Gasification

Woody Biomass to Energy Workshop
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Contents

• Definition
• Some History
• Gasifier Types
• Status
• Economics
• Conclusions
Thermal Gasification

• Gasification - high temperature conversion of (usually solid) carbonaceous fuels into a gaseous fuel
  – 1300 – 2200 °F (700-1200 °C)
  – Overall process is endothermic
    • Requires burning some of the fuel to provide heat for the process (i.e., partial oxidation)
    • Or heat is supplied to reaction from some external source / (indirect gasification)

Pyrolysis

   Usually means “thermal decomposition of solid/liquid fuel without air or oxidant”
   Can be optimized for liquid production (bio oil), or char (biochar). Also produces combustible gases.
Thermal Gasification

**Fuel + Oxidant/Heat**

- **Partial Oxidation:**
  - Air or Oxygen
  - Steam/Indirect Heating

**Equation:**

\[ \text{CO} + \text{H}_2 + \text{HC} + \text{CO}_2 + \text{N}_2 + \text{H}_2\text{O} + \text{Char/Ash} + \text{Tar} + \text{PM} + \text{H}_2\text{S} + \text{NH}_3 + \text{Other} + \text{Heat} \]
Uses of product gas

• Heat/direct use
  – Stoves or burners for space heat, boilers for steam, gas lamps

• Electricity
  – Boiler fuel for steam Rankine cycle
  – Fuel for reciprocating engines (internal combustion or Stirling)
  – Fuel for gas turbine

• Other Fuels
  – Liquids (Biomass to liquids, e.g. via Fischer-Tropsch)
  – Gases (e.g., synthetic natural gas)

• Chemicals
History

- **1790s**- Coal gas used for lighting factories in England and Philadelphia
  - Actually external heating vessel of coal w/o air (pyrolysis gas was combustible for heat and lighting purposes
  - Street lighting and 24/7 Factory Ops.
  - Significant environmental impacts – Tar/water disposal and air emissions
- **1860** Town gas is prevalent.
  - Lenoir develops reliable ‘explosion engine’ fueled by town gas to power machinery (3% thermal efficiency)
  - 1876 Otto develops the 4-stroke gaseous fuel engine (1883 Daimler and Benz develop carburetor to enable liquid fuel induction to 4-stroke engine)
- **~1919**- Town gas use reaches maximum
- **1920s**- Welding techniques allow piping natural gas under pressure--Town gas declines gone by 1960s
- **WW II** –Special case re: gasification
“Wood Gas” Vehicles

- Acute shortage of liquid fuels for civilian use during WW II
- Cars, trucks, fishing boats fueled by gasifiers Europe, Japan, China, Brazil, Australia
- Gas producers built by Volvo, Saab, Daimler-Benz, Peugeot, Renault, Fiat, Isuzu
- More than 1 million vehicles operated on producer gas during the war (350,000 in Germany)
History

- Resurgence of interest and research due to Arab oil embargo (1973)
- Led to fuels and power research at UCD and elsewhere
- Mid 1990s saw numerous advanced biopower gasification demo projects in Europe and US
- Energy prices, GHG policies, use of district heat, all contribute to many biomass gasification for combined heat and power (CHP) installations in Europe
Classification by Reactor Type: Fixed/Moving Beds

- **Updraft**
  - Countercurrent
  - Simplest
  - High moisture fuel (<60% wet basis)
  - High tar production except with post-reactor tar cracking/removal or dual stage air injection
  - Low carbon ash
  - Good for direct heat applications
  - Small to Medium Scale
  - Cigarettes are updraft gasifiers

- **Downdraft**
  - Cocurrent
  - Moisture < 30% (preferred <15)
  - Lower tar than uncontrolled updraft
  - Carbonaceous char
  - ‘Wood gas’ Vehicles
  - ~ 200 – 500 kW (electric) maximum
Classification by Reactor Type: Fluidized Beds

- “Fluidize” bed of hot sand – inject fuel – well mixed – speedy reactions

  - Bubbling beds
    - Lower velocity
    - Low entrainment/elutriation
    - Simple design
    - Moderate tar production
    - Medium to high capacity

  - Circulating beds
    - Higher velocity
    - Solids are recirculated
    - More complex design
    - Moderate tar production
    - Higher conversion rates and efficiencies
    - Medium to high capacity
Classification by Reactor Type: Entrained Beds

- Solids or slurry entrained on gas flow
  - Small particle size
  - Very low tar production
  - Often pure oxygen rather than air (yields higher temperature)
  - Economics favor very large capacity (>100 MW thermal input)
  - Likely biomass application is for syngas-to-liquids
  - "Slagging gasifier" design
    - Melt the ash for easy removal as liquid
Classification by Reactor Type: Indirect Heat

Battelle/ FERCO gasifier*

Fast Internal Circulating Fluidized Bed (FICFB) gasifier, Güssing, Austria

*(Mark Paisley, FERCO)
Relative characteristics, scale, tar production, energy in gas

<table>
<thead>
<tr>
<th>Scale (Fuel input)</th>
<th>Downdraft</th>
<th>Updraft</th>
<th>Bubbling FB</th>
<th>Circulating FB</th>
<th>Entrained Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MM Btu/hr)</td>
<td>&lt; 34</td>
<td>&lt; 70</td>
<td>34 - 340</td>
<td>34 - ??</td>
<td>&gt; 340</td>
</tr>
<tr>
<td>(Dry tons wood/hr)</td>
<td>&lt; 2</td>
<td>&lt; 4</td>
<td>2 - 20</td>
<td>2 - ??</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

Energy Content (Btu/ft³)

- **Air gasification** (partial oxidation in air)
  - Generates Producer Gas with high N₂ dilution low heating value.
  - ~ 100-200

- **Oxygen gasification** (partial oxidation using pure O₂)
  - Generates synthesis gas (Syngas) with low N₂ in gas and medium heating value.
  - ~ 300-400

- **Indirect heat w/ Steam gasification**
  - Generates high H₂ concentration, low N₂ in gas and medium heating value. Can also use catalytic steam gasification with alkali carbonate or hydroxide.
  - ~300-450

Natural Gas → ~ 1000 (Btu/ft³)

Status of Gasification

- Gasifiers for Heat, Power, and CHP are not new and are considered commercial in many places
  - India, China, some developing nations
    - Low labor rates allow simple manual operation
    - Emissions (air and liquid) regulations may not be as strict as here
  - Examples in Europe where economics allow (high feed-in tariffs, $ for RECs or carbon credits)
  - Examples in US where economic (direct heat applications, some steam power systems)
- In California and much of US, economics are marginal
  - Air Emissions (especially NOx) are difficult to meet in large areas of California (San Joaquin Valley, LA basin)- NOx control adds expense, and may not even be achievable
  - Labor costs (and emissions/discharge requirements) lead to more automation and sophistication increasing capital costs
## Gasifiers – An Incomplete List

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Type</th>
<th>Application</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioneer</td>
<td>Finland</td>
<td>Updraft</td>
<td>Heat or Steam</td>
<td>About a dozen - mid 1980s- 1990s</td>
</tr>
<tr>
<td>PRM Energy Systems</td>
<td>Hot Springs, AR</td>
<td>Updraft</td>
<td>Heat or Steam</td>
<td>~a dozen rice hull, straw for heat / steam (overseas, some Gulf States, US)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ 4 steam CHP (2 in the US?)</td>
</tr>
<tr>
<td>Nexterra</td>
<td>Vancouver, BC</td>
<td>Updraft</td>
<td>Heat or Steam</td>
<td>Recent installations</td>
</tr>
<tr>
<td>Energy Products of Idaho</td>
<td>Idaho</td>
<td>Bubbling Fluidized Bed</td>
<td>Heat or Steam</td>
<td>Several in North America (since mid 1980s)</td>
</tr>
<tr>
<td>Energy Products of Idaho</td>
<td>Idaho</td>
<td>Bubbling Fluidized Bed</td>
<td>Electricity (Steam Turbine)</td>
<td>~ 6 MW (one or two in US)</td>
</tr>
<tr>
<td>PRM Energy Systems</td>
<td>Hot Springs, AR</td>
<td>Updraft</td>
<td>Electricity (Engine)</td>
<td>~ 3 projects producing electricity (engines)</td>
</tr>
<tr>
<td>Nexterra</td>
<td>Vancouver, BC</td>
<td>Updraft</td>
<td>Electricity (Engine)</td>
<td>Marketing</td>
</tr>
<tr>
<td>Biomass Engineering, Ltd</td>
<td>UK</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>A dozen or so units reported in Europe (~ 100 - 400 kW)</td>
</tr>
<tr>
<td>Aruna</td>
<td>India</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Many small scale - rural electrification India (10-1-- kw)</td>
</tr>
<tr>
<td>Ankur Scientific</td>
<td>India</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Many in India (25 - 400 kW)</td>
</tr>
<tr>
<td>Ankur Scientific</td>
<td>US</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Demos/Research at Humboldt State and EERC, North Dakota. Phoenix Energy using Ankur design</td>
</tr>
<tr>
<td>Community Power Corp.</td>
<td>Colorado</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Perhaps a dozen demonstration units (25 -75 kW) throughout US (no known commercial units). Grant and Investor supported</td>
</tr>
</tbody>
</table>
## Gasifiers – Some Projects in California

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Type</th>
<th>Application</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix Energy</td>
<td>Proposed Modesto area</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Ankur design gasifier. ~ 500 kW (3300 $/kW estimated capital cost) Loan from CA Waste Board</td>
</tr>
<tr>
<td>Community Power Corp.</td>
<td>Winters, CA</td>
<td>Downdraft</td>
<td>Electricity (Engine)</td>
<td>Demo at Dixon Ridge Farms (walnut shell fuel) Several thousand hours of operation</td>
</tr>
<tr>
<td>Pro-Grow Nursery, Tom Jopson Owner</td>
<td>Etna, CA</td>
<td>Downdraft</td>
<td>Burner fuel (+ engine generator)</td>
<td>Built - beginning final testing stages. Replace propane for greenhouse heating. Fluidyne gasifier (Doug Williams, New Zealand) ~ 100 kWe, TR Miles Consulting, UC Davis Bio.&amp;Agr. Engr.</td>
</tr>
<tr>
<td>West Biofuels</td>
<td>Woodland, CA</td>
<td>Dual Fluidized Bed (indirect gasifier)</td>
<td>Syngas to liquid + engine generator</td>
<td>5 ton/day, Research and Demo (UC San Diego, Davis, Berkeley). Several Grants supporting work</td>
</tr>
<tr>
<td>Humboldt State, UC Davis, Riverside, Berkeley, San Diego, Merced</td>
<td>Throughout CA</td>
<td>various</td>
<td>Fundamental &amp; applied science, heat, power, liquids</td>
<td>Various research efforts underway</td>
</tr>
</tbody>
</table>
Air permit examples

Phoenix Energy Authority to Construct (SJVAPCD)

Emission Limits

<table>
<thead>
<tr>
<th>NOx (ppm)</th>
<th>CO (ppm)</th>
<th>VOC (ppm)</th>
<th>PM10 (g/hp-hr)</th>
<th>SOx (g/hp-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>75</td>
<td>25</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Ankur derivative downdraft gasifier, gas scrubbing/filtering, recip. engine-generator (~500 kWe)

CPC 50 kW at Dixon Ridge Farms (Winters, CA) [Yolo-Solano AQMD]

Emission Limits and Test Results

<table>
<thead>
<tr>
<th>Permit</th>
<th>NOx (ppm)</th>
<th>CO (ppm)</th>
<th>VOC (ppm)</th>
<th>PM10 (gr/dscf)</th>
<th>SO2 (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.8</td>
<td>2823</td>
<td>14.1</td>
<td>0.012</td>
<td>28.2</td>
<td></td>
</tr>
</tbody>
</table>

Source Test | NOx (ppm) | CO (ppm) | VOC (ppm) | PM10 (gr/dscf) | SO2 (ppm) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>362</td>
<td>ND</td>
<td>0.0005</td>
<td>&lt;0.4</td>
<td></td>
</tr>
</tbody>
</table>

New 3-way Catalytic converter just prior to source test

Downdraft gasifier, gas filtering, automotive V-8 engine-generator (~50 kWe)
Levelized Cost of Electricity - Biomass Power

Assumptions
- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
- Debt and Equity recovered over 20 yrs.
- 2.1% general inflation and escalation
- 23% Net Efficiency of Power Generation
- 85% Capacity Factor
- $0.025 / kWh Non-Fuel Operating Expenses

“Central Station: Biomass Boilers*
- 2660 – 3300 $/kW installed – Capital
- 0.10 - 0.11 $/kWh Levelized COE (using 43 $/dry ton fuel cost)

* Klein, J. (2009) 2009 IEPR CEC-200-2009-017-SD
Levelized Cost of Electricity - Biomass Power

Assumptions
- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
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Capital Costs of Gasifiers*
- Proposals ranging from 3300 - 5500 $/kW installed (maybe as high as $10,000/kW - CPC??)
- Those that are built seem to come in at ~ 5000 $/kW
- Target is 3000 $/kW

* Tom Miles, TR Miles Consulting

- 0.00
- 0.05
- 0.10
- 0.15
- 0.20
- 0.25

- Zero fuel cost
- $20/dry ton
- $40/dry ton
- $60/dry ton
- $80/dry ton

- Installed Capital Cost ($/kW)
- COE ($/kWh)
Levelized Cost of Electricity - Influence of Heat sales on COE

- Same Financial Assumptions as above
- $4000/kW cap. Fuel cost ~$40/dry ton
- 23% fuel-to-electricity efficiency
- 47% fuel-to-heat recovery efficiency
- Which gives 70% overall energy efficiency
Advantages of Gasification

• Produces fuel gas for more versatile application in heat and power generation and chemical synthesis.
• Smaller scale power generation than direct combustion systems although gas cleaning is primary concern and expense.
• Potential for higher efficiency conversion using gas-turbine combined cycle at larger scale (compared to combustion-steam systems).
  – Biomass-Integrated-Gasifier-Gas-Turbine-Combined-Cycle (BIGGCC) is Emerging Technology; Demonstrated but not commercial – no known currently operating
Gasification Challenges

• Fuel particle size and moisture are critical for downdraft gasifiers (which are most often used for small scale power using reciprocating engines)
• Gas cleaning required for use of fuel gas in engines, turbines, and fuel cells
  – For reciprocating engines, tar and particulate matter removal are primary concerns,
    • Tar removal difficult to achieve. Reactor designs influence tar production
    • Need for cool gas to maintain engine volumetric efficiency leads to tar condensation and waste water production (from wet scrubbing systems).
    • Engine derating for gas from air-blown reactors (low Btu gas).
  – Gas needs to be cleaner for gas turbines, and cleaner still for fuel cells and chemical or fuels synthesis
• In some air districts in California, meeting air emissions requirements is challenging
• Costs
Conclusions

• Gasifiers for heat, power, and CHP are employed in many parts of the world
• Some in the US, but fewer examples.
• For those contemplating biomass heat or power systems, need to understand the issues (real cost, risks, operational effort and potential problems).
• Accurate information about existing projects and demonstrations is needed
  – Need long-term operational data: [monitor mass and energy flows, emissions over time, document operating costs, etc.]
Acknowledgments, References and Information Sources

- TR Miles Consulting www.trmiles.com
- Gasifier page http://gasifiers.bioenergylists.org
- Gasification Discussion List Gasifiers.bioenergylists.org
- Biomass Energy Foundation www.woodgas.com
- Doug Williams Fluidyne Ltd. www.fluidynenz.250x.com
- IEA Task 33 Gasification of Biomass www.gastechnology.org/iea
Thank You

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Thermochemical Conversion
(combustion, gasification, pyrolysis / indirect gasification)

• **Combustion**
  Fuel + Excess Air → Heat + Hot Exhaust Gas + Ash

• **Direct Gasification**
  Fuel + Limited Air (N₂ & O₂) → “Producer Gas” + Heat + Char/Ash + Tar  (“Air Blown”)
  Fuel + Limited Oxygen → “Syngas” + Heat + Char/Ash + Tar  (“Oxygen Blown”)

• **Indirect Gasification and Pyrolysis**
  Fuel + Heat → “Syngas” or “Pyrolysis Gas” + Heat + Char/Ash + Tar (+ pyrolysis liquids)

Adapted from Paskach. (2010). Frontline Bioenergy
Coarse and Fine fabric filters

Air Intake

Contaminated Scrubber water

250 kW Diesel Engine

Scrubber water and condensate contain:

- PAHs
- Naphthalene
- Benzene, Toluene, Xylene

Contaminated waste water must be treated before discharge.

Community Power Corporation ‘Biomax’ – no liquid scrubbing of gas

- Fixed bed downdraft gasifier
- 12,15 & 50 (75?) kWe systems demonstrated
- Automotive spark ignition engine – generator
- Gas cooled to ~ 120 F & filtered to reduce tar and particulate matter for engine (no liquid scrubber- this is positive feature)
- 3-way automotive catalytic converter for emissions control

http://www.gocpc.com/technology.html