Preliminary Economics of Black Liquor Gasification with Motor Fuels Production

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Cost of fuel at pump
(incl. distribution cost, excl. taxes and profit)

Source: Swedish National Road Administration, 2002
Cost of fuel at pump
(incl. distribution cost, excl. taxes and profit)

Outline

• Background
• Process
• Mass and Energy Balances
• Costs and Benefits
• Conclusions
Driving Forces

- **Kyoto agreement:**
  - Reduce greenhouse gas emissions in OECD countries by 2012
  - European Union target: 8% decrease compared to 1990 levels
- **Proposed EU directive:**
  - 2% of motor fuels from renewables by 2005
  - 5.75% by 2010
- **Possibility to profit for those who own carbon-neutral feedstock!**

Alternative Fuels via Gasification

- Gasification
- Syngas
- Synthesis
- Methanol
- Dimethyl Ether (DME)
- Fischer-Tropsch Fuels
- Hydrogen
Methanol

+ Well established commodity, 30 MMt/y
+ Liquid at normal T and P
+ Suitable for blending
+ Only small modifications for Otto engines
+ Low HC emissions
+ Efficient conversion from syngas to MeOH
+ Can be used in fuel cells
- Toxic
- Corrosive
- “Cold start problem”
- Hydrophilic
- Aldehyde emissions
- Low energy density compared to gasoline

Dimethyl Ether (DME)

+ Non-toxic
+ Very efficient conversion from syngas to DME
+ Low emissions
+ Efficient in diesel cycles
+ Potential for no exhaust filter to fulfill emission norms Euro IV (-06) and V (-09) as well as EPA norm for (-10)
- Gas at normal T and P
- Not suitable for blending
- Requires modified (Diesel) engines
Fischer-Tropsch Fuels

+ Conventional HCs
+ High energy density
+ Easily introduced into existing distribution system

- Less efficient conversion from syngas
- Emissions similar to conventional fuels
- Need exhaust filters for particulates and NOx for coming Euro IV and V and EPA emission norms

Hydrogen

+ Efficient conversion from syngas
+ Can be used in fuel cells
+ No HC, CO, NOx emissions from vehicle

- Gas at normal T and P
- Large losses in distribution
- Explosive
- Very low energy density
- Difficult to store
Why Use Black Liquor As Feedstock?

• Energy Surplus
  - One way of exporting energy surplus of a modern market pulp mill
• Process more easily pressurized than with solid biomass
  - Pressurization improves heat recovery and yields higher efficiency
• Very low methane content in syngas
  - Simplifies methanol synthesis and increases yield
• Synergies with pulp production

BLGMF: Study Supported by the EU Altener II Program

• Duration: Feb 2002 - Nov 2003
• Total cost: €400,000
• Contents:
  - Process design
  - Mill integration
  - Energy balances
  - Cost estimate
  - Market barriers
Project Partners

- **NYKOMB SYNERGETICS**: Process engineering consultant
- **CHEMREC**: Gasification technology supplier
- **Methanex**: World’s largest methanol producer and distributor
- **OKO-GAS**: National gasoline and oil distributor
- **Ecotraffic**: Automotive fuel and engine consultant
- **Volvo**: World-known automotive and engine developer

**Black Liquor Gasification Combined Cycle (BLGCC)**

- **Air Separation**
- **Black Liquor**
- **Green Liquor**
- **Gasification & Gas Cooling**
- **Gas Clean-Up & Sulfur Handling**
- **Combined Cycle**
- **Electric Power**
- **High-Sulfidity Liquor**

**Syngas**

**Oxygen**
Black Liquor Gasification with Motor Fuels Production (BLGMF)

Air Separation → Oxygen

Black Liquor → Gasification & Gas Cooling → Syngas → Methanol or DME Synthesis

Green Liquor

Gasification & Gas Cooling → Gas Clean-Up & Sulfur Handling → High-Sulfidity Liquor

Methanol or DME Synthesis

Process Flow Diagram BLGMF

AIR SEPARATION

METHANOL SYNTHESIS

GASIFICATION

SULFUR RECOVERY
Basis for Comparison

- Modern market pulp mill & integrated mill
  - Compare recovery boiler, BLGCC and BLGMF
- Same steam demand for all cases
  - Market pulp 10 GJ/ADt, Integrated 16 GJ/ADt
  - Purchased biomass fuel, if necessary
  - Corresponding cogeneration of power
  - Remaining power purchased or generated in biomass-fired boiler/condensing steam turbine system

Reference Case: Recovery Boiler
Methanol Case: BLGMF Plant

Wood, 2200 t/d

PULP MILL
- Black Liquor
- Green Liquor

Internal requirement of electric power and heat

Heat / Power Boiler Plant

Biomass 215 MW

Methanol 140 MW, 610 t/d

Pulp, 1000 ADt/d

Biomass to Methanol Efficiency

- Calculated as:
  \[
  \frac{\text{Methanol Produced}}{\text{Total Incremental Biomass Used}}
  \]

- “Total Incremental Biomass” includes:
  - Fuel used in mill to meet steam demand
  - Fuel used in biomass-fired power plant (on-site or external) to make up for power not generated from black liquor
**Efficiency Comparison**

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeOH via Solid Biomass Gasification</td>
<td>45-50%</td>
</tr>
<tr>
<td>MeOH via Black Liquor Gasification</td>
<td>64-66%</td>
</tr>
</tbody>
</table>

**INVESTMENT, MSEK**

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Reference Mill 54%</th>
<th>BLGMF 54%</th>
<th>BLGMF 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 ADt/d market pulp mill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air separation unit</td>
<td>35</td>
<td>183</td>
<td>265</td>
</tr>
<tr>
<td>Gasification &amp; gas cooling</td>
<td>--</td>
<td>351</td>
<td>508</td>
</tr>
<tr>
<td>Gas clean-up (Rectisol), shift reactor &amp; compressor</td>
<td>--</td>
<td>170</td>
<td>246</td>
</tr>
<tr>
<td>Sulfur handling (H2S Reabsorption)</td>
<td>--</td>
<td>55</td>
<td>80</td>
</tr>
<tr>
<td>Methanol synthesis and distillation</td>
<td>--</td>
<td>172</td>
<td>249</td>
</tr>
<tr>
<td>Balance of plant</td>
<td>--</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>Recovery boiler</td>
<td>845</td>
<td>565</td>
<td>--</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>880</strong></td>
<td><strong>1531</strong></td>
<td><strong>1398</strong></td>
</tr>
<tr>
<td>Biomass boiler</td>
<td>--</td>
<td>--</td>
<td>530</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>185</td>
<td>76</td>
<td>75</td>
</tr>
<tr>
<td>Lime kiln + bark dryer</td>
<td>191</td>
<td>215</td>
<td>235</td>
</tr>
<tr>
<td><strong>TOTAL INVESTMENT</strong></td>
<td><strong>1256</strong></td>
<td><strong>1822</strong></td>
<td><strong>2238</strong></td>
</tr>
</tbody>
</table>

**Incremental Investment for BLGMF Model Mill**

| Corresponding amount in million USD                        | 566                | 982       |

*Includes site preparation, buildings, electrical, piping, instrumentation, engineering, license fees and contingencies. Estimated costs have been scaled from several sources with an initial accuracy of +/- 30%. Scaling adds an additional 30%.**
**BLGMF Investment Costs**

- Gas clean-up (Rectisol), shift reactor & compressor: 18%
- Sulfur handling (H2S Reabsorption): 6%
- Methanol synthesis and distillation: 18%
- Balance of plant: 4%
- Air separation unit: 19%
- Gasification & gas cooling: 35%

**Operating Costs/Benefits, excl. MeOH**

<table>
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<th>BLGMF 54%</th>
<th>BLGMF 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>MSEK/a</td>
<td>-85</td>
<td>59</td>
</tr>
<tr>
<td>Biofuels **</td>
<td>MSEK/a</td>
<td>-22</td>
<td>-17</td>
</tr>
<tr>
<td>Catalyst</td>
<td>MSEK/a</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Maintenance</td>
<td>MSEK/a</td>
<td>134</td>
<td>145</td>
</tr>
<tr>
<td>Incremental Labor</td>
<td>MSEK/a</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Net Operating Cost</td>
<td>MSEK/a</td>
<td>26</td>
<td>196</td>
</tr>
</tbody>
</table>

**Methanol Production Cost**

- Incremental Capital Cost: MSEK/a 57 98
- Incremental Operating Cost: MSEK/a 169 323
- Incremental Cost, Total: MSEK/a 226 421
- Methanol produced: ktonnes/a 201 373
- Cost of methanol produced: SEK/tonne 1123 1129
- SEK/l: 0.9 0.9
- SEK/l gasoline eq.: 1.8 1.8
- Corresponding in USD: USD/g gasoline eq.: 0.86 0.87

**Note:** low price for sold bark, high price for purchased wood residues
Estimated Competitive Sales Price, Including CO₂ Tax Credit (Sweden, 2003)

Consumer Price at Pump, 9.5 SEK/l (4.5 USD/gal)

- V.A.T.
- CO₂ tax***
- Energy tax***
- Distribution**
- Production*

Potential sales price at mill gate

Gasoline

- 1.90
- 2.94
- 1.05
- 1.83

Methanol

- 1.90
- 2.94
- 1.35
- 3.30

3.30 SEK/l.g.e. ↔ 1.62 SEK/l(MeOH) ↔ 2040 SEK/t(MeOH)

~255 USD/t

OPERATING COSTS/BENEFITS, incl. MeOH

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NET OPERATING BENEFIT

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<th></th>
<th>MSEK/a</th>
<th>SEK/ADt</th>
<th>54%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol Incremental Net Operating Benefit</td>
<td>241</td>
<td>383</td>
<td>438</td>
<td>695</td>
</tr>
</tbody>
</table>

corresponding in million USD per year

30 55

corresponding in USD per tonne of pulp

48 87
Sensitivity Analysis

Cost of fuel at pump
(incl. distribution cost, excl. taxes and profit)

Source: Swedish National Road Administration, 2002
Conclusions

• Energy Balance
  - About 600 tonnes MeOH per 1000 ADt pulp
  - Modern market pulp mill could produce MeOH from about 50% of the black liquor without purchasing any fuels

• Efficiency
  - Considerably better than for gasification of biomass to generate methanol

• Economics
  - Production cost low compared to other renewable fuels
  - Potentially large revenue stream for pulp mill
  - Very profitable if CO2 tax credit can be claimed

• Environment
  - Significant potential for reduction of CO2 emissions in some regions, e.g. 10% of total CO2 emissions in Sweden

Further Work

• Evaluation of DME case
• Refined investment estimate
• Detailed financial analysis
• Analysis of market barriers