Production and Utilization of Green Hydrogen

Mathias Mostertz
GAFOE Meeting, April 27, 2013
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program
2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications
3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification
4. Conclusion
The Linde Group
Structured in two main divisions

Linde Gas

Linde Engineering

(Headquarter Munich, Germany)

THE LINDE GROUP
(€ 15.3 billion revenue in 2012)
Clean Energy Technology Biomass Program
Overview of different pathways

**Land-based Biomass / Waste**
- Combustion
- Anaerobic digestion
- Pyrolysis/Torrefaction
- Gasification/Pyroreforming
- Hydrolysis/Fractionation
- Microbial electrolysis
- Hydrothermal Conversion
- Excretion
- Extraction
- Water splitting

**Water-based Biomass**
- Syngas
- Lignin
- Sugars
- H2
- CH4

**Artificial photosynthesis**
- Bio-oil
- CH4 (SNG)
- Ethanol
- Butanol

**Platform chemicals**
- Alcohols
- Syngas (Acetic acid, MeOH)
- Phenols
- Bio-ethylene
- Olefins

**Drop-in fuels**
- Gasoline
- Diesel
- Jet

**Other fuels**
- Hydrogen
- CH4 (SNG)
- Ethanol
- Butanol

**Energy**
- Electricity / Power
- Heat

**Combustion**
- IGCC
- Steam boiler
- SMR

**Dark**
- Bio-oil

**Syngas**
- Purification Shift/Rectisol/PSA

**Upgrade/Synthesis**
- Fermentation

**Lignin**
- Methanation (SMR)
- H2

**Sugars**
- H2

**H2 Separation/Concentration**
- Trans-Esterification
- Upgrade/Synthesis

**Energy**
- Electricity / Power
- Heat
Clean Energy Technology Biomass Program
Industrial Gas opportunities

- **Energy:**
  - Electricity / Power
  - Heat

- **Platform chemicals:**
  - Alcohols
  - Syngas (Acetic acid, MeOH)
  - Phenols
  - Bio-ethylene
  - Olefins

- **Drop-in fuels:**
  - Gasoline
  - Diesel
  - Jet

- **Other fuels:**
  - Hydrogen
  - CH4 (SNG)
  - Ethanol
  - Butanol
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program

2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications

3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification

4. Conclusion
Hydrogen Market
Existing markets and applications

- Further applications (<1000 Nm³/h): glass production, food (hydrogenation of fats), cooling of electric generators
- Only appr. 5% of produced H₂ is transported

Quellen: DOE, Fair-PR
Hydrogen Market
New and emerging markets and applications – Mobility

Conditioning
(Rectisol, PSA, liquefaction etc.)

Logistic

Front End: H₂-filling station

Automotive appl.
Combustion engine fuel cell

thermochemical H₂ generation

electrochemical H₂ generation

fossil feedstock

renewable feedstock

wind, hydro or solar power
Why Hydrogen as fuel?
New and emerging markets and applications

Hydrogen offers...

- CO2 reduction potentials
- Diversification of primary energy sources
- Zero emissions at the tailpipe
- Multiple application usages

* Especially compared to electricity based transportation

..just like batteries
Application areas for Hydrogen as fuel and Linde’s fuelling experience

**Linde’s experience**

- **Material Handling**
  - > 10 stations delivered
  - > 300,000 fuellings

- **Public Transport**
  - > 10 stations delivered
  - > 20,000 fuellings

- **Passenger Cars**
  - > 50 stations delivered
  - > 80,000 fuellings

- **Maritime / ships**
  - 2 stations delivered
  - ferry and submarines

- **Aviation**
  - Market studies

- **H2 Based CHP private homes**
  - Market studies

- **Backup Power**
  - > 10 units delivered

- **Portable Applications**
  - Market studies

Today’s focus
Linde covers the whole value added chain
Hydrogen mobility applications

<table>
<thead>
<tr>
<th>Production</th>
<th>Supply/Storage</th>
<th>Compression/Transfer</th>
<th>Dispenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional (e.g., SMR)</td>
<td>CGH₂ storage</td>
<td>Ionic compressor</td>
<td>350 bar</td>
</tr>
<tr>
<td>Green (e.g., BtH*)</td>
<td>LH₂ storage</td>
<td>Cryo pump</td>
<td>700 bar</td>
</tr>
<tr>
<td></td>
<td>Onsite SMR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Onsite Electrolysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Biomass to Hydrogen
Hydrogen Market
New and emerging markets and applications – Mobility

25% FCEV penetration in 2050 (hydrogen retail network covers 75% of EU29, giving local access to 97% of all cars)

Note: Small stations have maximum capacity of 400 kg H₂/day, medium have 1 tonne H₂/day and large have 2.5 tonnes H₂/day.

Source: EU coalition study
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program

2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications

3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification

4. Conclusion
Production of Green Hydrogen
Glycerine Pyroreforming – Linde pilot plant in Leuna (1)

Worldwide first plant for green hydrogen production from Glycerine (By-product of biodiesel production)
Start of operation: 2011
Capacity: 50 Nm³/h
NIP-funding

Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

Pyro-Reforming Unit
Glycerol Purification Unit
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program

2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications

3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification

4. Conclusion
Production of Green Hydrogen
Biomethane reforming – Linde steam methane reformer in Leuna

- Total biomethane feeding into NG grid, Germany, 2010*:
  30,650 m³(CH₄, STP)/h (0.27 % of NG consumption Germany)
→ it corresponds roughly to the NG consumption of both Leuna-SMR’s

Steamreformer I (35.000 Nm³/h hydrogen capacity)

Steamreformer II (35.000 Nm³/h hydrogen capacity)

* Biogas monitoring report 2011, Federal Network Agency Germany
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program

2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications

3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification

4. Conclusion
Production of Green Hydrogen
Gasification of solid cellulosic Biomass

**Multi-feed solid biomass**

**Hybrid biomass gasification**

**Gas processing**

- Process gas
  - H₂
  - CO
  - CO₂
  - CH₄

**Applications**

- Electricity
- H₂
- Fuel

**Goals:**
- Cost competitiveness compared to conventional small SMR
- Utilization of biomass that is not used for food or feed
- Versatile, decentralized technology
1. The Linde Group – General Overview
   - Clean Energy Technology Biomass Program

2. Utilization of Green Hydrogen
   - Existing markets and applications
   - New and emerging markets and applications

3. Production of Green Hydrogen
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Biomass gasification

4. Conclusion
Conclusions

— High amounts of conventional H₂ are already used in industry today

— Substitution by green hydrogen helps for reduction of emissions

— Today the chances/added value for companies consists in strengthening of its green image/perception and saving of CO₂-certificates

— A harmonization of the costs can be achieved by
  — further development of the technologies
  — price increase of fossil fuels
  — favorable political conditions and regulations

— Linde is active on:
  → worldwide first glycerine plant, biomass gasification, biomethane reforming, hydrogen by electrolysis
  → demonstration projects for various H₂ energy platform technologies
Thank you very much for your attention!