Hydrogen Applications Today and Tomorrow

Jens Luehring, Head of Americas and CFO
Industrial usage of hydrogen today
A wide range of markets and applications

Total production sufficient to fuel ~ 300,000,000 fuel cell cars!

Hydrogen

Refineries ~30%
- Hydrocracking
- Hydrotreating

Chemical Industry ~63%
- Ammonia 53% (Urea, Fertilizer)
- Methanol 8%
- Polymers 2% (Caprolactam, Adipic Acid → Nylon)
- Polyurethanes (MDI and TDI as Precursor for)

Metal & Glass Processing ~6%
- Direct Reduction of Iron Ore
- Forming & Blanketing Gas
- Float glass production

Others ~1%
- Rocket Fuel
- Semiconductor Industry (incl. Photovoltaic)
- Food processing
- Generator cooling

Food processing
Upcoming use of hydrogen as an energy carrier
Many new opportunities in mobility, power and heat
# Hydrogen energy & decarbonization

## Six things Linde is doing today

### Green H₂ production
- Production of certified green H₂ from bio-methane and renewable power
- R&D of new green & CO₂ reduced H₂ production technologies, H₂ recovery from blast furnace gas

### Power-to-X / Sector coupling
- Energiepark Mainz – world’s largest PEM electrolysis plant
- Development of processes for „E-Chemistry“/ „E-Fuels“
- Driving systematic investigation & implementation of Power-to-X options

### Carbon Capture & Utilization
- OASE® blue: Highly efficient CO₂ absorption from power plants and industry processes
- Development of technologies and applications for Utilisation of captured CO₂

### H₂ applications
- Development of new applications for hydrogen, e.g.
  - Portable H₂ fuel cell solution (HyMera)
  - Solutions for hydrogen as a transport fuel (forklifts, buses, trains, ships) & energy carrier
  - H₂Bike: H₂ powered E-bike

### H₂ Fueling Stations
- In-house technology „ionic compressor“ and „cryo pump“- more than 150 HFS equipped
- Active driver of H2Mobility in several world regions

### H₂ Carsharing
- „BeeZero“: world’s #1 car-sharing with FCEV
- 50 Hyundai FCEVs in Munich
- Easy access for the public
- Target: „Customer experience“, public acceptance of maturity and ease of handling
Deep dive: Energiepark Mainz
A global showcase for sector coupling

Key facts

— Connected to a wind-farm (8 MW)
— 6.3 MW peak electrolyser stacks (each 2.1 MW)
— 800 kg storage (25 MWh)
— 200 tons target annual output from 2017 onwards
— Injection in local gas grid and multi-use trailer-filling
— Budget: total 17 m€, funding: ~50% (BMWi)

Objectives

1. Local grid integration by storing fluctuating renewable power
2. Provision of ancillary services in the electricity grid
   Testing and further development of megawatt class PEM electrolysis
3. Intelligent and efficient H₂ conditioning, storage and handling, smart management structure
4. Research of effects of the increased H₂ concentrations in NG gas grid and end devices
Thanks for your attention.
Linde covers the entire hydrogen value chain. Value creation by proprietary technology and operation.

**Production**
- Conventional (e.g. SMR)
- Renewable (e.g. electrolyser)

**Conditioning**
- Compression
- Liquefaction

**Delivery/supply**
- CGH\(_2\) distribution/storage
- LH\(_2\) distribution/storage
- Pipeline distribution
- Onsite Electrolysis

**Industrial use**
- Desulphurization of fossil fuels
- Metal sintering and annealing
- Ammonia synthesis for fertilizers
- Plastics and solvent production
- Hydrogenation of oils
  - Wide range of required volumes
  - Typically low to medium pressure (from 1 to 50 bars)

**Refuelling / Mobility**
- Ionic compressor
- LH\(_2\) only
- Cryo pump
- 350 bar
- 700 bar
- 300 bar
- C\(_2\)H\(_2\)/LCH\(_2\)
Hydrogen value chain | Infrastructure
H₂ infrastructure initiatives in USA, Europe, and Japan

North America
- California H₂ Stations Road Map:
  By 2016: 51 stations
- Hot Spot California:
  CARB Advanced Clean Cars Programm/ZEV regulations
- First commercial market for utility fleet vehicles (FLT)

Europe
- 50 HFS Program of BMVI (NIP)
- Hot Spot Germany: Focus of German OEMs due to funding structure (NIP, CEP): H₂Mobility
- Various other projects in UK, Benelux, Scandinavia, etc.

Asia
- Japanese NEV funding 2016: > 80 stations
- Regional Korean HFS roll-out initiatives
- Hot Spots Japan & Korea: Focus of OEMs due to funding structure (esp. METI in Japan)
- China: growing activities

Hydrogen value chain | Hydrogen as a fuel
Fuel Cell Electric Vehicles (FCEV) best alternative

**Benefits of Fuel Cell Electric Vehicles (FCEV)**

- Zero emission tank–to-wheel
- With renewable hydrogen: near zero emission well-to-wheel
- Current ranges: 500 - 600 km
- Refuelling time: 3 – 4 min
- Silent driving like battery electric vehicles (BEV)

* Source: icct 2014
Action plan for the construction of a hydrogen refuelling network in Germany by 2023:

- ~400 stations will Germany’s public hydrogen refuelling network cover by 2023.
- ~90 kilometres lie between the H₂ fuelling stations on the motorways around the metropolitan areas by 2023.
- >10 H₂ fuelling stations will be available in each metropolitan area from 2023.

H₂ Mobility Goals:

- Synchronize HRS roll-out with FCEV ramp-up
- Create a common structure to de-risk HRS deployment
- 100 hydrogen refuelling stations in the next four years
- 200 to 400 hydrogen refuelling stations by 2023, distributed all over the country
- 250,000 FCEVs on the roads in 2023
- 350 MEUR planned investments
Hydrogen as a fuel | Bee Zero
World’s first hydrogen car sharing model

Targets

H₂ as fuel
Create awareness and bring “H₂-as-fuel” closer to the customer

Technology
Demonstrate validity of the technology and foster market development

Learning
Leverage learning experience for future H₂ projects

Data
Collect data and learn about user behaviour
Conclusion & Outlook

Energy applications @ Linde
— Well positioned due to unique competences and broad energy application portfolio
— Linde covering the full value chain creates competitive advantages

Next steps and key success factors
— Focused technology development and staged infrastructure build-up
— Stringent cost and product management e.g. for hydrogen fuelling stations

Bringing innovation to the market
— Innovations in the field of environment and resources will focus on:
  — Emission reduction & carbon footprint
  — Advanced energy conversion & clean fuels
  — Challenging feedstocks
Renewables need energy storage

- From a renewable power share of 30-50% and above, overgeneration (i.e. curtailment) and load ramping become critical and hinder further deployment
- Only storage can take up overgeneration, provide back-up capacity and ramping
- But: No single technology can fulfill all requirements

Power-to-Gas / hydrogen has unique strengths

Better than any other storage type, hydrogen can:
- create cross-links from renewable electricity to other sectors (fuels, chemicals)
- store large amounts of energy at reasonable costs (~170 GWh in one typical salt cavern ≈ ~ 2 hours of electricity consumption of Germany)
- facilitate seasonal storage (weeks to months)
Energiepark Mainz | Hydrogen in the energy system
A multitude of options for usage

- Wind park
- Electrolysis
- H₂ Storage
- Methanation
- Power generation
- Power grid
- Gas grid
- H₂ Car/Bus
- Industry / Refinery
- PtL fuel
- Power
- Hydrogen
- Methane
- CO₂
- PTL fuel

Substitution of combustion engine by fuel cell
Substitution of steam reformer hydrogen
Substitution of conv. fuel

* e.g. Fischer-Tropsch, Methanol synthesis, DME synthesis
The Group comprises three divisions: Gases, Engineering and Other Activities (the logistics services company Gist). The Healthcare product unit belongs to the Gases Division, which is divided into three reportable segments: EMEA (Europe, Middle East and Africa), Asia/Pacific and the Americas.

The five Global Governance Centres Merchant & Packaged Gases, Electronics, Healthcare, Operations and Deliver are centrally managed and operate across the regions. These units, will, for example, establish best practices and ensure that the process standards which have been defined are implemented and continually enhanced across the Group.
Gases Division
Wide range of products, services and applications

Gases
- Air Gases
  - Nitrogen (N₂)
  - Oxygen (O₂)
  - Argon (Ar)
  - Rare Gases
    - Krypton (Kr)
    - Neon (Ne)
    - Xenon (Xe)
- Other Gases
  - Acetylene (C₂H₂)
  - Helium (He)
  - Propane (C₃H₈)
  - Carbon Dioxide (CO₂)
  - Carbon Monoxide (CO)
  - Hydrogen (H₂)
- Specialty Gases
  - Pure Gases
  - Specialty Gas Mixtures
- Medical Gases
  - Medical Oxygen
  - Nitric Oxide (NO)
  - Nitrous Oxide (N₂O)

Services
- Administrative Efficiency
- Process Know-how
- Quality and Safety
- Supply Reliability

Applications
- Healthcare
- Chemistry & Energy
- Metallurgy & Glass
- Manufacturing
- Retail
- Food & Beverages
- Electronics
- Other

Linde gases are used, for example, in the energy sector, steel production, chemical processing, environmental protection and metal fabrication, as well as in glass production, food processing and electronics. The company is also a leading global supplier of premium healthcare products and services for patients with respiratory disorders.
Providing plants for chemical industry and energy-related industries

Engineering Division
Leading market position in a lot of segments

Air Separation Plants
Hydrogen and Synthesis Gas Plants
Petrochemical Plants
Natural Gas Plants

Providing plants for Linde Gas and third party customers

With around 1,000 process engineering patents and applications and about 4,000 completed plant projects, Linde Engineering is supporting the energy and environment megatrend and leveraging customer relationships for gas projects.