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)

Source: Swedish National Road Administration, 2002
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!**
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

- **STFi**
  Research centre for pulp and papermaking

- **CHEMREC**
  Gasification technology supplier

- **OKQ8**
  National gasoline and oil distributor

- **Methanex**
  World’s largest methanol producer and distributor

- **Ecotraffic**
  Automotive fuel and engine consultant

- **Volvo**
  World-known automotive and engine developer
Outline

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Black Liquor Gasification
Combined Cycle (BLGCC)

Air Separation

Oxygen

Gasification & Gas Cooling

Gas Clean-Up & Sulfur Handling

High-Sulfidity Liquor

Combined Cycle

Electric Power

Syngas
Black Liquor Gasification with Motor Fuels Production (BLGMF)

- Air Separation
- Oxygen
- Black Liquor
- Green Liquor
- Gasification & Gas Cooling
- Gas Clean-Up & Sulfur Handling
- Syngas
- Methanol or DME Synthesis
- Methanol or DME
Process Flow Diagram BLGMF

AIR SEPARATION

METHANOL SYNTHESIS

GASIFICATION

SULFUR RECOVERY
Outline

• Background
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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

Pulp, 1000 ADt/d

Wood, 2200 t/d

Internal requirement of electric power and heat

Black Liquor

Green Liquor

PULP MILL

Bark Boiler

Recovery Boiler

Electric Power 23 MW
Methanol Case: BLGMF Plant

- Wood, 2200 t/d
- Internal requirement of electric power and heat
- PULP MILL
  - Black Liquor
  - Green Liquor
- BLGMF Plant
  - 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

MeOH via Solid Biomass Gasification - 45-50%

MeOH via Black Liquor Gasification - 64-66%
Outline

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

**Incremental Investment for BLGMF Model Mill**

| Corresponding amount in million USD | 71 | 123 |

*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*
BLGMF Investment Costs

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

#### 2000 ADt/d market pulp mill

<table>
<thead>
<tr>
<th>Description</th>
<th>Reference</th>
<th>BLGMF Mill</th>
<th>BLGMF 54%</th>
<th>BLGMF 100%</th>
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<tbody>
<tr>
<td>Electricity</td>
<td>MSEK/a</td>
<td>-85</td>
<td>59</td>
<td>87</td>
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<tr>
<td>Biofuels **</td>
<td>MSEK/a</td>
<td>-22</td>
<td>-17</td>
<td>95</td>
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<tr>
<td>Catalyst</td>
<td>MSEK/a</td>
<td>0</td>
<td>5</td>
<td>10</td>
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<tr>
<td>Maintenance</td>
<td>MSEK/a</td>
<td>134</td>
<td>145</td>
<td>154</td>
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<tr>
<td>Incremental Labor</td>
<td>MSEK/a</td>
<td>0</td>
<td>4</td>
<td>4</td>
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<tr>
<td><strong>Net Operating Cost</strong></td>
<td>MSEK/a</td>
<td>26</td>
<td>196</td>
<td>349</td>
</tr>
</tbody>
</table>

### METHANOL PRODUCTION COST

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<th>Description</th>
<th>Reference</th>
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<th>BLGMF 100%</th>
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</thead>
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<tr>
<td>Incremental Capital Cost</td>
<td>MSEK/a</td>
<td>57</td>
<td>98</td>
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<tr>
<td>Incremental Operating Cost</td>
<td>MSEK/a</td>
<td>169</td>
<td>323</td>
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<tr>
<td>Incremental Cost, Total</td>
<td>MSEK/a</td>
<td>226</td>
<td>421</td>
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<tr>
<td>Methanol produced</td>
<td>ktonnes/a</td>
<td>201</td>
<td>373</td>
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<tr>
<td><strong>Cost of methanol produced</strong></td>
<td>SEK/tonne</td>
<td>1123</td>
<td>1129</td>
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<tr>
<td>Cost per litre</td>
<td>SEK/l</td>
<td>0.9</td>
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<tr>
<td>Cost per litre gasoline eq.</td>
<td>SEK/l</td>
<td>1.8</td>
<td>1.8</td>
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<tr>
<td><strong>Corresponding in USD</strong></td>
<td>USD/g</td>
<td>0.86</td>
<td>0.87</td>
</tr>
</tbody>
</table>

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

Gasoline:
- V.A.T.: 1.90
- CO2 tax: 1.77
- Energy tax: 2.94
- Distribution: 1.05
- Production: 1.83

Methanol:
- V.A.T.: 1.90
- CO2 tax: 2.94
- Energy tax: 1.35
- Distribution: 3.30

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

Potential sales price at mill gate
<table>
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<tr>
<td><strong>2000 ADt/d market pulp mill</strong></td>
<td></td>
<td>54%</td>
<td>100%</td>
</tr>
<tr>
<td>Methanol</td>
<td>MSEK/a</td>
<td>411</td>
<td>760</td>
</tr>
<tr>
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<td>MSEK/a</td>
<td>85</td>
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<td>MSEK/a</td>
<td>-4</td>
<td>-4</td>
</tr>
<tr>
<td><strong>NET OPERATING BENEFIT</strong></td>
<td>MSEK/a</td>
<td>-26</td>
<td>215</td>
</tr>
</tbody>
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**Incremental Net Operating Benefit**

- MSEK/a: 241, 438
- SEK/ADt: 383, 695

*corresponding in million USD per year*

- 30, 55

*corresponding in USD per tonne of pulp*

- 48, 87
Sensitivity Analysis

Methanol Production Cost
(SEK/l.g.e.)

Investment
Electricity
Biomass
Annuity factor

Sensitivity Analysis

Methanol Production Cost
(USD/gal.g.e.)

-50% -25% 0% 25% 50% 75% 100%
Outline

• Background
• Process
• Mass and Energy Balances
• Technology Status
• Conclusions
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
Thank You!