Challenges and opportunities of advanced- and biofuels for transport sector decarbonisation

“Air Liquide as facilitator for the energy transition to decarbonize the industry and transport sector”

EU-India Conference on Advanced Biofuels New Delhi 6th-8th March 2018

Dr. Armin Günther, Air Liquide Global E&C Solutions
Air Liquide Group - Key Figures
(Following the acquisition of Airgas on May, 2016)

~65,000 EMPLOYEES (1)

Present in 80 COUNTRIES

Revenue €18.1 BILLION (2)

Net profit €1.844 BILLION

More than 3 MILLION CUSTOMERS & PATIENTS

(1) As of August 1st, 2017.
(2) Excluding Welding and Diving, restated as discontinued operations.
Air Liquide - The innovative Powerhouse

5,700 employees contribute to the Group’s innovation approach which leverages: science, technologies, customer experience and the incubation of new activities

€288 million innovation expenses (2016)

296 new patents filed (2016)
AL Engineering & Construction - Our Expertise

**WITHIN AIR LIQUIDE GROUP**

- Design and build Group’s industrial gas production units
  - Solution oriented towards our gas customers
  - Plant life-cycle optimization
  - Supporting operations

**FOR OUR EXTERNAL CUSTOMERS**

- Sustainable and competitive technology & process solutions
  - Industrial gases (O2, N2, H2, CO, CO2, rare gases)
  - Energy conversion, cleanfuels, biofuels, Methanol etc.
  - CO2 capture
  - Gasification, Gas conditioning and purification

Dr. Armin Günther, EU-India Conference, 6-8 March 2018

Advanced- and biofuels for transport sector decarbonisation
Motivation - Science based

The 2015 Paris climate agreement has set a 2°C warming cap that requires a sharp reduction in the planet's GHG emissions in the next decades.

Transport sector

-> Contributes currently ~7,5 Gt of CO2 eq.

Air Liquide has the ambition to facilitate the energy transition and contribute to the decarbonisation of the Industry and transport sectors.

Global greenhouse gas emissions under different scenarios and the emissions gap in 2030.

The Emissions Gap Report 2017 - A UN Environment Synthesis Report
Technology Map: selected technologies for advanced fuels and biofuels

Feedstock:
- Vegetable Oils
- Animal Fats
- Wet biomass, landfill
- Vegetable Oils
- Animal Fats
- Biomass, Ligno MSW (Waste) conversion
- CO2 - PtX/Power to Liquid
- Ligno Cellulose, sugars

Process:
- Trans esterification
- Fermentation, Purification
- Hydroprocessing
- Thermochemical conv., Pyrolysis, Gasification, Synthesis...
- CCU, H2, CO2 separation, synthesis
- Biochemical breakdown, fermentation

Output:
- Bio Diesel
- Biomethane, ->”Blue” H2
- “Bio- & advanced fuels”, renewable H2
- MeOH, CH4
- Renewable fuels….; Chemicals

Generations of renewable/advanced fuels
Decarbonisation of the transport sector and why liquid/gaseous renewable fuels?

Renewable and reliable energy supply -> a hot topic

- CO₂ reduction
- Fuels should not be in competition to the food chain
- Return towards renewable fuels
  - View in Germany/EU: biofuels to complement energy turn-around in addition to strong focus on renewable electricity as currently perceived in the “Energy turnaround”
  - Use of existing infrastructure,
  - Demand for fuels & independence

Example for Germany; source: AGEB Arbeitsgemeinschaft Energiebilanzen status: Jan.2018
Example Methanol: - a promising Molecule, fuel - chemical

One of the largest volume chemicals in the world (about 67 MMTPY), Growing market (about +6% CAGR / year)
Potential sink for large quantities of CO2, Lowest cost liquid chemical to store energy

Air Liquide’s Methanol Track Record

- **Usage of all different feedstock**
  - Natural gas, naphtha, coal, residue..... 59 plants: total capacity of 47.0 MMTPY
- **Longstanding catalyst cooperation with Clariant**
- **R&D facilities within Air Liquide**
  - Continuous development process, screening of catalyst
- **Full service portfolio for methanol**
  - Licensing & proprietary design, Basic & detailed engineering
  - Construction, provision of industrial gases
Air Liquide Methanol - Evolution of Methanol Synthesis

**Methanol 1.0**
- High p (200 - 300 bar)
- High T (350 - 400 °C)

- 1960

**Methanol 2.0**
- Low p (<100 bar)
- Low T (<300 °C)
- Cu/Zn/Al₂O₃ (Up to 2,500 tpd)

- 1960 -

**Methanol 3.0**
- Lurgi MegaMethanol™ (5,000+ tpd)
- GigaMethanol (10,000 tpd)

- 2000 -

**Methanol 4.0**
- New reactor concept
- New catalysts
- CO₂ conversion
- Small scale
- Energy storage

- 2015 -

Advanced- and biofuels for transport sector decarbonisation
CCU - CO₂-based Methanol - a promising Concept

- flue gases
- atmosphere
- off-gases (steel, cement)
- renewable energy
- biogas
- biomass

CO₂ separation & purification → CO₂ → methanol production*

- electrolysis
- SMR*
- biomass gasification*

H₂

- gasoline (blending)
- gasoline (via MTG)
- maritime fuels
- biodiesel
- olefins (via MTP)
- energy storage
- MTBE

*co-feeding also possible
Up-scaling of a Development

Catalyst Test Unit  | Process Development Unit  | Commercialization  | Full Industrialization

Test at ideal conditions - once-through operation  | Similar to commercial plant design concept (including recycle)  | First operation at fully validated operation parameters  | Product defined and validated - implement in various projects

Advanced- and biofuels for transport sector decarbonisation
CCU - PtL - Methanol Production from CO₂ - Economics

Key messages:

- High influence of CapEx for electrolyzers
- CO₂ tax influence minor
- High influence on OpEx by electricity price and efficiency
- Limited scalability for electrolyzers capacity
- High onstream time is indispensable to master economics

![Graph showing methanol production cost vs. operating hours per year.]

Variation:
- CapEx and efficiency for electrolysis
- Cost for electricity (Exemplary calculation)
**Methanol Production from CO\(_2\) - Economics (2 / 2)**

**Key messages:**

- Strong dependency on Hydrogen price
- Biogas as source for green H\(_2\)
- Improved scalability in case of H\(_2\) from Biogas via SMR
- Prices in a range of expected green and advanced fuels for Methanol
- Mixtures of green and conventional H\(_2\) possible

---

**CO\(_2\) Utilization to Methanol (250 tpd case study)**

- Black H\(_2\) (Natural Gas) versus green H\(_2\)

---

**Chart Details:**

- **Price of Methanol [€/ton]**
- **Price of H\(_2\) [€/kg]**

- **Natural Gas based H\(_2\)**
- **Future perspective on Biogas based H\(_2\)**
- **Biogas based H\(_2\)**

---

**Graph:**

- **Renewable**
- **Black H\(_2\)**
- **Biogas based H\(_2\)**

---

**Table:**

<table>
<thead>
<tr>
<th>Price of Methanol [€/ton]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of H(_2) [€/kg]</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>750</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>250</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

---

**Graph:**

- **Price of Methanol [€/ton]**
- **Price of H\(_2\) [€/kg]**

---

**Notes:**

- Dr. Armin Günther, EU-India Conference, 6-8 March 2018
- Advanced- and biofuels for transport sector decarbonisation
Conclusion

- CO₂ reduction and independence from conventional energy carriers are the main drivers for new developed biofuels and advanced fuels which are not in competition to the food chain
- PtL for “large commodity Methanol”: enables green energy storage and subsequent chemical conversion
- Proven technology at challenged economics for methanol production from CO₂ and H₂
- Solutions to capture the added value from green methanol have to be identified (e.g. integration of downstream products)
- Air Liquide is your clean conversion partner and your partner along the renewable and CCU value chain
Any Questions?

For local contact:
Air Liquide Global E&C Solutions India private Ltd
A24/10 Mohan Cooperative Industrial Estate Mathura
Road, Delhi 110 044 India +91 11 42 59 50 50