Innovation & Experience.
Hydrogen Technology and Infrastructure.

Thomas Zorn
1879 Foundation of “Linde Eismaschinen AG” in Wiesbaden, Germany
1895 Carl von Linde patents “process of air liquefaction”
1907 Foundation of Linde Air Products, USA
1929 Acquisition of Güldner-Motoren-Gesellschaft (Diesel engine)
1959 Linde starts production of forklifts

1991 Acquisition of company Technoplyn, Czech Republic
2000 Acquisition of gas company AGA, Sweden
2006 Acquisition of BOC, Great Britain. Linde becomes The Linde Group.
2012 Acquisition of Lincare, USA.
2013 Globally Leading Industrial Gas and Engineering Company
Mega trend: Growth markets
> 100 countries, 63’ people and € 16.7 Bn revenue (2013)

Market leader in 4 out of 5 Growth markets

- #1 South & East Asia
- #1 Greater China
- #1 Eastern Europe
- #1 South Africa
- #2 South America

Market size estimates

<table>
<thead>
<tr>
<th>Mature markets</th>
<th>2013</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~40</td>
<td>~53</td>
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<table>
<thead>
<tr>
<th>Growth markets</th>
<th>2013</th>
<th>2020</th>
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<tbody>
<tr>
<td></td>
<td>~19</td>
<td>~35</td>
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2013-2020 CAGR: ~4%
2013-2020 CAGR: ~9%

No major activity

Source: Linde data May 2013, figures for industrial gases and respiratory healthcare, excl. Japan, equipment and major impacts out of future mega-projects in energy/environment
Mega trends
Leveraging growth with our Gases & Engineering set-up

Growth Markets

Energy & Environment

Healthcare
# Technology portfolio

**Clean energy growth markets for Linde**

<table>
<thead>
<tr>
<th>Merchant Liquid Natural Gas (LNG)</th>
<th>Enhanced Oil Recovery (EOR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>![LNG Image]( Merchant Liquid Natural Gas (LNG))</td>
<td>![EOR Image]( Enhanced Oil Recovery (EOR))</td>
</tr>
<tr>
<td>— Oil vs. NG spread</td>
<td>— Maturing oil fields</td>
</tr>
<tr>
<td>— CO₂ reduction</td>
<td>— High oil prices</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Carbon Capture &amp; Storage / Usage</th>
<th>H₂ as fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>![CCS Image]( Carbon Capture &amp; Storage / Usage)</td>
<td>![H₂ Image]( H₂ as fuel)</td>
</tr>
<tr>
<td>— Regulations</td>
<td>— Zero emissions</td>
</tr>
<tr>
<td>— Funding</td>
<td>— Drive performance</td>
</tr>
<tr>
<td>— Coal reserves</td>
<td></td>
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<table>
<thead>
<tr>
<th>CO₂ Networks</th>
<th>Photovoltaic</th>
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<tr>
<td>![CO₂ Networks Image]( CO₂ Networks)</td>
<td><img src="Photovoltaic" alt="Photovoltaic Image" /></td>
</tr>
<tr>
<td>— Increasing need for CO₂ recycling</td>
<td>— Environmental impact</td>
</tr>
<tr>
<td>— Integrated solutions</td>
<td>— Efficiency-driven</td>
</tr>
</tbody>
</table>
### Application areas for Hydrogen as fuel and Linde’s experience

<table>
<thead>
<tr>
<th>Focus areas</th>
<th>Linde’s experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>-&gt; 100 stations delivered&lt;br&gt;-&gt; 120,000 fuellings</td>
</tr>
<tr>
<td>Public transport</td>
<td>-&gt; 10 stations delivered&lt;br&gt;-&gt; 30,000 fuellings</td>
</tr>
<tr>
<td>Material handling</td>
<td>-&gt; 15 stations delivered&lt;br&gt;-&gt; 1,000,000 fuellings</td>
</tr>
<tr>
<td>Backup power</td>
<td>-&gt; 10 units delivered</td>
</tr>
<tr>
<td>Maritime</td>
<td>-&gt; 2 stations delivered&lt;br&gt;Ferry and submarines</td>
</tr>
<tr>
<td>Aviation</td>
<td>-&gt; Supply of pilot projects&lt;br&gt;Market studies</td>
</tr>
<tr>
<td>Portable power</td>
<td>-&gt; Early market&lt;br&gt;Economical advantages</td>
</tr>
<tr>
<td>Advanced customer applications</td>
<td>-&gt; Multiple projects implemented</td>
</tr>
<tr>
<td>Year</td>
<td>Project/Model</td>
</tr>
<tr>
<td>------</td>
<td>---------------</td>
</tr>
<tr>
<td>2003-09</td>
<td>Hyundai Tucson iX FC</td>
</tr>
<tr>
<td>2010</td>
<td>Hyundai 1000 ix35 FCEV</td>
</tr>
<tr>
<td>2011</td>
<td>Hyundai 100 FCEV adv.</td>
</tr>
<tr>
<td>2012</td>
<td>BMW 100 BMW 7 Series H2</td>
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<tr>
<td>2013</td>
<td>Honda 200 FCX Clarity</td>
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<tr>
<td>2014</td>
<td>GM 110 Equinox</td>
</tr>
<tr>
<td>2015</td>
<td>Mercedes-Benz 200 B-Class F-Cell</td>
</tr>
<tr>
<td>2016</td>
<td>Ford 30 FCEVs</td>
</tr>
<tr>
<td>2017</td>
<td>Nissan 20 X-Trail FCVs</td>
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<tr>
<td>2018</td>
<td>SAIC 65 ROEWE 750</td>
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<tr>
<td>2019</td>
<td>Volkswagen 5 Tiguan HyMotion</td>
</tr>
<tr>
<td>2020</td>
<td>Fiat 20 Panda HyTran</td>
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<tr>
<td></td>
<td>PSA 307 CC FySiPAC</td>
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</table>
Forming of OEM alliances for FC-development
Milestones 2012/2013 - OEMs which actively work on FCEVs represent 66% of today’s world market

Market share by volume, 2011

Source: "WORLD MOTOR VEHICLE PRODUCTION OICA correspondents survey WORLD RANKING OF MANUFACTURERS Year 2011", OICA
Today numerous initiatives are ongoing in USA, Europe, and Japan.

**North America**
- **H2 as Fuel**
  - Hot Spot California: CARB Advanced Clean Cars Program / ZEV regulations
  - First commercial market for utility fleet vehicles (FLT)
- **H2 infra.**
  - California H2 Stations Road Map
  - By 2016: 68 stations.

**Europe**
- **Hot Spot Germany**: Focus of German OEMs due to funding structure (NIP/CEP)
- Various other projects in UK, Benelux, Scandinavia, etc.
- 50 HFS Program of BMVBS (NIP)
- EU: Clean Power for Transport Directive, Alternative Fuels Strategy

**Asia**
- **Hot Spot Japan & Korea**: Focus of OEMs due to funding structure (METI)
- China fast follower (?)
- Japanese HySUT Program
  - By 2015: 100 stations
- Korean HFS roll-out scenario
Linde covers the entire hydrogen value chain with in-house technology & developments

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

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 production: Variety of feedstock allows for a broad diversification and CO2 reduction.

**Conventional**
- Natural gas
- Coal gasification
- Chemical processes
- By product H2
- Grid electricity

**Renewable**
- Wind/Water/Solar power
- Biological metabolism (e.g. algae)
- Biomass gasification (e.g. wood)
- Biogas (e.g. landfill-, sewage gas)
- Bioliquid reforming (e.g. glycerol)
- Solid biomass (e.g. wood)
- Liquid biomass (e.g. glycerol)
Hydrogen production pathways
Focus: Intermittent power to hydrogen

Basic flow chart: Wind to hydrogen

Wind power → Grid → Electrolysis & Compression → Dispenser → Application / Usage

Vattenfall HafenCity, Hamburg
Milestones 2014
Opening of power to gas & multi energy station

- Total, Linde and Enertrag erect a hydrogen refuelling station including electrolysis from windpower and a trailer filling plant at the new Berlin airport.
- Electrolysis provided by Enertrag (500 kW$_{el}$; hydrogen output $\sim$100 Nm$^3$/h or 9 kg/h)
- Hydrogen fuelling station operated by Total (350/700 bar; cars and buses)
- Linde will build ionic compression, storage and trailer filling plant to take off excess hydrogen or supply additional hydrogen
- Funding via National Innovation Programme Hydrogen and Fuel Cells

Key facts
Linde’s advanced hydrogen fuelling technologies

**The Ionic Compressor**
- High throughput of 35 kg/h @ 900 bar\(^1\)
- Energy consumption reduced by 25\(^\circ\)
- Very small number of moving parts (liquid piston)
- Reduced wear and long service life
- Four times longer maintenance intervals*
- Fulfils industry standard SAE J 2601

**The Cryo Pump**
- Very high throughput of up to 120 kg/h @ 900 bar
- Energy consumption reduced by 70\(^\circ\)
- Hydrogen with highest purities
- No additional cooling system
- High reliability, little maintenance effort and low costs
- Fulfils industry standard SAE J 2601

\(1\) For one system. Modular setup allows for higher throughputs.
\(2\) In comparison to a conventional piston compressor
Progress in Hydrogen fuelling station technology development: Example Footprint

Ionic compressor, 700bar station

- 2009
- 2012

Cryopump, 700bar station

- 2013

The next step in space saving: underground storage
1. The Linde Group & Clean Energy

2. Linde’s Hydrogen Value Chain

3. Innovation & Experience in Hydrogen Refueling

4. Reference Hydrogen Refueling Stations
Linde hydrogen refueling solutions.
Reference projects prove technological maturity.

Linde reference projects

OMV, Stuttgart
TOTAL/CEP, Berlin
AC Transit, SFO Bay
Shell/CEP, Berlin
Linde Hydrogen Center Munich
Zero Regio, Frankfurt

Key facts

— More than 100 hydrogen stations equipped in 15 countries
— More than 1,000,000 successful fuelings
— Leading supplier of hydrogen fueling technologies

Key learnings

— Technological maturity reached
— High level of standardization reached
  — Standardized fueling protocol
  — Common fueling interface
— User-friendly fueling process
  — 3 min / fueling
  — Touch & feel like conventional stations
  — Integration into existing infrastructure
Hydrogen Trailer 500 bar.

Project description

— 2010: start of development of a new high-pressure tube trailer composed of modern carbon fiber-wrapped cylinder
— Extension of existing filling plant with modern compression technology from Linde for 500 bar
— 50% public funding from German government

Progress and Status

— Trailer on the road since June 2013
— > 45,000 kg successfully delivered to customer
— > 40 fillings at 500 bar
— Technical requirements: met as specified

Technical Data

— No. of composite cylinders: 100
— Operating pressure: 500 bar
— Hydrogen capacity: 1,100 kg
— Loading/unloading time: 45-60 min
Green hydrogen
Alternative feedstocks and processes

1. E.g. sewage gas, landfill gas, mine gas, etc.
2. With e.g. energy maize, liquid manure, etc. as feedstock for biogas production
3. Mainly solid biomass like woody biomass, straw, solid & lignocellulosic by-products
4. Either direct H₂ production or alternatively NH₃ generation as H₂ carrier
5. Algae biomass can be used as feedstocks for gasification and fermentation theoretically
DLR Cologne, test facility
In operation since December 2012
Linde & Daimler invest in 20 additional fuelling stations (as part of the 50 HFS program)

Key facts

— Initiative by Daimler and Linde

— Bridge the gap between demonstration (CEP) and commercialization (H2 Mobility)

— 10 + 10 additional public hydrogen stations in Germany

— Build-up in 2013, 2014, and 2015

— Strengthen existing cluster and establish links

— Will allow to drive through Germany with hydrogen cars

Distribution of stations (preliminary)
Ionic compressor 90MPa - IC90

functionality

Input 5-10bara

14bara  40bara  113bara  318bara  900bara

Stage 1  Stage 2  Stage 3  Stage 4  Stage 5

Output 900bara (1,000bara max.)

Coalescer for ionic liquid

Hydrogen 5 to 900bara

Ionic liquid

Hydraulic oil

Hydraulic/radial piston engine
Cryo Pump technology

Key facts:

- Super insulated Design
- Slow frequency drive (1.44 Hz),
- Cylinder Volume design for 120 kg/h
- Pump immersed in liquid hydrogen
- Double stage compression with LH2 feeding piston
— Stadtwerke Mainz (SWM, municipal utility), Linde, Siemens and Hochschule RheinMain are planning an electrolysis and hydrogen storage facility in Mainz/Germany

— Total investments EUR 17 m – the biggest project of this kind so far, supported by federal Ministry of Economic Affairs and Technology

— Renewable electricity (up to 6 MW) will come from a wind park

— Hydrogen storage and handling technology by Linde, including proprietary ionic compression technology

— Multiple options for H₂ product which can be …
  — delivered to H₂ fuelling stations
  — fed into the natural gas grid
  — re-electrified in one of SWM's gas-powered power plants

— Construction to start beginning of 2014, completion expected in spring 2015
## Reference project
Mobile Refueling Truck TrailH2gas™, Europe

<table>
<thead>
<tr>
<th>Start of operation:</th>
<th>2008</th>
</tr>
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<tbody>
<tr>
<td>Dispensing lines:</td>
<td>1 x 700 bar car 1 x 350 bar car</td>
</tr>
<tr>
<td>Technology:</td>
<td>Dry Runner</td>
</tr>
<tr>
<td>Main user:</td>
<td>Car OEMs &amp; Customer trials</td>
</tr>
</tbody>
</table>

### Key Features:
- Easy and flexible set-up
- Event, test & demo refueling
Thank you for your attention.