Hydrogen refuelling station – Linde’s technologies

Marek Gorecki

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The Linde Group is one of the world leading concerns producing and distributing gases and gas technologies, as well as constructing industrial installations. It employs ca. 52 thousand employees and operates in ca. 100 countries worldwide. The concern has a over century-long tradition.

The Linde Group comprises three divisions: Gases and Engineering (the two core divisions) and Other Activities. The largest division is Gases.

Linde Gaz Polska has been present in Poland since 1993 and still is one of the leading companies in the market, offering complex solutions for gas deliveries and gas technologies. The headquarters is located in Cracow and the production facilities are spread over Poland.
2.1 Introduction to hydrogen refuelling station

The Linde Group - as a world-leading hydrogen plant engineering company - is one of the driving forces behind the advancement of hydrogen production, distribution and fuelling technologies for mobility applications.

The Linde Group participates in many hydrogen projects and initiatives on hydrogen mobility matured markets.

Our technologies use in hydrogen infrastructure are patented.

Every station is extensively tested before delivery.

Delivery time is 10-12 months.
2.1 Introduction to hydrogen refuelling station

Key elements of hydrogen fuelling station

Production → Distribution → Fuelling → Vehicles

Linde hydrogen competence

Stationary applications
2.2 Hydrogen production processes

Hydrogen production pathways

**Conventional**
- By-product H₂
- Coal
- Chemical processes
- Coal gasification**
- Natural gas
- Steam Methane Reforming**

**Renewable**
- Wind/Water/Solar power*
- Biological processes (e.g. algae)
- Biological metabolism
- Biomass gasification
- Biomass gasification
- Bioliquid reforming
- Solid biomass (e.g. wood, straw)
- Liquid biomass (e.g. glycerol)
- Biogas (e.g. landfill/sewage treatment, animal waste)***

*) Intermittent power sources  **) With or without Carbon Capture and Storage  ***) Requires purification before processing in SMR
2.2 Hydrogen production processes

Conventional through steam reforming of fossil fuels such as natural gas.

Renewable such as biogenous processes or electrolysis of water with wind power, water power or solar energy.

Though hydrogen as fuel creates no emissions at the tailpipe, the production of hydrogen still generates carbon dioxide (CO2). The highest CO2 reduction can be reached by using renewable energies such as wind power, water power, solar energy and biomass. Definition of green hydrogen has to be determined.

Hydrogen quality standards (as vehicles fuel) are currently under development in SAE International (e.g., SAE J2719 “Hydrogen Specification Guideline for Fuel Cell Vehicles”) and in ASTM International.
# 2.3 Hydrogen distribution and storage pathways

## Hydrogen supply methods at a glance

<table>
<thead>
<tr>
<th>Distribution method</th>
<th>Facts</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| CGH₂ trailers       | → Transport at 20 MPa and higher  
                      → Capacity: 10,000 Nm³ | → Economical transport for short  
                      → to medium distances | → Comparatively low capacity  
                      (high delivery frequency)  
                      → Comparatively large on-site footprint (required space) |
| LH₂ trailers        | → Transport at -253 °C  
                      → Capacity: 40,000 Nm³ | → Economical transport for medium to long distances  
                      → Comparatively small footprints | → Comparatively high energy requirement (for hydrogen liquefaction) |

## On-site production

<table>
<thead>
<tr>
<th>Facts</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| → Production through steam reforming or electrolysis  
   → On-site production directly at the station  
   → Typical capacity:  
     SMR: 300 Nm³/h,  
     electrolyser: 5–100 Nm³/h (modular) | → No hydrogen transport costs | → Comparatively low output/capacity flexibility  
                      → Comparatively large footprint and complex permission process |
2.3 Hydrogen storage and distribution pathways

The methods of hydrogen distribution and storage are closely interconnected.

The main hydrogen distribution concepts based on gaseous and liquid storage systems are **CGH2/LH2 trailers** – road transport.

- **Compressed Gaseous Hydrogen (CGH2)** is stored in pressure-tight containers like cylinders, cylinder bundles, tanks, pipes.

- **Cryogenic Liquid Hydrogen (LH2)** is stored in specially insulated LH2 tanks, at minus 253 deg C.
2.3 Hydrogen distribution and storage pathways

**On-site production** - as an alternative to producing hydrogen at one place and then delivering it to the hydrogen fuelling station. Hydrogen is produced and stored directly at the hydrogen fuelling station, eliminating the cost and effort of hydrogen distribution. Two on-site hydrogen production methods are steam reforming of natural gas and electrolysis of water.

**The proper method of hydrogen supply** to fuelling stations depends on a wide range of various factors e.g.:

- the amount of hydrogen

- the distance between the hydrogen production and fuelling sites

- the required frequency of hydrogen deliveries
2.4 Hydrogen compression technologies

The compression technology is one of the most important technical elements within a hydrogen fuelling station. The choice of the proper compression technology depends on various factors:

- is the hydrogen feed liquid or gaseous?
- how much hydrogen is needed per hour?
- what is the required pressure?
- what kind of hydrogen vehicles are to be fuelled?
- what are investment and operation costs?

Linde’s hydrogen compression technology portfolio is for CGH2 and LH2, for mobile and stationary fuelling of cars, buses and forklift trucks, at pressures from 35 to 70 MPa. Linde achieves a leading TCO (Total Cost of Ownership) position with its ionic compressor and cryo pump technologies.
2.4 Hydrogen compression technologies

The ionic compressor

The basic principle is the replacement of the conventional metal piston with a ionic liquid. The gas is compressed in the cylinder by the up-and-down motion of the liquid column. Ionic liquids are made of molecules that have special physical and chemical properties: no vapor pressure, lubricating properties, no gas solubility, thermal stability and no flammability, high heat capacity.

Linde’s ionic compressor virtually eliminates mechanical wear and removes the compression heat directly in the cylinder where it is generated. The result is a compression process independent of the hydrogen supply form, which is physically ideal (almost isothermal compression).
2.4 Hydrogen compression technologies

Advantages of the ionic compressor:
- Close to 100 % energy conversion efficiency
- Low energy consumption
- Very small number of moving parts (due to use of ionic liquid as piston)
- Reduced wear and long service life
- Little maintenance effort and low costs
- Low material costs
- Low noise emission
- Conformity with fuelling standard SAE J 2601

E.g. IC90 - output: 25kg/h
  - pressure inlet/outlet: 5-200 bar/1’000 bar
  - power consumption: 75 kW
2.4 Hydrogen compression technologies

The cryo pump

The process takes full advantage of the direct compression of liquid hydrogen and by this reduces energy requirements at the hydrogen fuel system.

By using the cooling capacity of liquid hydrogen, no additional cooling of the compression process is required, which also reduces space requirements. A specially designed ambient air heat exchanger and temperature conditioning system raises the temperature of the cryogenic gas to -40 deg C. The fuelling can be carried out through a standard hydrogen dispenser.

The cryo pump allows a maximum pressure of up to 90 MPa with a fuelling capacity of up to 120 kg of hydrogen per hour.

The cryo pump is ready for operation at the push of a button, 24 h a day.
2.4 Hydrogen compression technologies

Advantages of the cryo pump:
- High throughput
- Very low energy consumption
- Hydrogen with highest purity
- No additional cooling system
- High reliability
- Little maintenance effort and low costs
- Low noise emission
- Conformity with fuelling standard SAE J 2601
2.5 Hydrogen high pressure storage system

- Hydrogen stored at high pressure - ready to immediately use
- 200 bar up to 1’000 bar
- No refill through trailers
- Only 20-30 % of \( \text{H}_2 \) usable
- Small capacity
2.6 Hydrogen fuelling dispensers

The dispenser
The last stage of the hydrogen fuelling process takes place at the hydrogen dispenser. The fuel is transferred into the storage tank on board of the hydrogen vehicle.

Linde has various types of fuelling dispensers for cars, buses and forklift trucks.

<table>
<thead>
<tr>
<th>Hydrogen fuelling dispenser portfolio</th>
<th>Name</th>
<th>Max. inlet pressure [MPa]</th>
<th>Max. fuelling pressure [MPa]</th>
<th>SAE J 2601¹</th>
<th>IR com²</th>
<th>Max. flow rate [g/sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGH₂ dispenser</td>
<td>25fork</td>
<td>42</td>
<td>31.2</td>
<td>No</td>
<td>No</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>35HF</td>
<td>50</td>
<td>43.8</td>
<td>No</td>
<td>No</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>35A</td>
<td>50</td>
<td>43.8</td>
<td>Yes</td>
<td>Yes/option</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>35B</td>
<td>50</td>
<td>43.8</td>
<td>Yes</td>
<td>Yes/option</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>70A</td>
<td>90</td>
<td>87.5</td>
<td>Yes</td>
<td>Yes</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>70B</td>
<td>90</td>
<td>87.5</td>
<td>Yes</td>
<td>Yes</td>
<td>60</td>
</tr>
<tr>
<td>LH₂ dispenser</td>
<td>LH2 A</td>
<td>0.5 (liquid)</td>
<td>1.0 (liquid)</td>
<td>Not applicable</td>
<td>Yes (wired)</td>
<td>60</td>
</tr>
</tbody>
</table>

¹) Society of Automotive Engineering (SAE) J 2601, industry wide fuelling protocol for gaseous hydrogen
²) Infrared communication
2.6 Hydrogen fuelling dispensers

The dispenser with IR communication to measure/read:
- hydrogen pressure
- hydrogen temperature
- vehicle tank capacity
2.7 Hydrogen refuelling station

Vehicle type: 700 bar car
            350 bar bus - optional
Compressor: IC 90
Max. output: 6 cars/h
Power supply: 105 kW
Supply: CGH2/LH2
SAE: yes
3. Selected references

Italy, Bolzano

The H₂ refuelling station is one of the biggest of its kind. It fuels 6 local city busses and a fleet of semi-public H₂ cars. The hydrogen is produced, stored and supplied on-site making it a self-sufficient system. Additionally the required power comes 100% from hydroelectric plants in the nearby mountains.

<table>
<thead>
<tr>
<th>H₂ Supply</th>
<th>Compressor</th>
<th>Dispenser</th>
<th>Start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3x electrolyzer</td>
<td>2x IC 90</td>
<td>2x 350 bar bus</td>
<td>2014</td>
</tr>
<tr>
<td></td>
<td>3x IC 50 (booster)</td>
<td>1x 700 bar car</td>
<td></td>
</tr>
</tbody>
</table>
USA, Spartanburg

The BMW factory is the biggest H$_2$ refuelling station for forklifts worldwide. It needs approximately 1’000 kg H$_2$ per day and supplies around 350 forklifts through 18 dispensers that are located throughout the facility. The factory is supplied by trailers with liquid H$_2$.

<table>
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<th>Dispenser</th>
<th>Start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH$_2$ delivery</td>
<td>6x IC 50</td>
<td>18x 350 bar forklift</td>
<td>2008</td>
</tr>
</tbody>
</table>
Scotland, Aberdeen

The H₂ bus refuelling station supplies the largest H₂ bus fleet in Europe, maintaining a small footprint. The electrolyzers can power up to 20 busses a day and are designed to extend to H₂ car dispensers. A second H₂ refuelling station is planned by the city in order to become the hydrogen avant-garde in Europe.

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<tr>
<td>3x electrolyzer</td>
<td>2x IC 90</td>
<td>2x 350 bar bus</td>
<td>2015</td>
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3. Selected references

Switzerland, Hunzenschwil

COOP has inaugurated the first H2 refuelling station for trucks worldwide, in line with its corporate goal of a emission-free supply chain. The station is publicly accessible and refuels both fuel cel trucks as well as fuel cell cars. More stations are planned to create a network for fuel cell trucks.

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<th>Start of operation</th>
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<tbody>
<tr>
<td>CGH2 delivery</td>
<td>2x IC 90</td>
<td>1x 350 bar bus</td>
<td>2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1x 700 bar car</td>
<td></td>
</tr>
</tbody>
</table>
4. The Linde Group – your partner for hydrogen projects

Everyone doing business with us has access to high quality gases CGH2/LH2, innovative technologies, extensive services, customised solutions.

Turnkey technologies are developed and engineered by our qualified staff.

Safety is our top priority - especially when working with hydrogen.

Marek Gorecki – Application Engineer

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Thank you for your attention.