Pulp Mill Integrated Gasification-Based Liquid Biofuels Production

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Synthesis of Liquid Fuels from Synthesis Gas (CO+H₂)

- Fuel product (vapor) + unreacted syngas
- Disengagement zone
- Catalyst powder slurried in oil
- Steam
- Cooling water
- Synthesis gas (CO + H₂)
- Catalyst

Liquid-Phase Synthesis
P = 50-100 atm.  
T = 200-300°C


catalyst

CH₃OCH₃  
CH₃OH  
CₙH₂n₊₂  
(depending on catalyst)
**Gasification-Based Liquid Fuels**

**Fischer-Tropsch Liquids (FTL)**
- Synthetic crude refinable to zero-sulfur, high-cetane, low-particulate diesel blendstock and gasoline blendstock.
- Large global investments in gas-to-liquids GTL (e.g., Qatar, Nigeria)
- Growing investments in coal-to-liquids, CTL (China, USA).
- Initial commercial investment in biomass-to-liquids, BTL (Germany)

**Dimethyl Ether (DME) (first cousin of methanol)**
- Propane substitute/blendstock or zero-S, zero-PM, high-cetane diesel fuel.
- Huge commercial investments in DME and methanol from coal in China;
- Growing investments in DME from gas in Iran, China, and (as buyer) Japan;
- Swedish interest in DME from biomass.

**Mixed alcohols (MA)**
- Mixture of ethanol and higher alcohols as a gasoline blendstock.
- No commercial synthesis technology available today.
- Demonstrated catalyst performance (modified methanol or modified FTL catalysts) does not yet approach MeOH or FTL catalyst performance.
- Interest exclusively in U.S.A., driven largely by policy emphasis on ethanol.

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**Bioenergy in the Kraft Pulp Industry**

- United States kraft pulp industry generates and uses over 1.5 quads/year of bioenergy: ~80% black liquor and ~20% woody residues.
- Fleet of Tomlinson black liquor boilers is aging and approaching retirement.

- Tough global competition for northern-hemisphere pulp industry ➔ Diversify to stay competitive, e.g., fuels/chemicals production?
- Window of opportunity for introducing gasification/biorefining.
Reference 2010 Kraft Pulp/Paper Mill

Same reference mill as in 2003 BLGCC study:
- Uncoated freesheet (65% HW, 35% SW), Southeast USA
  - 1,580 metric t/d unbleached pulp rate (bone dry)
  - 1,725 metric t/d paper rate (machine dry).
- Process steam use for projected state-of-art 2010 mill.
- Pulping technology adopted
  - Conventional kraft with Tomlinson chemical recovery.
  - Polysulfide with gasification chemical recovery.

Power/fuels/recovery area:
- 6 x 10^6 lbs/day black liquor solids (2721 metric t/d) with conventional kraft; 5.4 x 10^6 lbs/day with polysulfide.
- Hog fuel from pulpwood + purchased residues if needed.
- Delivers all mill process steam and some electricity.

Pulp Mill-Integrated Biorefining

Pressurized, high-temperature, O_2-blown (Chemrec) black liquor gasifier adopted in our biorefinery designs:
- Pilot-scale (20 tpd BLS) pressurized gasifier tests ongoing in Sweden since mid-2006.
- Commercial demo under planning for implementation by 2010 in Sweden.
- American company (VantagePoint Venture Partners) is major owner.
7 Detailed Biorefinery Designs Developed

Technology in Our Biorefinery Designs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Status*</th>
<th>FTa</th>
<th>FTb</th>
<th>FTc</th>
<th>DMEa</th>
<th>DMEb</th>
<th>DMEc</th>
<th>MA</th>
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<tbody>
<tr>
<td>Black Liquor Gasification Island</td>
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<td>Entrained flow gasifier Quench O₂ feed</td>
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<td>Pilot</td>
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<td>Woody Biomass Conversion</td>
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<tr>
<td>Fluid-bed gasifier Syngas cooler</td>
<td>Pilot</td>
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<td>Hot gas filter Quench cleanup O₂ feed Boiler</td>
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<td>H₂S Capture and Recovery</td>
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<td>Rectisol® Selexol® Claus/SCOT</td>
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<tr>
<td>Slurry bed reactor Fixed-bed reactor Syngas recycle</td>
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<td>Power Island</td>
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<tr>
<td>Gas turbine Back pressure ST Condensing ST</td>
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* Com = commercially-offered; Pilot = Demonstrated at pilot scale; Lab = Demonstrated in Laboratory
Overall Energy In and Out

“Nth Plant” Performance Predictions

<table>
<thead>
<tr>
<th>Energy Inputs</th>
<th>Tomlinson</th>
<th>BLGCC</th>
<th>FTa</th>
<th>FTb</th>
<th>FTC</th>
<th>DMEa</th>
<th>DMEb</th>
<th>DMEc</th>
<th>MA</th>
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<tbody>
<tr>
<td>Black liquor dry solids, kg/s</td>
<td>31.5</td>
<td>28.5</td>
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<td>Dry solids fraction, %</td>
<td>80</td>
<td>80</td>
<td>80</td>
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<td>80</td>
<td>80</td>
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<tr>
<td>Total black liquor, MW t LHV</td>
<td>393</td>
<td>351</td>
<td>351</td>
<td>351</td>
<td>351</td>
<td>351</td>
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<tr>
<td>Total wood residuals, kg/s</td>
<td>7.12</td>
<td>19.2</td>
<td>52.0</td>
<td>62.2</td>
<td>16.2</td>
<td>30.7</td>
<td>15.7</td>
<td>17.6</td>
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<td>Purchased wood residuals, kg/s</td>
<td>7.74</td>
<td>54.0</td>
<td>54.0</td>
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<tr>
<td>Lime kiln fuel oil, MW t LHV</td>
<td>31.1</td>
<td>35.9</td>
<td>35.9</td>
<td>35.9</td>
<td>35.9</td>
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<table>
<thead>
<tr>
<th>Power/Recovery/Refinery Outputs</th>
<th>Tomlinson</th>
<th>BLGCC</th>
<th>FTa</th>
<th>FTb</th>
<th>FTC</th>
<th>DMEa</th>
<th>DMEb</th>
<th>DMEc</th>
<th>MA</th>
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</thead>
<tbody>
<tr>
<td>FT crude or DME, MW t LHV</td>
<td>-</td>
<td>112.0</td>
<td>112.0</td>
<td>343.0</td>
<td>168.0</td>
<td>168.0</td>
<td>74.0</td>
<td>60.0</td>
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<tr>
<td>Biomass syngas expander output, MWel</td>
<td>-</td>
<td>87.0</td>
<td>83.9</td>
<td>186.5</td>
<td>89.7</td>
<td>89.5</td>
<td>82.9</td>
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<tr>
<td>Total gross production, MWel</td>
<td>72.0</td>
<td>135.1</td>
<td>119.5</td>
<td>278.7</td>
<td>138.3</td>
<td>35.9</td>
<td>138.5</td>
<td>123.6</td>
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<td>Recovery/power/biorefinery consumption, MWel</td>
<td>7.7</td>
<td>20.5</td>
<td>31.3</td>
<td>49.2</td>
<td>60.4</td>
<td>34.3</td>
<td>48.1</td>
<td>32.4</td>
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<tr>
<td>Mill demand, MWel</td>
<td>100.1</td>
<td>100.1</td>
<td>100.1</td>
<td>100.1</td>
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<tr>
<td>Net power available for export, MWel</td>
<td>-35.8</td>
<td>14.6</td>
<td>-12.4</td>
<td>128.8</td>
<td>-22.8</td>
<td>99.6</td>
<td>-12.3</td>
<td>-9.6</td>
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</tbody>
</table>

[Diagram of Power inputs and outputs, MW]

[Table of Energy Inputs and Power/Recovery/Refinery Outputs]

[Table of “Nth Plant” Performance Predictions]
Comparing Effective Liquid Fuel Yields

A biorefinery integrated with a pulp mill effectively requires much less biomass per unit of liquid fuel produced vs. "stand-alone" biofuel production.

The reason is that black liquor (and some biomass) are charged against services provided to the mill (chemical recovery, process steam and power) – not against liquid fuel.

“Nth Plant” Installed Capital Costs

- New Tomlinson boiler system: ~$140 million.
- New gasification-based biorefinery: $250-500 million.
$330 million incremental capital investment

$50/bbl Crude Oil Scenario (AEO '06 Reference Projection)

Electricity sale price: 5.3 c/kWh (without incentives)

Incentives examined:
- Excise Tax Credit (ETC): Equivalent to existing $0.51/gal for ethanol on energy basis.
- Investment Tax Credit (ITC): 20% gasification tax credit (under EPAct 2005).
- Production Tax Credit (PTC): $9/MWh for 10 years (on incremental electricity relative to Tomlinson).
- Renewable Energy Credit (REC): $20/MWh (e.g., under RPS or green credits). Applies only to incremental electricity.
- CO2 Credits: $25/metric ton CO2 applied to net reductions (including grid offsets and petroleum displaced).

Internal Rate of Return Analysis: FTc

Pulpmill Biorefinery Financial Performance

$50/bbl Crude Oil Scenario, without and with incentives
25-Year Fossil Energy Savings
Up to 16 quads, Mostly Petroleum

Cumulative (2010-2034) Fossil Energy Savings (Aggressive Market Penetration Scenario)

Notes:
• Transportation of the crude FT product to the oil refinery included in FT cases.
• Vehicle end case FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines.
MA case assumes low-level blend with gasoline.

U.S. Pulp/Paper Industry Technical Potential for Biofuel Production in 2034
(billion gallons per year ethanol equivalent)

• FT configurations: 5 to 14 billion gal/yr
• DME configurations: 3 to 7 billion gal/yr
• For comparison:
  • 2005 corn ethanol production: 4 billion gallons
  • Latest administration goal: 35 billion gallons in 2017
Final Comments

- Pulpmill-integrated Nth-plant biorefinery economics are favorable due to integration → capital cost shared with mill and low effective feedstock costs.
  - Production cost of FT syncrude or of DME ranges from $0.7 to $1.3 per gallon ethanol equivalent.
- Most needed technology is already commercial (in other industries), gasification is not (yet) off-the-shelf, so there are risks for the 1st or 2nd full-scale biorefinery.
- How to get started?
  - Woody biomass gasification for IGCC-electricity and/or liquid fuels, and/or
  - Partial BLG (Weyerhaeuser New Bern model).
  - Partnership with energy-industries and government to help manage risk and also bring in energy-industry competences.

Thank you!

Steering Committee
- Craig Brown/Del Raymond – Weyerhaeuser
- Theo Fleisch/Mike Gradassi – BP
- Paul Grabowski – U.S. Department of Energy
- Jennifer Holmgren – UOP
- Tom Johnson – Southern Company
- Mike Pacheco – National Renewable Energy Laboratory
- Steve Kelley – North Carolina State University
- Lori Perine – American Forest & Paper Association
- David Turpin – MeadWestvaco

Additional Resource Persons
- Ron Reinsfelder – Shell Global Solutions
- Gord Homer – Air Liquide

Many Others!

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www.princeton.edu/~energy


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