Power and CO$_2$ emissions to methanol

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Director of Business Development
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Brief history of CRI

2007
Company launched in Reykjavik

2008
Technology development

2009
Pilot plant production

2010
Plant engineering

2011
Plant construction

2012
Plant opening with 1,300 t/yr capacity
First sales (exports and domestic) Methanex invests

2013
Plant expanded to 4,000 t/yr capacity

2014
Geely (owner of Volvo Cars) invests

2015
Marketing of technology & partnerships

CO2 to fuel?
Low carbon intensity methanol: energy carrier

Renewable power or byproduct hydrogen

Transport and industry

Flue gas emissions

Methanol (or derivatives)

CRI Power-to-Liquids technology
CRI’s Power-to-Liquids platform

**Industry partners**
- Industry emissions
- Electricity
- Industry H₂ byproduct

**CRI integrated CCU and PtL solution**
- CO₂ Capture
- Hydrogen Generation
- Clean Conversion
- Low carbon-intensity methanol CH₃OH

**Offtake**
- Offtake
ETL mass energy balance and efficiency: electrolysis

Total electrical energy 9.5 MWh/t methanol with overall efficiency of 60%

0.8 MWh$_{\text{LHV}}$ thermal
0.45 MWh$_{\text{LHV}}$ electric

Flue gas
Carbon Capture
1.4 t CO$_2$

Electricity
Electrolysis
0.193 t H$_2$; 6.45 MWh$_{\text{LHV}}$

Water
O$_2$

Compression

Reaction
$\eta$=99%

Distillation
1 t MeOH
5.58 MWh$_{\text{LHV}}$

0.59 t H$_2$O
CRI first of its kind Power-to-Liquids facility in Iceland

George Olah CO₂ to methanol plant, Orkubraut 2, Grindavik, Iceland
First commissioning: 2012
Capacity expansion: 2015
CCU throughput: 5,600 t/yr CO₂
Electrolyzer capacity: 800 t/yr H₂ (1200 Nm³/hr)
Production capacity: 4,000 t/yr methanol
Framework to compare CO₂ life cycle emissions of fuels

**Gasoline & diesel**

- CO₂ → CO₂ → CO₂ → CO₂
- =84 gCO₂/MJ

**Biofuels**

- CO₂ → CO₂ → CO₂ → CO₂
- =33-54 gCO₂/MJ

- CO₂ → CO₂ → CO₂ → CO₂
- =1-8 gCO₂/MJ
First PtL plant with ISCC+ certification of sustainability

### Actual GHG emission values using ISCC EU GHG module*

<table>
<thead>
<tr>
<th></th>
<th>kgCO2e/t RM</th>
<th>gCO2e/MJ RM LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions related to raw-material:</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Emissions of electricity production (grid)</td>
<td>134</td>
<td>6.71</td>
</tr>
<tr>
<td>Emissions of steam production</td>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>Emissions of process specific inputs:</td>
<td>4</td>
<td>0.21</td>
</tr>
<tr>
<td>Emissions of waste water treatment:</td>
<td>1</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Total process-specific emissions:</strong></td>
<td>143</td>
<td><strong>7.2</strong></td>
</tr>
<tr>
<td>Plant-to-port (50 km by road)</td>
<td>7</td>
<td>0.34</td>
</tr>
<tr>
<td>Port-to-port (2000 km container ship)</td>
<td>20</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Total transport-specific emissions</strong></td>
<td><strong>27</strong></td>
<td><strong>1.3</strong></td>
</tr>
<tr>
<td><strong>Total emissions CIF Rotterdam</strong></td>
<td><strong>170</strong></td>
<td><strong>8.5</strong></td>
</tr>
</tbody>
</table>

Compared to reference value of 83.8 gCO2e/MJ fossil: >90% reduction

*Based on EU directive 2009/30/EC (FQD)
## Streams of innovation

<table>
<thead>
<tr>
<th>CRI firsts</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used CO₂ capture from industrial sources to make transport fuel</td>
<td>▶ Processes 15 mt CO₂ / day into transport fuel</td>
</tr>
<tr>
<td>Implemented large-scale electrolysis for power-to-liquids applications</td>
<td>▶ Installed capacity of multi-MW alkaline electrolyzers for hydrogen production</td>
</tr>
<tr>
<td>Delivered renewable fuel of non-biological origin to EU market</td>
<td>▶ Gasoline blending and in biodiesel in Netherlands, Sweden and Iceland</td>
</tr>
<tr>
<td>Received certification for renewable fuel of non-biological origin</td>
<td>▶ Certification of 90% reduction of CO₂ according to EU Renewable Energy Directive</td>
</tr>
</tbody>
</table>
Mitsubishi-Hitachi Power Systems Europe (MHPSE) and CRI have combined their resources to offer integrated industrial solutions for carbon capture and power-to-methanol production. By joining forces, the two companies can offer clients a complete suite of services from:

- Feasibility studies;
- Turn-key contracts, including design, construction of modularized systems;
- Pre-commissioning, erection, on-site commissioning, operator training;
- Post-purchase services and off-take contracts.
Three applications of CRI PtL platform

Energy Upgrade

Recover hydrogen released by chemical and steel plants

Capacity Utilization

Use excess thermal capacity to make hydrogen

Renewable Fuel

Use renewable energy to make hydrogen
Project at Steag Lünen coal-power plant, Germany

Input: 1 MW electric + 500 t/yr CO₂
Output: 400 t/yr methanol
Capacity: 1 t/day

MethCO₂-Horizon 2020 (€8.6/m)
Collaboration with STEAG, MHPSE, Hydrogenics and EU universities
Sources of Carbon Dioxide

Capturing carbon dioxide from flue gas with concentration >15%

Locations of concentrated CO₂

Concentrated CO₂ in EU: >1.3 billion tons
Equivalent to >27000 sites with 100 t/day capacity

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂ Mt/year</th>
<th>Number of sources</th>
<th>CO₂ percent in flue-gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power plants</td>
<td>1033</td>
<td>795</td>
<td>15%</td>
</tr>
<tr>
<td>Steel</td>
<td>153</td>
<td>62</td>
<td>15-30%</td>
</tr>
<tr>
<td>Cement</td>
<td>125</td>
<td>215</td>
<td>15-30%</td>
</tr>
<tr>
<td>Ammonia</td>
<td>17</td>
<td>42</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1328</strong></td>
<td><strong>1114</strong></td>
<td></td>
</tr>
</tbody>
</table>
Sources of hydrogen

Focusing on locations with concentrated sources of H₂ in Europe

Chemical production sites with H₂ as a by-product and concentrated CO₂

Equivalent to >100 sites with 100 t/day capacity

Long term total production of methanol 6 million tons per year
ETL mass energy balance and efficiency: captured H₂

Total energy input: 7.7 MWh/t methanol with overall efficiency >70%

- Flue gas
- COG

**Carbon Capture**
- 0.8 MWh\(_{\text{LHV}}\) thermal
- 0.193 t H\(_2\); 6.45 MWh\(_{\text{LHV}}\)
- 1.4 t CO\(_2\)

**PSA**
- 0.45 MWh\(_{\text{LHV}}\) electric
- Off gas

**Compression**
- 0.193 t H\(_2\); 6.45 MWh\(_{\text{LHV}}\)

**Reaction**
- \(\eta=99\%\)
- 0.59 t H\(_2\)O

**Distillation**
- 1 t MeOH
- 5.58 MWh\(_{\text{LHV}}\)

*Not including PSA*
Low Carbon Intensity Methanol production processes

Energy source: Electricity

Upstream technology:
- Water electrolysis
- Sodium chloride electrolysis
- Hydrocarbon arc furnace
- Hydrogen separation process

LCIM feedstocks:
- CO2
- H2

LCIM output:
- Low carbon intensity methanol
Opportunities for power-to-methanol in EU-28

Electricity market 5120 TWh*

- Unused capacity nuclear and thermal 2330 TWh
- Electricity demand 2140 TWh
- RES 660 TWh

Road fuel market 4157 TWh*

- Diesel 2970 TWh/a
- Gasoline 970 TWh
- Gas 210 TWh

Energy recovery

- Hydrogen from chlor-alkali process 9 TWh
- Hydrogen from coke-oven gas 37 TWh

Power-to-liquids

- 640 TWh

Supply of PtL methanol

- "Green" methanol 80 TWh
- Low CO₂ methanol 310 TWh

Current gasoline cons.

**33 million metric tons of oil equivalent

*Total generating capacity

Methanol from CO2 and electricity for transition to renewable power and clean fuel

1. Intermittent energy sources
2. Load-balancing power generation
3. Load-balancing PtL production
4. Low CO2 liquid fuel
5. M15-M100 Fuel blend
6. Balanced grid supply
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