Practical experience of large scale CO2-to-methanol production and sales

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Recent milestones

- 4 kt/yr plant in continuous operation since 2012; 3x capacity expansion in 2015
- Renewable methanol used as fuel in Iceland, Sweden, Netherlands, Denmark
- CRI developing new projects in EU and China
- Equity injections enable expanded engineering team, project management and research
- EU research grants awarded to build power-to-methanol plants in Germany and Sweden
## Global partnerships

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitsubishi Hitachi Power Systems Europe</td>
<td>Expert in thermal power plants. Partner in marketing CRI and Mitsubishi Hitachi technology to clients in EU</td>
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<tr>
<td>ENGIE Fabricom</td>
<td>Expert in building chemical production systems. Partner in building and commissioning solution.</td>
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<td>GEELY</td>
<td>Global car manufacturer. Investor in CRI and partner in Chinese projects and testing methanol cars.</td>
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<tr>
<td>VARO Energy</td>
<td>Through Argos Energies (NL) EU energy company and refiner. Markets methanol-gasoline blends.</td>
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<tr>
<td>Methanex</td>
<td>World largest methanol producer. Investor in CRI and potential investment and operations partner.</td>
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<tr>
<td>Perstorp</td>
<td>EU chemical company and biodiesel manufacturer. Partner in marketing low carbon intensity biodiesel.</td>
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<tr>
<td>SOLVAY</td>
<td>Global chemical company with own CC technology and interest in in power-to-methanol plants</td>
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</table>
Enabling a virtuous industrial carbon cycle with low carbon intensity methanol as an energy carrier
CRI’s integrated solution

- Industry partners
  - Industry emissions
    - Electricity generation
    - Industry H\textsubscript{2} byproduct

- Integrated CCU and Power-to-Liquids solution
  - CO\textsubscript{2} Capture
  - Hydrogen Generation
  - Clean Conversion
    - Low carbon-intensity methanol CH\textsubscript{3}OH

- Offtake
CRI first of its kind Emissions-to-Liquids facility - Iceland

Clean conversion

CO₂ capture

Output 4000 t/yr methanol from 6000 t CO₂ using 6 MWe electrolyzers

Water electrolysis
Realized plants, next projects and developing projects

CRI Iceland 2012: 4 kt

2018: 0.4 kt

EU projects
5 kt - 200 kt

2019: 0.4 kt

FreSMe

MefCO₂

CN projects
50 kt – 100 kt
(Some) Low Carbon Intensity Methanol processes

Energy source

Upstream
- Water electrolysis
- Sodium chloride electrolysis
- Hydrocarbon arc furnace
- Separation of H₂

Downstream (CRI)
- CO₂
- H₂

Output
- Low carbon intensity methanol

Gasification of waste

Syngas
EU demand for renewable fuels in 2020

Liquid automobile fuels
290 million tons oil equivalent

Petrol
74.2

Gasoline
82.4

Renewable
8.2

Bioethanol
5.8

2nd gen
2.4

Renewable methanol
1.3

Other
1.1*

Gasoil
185.9

Renewable
20.8

Gasoil
185.9

Biodiesel
13.0*

2nd gen
7.8*

Renewable
20.8

Estimated addressable market for renewable methanol:

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
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<tbody>
<tr>
<td>MeOH</td>
<td>4.3 toe</td>
<td>22.4 toe</td>
</tr>
<tr>
<td>MeOH</td>
<td>1.3</td>
<td>1.3</td>
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<tr>
<td></td>
<td>1.3</td>
<td>1.1</td>
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</table>

Fleet study with Geely M100 cars in Iceland

Geely Emgrand 7 2016
1.8 L spark-plug ignited engine
50 L M100 tank
10 L Gasoline tank
18 L MeOH/100 km
Power-to-methanol mass energy balance and efficiency

- **Flue gas** to **Carbon Capture**
  - 1.4 t CO₂

- **Electrolysis**
  - 0.193 t H₂
  - 6.45 MWh LHV
  - 1.53 t O₂

- **Compression**
  - Heat

- **Reaction**
  - η=99%

- **Distillation**
  - 1 t MeOH
  - 5.58 MWh LHV
  - 0.59 t H₂O

- **Process**
  - H₂ separation

- **Auxiliary load**
  - Heat

- **Heat**
Electricity use a matter of investment choices and scale

- 100% conversion: 9.4 MWh/t
- 91% conversion: 11.4 MWh/t

Equipment for electrolysis and compression

Equipment to manage H₂ use

Electricity Conversion Efficiency (%) vs. kWh/ Nm³ H₂
Stylized economics of production from electricity

Value “green” methanol
Premium of €250/t CO2 reduction

Price “grey” methanol
EU contract price Q4 2016: €250/t ($50/bbl)

Variable + fixed production cost*

*Including energy, consumables and labor

EU contract price Q4 2016: €250/t ($50/bbl)
Determination of market value of ‘ton of CO2 reduced’

<table>
<thead>
<tr>
<th>Date</th>
<th>Price biodiesel</th>
<th>Price diesel</th>
<th>Value of t CO2 saved:</th>
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<tbody>
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<tr>
<td>7/1/13</td>
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<tr>
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</table>

† 1.98 = 55% × 302 gCO2/MWh × 11.9
i.e. offset × diesel emissions/MWh × MWh/t

E.g.: \[
\frac{918 - 381}{1.98} = 270/tCO_2
\]
Gross margin based on price of “green methanol”

- €600/t Gross Margin
- €70/MWh electricity
- $75/bbl crude oil
- $50/bbl

Breakeven at $50/bbl and $75/bbl.
Business model based on connecting 3 industries

Manufacturing

Government

Energy

Transport

Biofuels industry
Business model based on connecting 3 industries

Manufacturing €7/tCO₂

Government

Energy €30/tCO₂

Biofuels industry

Transport €250/tCO₂
EU framework mixes two metrics: CO$_2$ reduction per unit energy and overall share of renewable energy.

- 35% min. reduction
- CO$_2$ reduction -83.8 g/MJ

Sustainable

Unsustainable

Fossil comparator

Renewable energy share 100%
The share of renewable energy and carbon footprint of electricity determine where the PtM product fits.
The share of renewable energy and carbon footprint of electricity determine where the PtM product fits.
Summary

- Power-to-methanol technology is market ready and demonstrated at scale
- Use of byproduct hydrogen can enable more rapid scale up
- EU needs to present clearer mandate and address the issue of GoO for PtX
- Blending standards for oxygenates and MtX technology important drivers