Agenda

1. The Linde Group – General Overview

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

3. Pathways to green Hydrogen
   - Electrolysis of water by renewable electricity
   - Chlorine-Alkali-Electrolysis with renewable electricity
   - Glycerine Pyroreforming
   - Biomethane reforming
   - Gasification of solid Biomass

4. Conclusion
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4. Conclusion
The Linde Group
Structured in two main divisions

Linde Engineering
Linde Gas

(€ 13.8 billion revenue in 2011)

(Headquarter Munich, Germany)
Product Range

- Oxygen, nitrogen, argon
- Acetylene and other fuel gases
- Welding process shielding gases
- Carbon oxide
- Hydrogen
- Medical gases
- Rare gases
- Ultra-high purity gases
- Gas application processes and services
Product Range

- Petrochemical plants
- Polyolefin plants
- LNG plants
- Natural gas processing plants
- Gas processing plants
- Hydrogen- and synthesis gas plants
- Adsorption plants
- Air separation plants
- Cryogenic plants
- Biotechnological plants
- CO$_2$-plants
- Manufacturing of plant components and modules
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Hydrogen Market
Existing markets and applications

- Further applications (<1000 Nm$^3$/h): glass production, food (hydrogenation of fats), cooling of electric generators
- Only approx. 5% of produced H$_2$ is transported
Hydrogen Market
New and emerging markets and applications – Mobility

Conditioning (Rectisol, PSA, liquefaction etc.)

Logistic

Front End: H₂-filling station

thermochemical H₂ generation

electrochemical H₂ generation

Automotive appl. Combustion engine fuel cell

fossil feedstock

renewable feedstock

wind, hydro or solar power
Linde covers the whole value added chain
Hydrogen mobility applications

Production
- Decentralization
  - Conventional (e.g., SMR)
  - Green (e.g., BtH*)

Supply/Storage
- CGH₂ storage
- LH₂ storage
- Onsite SMR
- Onsite Electrolysis

Compression/Transfer
- Ionic compressor
- Cryo pump

Dispenser
- 350 bar
- 700 bar

* 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
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Pathways to green Hydrogen
Electrolysis of water by renewable electricity – concept and status

**Status Technology**

**State of the Art:**
- Production of renewable electricity (Wind-, Hydro & PV-Power)
- Alkaline electrolysers (atmospheric and pressurised); small PEM electrolysers

**R & D / Demonstration Needs:**
- Use of excess power as feedstock
- Scale up to commercial capacity
- Dynamic operation of an electrolyzer, trailer filling, liquefier...
- Efficient purification of product gas from electrolysis
- System Integration and remote operation

**Implication**

- In Germany the EEG structure defines the value for electricity from renewable feedstocks
- Economics of Hydrogen production from renewable electricity is influenced by legislations
- **Lever for economics:**
  - Reduction of specific investment costs for electrolysis plants
  - Use of cheaper “low value” electricity like excess electricity
Pathways to green Hydrogen
Electrolysis of water by renewable electricity – HFS project

Description
— Production of green hydrogen requires renewable energy sources
— No GHG emissions for distributing and reduced CO₂ emissions according to electricity mix of the grid

Scope
— Integration of electrolyzer systems in fuelling stations and tying into the hydrogen fuelling system pathway
— Remote operation and control of the systems

Reference project
— Fuelling station in Hamburg built for Vattenfall Europe, opened in February 2012
— 2 x 60 Nm³/h electrolyzer systems installed using regenerative energy sources
— Providing CO₂-free hydrogen for inner-city transportation

| Capacity/scale | small |
| CO₂ footprint | low |
| Techn status | demo |
| Ops flexibility | good |
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The Sodium Chlorate Plant is a simple electrochemical cell that uses brine as feed and power input to produce chlorine.
Pathways to green Hydrogen
Chlorine-Alkali-Electrolysis with renewable electricity Magog plant

Description
— Liquefaction of H₂ is energy intensive
— Clean electricity generated from hydro energy is used to liquefy hydrogen

Scope
— Fossil energy is replaced by renewables

Reference project
— Linde plant located in Magog, Québec, Canada
— Plant has been in operation since early ‘90s
— Feed gas to the plant: Off-gases from sodium chlorate (electrolytic) manufacturing facility
— Capacity: 15 tons per day H₂ purification and liquefaction facility
— More than 97% of the power supply to the sodium chlorate plant and the H₂ liquefaction plant is from hydroelectric generation

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Pathways to 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
Pathways to green Hydrogen
Glycerine Pyroreforming – Linde pilot plant in Leuna (2)

— Cost-competitive technology (small to medium scale)
— Capitalizing on existing Linde technologies
— Approx. 140 kg H₂/t Glycerol
— Sustainable CO₂-footprint (CO₂ savings 46 – 80%)
— Broad range of alternative biogenic feedstocks under investigation

Glycerol, e.g., from Biodiesel production

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Pathways to 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
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Gasification of solid Biomass

**Multi-feed solid biomass**

**Hybrid biomass gasification**

**Gas processing**

**Applications**

- Multi-feed solid biomass
- Hybrid biomass gasification
- Gas processing
- Purification unit
- Process gas
  - $H_2$
  - $CO$
  - $CO_2$
  - $CH_4$
- Purified synthesis gas

**Goals:**
- Cost competitiveness compared to conventional small SMR
- Utilization of biomass that is not used for food or feed
- Versatile, decentralized technology

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Pathways to green Hydrogen
Basic Process Concept

**Advantages:**
- Compact design
- Controllability = easy
- Purified process gas

**Disadvantages:**
- Diluted process gas
- Tar formation

**AUTOTHERMAL**

**ALLOthermal**

**HYBRID**
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4. **Conclusion**
Conclusions

— High amounts of fossil H\textsubscript{2} are already used in industry today
— Substitution by green hydrogen helps for reduction of emissions
— The chances/added value for companies consists in strengthening of its green image/perception and saving of CO\textsubscript{2}-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:
  ➔ decentralised modules for green hydrogen production
  ➔ worldwide first glycerine plant, biomass gasification, biomethane reforming, hydrogen by electrolysis
  ➔ demonstration projects for various H\textsubscript{2} energy platform technologies