Potential for Bio-CCS in the pulp and paper industry

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Market and regulatory issues related to Bio-CCUS Workshop Brussels, 16 January 2018
Bio-CCS $\rightarrow$ negative CO$_2$ emissions

<table>
<thead>
<tr>
<th>CARBON POSITIVE</th>
<th>CARBON NEUTRAL</th>
<th>CARBON NEGATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 100°C</td>
<td>100°C</td>
<td>100°C</td>
</tr>
<tr>
<td>FOSSIL FUEL 100°C</td>
<td>100°C</td>
<td>+ 10°C</td>
</tr>
</tbody>
</table>

Fossil fuel without CCS  Biomass without CCS  Biomass with CCS
Pulp and paper mill

Wood yard

Cooking

Washing

Delignification

Bleaching

Oxygen plant

Bleaching chemical preparation

Evaporation

Recovery boiler

Multi-fuel boiler

Power generation

Recausticizing

Lime kiln

Courtesy of Valmet
Battery limits reference cases

Integrated pulp and board mill

Market pulp mill

Pulp mill

Board mill

800 000 adt/a

400 000 adt/a

740 000 adt/a

Total CO₂ 2.19 Mt/a
Biogenic CO₂ 2.07 Mt/a
## Case studies

<table>
<thead>
<tr>
<th>Capture case description</th>
<th>Total emissions (site after CCS) [MTPY]</th>
<th>Total CO₂ captured [MTPY]</th>
<th>Overall CO₂ capture rate [%]</th>
<th>Total direct CO₂ avoided [%]</th>
<th>Negative CO₂ emissions [MTPY]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KRAFT PULP MILL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Recovery boiler</td>
<td>684 000</td>
<td>1 478 000</td>
<td>68.4</td>
<td>68.4</td>
<td>1 478 000</td>
</tr>
<tr>
<td>2. Multi-fuel boiler</td>
<td>1 892 000</td>
<td>271 000</td>
<td>12.5</td>
<td>12.5</td>
<td>271 000</td>
</tr>
<tr>
<td>3. Lime kiln</td>
<td>1 965 000</td>
<td>197 000</td>
<td>9.1</td>
<td>9.1</td>
<td>111 000</td>
</tr>
<tr>
<td>4. Recovery boiler and multi-fuel boiler</td>
<td>413 000</td>
<td>1 749 000</td>
<td>80.9</td>
<td>80.9</td>
<td>1 749 000</td>
</tr>
<tr>
<td>5. Recovery boiler and lime kiln</td>
<td>487 000</td>
<td>1 675 000</td>
<td>77.5</td>
<td>77.5</td>
<td>1 589 000</td>
</tr>
<tr>
<td><strong>6. Recovery boiler, multi-fuel boiler and lime kiln</strong></td>
<td><strong>216 000</strong></td>
<td><strong>1 946 000</strong></td>
<td><strong>90.0</strong></td>
<td><strong>90.0</strong></td>
<td><strong>1 860 000</strong></td>
</tr>
<tr>
<td><strong>INTEGRATED PULP AND BOARD MILL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Recovery boiler²</td>
<td>834 000</td>
<td>1 478 000</td>
<td>64.0</td>
<td>61.5</td>
<td>1 478 000</td>
</tr>
<tr>
<td>2. Multi-fuel boiler</td>
<td>1 892 000</td>
<td>271 000</td>
<td>12.5</td>
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<td>111 000</td>
</tr>
<tr>
<td>4. Recovery boiler and multi-fuel boiler²</td>
<td>646 000</td>
<td>1 749 000</td>
<td>73.1</td>
<td>70.1</td>
<td>1 749 000</td>
</tr>
<tr>
<td>5. Recovery boiler and lime kiln²</td>
<td>706 000</td>
<td>1 675 000</td>
<td>70.4</td>
<td>67.3</td>
<td>1 589 000</td>
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<tr>
<td>6. Recovery boiler, multi-fuel boiler and lime kiln²</td>
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<td>1 946 000</td>
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<td>73.8</td>
<td>1 860 000</td>
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</tbody>
</table>

1 MP steam at 13 bar to supply CO₂ capture plant 2 CO₂ compressors driven by backpressure steam turbines. Auxiliary boiler needed
## Levelized cost of pulp (LCOP) and associated cost of CO₂ avoided

<table>
<thead>
<tr>
<th>Case</th>
<th>Kraft pulp mill</th>
<th>Integrated pulp and board mill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LCOP €/adt pulp</td>
<td>CAC €/t CO₂</td>
</tr>
<tr>
<td>Reference market pulp mill without CO₂ capture</td>
<td>523</td>
<td>-</td>
</tr>
<tr>
<td>Capture of CO₂ from recovery boiler only</td>
<td>643</td>
<td>65</td>
</tr>
<tr>
<td>Capture of CO₂ from multi-fuel boiler only</td>
<td>554</td>
<td>91</td>
</tr>
<tr>
<td>Capture of CO₂ from lime kiln only</td>
<td>543</td>
<td>83</td>
</tr>
<tr>
<td>Capture of CO₂ from recovery boiler and multi-fuel boiler</td>
<td>659</td>
<td>62</td>
</tr>
<tr>
<td>Capture of CO₂ from recovery boiler and lime kiln</td>
<td>652</td>
<td>62</td>
</tr>
<tr>
<td>Capture of CO₂ from all three sources</td>
<td>677</td>
<td>63</td>
</tr>
</tbody>
</table>

*adt = air dried tonne*
Effect of electricity price on LCOP, pulp mill

Breakeven price of pulp [€/adt]

Electricity price [€/MWh]

- Base Case
- REC
- MFB
- LK
- REC + MFB
- REC + LK
- REC + MFB + LK
Potential for Bio-CCS with negative emission credits, pulp mill

Breakeven price of pulp [€/adt] vs. Negative CO₂ emission credit [€/t] for different scenarios:
- Base Case
- REC
- MFB
- LK
- REC + MFB
- REC + LK
- REC + MFB + LK
Potential for income with CCU, pulp mill

- CO\textsubscript{2} avoided cost [€/t]
- CO\textsubscript{2} income [€/t]
Concluding remarks

- Pulp and paper potential candidate for industrial Bio-CCS demonstration
  - 75-100% biogenic CO$_2$ emissions
  - Low-hanging fruit
  - Negative emissions

- Feasibility of Bio-CCS is dependent on policy framework
  - CO$_2$ emission tax
  - Renewable energy incentives
  - Negative CO$_2$ emissions
    - ETS for feasible CO$_2$ capture from pulp and paper industry = 60 – 70 €/t
    - Long-term political instability is detrimental

- Assessment done for the pulp and paper industry, but the principals are at large the same for any industry sector emitting biogenic CO$_2$ emissions
  - Waste to energy
  - Biofuel production
  - Biomass-fired power and heat generation
  - Replacing coal or other fossil fuels with biomass (iron and steel, cement)
Full report: http://ieaghhg.org/publications/technical-reports


Thank you for your attention!