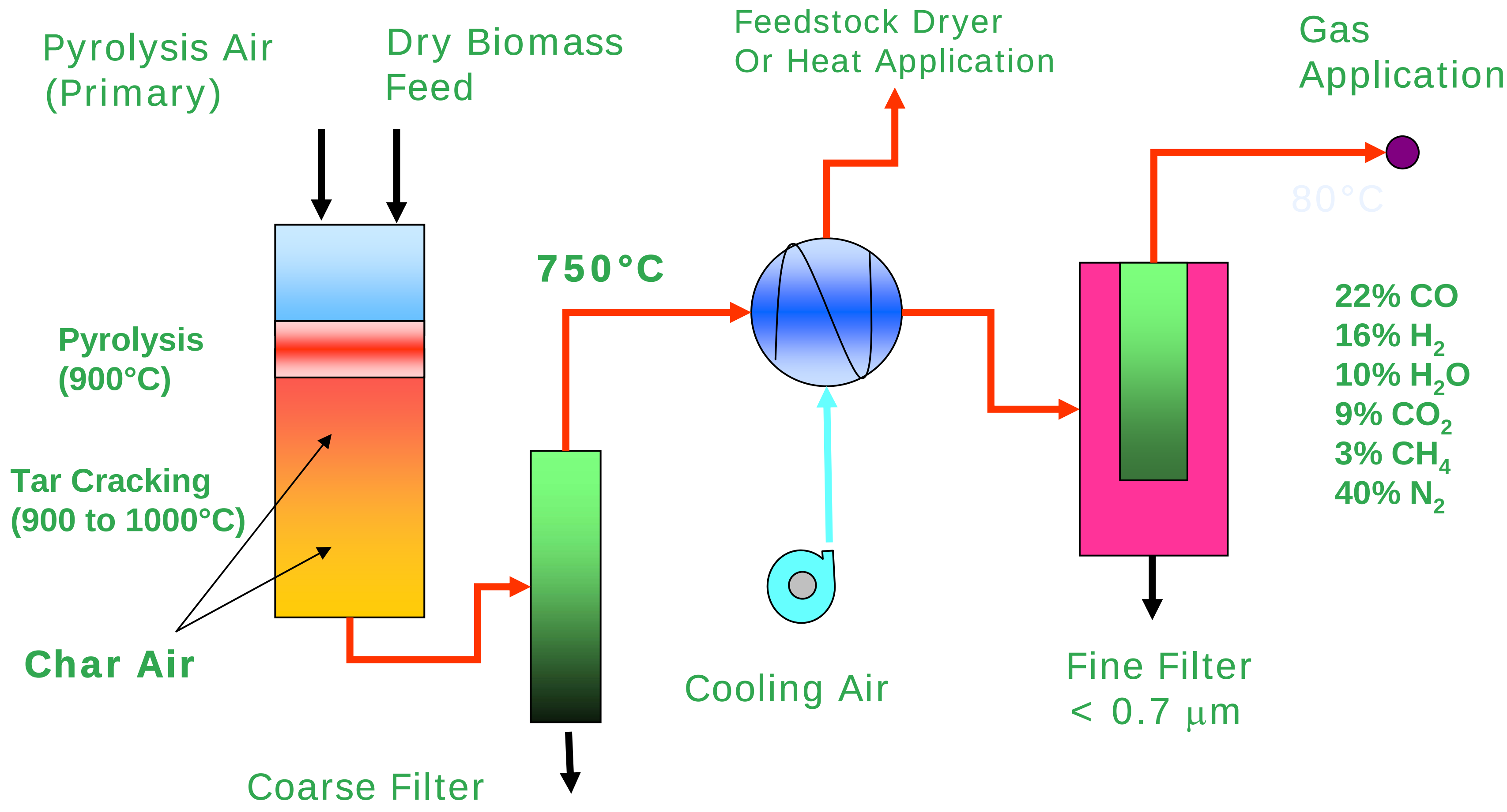


DOE and the USDA Forest Service have supported development Community Power Corporation's BioMax Modular Biopower System

5, 15, 50 kW systems

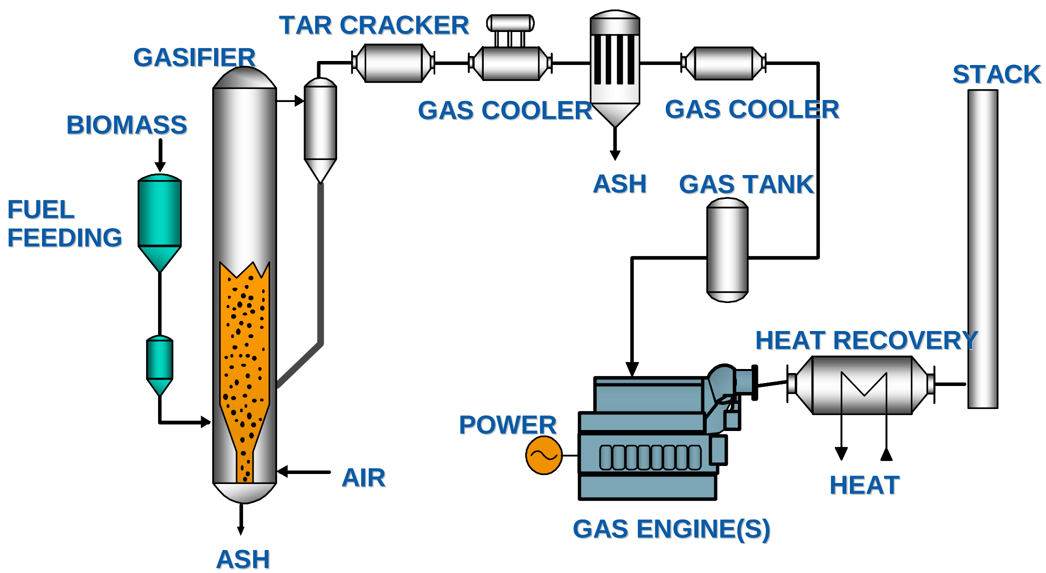


CPC's direct air gasification produces no waste water



70% of Biomass Energy = Chemical Fuel
15% of Biomass Energy = Recoverable Heat, Gas Cooling

DOE, the European Union, the Danish government, Skive Fjernvarme, and Carbona are cooperating in the 5MWe Carbona Project in Skive, Denmark

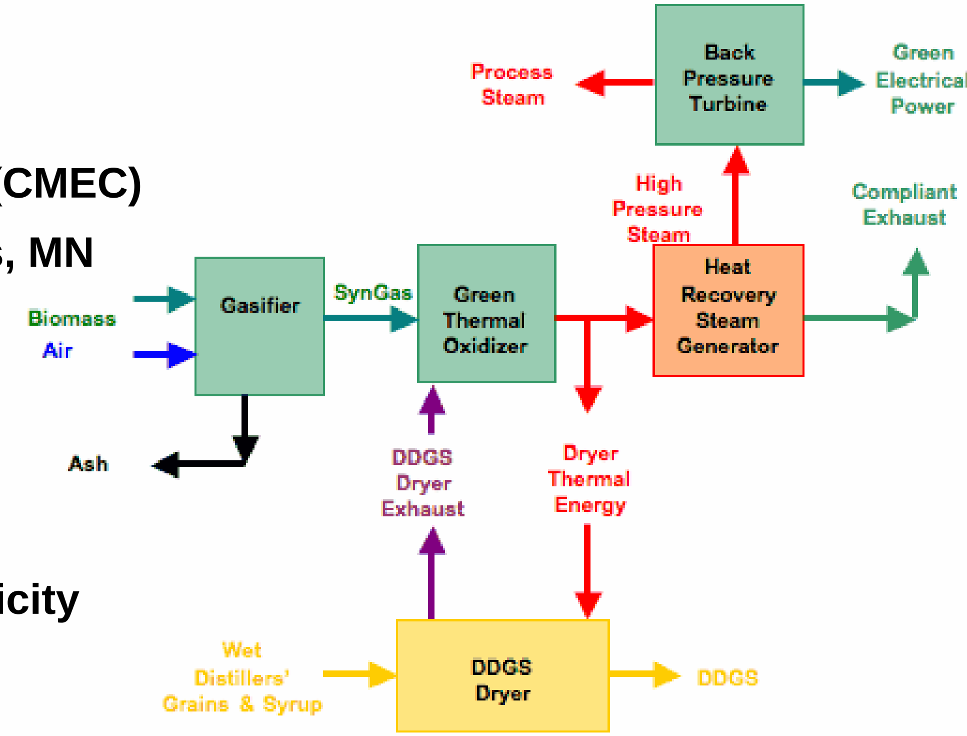


- 110 tpd wood pellets
- 5.4 MW electric power
- 11.5 MW thermal
- 30, elec LHV eff, 90% overall

National Renewable Energy Laboratory

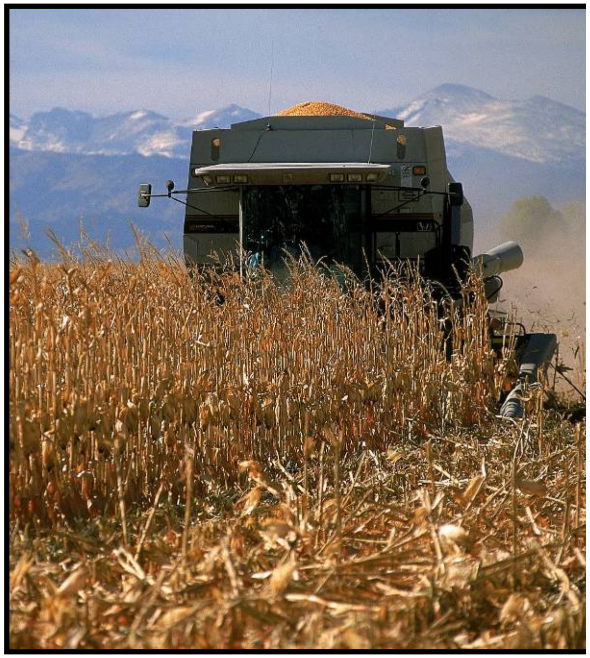
Producers are starting to use biomass gasifiers for CHP in corn ethanol facilities

- Central Minnesota Ethanol Cooperative (CMEC)
- 15million gpy ethanol plant in Little Falls, MN
- Funding – USDA, XCEL Energy, Private
- E&C – Sebesta Blomberg
- Gasifier – Primenergy
- 280 tpd wood
- 50 k-lb/hr high pressure steam for electricity
- 35 MMBtu/hr thermal energy



http://www.primenergy.com/Projects_detail_LittleFalls.htm **8/28/06**

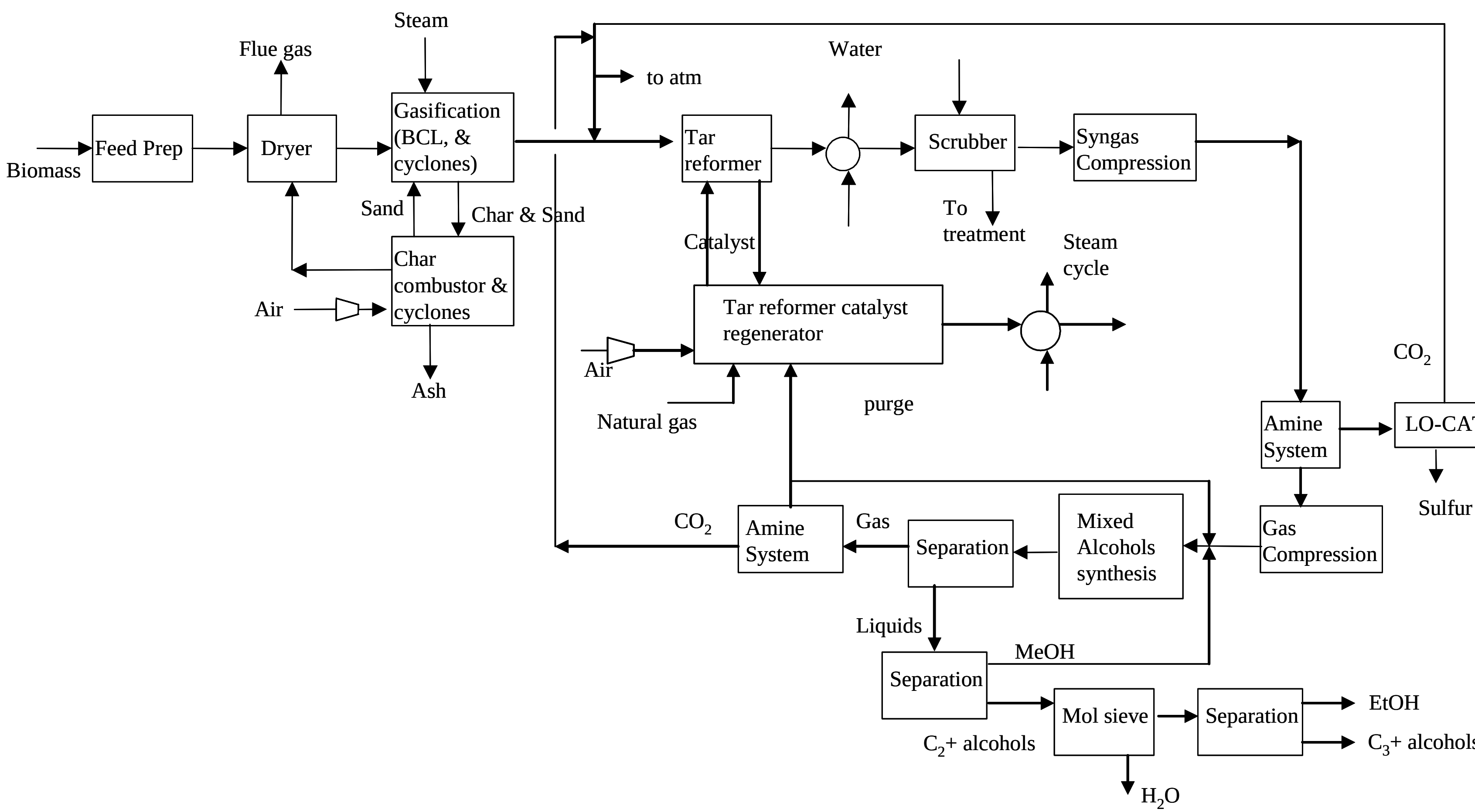
Chippewa Valley Ethanol Company has entered into an agreement with Frontline Bioenergy to support the installation of a prototype gasifier at the CVEC Benson, MN ethanol plant.



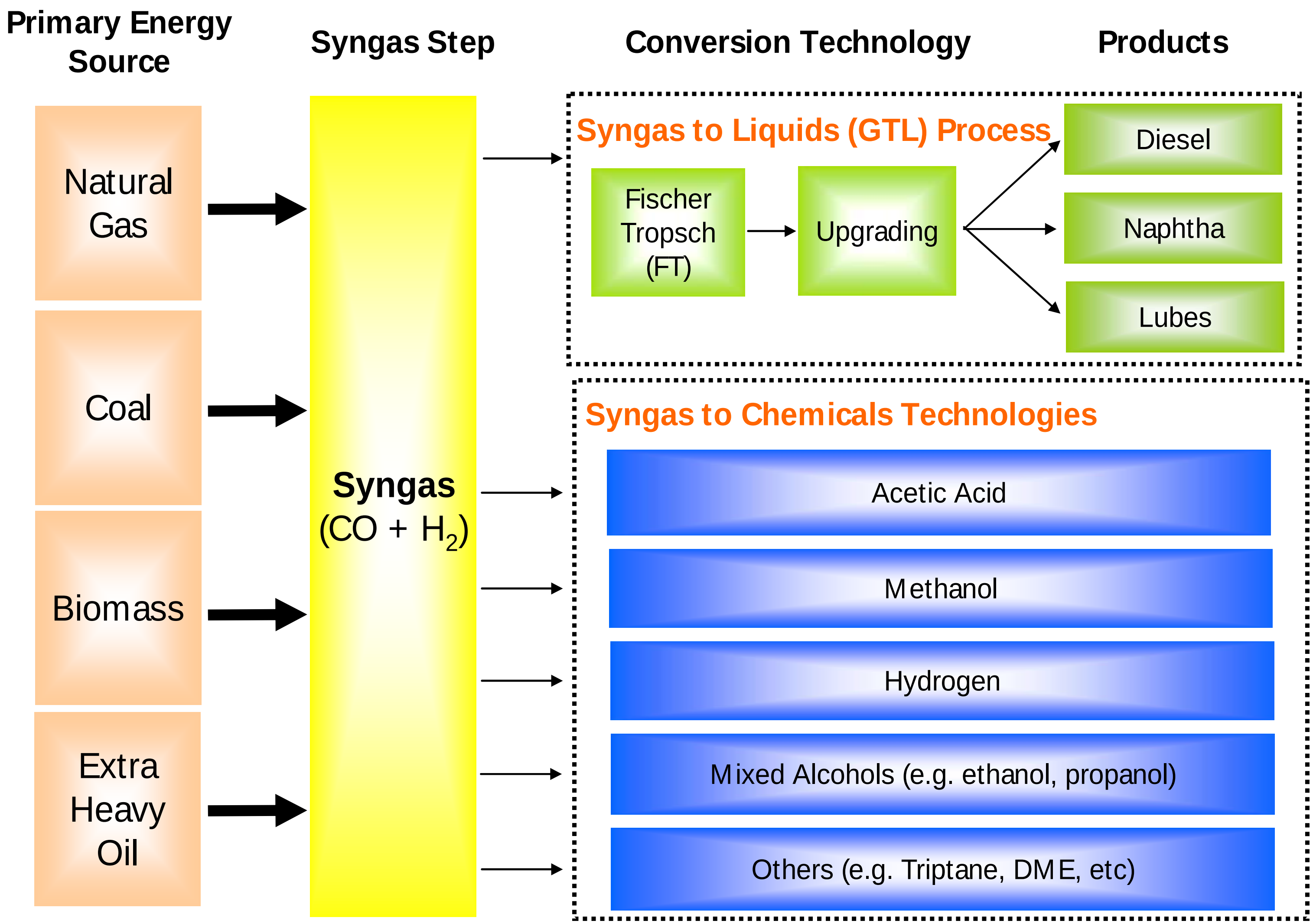
- **The objective is to replace all of the plant's natural gas usage**
- **45 mil gal/yr plant with $20 million in annual natural gas costs**
- **$3.4 million in research services**
- **$12.4 million in equipment and materials**

Source: frontlinebioenergy.com 8/29/06

Transportation fuels production will probably be at larger scale because of process complexity and capital intensive nature. There may be opportunities for smaller modular "skid mount" systems.

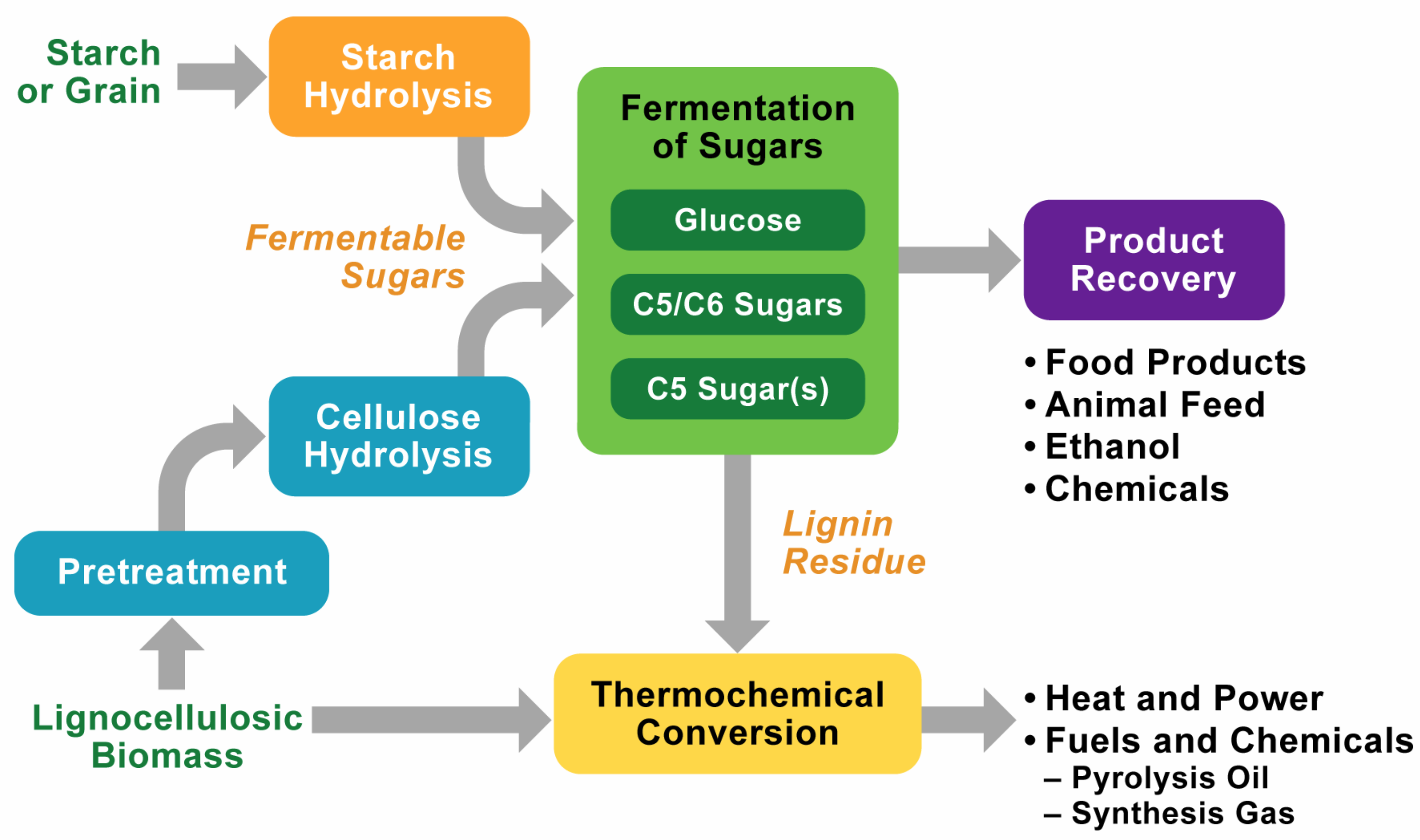


Hydrocarbon fungibility will be a key to success



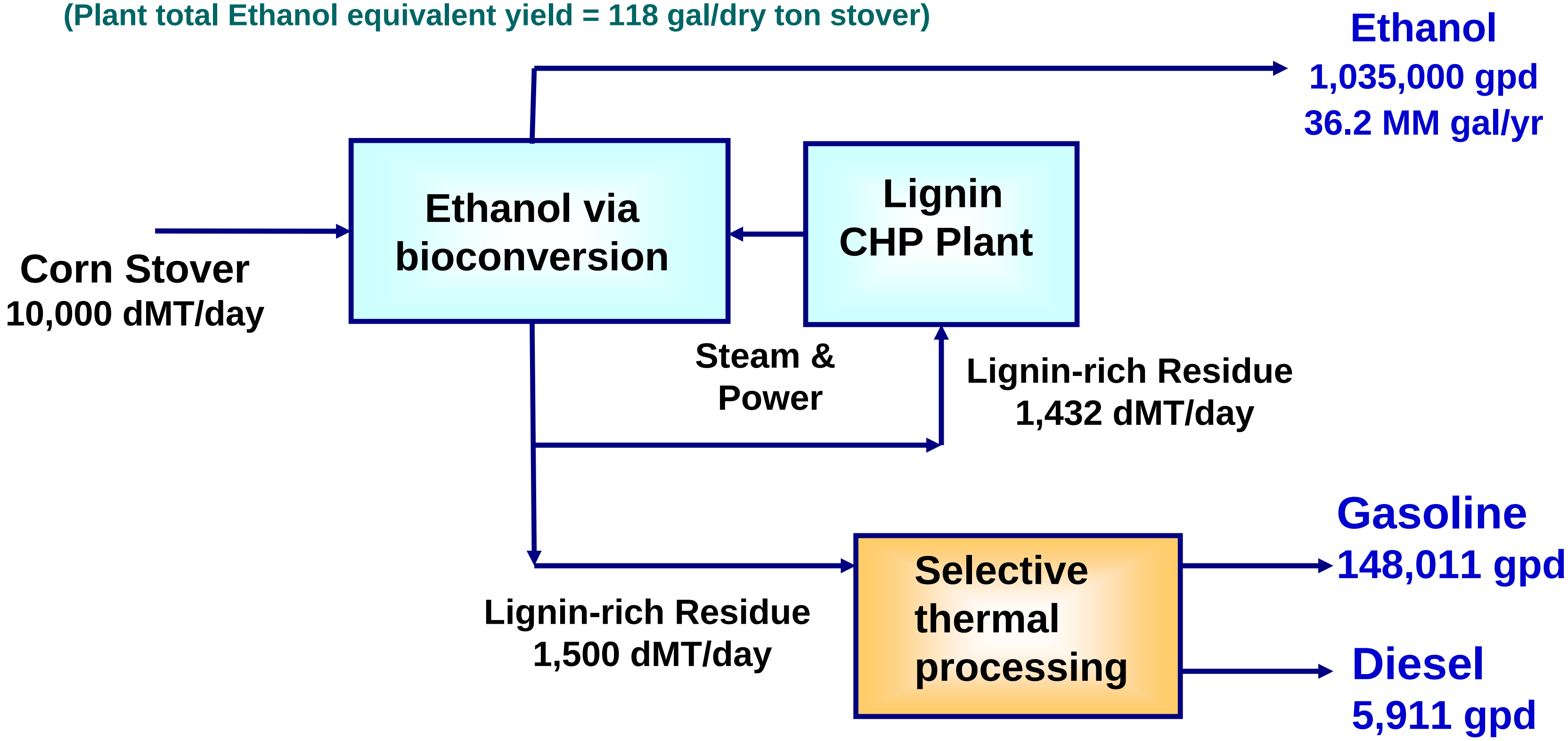
Source: BP

Integrated biorefineries involve both biochemical and thermochemical processes



A 30x30 advanced integrated biorefinery scenario, i.e., the E85 Refinery, includes both thermochemical and biochemical processing

Ethanol yield = 94 gal/dry ton stover
Gasoline yield = 90 gal/dry ton of lignin (13 gal/ton of stover)
(Plant total Ethanol equivalent yield = 118 gal/dry ton stover)

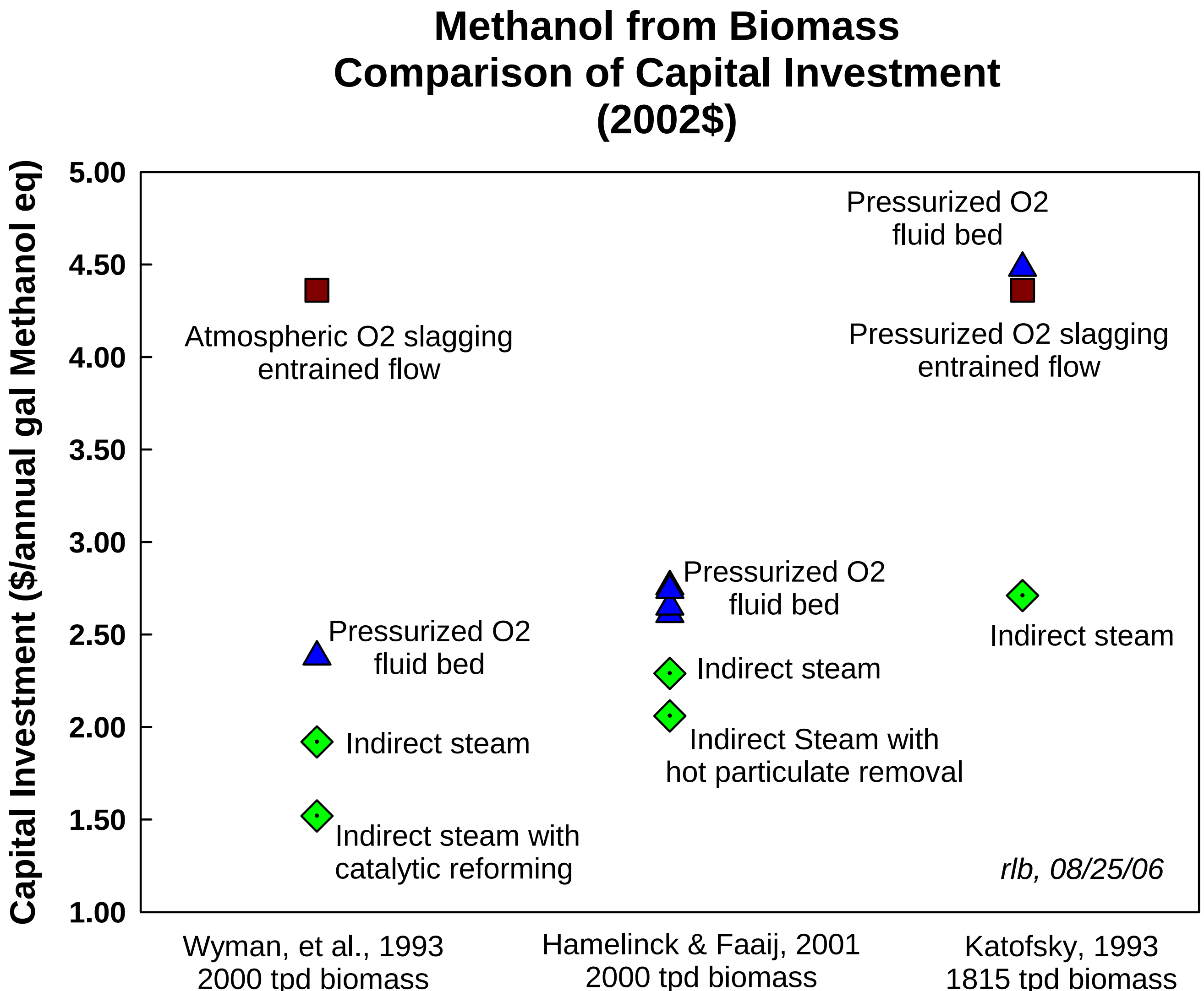


Minimum gasoline selling price = $0.51/gal gasoline
(Minimum Ethanol equivalent selling price = $0.35/galEtOH)

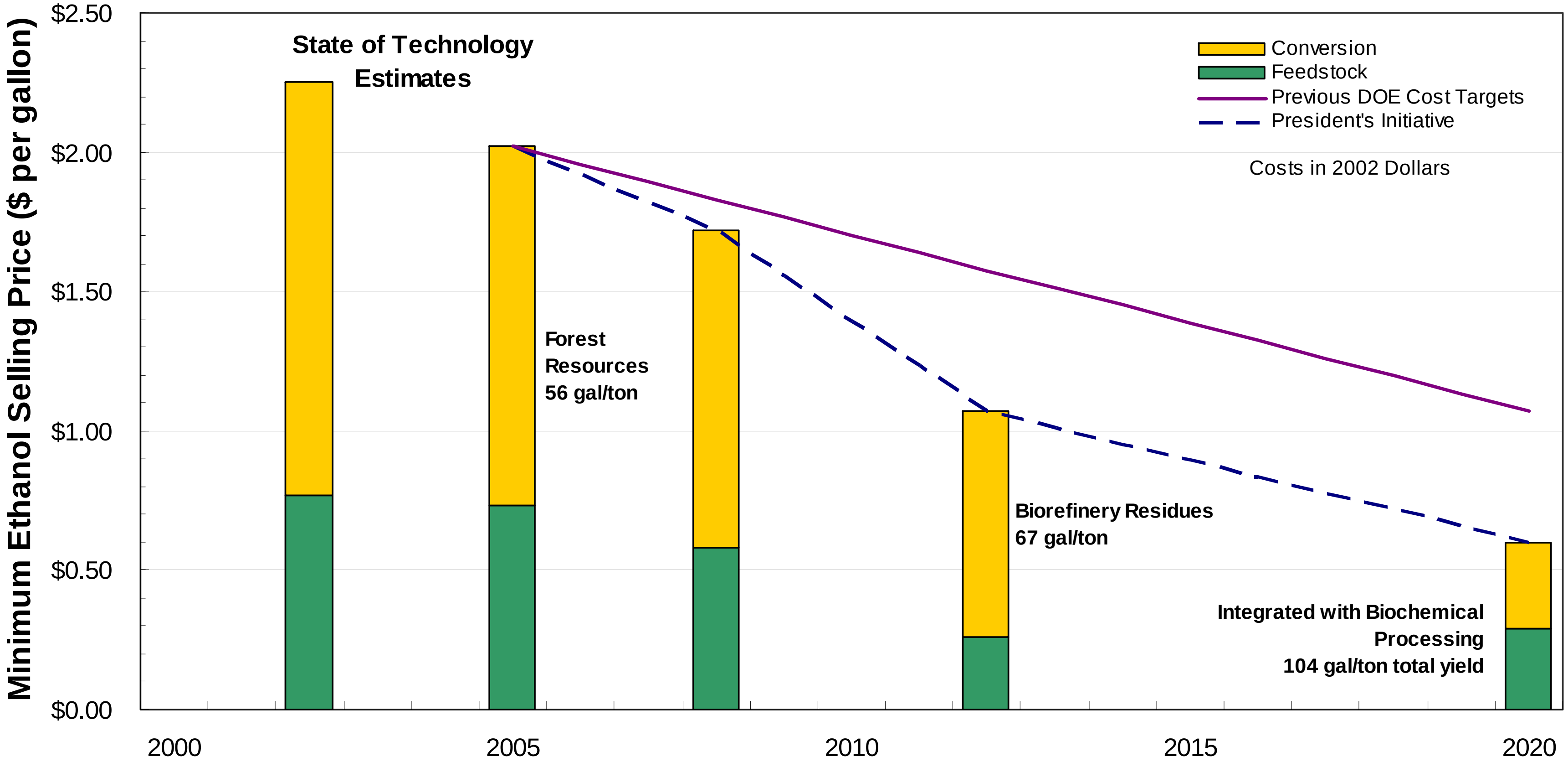
(Diesel is recycled to produce a lignin slurry feed)

Plant Minimum Ethanol equivalent selling price = $0.57/gal EtOH

Although ethanol and Fischer-Tropsch liquids are presently preferred products, previous work on methanol can help guide analysis



Analysis of ethanol from TC mixed alcohols shows the potential to reach the DOE goal of $1.07/gal in 2012



Questions and Answers

What is the scale of proposed processes?

The scale can range from 15 kg/hr for home-based systems to 400 tons/hr for large nth plant central facilities.

What feedstocks care appropriate for gasification?

Almost any biomass feed is suitable. Certain high moisture feeds like wet manure may be uneconomic because of high drying costs. Feeds high in potassium, e.g., alfalfa, may require special processing.

What feed preparation, storage, and handling is required?

Feed preparation is specific to the gasifier being used.

- **Certain gasifiers require defined particle sizes, e.g., downdraft – no fines, or entrained flow - very small particles. Almost all gasifiers require particle size less than 1.5 inches.**
- **Others require low moisture content, e.g. downdraft**

Typically screening of oversize materialand metal removal is required

Storage requirements are standard. On site typically 3 – 7 days.

Handling requirements are a function of the form of biomass at the plant gate.

What are the estimated efficiency of gasification processes?

Gasification efficiency is a function of the feed, gasification process and final product. Typical values from operating experience and technoeconomic analyses are.

- **Combined heat and power, 90%**
- **Electricity only, 25 – 35%**
- **Methanol, 60%**
- **DME, 54%**
- **FTL, 45%**
- **Mixed alcohols, 40-45%**

What co-products could be marketed, and what further processing would they require?

This is process specific. An example would be a mixed alcohols process where higher alcohols could be produced along with ethanol. Generally, separation and purification to meet commercial specifications is required. Specifications are generally defined by ASTM standards.

How would product quality be assured?

through standard business practices defined by contracts and standards

What equipment maintenance would be required, and how would maintenance be handled?

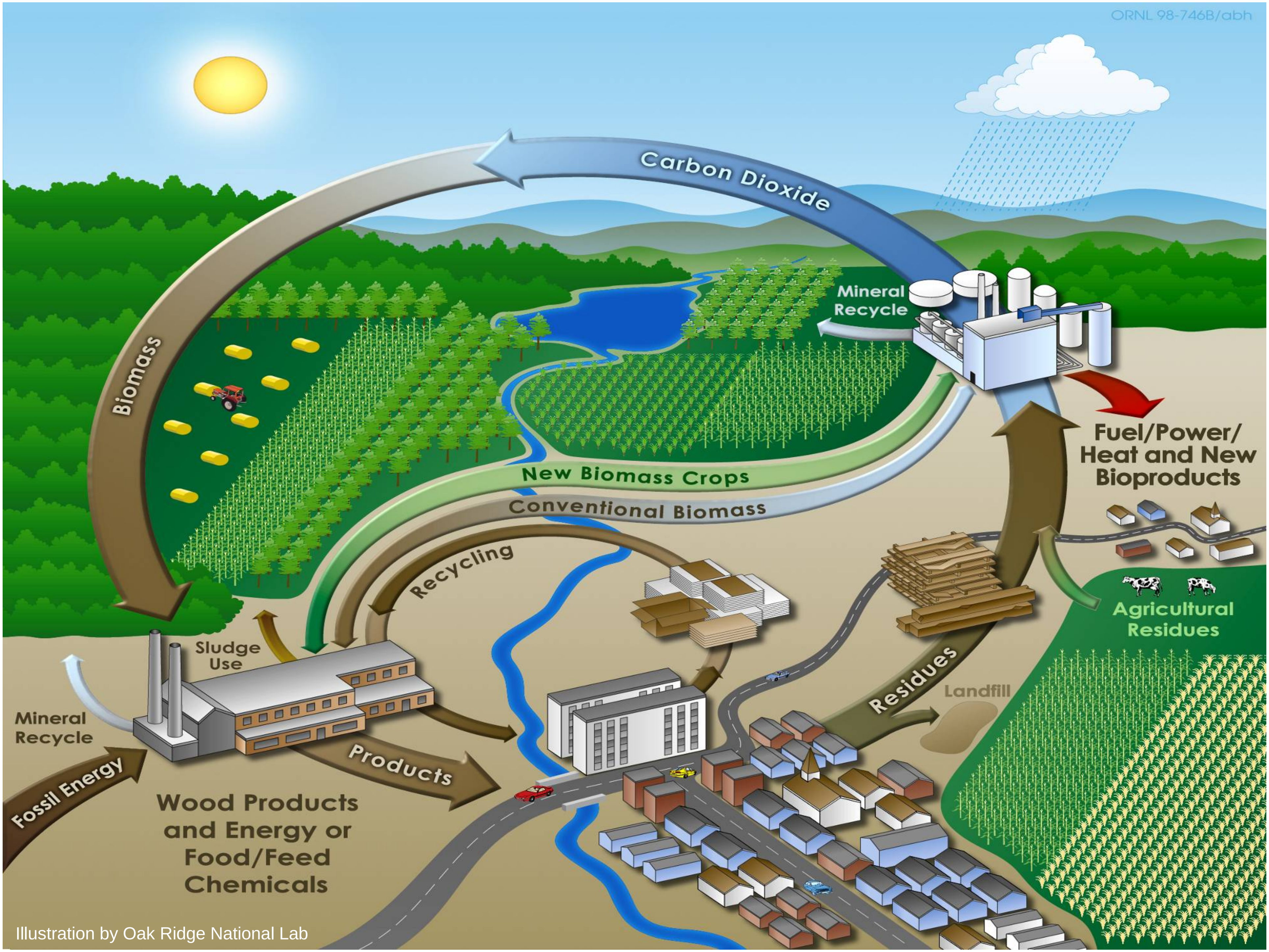
This is project specific.

It will be a function of project size.

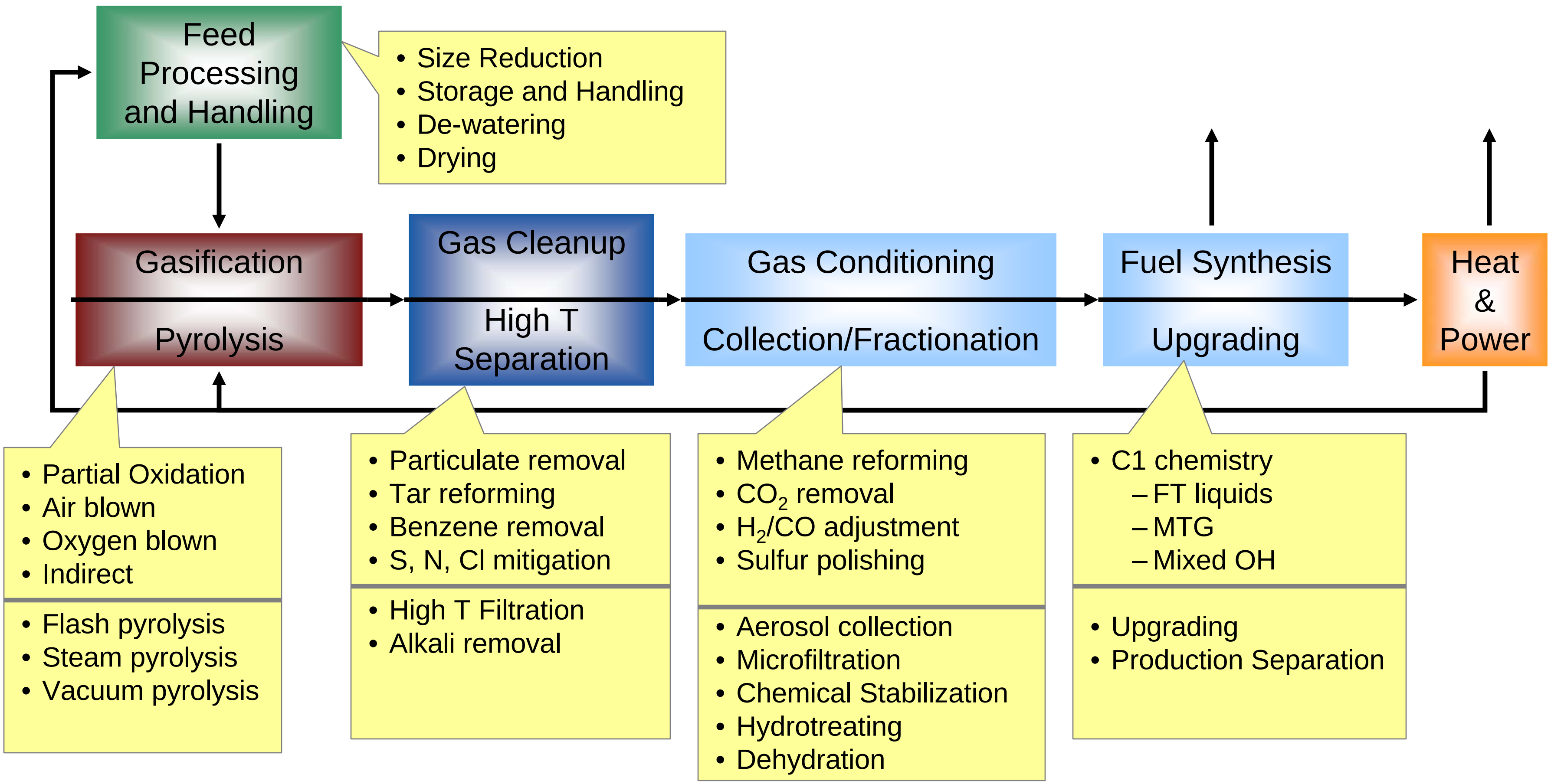
What are the emissions and waste disposal issues or uncertainties?

All processes have to be permitted and limits are set by the permitting agencies. Emissions estimates based on existing processes can be used, e.g., EPA AP-42 for CHP, or can be estimated by E&C contractors.

Probably the biggest unkown is ash disposal.


ORNL 98-746B/abh
Carbon Dioxide
Biomass
Mineral Recycle
New Biomass Crops
Conventional Biomass
Recycling
Sludge Use
Mineral Recycle
Fossil Energy
Products
Wood Products and Energy or Food/Feed Chemicals
Fuel/Power/ Heat and New Bioproducts
Agricultural Residues
Residues
Landfill
Illustration by Oak Ridge National Lab

There are technical barriers needing addressing in the major processing steps in thermochemical conversion



Barriers and R&D needs were identified by a panel of expert stakeholders at the DOE 30 x 30 Workshop in August

- **Technology issues with scale and syngas quality, and process integration**
  - **Feeder systems**
  - **Gas cleanup: tars, sulfur, particulates, etc.**
  - **Matching scale to economy**
  - **Lack of demonstration plants**
- **Other**
  - **Business links: fuel resources > conversion > product distribution**
  - **Competition between biomass, coal, natural gas, and tar sands for talent, construction materials, capital**
  - **Competing markets for resources**
  - **Permitting issues**

The 30 x 30 panel also developed a set of R&D needs

- Feeders (solid biomass)
- High temperature materials, esp. for black liquor gasification
- Syngas conversion to match scale – better processes/catalysts
- Gas cleanup
- Gasifier type
- Blended fuels
- Technology demonstrations