Thermal conversion of biomass

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Thermal conversion of biomass

- Outline

1. Introduction
2. Combustion and biomass fuel properties
3. Gasification to produce combustible gas
4. Gasification to produce synthesis gas
5. Pyrolysis to produce bio-oil
6. Black liquor: recovery boiler or gasifier?
7. Summary
Use of Wood in Finland

(VTT 2000)
Kraft Pulp Mill

- Forest harvesting
  - Round wood
    - Debarking
      - Bark
        - Bark harvest
          - Pulping chemicals
            - Heating & power
              - Emissions
                - Ash
  - Stemwood
    - Chipping
      - Chips
        - Pulping
          - Black liquor
            - Pulp
              - Paper
Conversion Routes for Cellulosic Biomasses

Cellulosic Biomass
- Combustion
- Gasification
- Pyrolysis etc.
- Hydrolysis etc.

Heat & Power
- Combustion
- Fischer-Tropsch
- Methanol
- Water-Gas Shift

SynGas (CO₂+H₂)
- Dehydroxylation
- Zeolite Upgrading

Bio-oils
- Fermentation
- Dehydration
- Aq.-Phase Processing
- Lignin Upgrading

Aqueous Sugars
- Ethanol
- Aromatic Hydrocarbons
- Liq. Alkanes or H₂

Lignin
- Etherified Gasoline

Liquid Fuels
Conversion Routes for Cellulosic Biomasses

Cellulosic Biomass → Heat & Power

Combustion
Fischer-Tropsch
Methanol
Water-Gas Shift
Dehydroxylation
Zeolite Upgrading
Fermentation
Dehydration
Aq.-Phase Processing
Lignin Upgrading

SynGas (CO₂+H₂) → Methanol, DME → Alkanes

Bio-oils → Liquid Fuels
Ethanol
Aromatic Hydrocarbons
Liq. Alkanes or H₂
Etherified Gasoline

Aqueous Sugars → Ethanol

Lignin → Etherified Gasoline

Pyrolysis etc. → Bio-oils

Thermal Conversion
Hydrolysis etc.
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Heat & Power
- Combustion
- Alkanes
- Methanol, DME
- Hydrogen

Liquid Fuels
Single Particle Burning System
(Source: Åbo Akademi)
Single Particle Burning of Wood
– 92.6 mg
800 °C
21 % O₂ (air)
Fuel Particle Burning Stages

Solid fuel

Drying

H₂O

CO, CO₂, H₂O

Pyrolysis/devolatilisation and gas combustion

Air

CₓHᵧ

O₂

Char combustion

CO, CO₂

O₂

Combustion of a solid fuel

Ash
Single Particle Burning -
On-line CO$_2$ Analysis

![Graph showing CO$_2$ formation over time (seconds)](image-url)
Single Particle Burning – Volatile Carbon vs. Char Carbon

![Graph showing Volatile carbon and Char carbon over time.](image)
Bubbling Fluidized Bed Boiler (Metso Power)

E.ON UK
Steven’s Croft Power Station
Lockerbie
UK

Steam
126 MW$_{th}$
48 kg/s
137 bar
537 °C

Fuels
Wood chips, sawdust, bark,
recycled wood

Start-up
2007
Bubbling Fluidized Bed Furnace
Use of Wood in Finland

(VTT 2000)
Five Spruce Tissues

Wood
Shoots

Bark

Twigs

Needles
Ash Elements in Spruce Tissues
(J. Werkelin 2005)
Fouling and Corrosion
due to Unsuitable Fuel Mixture
Summary 1: Biomass Combustion for Heat & Power

- Dominating biomass-to-energy technology
- Finland strong with FBC technology
- Research on demanding feedstocks: moisture, heating value, ash, emissions
- Research on improved power production – controlling superheater corrosion
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Combined Heat & Power

Combustion
Gasification
What Happens in a Gasifier?

- **Drying**: Moisture
- **Pyrolysis**: Volatiles, tars
- **Char gasification**: H₂, CO
- **Ash**: CO₂, H₂O

Droplet → Solids → Char
What Happens in a Gasifier?

Product gas / Syn Gas

Drying → Pyrolysis → Char gasification

- Droplet
- Solids
- Char
- Ash
- CO₂, H₂O
CFB Gasifier

Foster Wheeler

- Reactor
- Uniflow Cyclone
- Gasification Air Fan
- Air Preheater
- Return Leg
- Hot Low Calorific Gas (750 - 650 °C)
- Cooling Water
- Bottom Ash Cooling Screw
- Bottom Ash
BIOMASS GASIFICATION - COAL BOILER - LAHTI PROJECT

Biomass

300 GWh/a -15 % fuel input

Processing

350 MW
540 °C/170 bar

CO₂ Reduction - 10 %

Power
* 600 GWh/a
District Heat
* 1000 GWh/a

Gasifier

50 MW

Gas flame

Pulverized coal flames

Biomass

50 MW

50 MW

50 MW

Coal

1050 GWh/a -50 %

Natural Gas

650 GWh/a -35 %

Fly ash

Bottom ash

Bottom ash

Foster Wheeler
Summary 2: Biomass Gasification & Combustion of the Gas for Heat & Power

• Simple process – de facto partial oxidation of the fuel into a combustible gas mixture (air ratio 30-40 %)
• Used instead of direct combustion in special applications: lime kilns, co-firing with coal
• Challenges to achieve complete conversion of the biomass fuel
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Ethanol

Aromatic Hydrocarbons

Liquid Fuels
Biodiesel Production in Pulp Mill

Wood, straw, energy crops, peat, RDF

Paper & pulp

Power plant

Fuel gas + steam

FT-synthesis & upgrading

Wood Diesel

Biomass handling and drying

Pulp and paper mill

Energy to drying

Gasification and gas treatment

Steam & oxygen

Bark, forest residues, other biomass
Pressurized Gasifier for Syngas Production (VTT)

- Fuel capacity 500 kW
- Pressurised fluidised-bed gasifier
- Air-blown gasification for IGCC applications
- Steam/O2-blown gasification for synthesis gas
- Advanced High-Temperature Filtration
- Catalytic reforming of tars and hydrocarbon gases
- Slip-stream gas purification, conditioning and synthesis testing
Stora Enso - Neste
BTL Gasification Project

UCG R&D programme 2004-2007

Long term demonstration in atmospheric conditions 2009 =>

Commercial scale 200-300 MWth pressurized unit in operation
Biomass Gasifier for Biodiesel
Demo by Stora Enso - Neste in Varkaus, Finland
Summary 3: Biomass Gasification for Synthesis gas and Liquid Biofuels

• Under development - no plants in operation (applied for coal in South-Africa)
• Demanding technology: Pressurized, oxygen blown gasifier
• Advanced syngas cleaning
• Various options for synthesis: FT Diesel, Methanol, DME
• Very hot topic - political pressure
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Fray Bentos, Uruguay (Andritz)
Hainan Jinhai, Kiina (Metso 2007)
Kraft Pulp Mill

Chips → Digester → Black liquor (15% solids) → Black liquor concentration → Steam turbine (power) → Process steam → Recovery boiler → Recovery boiler output (Black liquor 75% solids) → Smelt → Green liquor → Dissolving tank → Water

Chips → Digester → Black liquor (15% solids) → Black liquor concentration → Lime kiln (CaCO₃, CaO) → White liquor → Causticizing (CaO) → White liquor output (NaOH, Na₂S) → Causticizing output (Na₂CO₃, Na₂SO₄)
The Pulp Mill as a Biorefinery for Production of Transportation Fuels

Chips → Hemicellulose extraction → Fermentation → Ethanol → Pulp

Black liquor → Gasification → Syngas cleaning → Syngas conversion → Hydrocarbons, Methanol

White liquor
Black Liquor Gasification for Syngas (Chemrec)

Synthesis of:
- Methanol
- DME
- FT Hydrocarbons
Summary 5: Biorefinery & Energy

1. Biomass molecules can be extracted as valuable chemicals (fractionation)
2. Biomass can be converted thermally to heat and/or power
   - combustion (commercial)
   - gasification for combustion (commercial)
3. Residues may also be used for production of liquid biofuels:
   - pyrolysis for bio-oil (under development)
   - gasification for synthesis (under development)
4. Need for intense research: The devil is in the (chemical) details