CHEMREC

Black Liquor Gasification Technology

Presentation at
Workshop on Liquid Biofuels from Black Liquor Gasification

IEA Bioenergy ExCo Meeting
Ottawa, Canada October 6, 2004

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www.chemrec.se
CHEMREC SCOPE OF BUSINESS

The Scope of Business of Chemrec AB shall be:

“Technical Development and Commercialisation of energy and chemical recovery systems based on black liquor gasification”.
Contents

3. The Chemrec BLGMF concept
4. Impact of introducing the BLGMF concept
   - Sweden
   - Canada and the US
5. BLGMF economics
6. Development status
7. Funding requirement and structure
The Pulp Mill
Composition of Wood and Black Liquor

<table>
<thead>
<tr>
<th>Wood Type</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Lignine</th>
<th>Extractives + others</th>
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<tbody>
<tr>
<td>Spruce</td>
<td>42%</td>
<td>28%</td>
<td>27%</td>
<td>3%</td>
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<tr>
<td>Fir</td>
<td>41%</td>
<td>28%</td>
<td>27%</td>
<td>4%</td>
</tr>
<tr>
<td>Birch</td>
<td>41%</td>
<td>34%</td>
<td>21%</td>
<td>4%</td>
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Black Liquor Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>% Mass</th>
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<tbody>
<tr>
<td>C</td>
<td>34.55</td>
</tr>
<tr>
<td>H</td>
<td>3.59</td>
</tr>
<tr>
<td>S</td>
<td>4.35</td>
</tr>
<tr>
<td>O</td>
<td>34.70</td>
</tr>
<tr>
<td>Na</td>
<td>18.45</td>
</tr>
<tr>
<td>K</td>
<td>2.96</td>
</tr>
<tr>
<td>Cl</td>
<td>1.40</td>
</tr>
<tr>
<td>N</td>
<td>-</td>
</tr>
<tr>
<td>Total (%)</td>
<td>100.0</td>
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Combustible Characteristics

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<tr>
<th>BL, Dry Solids</th>
<th>% Mass</th>
<th>HHV MJ/kg, DS</th>
<th>NHV MJ/kg, DS</th>
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<tr>
<td></td>
<td>80%</td>
<td>14.2</td>
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## Recovery Boilers in Sweden

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<th>Site Nr.</th>
<th>Mill - Owner</th>
<th>Capacity tDS/24h</th>
<th>Start-up</th>
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<td>1250</td>
<td>1980</td>
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<tr>
<td>2</td>
<td>Munksund - SCA</td>
<td>600</td>
<td>1965</td>
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<td>3</td>
<td>Kraftliner Piteå - Kappa</td>
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<td>1972</td>
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<td>4</td>
<td>Obbola - SCA</td>
<td>850</td>
<td>1962</td>
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<tr>
<td>5</td>
<td>Husum - M-Real</td>
<td>750</td>
<td>1965</td>
</tr>
<tr>
<td>6</td>
<td>Husum - M-Real</td>
<td>700</td>
<td>1978</td>
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<td>7</td>
<td>Domsjö</td>
<td>1100</td>
<td>1988</td>
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<tr>
<td>8</td>
<td>Dynäs - Frantschach</td>
<td>375</td>
<td>1958</td>
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<td>9</td>
<td>Östrand - SCA</td>
<td>375</td>
<td>1964</td>
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<td>10</td>
<td>Iggesund - Holmen</td>
<td>915</td>
<td>1978</td>
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<td>11</td>
<td>Husum - M-Real</td>
<td>1500</td>
<td>1982</td>
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<td>12</td>
<td>Iggesund - Holmen</td>
<td>520</td>
<td>1966</td>
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<td>13</td>
<td>Karlsborg - Billerud</td>
<td>1000</td>
<td>1999</td>
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<tr>
<td>14</td>
<td>Norrsundet - Stora</td>
<td>540</td>
<td>1970</td>
</tr>
<tr>
<td>15</td>
<td>Norrsundet - Stora</td>
<td>460</td>
<td>1965</td>
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<td>16</td>
<td>Korsnäs - Kinnevik</td>
<td>865</td>
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<td>17</td>
<td>Korsnäs - Kinnevik</td>
<td>1550</td>
<td>1987</td>
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<td>Skutskår - STORA</td>
<td>585</td>
<td>1967</td>
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<td>19</td>
<td>Skutskår - STORA</td>
<td>1500</td>
<td>1976</td>
</tr>
<tr>
<td>20</td>
<td>Frövi - ASSI Domän</td>
<td>520</td>
<td>1970</td>
</tr>
<tr>
<td>21</td>
<td>Skoghall - STORA</td>
<td>300</td>
<td>1957</td>
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<td>22</td>
<td>Skoghall - STORA</td>
<td>910</td>
<td>1969</td>
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<td>23</td>
<td>Gruvön - Billerud</td>
<td>500</td>
<td>1959</td>
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<tr>
<td>24</td>
<td>Gruvön - Billerud</td>
<td>760</td>
<td>1972</td>
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<td>25</td>
<td>Gruvön - Billerud</td>
<td>2500</td>
<td>2000</td>
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<tr>
<td>26</td>
<td>Billingsfors - Munksjö</td>
<td>230</td>
<td>1976</td>
</tr>
<tr>
<td>27</td>
<td>Bäckhammar</td>
<td>570</td>
<td>1976</td>
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<td>28</td>
<td>Aspa - Munkajö</td>
<td>510</td>
<td>1973</td>
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<td>Skärblacka - Billerud</td>
<td>600</td>
<td>1962</td>
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<td>Skärblacka - Billerud</td>
<td>1250</td>
<td>1976</td>
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<tr>
<td>31</td>
<td>Vårö - Södra</td>
<td>1400</td>
<td>1972</td>
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<td>32</td>
<td>Vårö - Södra</td>
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<td>33</td>
<td>Mönsterås - Södra</td>
<td>1800</td>
<td>1979</td>
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<td>34</td>
<td>Mönsterås - Södra</td>
<td>4000</td>
<td>1996</td>
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<tr>
<td>35</td>
<td>Mörrum - Södra</td>
<td>2000</td>
<td>1995</td>
</tr>
<tr>
<td>36</td>
<td>Mörrum - Södra</td>
<td>740</td>
<td>1970</td>
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</tbody>
</table>

### Total No. of boilers: 37
### Total capacity: 36195 tDS/24h

39 TWh (LHV) Year 2000
Illustration of Recovery Boiler Capacities in Europe

- • clusters of mills together having a large boiler capacity
- • important single mill
Contents

3. The Chemrec BLGMF concept
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Drivers for Technology Change

<table>
<thead>
<tr>
<th>Possible Achievements with Gasification</th>
<th>Atmospheric Booster</th>
<th>Pressurized BLGCC/MF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop Technology for Incremental Capacity</td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>Improved Cooking Methods (More pulp per ton of wood)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Improved Energy Recovery (Power or Automotive Fuels)</td>
<td></td>
<td>X</td>
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<tr>
<td>Improved Safety</td>
<td>X</td>
<td>X</td>
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</table>
Years of Start-up and Re-build of North American Recovery Boilers

Number of boilers


SOURCE: Weyerhaeuser

10/6/2004 11

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START-UPS RE-BUILDS
1000 Years of Global CO$_2$ Change
Oil- and Natural Gas Consumption History and Prognoses

- Crude oil supply
- Unconventional oil
- Heavy etc.
- Polar
- NGL
- Natural gas supply
- Non-con gas
- Total oil and gas demand
- Discovered oil fields

Discoveries (Oil and Gas)

Oil Consumption

Oil and Gas

Gigabarel oil equivalent

Years: 1930 to 2050

Oil and Gas Consumption
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Technology of today for the Recovery of Cooking Chemicals

Wood chips → Digester → Weak black liquor → Concentrators

White liquor → Causticizing → Green liquor → Dissolving tank

Strong black liquor → Recovery Boiler

Steam → Boiler

Flue gas → Smelt

Weak wash → Recovery Boiler
Gasification Technology for the Recovery of Cooking Chemicals

Wood chips → Digesters → Weak black liquor → Concentrators → Strong black liquor → Gasifier

White liquor → Causticizing

Green liquor → Causticizing

RAW GAS
Main Blocks in a Pulp & Paper Mill

Pulp Wood

Internal heat and power

Pulp Mill

Black Liquor

Green Liquor

Pulp

Power Boiler

Recovery Boiler

Pulp
P&P Mill with Motor Fuel Production and Heat/Power Unit

- Pulp Wood
- Internal heat and power
- Biomass fed power boiler or IGCC
- Additional Renewable Energy
- Black Liquor
- BLGMF
- Methanol/DME
- Green Liquor
- Pulp
- Pulp Mill

Additional Renewable Energy

Methanol/DME

BLGMF

Green Liquor

Pulp

Pulp Mill

Internal heat and power

Biomass fed power boiler or IGCC

Additional Renewable Energy

Methanol/DME

BLGMF

Green Liquor

Pulp

Pulp Mill
Black Liquor Gasification with Motor Fuels Production (BLGMF)

Air Separation

Gasification & Gas Cooling

Gas Clean-Up & Sulfur Handling

Methanol / DME Synthesis

Oxygen

Black Liquor

Green Liquor

Syngas

High-Sulfidity Liquor

Methanol / DME
Gasification Technology Principles

- Black Liquor
- Atomizing medium
- Oxygen
- GASIFIER
- GAS AND SMELT SEPARATION
- QUENCH
- ATOMISATION
- GAS COOLER
- C.W
- BFW
- CLEAN COOLED SYNGAS
- LP-Steam
- MP-Steam
- Raw Syngas
- HX
- Green Liquor
- Weak wash
- PARTICULATE REMOVAL & CONDENSATE RECOVERY
- Condensate
BLGMF Process: Biomass-to-fuel Efficiency

Case: Power Boiler

Production Efficiency = \frac{\text{Methanol/ DME}}{\text{Additional Renewable Energy}} = 65-70\%
BLGMF Process: Biomass-to-fuel Efficiency
Case: Power IGCC

Production Efficiency = \frac{\text{Methanol/ DME}}{\text{Additional Renewable Energy}} = 80-90 \%
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Production potential in Sweden

Available black liquor energy in Swedish pulp mills

- 20 TWh* DME
- 20 TWh Metanol
- 24 TWh Hydrogen

Case with biomass fed power boiler

30 TWh added biomass

Black Liquor energy
39 TWh

* Corresponds to approx. 30% of Swedish consumption of gasoline and diesel year 2000
Overall energy balance for all Swedish pulp Mills (figures for year 2000)

Swedish Pulp Mills year 2000

17 TWh bioenergy, 5 TWh oil and 20 TWh el. (1999/2000)

PULP WOOD *)
Approx. 90 TWh

PULP
ca 50 TWh

*) As pulp wood and as biomaterial from saw mills
Overall energy balance – Fuel generation at all Swedish pulp Mills using the BLGMF process (figures for year 2000)

PULP WOOD *)

Approx. 90 TWh

Swedish Pulp Mills year 2000

17 TWh bioenergy, 5 TWh oil and 20 TWh el. (1999/2000)

20-30 TWh **)

PULP
ca 50 TWh

Automotive Fuels (DME and/or Methanol)

20 TWh

*) As pulp wood and as biomaterial from saw mills

**) Depending on energy conversion technology

Volvos new D9A engine will be adopted for DME
## Recovery Boilers in Canada

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
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<td>Canada</td>
<td>ABITIBI-CONSOLIDATED INC.</td>
<td>ABT-BC-CONSOLIDATED BC</td>
<td>FORT FRANCES, ON</td>
<td>340</td>
<td>190</td>
<td>1</td>
<td>956</td>
<td>1971</td>
<td>1865</td>
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<td>1866</td>
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<td>AVENOR INC.</td>
<td>ROCKY MOUNT CORPORATION</td>
<td>CATTARAUGUS, NY</td>
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<td>270</td>
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<td>344</td>
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<td>1</td>
<td>1100</td>
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<td>1866</td>
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<td>1045</td>
<td>1990</td>
<td>1866</td>
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</table>

**Total**:

- Total Pulp Capacity: 15322 tpd
- Chemical Pulp Capacity: 13062 tpd
- Recovery Boilers: 72026
- Recovery Boiler Capacity (Yield): 95 TWh/yr

**Notes**: 72026 tpd => 95 TWh/yr
Pulp and Paper Mills in Canada
Production Potential – North America

Biomass Boiler Case

260 TWh Biomass Energy

Equals

50 milj metric tons dry biomass

Available black liquor Energy in North American pulp mills

Black Liquor energy 350 TWh

175 TWh* DME

or

175 TWh* Methanol

or

210 TWh Hydrogen

* Corresponds to 7% of Canadian plus 2% of US automotive fuels consumption
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The “BLGMF” Study
Supported by the EU Altener II Program and the Swedish National Energy Administration

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

NYKOMB SYNERGETICS
Process engineering consultant

STFI
Research centre for pulp and papermaking

National gasoline and oil distributor

Chemrec
Gasification technology supplier

Methanex
World's largest methanol producer and distributor

Ecotraffic
Automotive fuel and engine consultant

Volvo
World-known automotive and engine developer
### Cost of fuel at pump, EUR or SEK per liter gasoline equivalent

*(incl. distribution cost but excl. taxes)*

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>SEK/l.g.e.</th>
<th>EUR/l.g.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>10.0</td>
<td>1.25</td>
</tr>
<tr>
<td>EtOH (Wheat)</td>
<td>11.0</td>
<td>1.37</td>
</tr>
<tr>
<td>EtOH (Wood)</td>
<td>11.0</td>
<td>1.37</td>
</tr>
<tr>
<td>MeOH (NG)</td>
<td>9.0</td>
<td>1.12</td>
</tr>
<tr>
<td>MeOH (Biomass gasification)</td>
<td>8.0</td>
<td>1.00</td>
</tr>
<tr>
<td>MeOH/DME, this study</td>
<td>4.5</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*Source: Swedish National Road Administration, 2002*

- CO$_2$ tax: 2 USD/gal
- Gas prices: 1.5 USD/gal

**Legend:**
- **Yellow Bars:** Fuel cost projections
- **Red Bar:** MeOH/DME, this study
Fuel output from use of 1 MJ of energy

The BLGMF study

Source: Volvo

* Same for MeOH
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Pressurised BLG Development

- Air separation
- Oxygen
- MP/LP Hot Steam water
- Gasification
- Gasifier
- Quench
- Counter Current Condenser
- Gas cooling
- Raw gas
- Condensate
- Syn Gas
- Gasifier
- Quench
- Gasification
- Condensate
- Gas Clean-up
- Absorber
- Stripper
- Sulphur handling
- Sulphur generation
- Polysulfid - generation
- Sulphur handling
- Polysulfide
- White Liquor
- Gas
- Electric Power or Synfuel Plant
- Electric Power or Methanol/ DME
## CHEMREC DEVELOPMENT PLANTS
### DP-1 & DP-2

<table>
<thead>
<tr>
<th>Plant</th>
<th>Location</th>
<th>Process Units</th>
<th>Capacity tDS per d / MW$_{t}$</th>
<th>Pressure (bar)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP1*)</td>
<td>Piteå, North Sweden</td>
<td>- Gasification</td>
<td>20 / 3</td>
<td>32</td>
<td>- Verify Plant technical features.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Gas Cooling</td>
<td></td>
<td></td>
<td>- Secure performance for DP-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Gas Cleaning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP2*)</td>
<td>Kappa Kraftliner</td>
<td>- Full BLGCC concept</td>
<td>~300 / 45</td>
<td>32</td>
<td>- Fully develop the BLGCC concept.</td>
</tr>
<tr>
<td></td>
<td>Piteå</td>
<td></td>
<td></td>
<td></td>
<td>- Net product approx .10 MW$_{e}$ and 35 t/h of steam.</td>
</tr>
</tbody>
</table>

*) Plant Investments Supported by a Grant from the Swedish Government of 238 MSEK, approx 25 Mill €
CHEMREC’S DP-1 PLANT AT PITEÅ
DP1 Piping Model – From the mill side
## Time Schedule Pressurized BLG Development

A US CD-plant project is planned to start after evaluation of Swedish DP-1 operating results.
The RENEW Project: Biomass to Liquid Fuels
A Project within EU’s 6th Framework Program

Wood
- SP1: Entrained Flow CarboV at Atm. Pressure
- SP2: Press. Entrained Flow at 30 bar
- SP3: Entrained Flow Gasification of Black Liquor

Straw
- SP1: Gas treatment
- SP2: Gas Cleaning
- SP3: Gas treatment

Energy Crops
- SP4: Thermochemistry for Bioethanol & Enzymatic pathway
- SP4: Gas treatment
- SP2: Catalytic Cracking

Chemec
- Fluidized bed reactor
  Used for SP2 FT-fuel

Volvo

STFI

Södra Cell

Ecotraffic

Coordinator: Volkswagen

4 years
30 partners
~30 MMUSD

Liquid Fuels

Gaseous Fuels

BTL Fuel

DME / Methanol

Automotive Testing

Biofuel Assess.

Optimum fuel production
Indust. & Polit. Recommendations

41
Overall Concept for the SP3 BLGMF Plant

~35MW Extra Biomass to compensate BLGMF Fuel generation

Södra Cells Pulp Mill at Mörrum

WOOD FOR PULPING

45 MW Black Liquor

Green Liquor

Gasification

Gas Cleaning + Synthesis

BLGAMF PLANT

O2 Plant

CO2

Sulphur

PULP/PAPER

Expanded Mill incl. BLGMF

22 MW ~ 4 t/h of MeOH (or corresp. DME)
Renew SP3

SP3 will determine technical and commercial impact of locating a small BLGMF plant at a pulp mill

Key input from work at four locations:

1. Chemrec’s Development Plant under construction in Piteå, north Sweden – Start-up 4th quarter 2004
2. Södra Cell’s pulp Mill in Mörrum, South Sweden
3. STFI laboratories in Stockholm
4. VOLVO Engine Development Laboratories in Gothenburg
Södra Cell Mörrum Mill
Södra Cell Mörrum Mill with Planned BLGMF Plant

Biomass To the Mill: ~650MW

Black liquor usage: ~360MW

Black liquor: ~45MW

Planned BLGMF Demonstration

DME & Methanol
Contents

3. The Chemrec BLGMF concept
4. Impact of introducing the BLGMF concept
   - Sweden
   - Canada and the US
5. BLGMF economics
6. Development status
7. Funding requirement and structure
Chemrec New Financial Structure (Capital Requirement, MUSD)

Participants

- Pulp & Paper Industry
- STEM
- Research Foundations
- Energy Industry

Swedish Universities

BLG Program including
1. The R&D pgm
2. The development plant

Shareholders

- Engineering Services Supplier
- Industrial Actor
- Financial investor
- Nykomb Synergetics

Chemrec AB

Swedish Energy Agency

Capital Requirement: 1.6 MUSD

- 8.4
- 1.1
- 4.0
- 1.3
- 1.3
- 1.3
- 1.3

10/6/2004
Two Phases in the BLG R&D Program

0. Co-ordination
1. Reactor/nozzle CFD modeling
2. Quench/Cooler CFD modeling
3. Inorganic Chemistry
4. Reaction kinetics
5. Direct Caustication with borates
6. Alternate cooking cycles
7. Non process elements
8. Construction mtrl for green liquor
9. Multi-disciplinary System Analysis

Phase 1

Phase 2

MUSD / phase

2.4

5.7

2001 - 2003

2004 - 2006
Chemrec New Financial Structure (Capital Requirement, MUSD)

Financing in Place

Participants

- Pulp & Paper Industry
- STEM
- Research Foundations
- Energy Industry
- Swedish Universities
- BLG Program including
  1. The R&D pgm
  2. The development plant

Shareholders

- Engineering Services Supplier
- Industrial Actor
- Financial investor
- Nykomb Synergetics

Swedish Energy Agency

1.6

1.3

4.0

1.1

8.4

Financing in Place

10/6/2004
## Chemrec Pitea BLG User Group

<table>
<thead>
<tr>
<th>Nordic Companies:</th>
<th>Status re. User Group participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa Kraftliner</td>
<td>Provides land for DP-1 and favourable media supply</td>
</tr>
<tr>
<td>SCA</td>
<td>Committed to contribute cash and in kind</td>
</tr>
<tr>
<td>SVEASKOG</td>
<td>Committed to contribute cash</td>
</tr>
<tr>
<td>Södra Cell</td>
<td>Committed to contribute cash and participates with Chemrec in Renew EUproject</td>
</tr>
<tr>
<td>Vattenfall</td>
<td>Committed to contribute cash</td>
</tr>
</tbody>
</table>
Chemrec Pitea BLG User Group

North American Companies:  

- Weyerhaeuser  
- International Paper  
- Georgia Pacific  
- StoraEnso NA  
- Mead Westvaco

Status re. User Group participation

Since several years these companies work together with the DOE in the area of biomass and black liquor gasification. Meetings have been held in June and July, 2004 for definition of a novel “US Biorefinery concept”

Objective: The above companies discuss to formalize a USBLG consortium in a legal entity owned jointly by the companies and partly funded by the DOE. Chemrec AB hope that the consortium during the second half 2004 will negotiate participation in Chemrec’s DP-1 effort in Piteå.
One solution! Questions?

NO NEED TO WORRY ABOUT PETROLEUM RESERVES... OUR LATEST SPORT UTILITY VEHICLE IS EQUIPPED WITH ITS OWN DRILLING RIG!