Making our world more productive

Tomorrow's fuel today

Linde H_2 refueling technologies



H_2 fueling

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The hydrogen path to a more sustainable energy economy

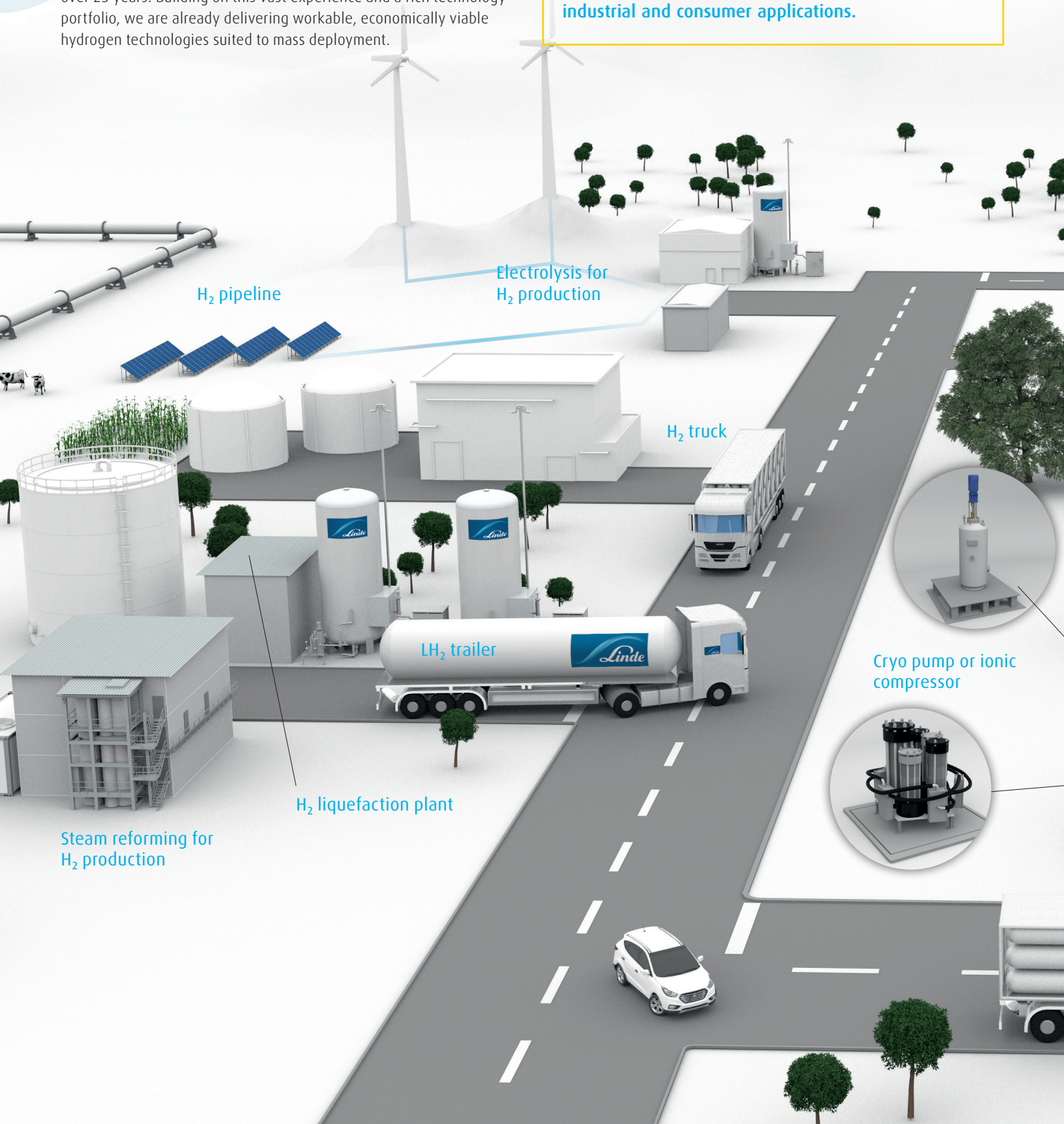
Hydrogen is set to play a key role in the gradual transition to a more sustainable energy economy. Supporting current energy models, it can be generated from natural gas and non-renewable by-products while still offering a lower carbon footprint than fossil fuels. Already today, it can be produced at scale with a zero-carbon footprint by using renewable energy such as wind power, for instance, to split water.

The range of potential applications is vast. Hydrogen is a zero-emissions source of fuel for trains, buses, trucks, cars, forklifts and ships. It is also used as a feedstock gas for industries such as steel and refining. In addition, it is a source of heat and power for buildings and an ideal buffer to store energy generated from renewable sources.

Think Hydrogen. Think Linde.

As demand for clean sources of energy like hydrogen rises, so too will the need for companies with the expertise to generate, process, distribute and deliver hydrogen at the point of use. Linde has over 100 years' experience in the production of hydrogen (H_2) and has been pioneering H_2 technologies, research and flagship mobility projects for over 25 years. Building on this vast experience and a rich technology portfolio, we are already delivering workable, economically viable hydrogen technologies suited to mass deployment.

We are the only company to cover every step in the hydrogen value chain from production and processing (including purification and liquefaction) through distribution and storage to everyday industrial and consumer applications.



To date, we have built over 500 H_2 production plants worldwide scaling from small series to large facilities – more than 100 of which are operated by Linde experts. These plants can handle all petrochemical feedstocks – from natural gas to heavy oil and coal. Leveraging processes such as steam methane reforming, gasification and partial oxidation, our H_2 plants provide highly efficient paths to syngas containing hydrogen and carbon monoxide, and to products such as ammonia. Looking towards a zero-emissions hydrogen energy economy, we have also engineered green hydrogen production plants that harness renewable sources of energy to power electrolysis or biogas reforming.



Leading expertise and know-how

The vision of hydrogen-powered mobility is compelling: Mass market cars with a built-in power plant that matches the range of combustion engines are two or even three times more efficient and emit nothing but droplets of clean water.

Some 400 million cars, 15–20 million trucks and around 5 million buses could be powered by hydrogen by 2050, according to projections by the Hydrogen Council, an industry group of which Linde is a member, which was formed to drive H_2 infrastructure build-out. This would contribute more than one-third of the total CO_2 reduction required for the road transportation sector in the 2 °C climate change scenario.

The most refueling stations worldwide

Having engineered and built more than 200 hydrogen fueling stations, Linde Hydrogen FuelTech has the most experience and the biggest installed base worldwide. Cars, buses and forklifts have already refueled over 1.5 million times using our technology. Today, we are building major bus depots in locations all around the world. We also supplied the world's first H_2 station for passenger trains. In addition, we are the only provider of liquid hydrogen fueling technologies.



BMW manufacture, Greer (SC), USA

- 14 H_2 dispensers for hydrogen-fueled material handling vehicles
- Fueling of more than 380 material handling vehicles
- Fueling in only 3 minutes
- More than 3,000 m of pipeline from the compressor to the dispensers
- 2.5 MPa (IC with additional capacity)



Aberdeen, Scotland

- Largest hydrogen fueling station in Europe
- Fueling of Europe's largest H_2 bus fleet
- More than 80 t H_2/year
- Alkaline water electrolyzers, hydrogen generation based on green electricity
- 35 MPa (2 × IC 90)



Sacramento (CA), USA

- Linde's first H_2 fueling station in the US
- 11,000-liter LH_2 tank
- Ionic Compressor IC 90
- 35/70 MPa



Emeryville (CA), USA

- First public H_2 fueling station in the Bay Area
- Extended by 350 bar dispenser for buses
- Public bus operator AC Transit fuels 12 buses per day (30 kg each)
- Ionic Compressor technology



Energiepark Mainz, Germany

- Power to gas
- Production of green H_2 for mobility applications by electrolysis with renewable energies
- Storage capacity: 1,000 kg
- Ionic Compressor technology for trailer filling



ESWE, Wiesbaden, Germany

- H_2 bus fueling station for 8 buses
- TWIN IC 60/60 (one IC 60 in operation, one being used as fall-back)
- Station capacity: 300 kg in 8 hours
- Supplied with green hydrogen from Linde's power-to-gas plant in Mainz, Germany



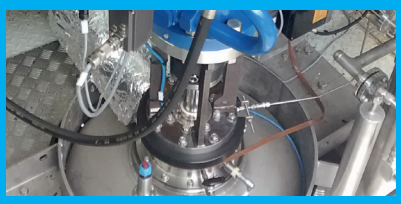
Arlanda Airport, Stockholm, Sweden

- Sweden's first public H_2 fueling station
- Capacities for up to 180 fuelings per day
- 70 MPa



CEP/Vattenfall, Hamburg, Germany

- Capacities for a large fleet of up to 20 H_2 buses
- Integration of two electrolyzers for on-site H_2 production
- 35/70 MPa (2 x Ionic Compressors)



CEP/Total, Munich, Germany

- Public fueling station
- Cryo Pump with a capacity of 100 kg/h
- 70 MPa (30 MPa for cryo-compressed fueling (CCH_2)



Iwatani, Amagasaki City, Japan

- Japan's first commercial H_2 fueling station LH_2 tank
- Ionic Compressor IC 90
- 35/70 MPa



CEP/Shell am Sachsendamm, Berlin, Germany

- One of the world's most powerful H_2 fueling stations with a capacity of up to 200 kg/h
- Below-ground installation of the storage tank and the compressor system (two Cryo Pumps)
- 35/70 MPa



Iwatani, Tokyo Ariake, Japan

- H_2 bus fueling station for the Olympic Summer Games 2021
- Cryo Pump CP 90/100
- Capacity of 100 kg/hour



OMV, Vienna, Austria

- Built in record time of less than 6 months
- Small footprint
- Austria's first public H_2 fueling station
- 70 MPa (piston compressor MF 90)



Shanghai Yilan Energy Technology, China

- The first 700 bar H_2 refueling station in China
- Equipped with IC 90/30
- 350 and 700 bar dispenser for fueling of minibuses, delivery trucks and passenger cars

Highly efficient fueling concepts

Building out the H_2 refueling infrastructure

The undisputed world leader in hydrogen fueling infrastructure, Linde Hydrogen FuelTech offers a one-stop service spanning, fueling station systems and professional services including project execution, maintenance and repairs. Our innovative solutions cover the entire range of H_2 fueling technologies – from the manufacture of dispensers for H_2 material handling vehicles to complete fueling stations for H_2 bus or car fleets.

Linde Hydrogen FuelTech specializes in ultra-efficient storage, compression and dispensing technologies offering the lowest total cost of ownership per kg and the smallest footprint per output. The company works closely with its customers to deliver hydrogen infrastructure solutions – all designed to the highest safety standards. Customers can choose the supply mode best suited to their needs – whether that be gaseous (GH_2), liquid (LH_2) or an on-site generation solution.

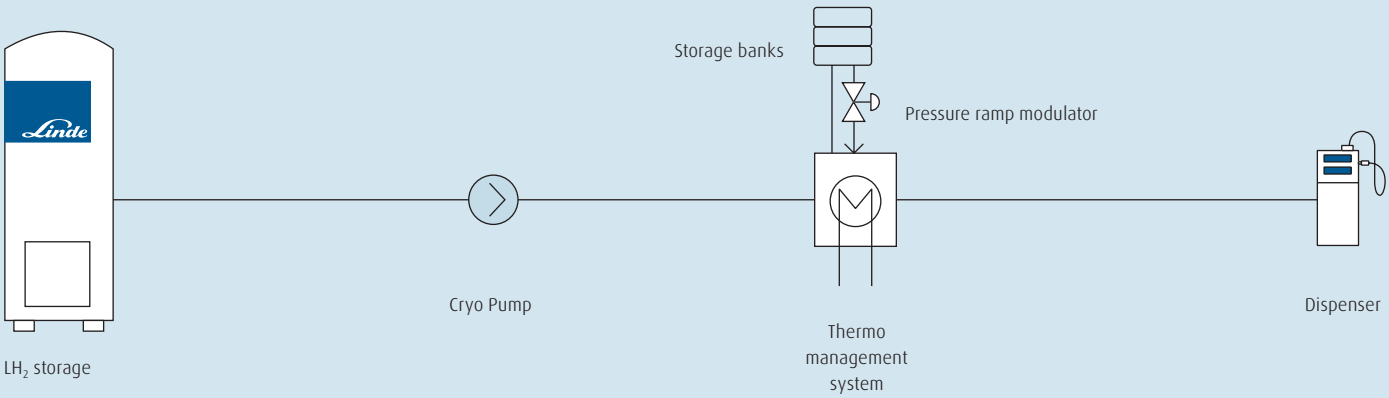
Pioneering compression and dispensing technologies

At the heart of all hydrogen fueling stations is the compressor unit. This is because hydrogen gas stored at low pressure must be compressed to increase the pressure before it can be fed into the vehicle's fuel tank. Today, hydrogen is typically transported to fueling stations as a gas. Our custom-developed, patented Ionic Compressor gradually compresses this gas to a pressure of 900 bar so it can be used to fuel vehicles. For passenger cars, for example, the gas must be at a pressure of 700 bar while larger vehicles such as buses and trains require 350 bar.

Complementing this compressed gas fueling solution, we also offer a refueling concept that enables hydrogen to be stored as a liquid. The major benefit here is that liquid hydrogen has a much higher energy density than gaseous hydrogen.

This makes LH_2 a particularly interesting option for densely populated areas where there is limited space for building or expanding fueling stations. To meet this need, we developed a series of patented Cryo Pumps for LH_2 fueling stations.

Basic concept: Cryo Pump system



Ionic Compressor and Cryo Pump highlights:

Low energy consumption

Small footprint

Low maintenance requirements &
long service life

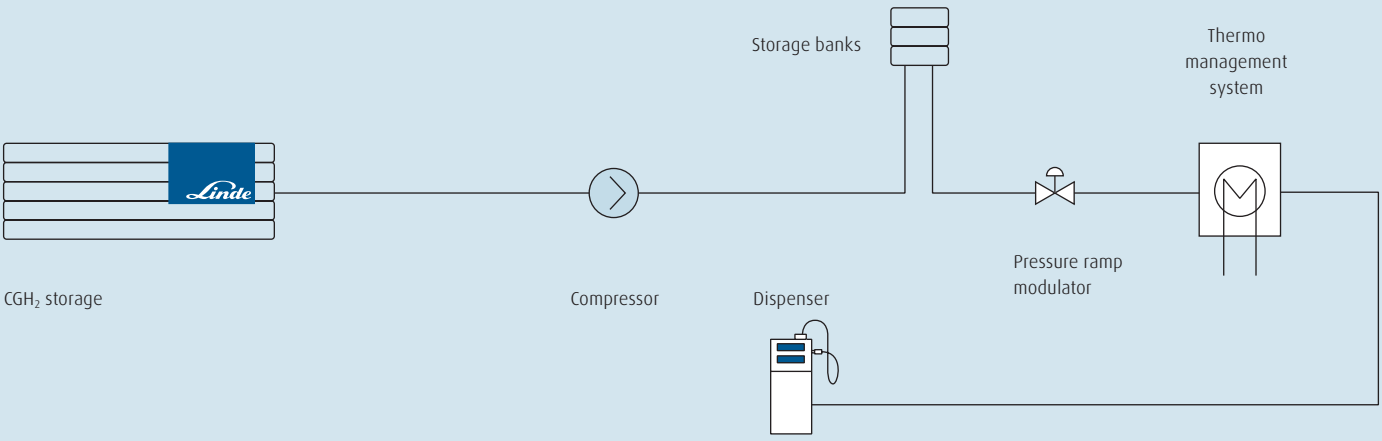
High reliability

Low noise emission



A special dispenser fills the vehicle with the hydrogen

Basic concept: Ionic Compressor system



Enabling technologies in focus





The Ionic Compressor

Designed to handle gaseous hydrogen, our patented Ionic Compressor uses five hydraulic pistons to gradually compress hydrogen to just the right pressure. Hydraulic oil below the pistons enables them to move up and down. Highlights of this compressor include the use of an ionic liquid, which does not bond with the gas. The ionic liquid on top of the pistons is compressed along with the hydrogen as a result of the upward movement. It acts as both a lubricant and coolant, and thus significantly reduces wear and tear. Additionally, the Ionic Compressor has fewer moving parts than a typical piston compressor. The liquid also increases the compressor's energy efficiency due to better cooling and fewer dead spots during the compression process. At the end of the compression cycle, any ionic liquid molecules in the hydrogen are separated and fed back to the process flow.

By eliminating the need for lubricants, the Ionic Compressor protects the hydrogen against the risk of contamination. This ensures high purity levels, making the compressor ideal, for example, for purity-critical fuel-cell applications.

The Cryo Pump

Our Cryo Pump is the solution of choice for liquid hydrogen. The LH_2 flows into the first of two pump chambers at a temperature of –253 °C. This two-chamber system is completely immersed in the cryogenic liquid. The upward movement of the piston compresses the hydrogen to approximately 6 bar and simultaneously pumps it into the second chamber. There, it is further compressed to 900 bar, where it is gaseous and at the right pressure for fueling vehicles. Subsequently, the temperature of the cryogenic gas is increased up to the fueling temperature of –40° C. During all of these process steps, the high purity level of the hydrogen is maintained.

In addition to its small footprint and high capacity, the Cryo Pump minimizes the energy required by the fueling station. Because it compresses liquid hydrogen directly, the Cryo Pump only needs 10–20 percent of the energy required by a conventional compressor. The compressed hydrogen flows through a sophisticated cooling system directly into the car. This eliminates the need for an external cooling system for the supply line. And the low-maintenance design cuts operating costs further.

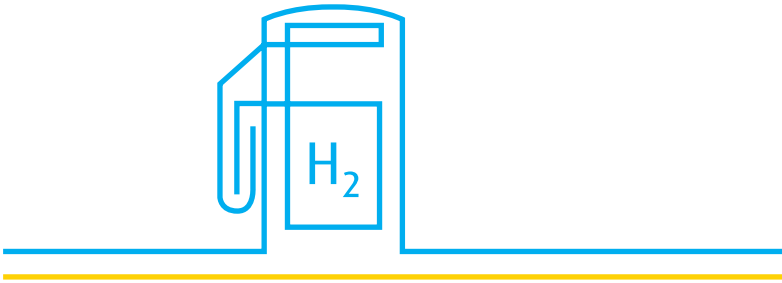
Over 200 fueling stations
with Linde H_2 technologies

Over 1.5 million fuelings
with Linde H_2 technologies

Perfect fit with wide portfolio of standardized models

At Linde Hydrogen FuelTech, we understand that fueling station needs vary considerably depending on the location and available space, the type of vehicle to be served, the expected daily throughput (i.e. capacity requirements) and the H_2 supply mode (gaseous or liquid). We have designed standardized solutions that combine the benefits of proven technologies with adaptable technical specifications to reduce costs, accelerate and simplify deployment and match performance to actual needs.

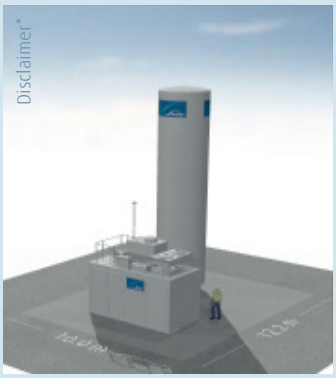
Designed for full compliance with the SAE J 2601 fueling standard, these highly compact, containerized Ionic Compressor (IC) and Cryo Pump (CP) designs scale from small series to ultra-high-volume throughputs to support all capacity requirements.



Standard fueling solutions

700 bar applications

GH_2



IC 90/30-S

- Ionic Compressor technology for GH_2 supply
- For smaller fleets of 700 bar vehicles (e.g. lightweight passenger or utility vehicles)
- Max. daily capacity: 450 kg (< 90 fuelings)
- Optional: 350 bar extension, on-site electrolysis

LH_2

350 bar applications

GH_2



IC 50/30-S

- Ionic Compressor technology for GH_2 supply
- For smaller fleets of 350 bar vehicles (e.g. buses, trucks, trains or forklifts)
- Max. daily capacity: 450 kg (< 15 fuelings)
- Optional: 700 bar extension, on-site electrolysis

LH_2

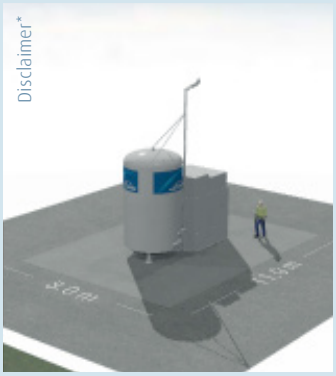
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Fueling demand



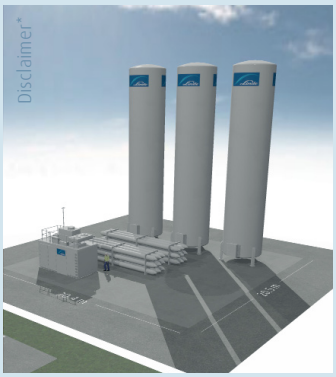
Twin IC 90/60-L

- Ionic Compressor technology for GH_2 supply
- For larger fleets of 700 bar vehicles (e.g. lightweight passenger or utility vehicles)
- Max. daily capacity: 900 kg (< 180 fuelings)
- Optional: 350 bar extension, on-site electrolysis



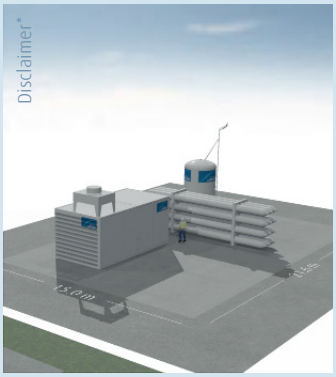
CP 90/40-L

- Cryo Pump technology for LH_2 supply
- For larger fleets of 700 bar vehicles (e.g. lightweight passenger or utility vehicles)
- Max. daily capacity: 950 kg (< 200 fuelings)
- Optional: 350 bar extension



Twin IC 50/60-L

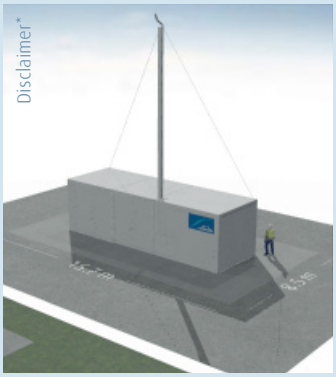
- Ionic Compressor technology for GH_2 supply
- For larger fleets of 350 bar vehicles (e.g. buses, trucks, trains or forklifts)
- Max. daily capacity: 900 kg (< 30 fuelings)
- Optional: 700 bar extension, on-site electrolysis



CP 50/40-L

- Cryo Pump technology for LH_2 supply
- For larger fleets of 350 bar vehicles (e.g. buses, trucks, trains or forklifts)
- Max. daily capacity: 950 kg (< 30 fuelings)
- Optional: 700 bar extension

L



CP 90/100-XL

- Cryo Pump technology for LH_2 supply
- For very large fleets of 700 bar vehicles (e.g. lightweight passenger or utility vehicles)
- Max. daily capacity: 2,400 kg (< 400 fuelings)
- Optional: 350 bar extension



IC P/140-XL

- Ionic Compressor technology for GH_2 supply
- For very large fleets of 350 bar vehicles (e.g. buses, trucks, trains or forklifts)
- Max. daily capacity: 2,400 kg (< 80 fuelings)
- Optional: 700 bar extension, on-site electrolysis



CP 50/100-XL

- Cryo Pump technology for LH_2 supply
- For very large fleets of 350 bar vehicles (e.g. buses, trucks, trains or forklifts)
- Max. daily capacity: 2,400 kg (< 80 fuelings)
- Optional: 700 bar extension

XL

*Linde branding details on final assets may differ.

Flagship projects

First LH_2 station in California (USA)

With three times the capacity of all the existing GH_2 stations, we have built the largest public fueling station in Oakland (CA) based on our Cryo Pump technology.

- Linde H_2 station CP 90/40-L with a fueling capacity of 40 kg/hour[1]
- Fully integrated into existing conventional fueling station (First Element)
- High storage capacity of 800 kg (LH_2) to keep up with growing demand
- Very small footprint of 10 m (length) × 3 m (width)
- Simultaneous refueling on a double 700 bar (cars) and 350 bar (buses) dispenser

[1] inlet pressure of 2 bar



Refueling station in Oakland (California)

Future-proof fueling depot for floor-borne vehicles

Fueling station at Daimler's production site in Düsseldorf, Germany, for fuel cell forklifts and tractors and possibly also light fuel cell vehicles like passenger cars.

- Fueling station based on IC 90/30 technology with a capacity of 28 kg/hour
- Fueling of up to 30 floor-borne vehicles per hour
- Extendable to passenger car fueling
- Specially designed dispenser for indoor production site
- High flexibility thanks to two dispensers that can be installed at two different locations



Fuel cell forklifts fueling station



First hydrogen refueling station in South East Asia

H_2 fueling stations in Malaysia produce hydrogen by means of electrolysis. This flagship project includes 350 and 700 bar dispensing lines.

- Linde H_2 station Twin IC 90/60-L with a fueling capacity of 58 kg/hour
- Fully containerized, highly compact design
- Serves local bus fleet with fueling capacity of 1,200 kg/day (20 hours of operation)
- Max. outlet pressure 900 bar
- Low maintenance, low noise, high reliability



Refueling station in Sarawak (Malaysia)



The world's first H_2 fueling station for passenger trains

Linde Hydrogen FuelTech is the supplier of the world's very first H_2 refueling station for passenger trains. The new depot is located in northern Germany and will fuel 12 Alstom Coradia iLint fuel cell trains, each with a 180 kg tank capacity.

- Fueling station based on three Twin IC 90/60 compressors (58 kg/hour each)
- Fueling capacity of 1,800 kg/day (12 fuelings in 24 hours)
- Total GH_2 storage at site is 4900 kg
- 2 × 250 bar dispenser line
- Application of innovative constant pressure tubes to minimize maintenance efforts



H_2 passenger train

Technical specifications of all standard solutions

	Performance/technical specification								
Standard station name	Outlet pressure	Capacity/ hour	Inlet pressure	Max. operation hours / day	Max. capacity per day	Estimated fuelings per day	Power consumption[a]	Connecting power[a]	Type of hydrogen
IC 90/30-S	< 900 bar	28 kg	nominal: 6–200 bar	16	450 kg	90	1–3.3 kWh/kg	93 kW[b]	GH_2
Twin IC 90/60-L	< 900 bar	56 kg	nominal: 6–200 bar	16	900 kg	180	1–3.3 kWh/kg	186 kW[b]	GH_2
IC 50/30-S	500 bar	28 kg	nominal: 6–200 bar	24	672 kg	22	1–2.8 kWh/kg	93 kW[b]	GH_2
Twin IC 50/60-L	500 bar	56 kg	nominal: 6–200 bar	24	1,344 kg	45	1–2.8 kWh/kg	186 kW[b]	GH_2
IC P/140-XL	20/50/150/ 500 bar	140 kg	nominal: 6/ 15/50/150	24	3,360 kg	74	0.68–2.7 kWh/kg	372 kW[b]	GH_2[c]
CP 90/40-L	< 900 bar	40 kg	2 bar	24	950 kg	200	1.3 kWh/kg	45 kW	LH_2
CP 90/100-XL	< 900 bar	100 kg	2 bar	24	2,400 kg	400	1.5 kWh/kg	120 kW	LH_2
CP 50/40-L	500 bar	40 kg	2 bar	24	950 kg	30	1.3 kWh/kg	45 kW	LH_2
CP 50/100-XL	500 bar	100 kg	2 bar	24	2,400 kg	80	1.5 kWh/kg	120 kW	LH_2

[a] compressor/pump plus thermal management
[b] without H_2 precooling
[c] LH_2 @5bar as backup possible
[d] adding 1.000 bar cylinders
[e] adding 5th stage/1.000 bar cylinders

Station configuration				Possible system extension	
Low pressure storage	Compression	High/medium pressure storage	Dispenser	Electrolysis	700/350 bar combination
1 × 50 m^3, 50 bar (≈200 kg)	Ionic Compressor	24 × 1,000 bar cylinders	Single 700	Yes	Yes
1 × 115 m^3, 50 bar (≈470 kg)	Ionic Compressor	24 × 1,000 bar cylinders + 3 × 500 bar tubes	Dual 700/700	Yes	Yes
2 × 70 m^3, 50 bar (≈580 kg)	Ionic Compressor	9 × 500 bar tubes	Single 350	Yes	Yes[d]
3 × 115 m^3, 50 bar (≈1,410 kg)	Ionic Compressor	18 × 500 bar tubes	Dual 350/350	Yes	Yes[d]
8 × 115 m^3, 50 bar (≈3,760 kg)	Ionic Compressor	30 × 500 bar tubes	Dual 350/350	Yes	Yes[e]
1 × 6 m^3, 2.5 bar (400 kg)	Cryo Pump	15 × 1,000 bar cylinders	Single 700	No	Yes
1 × 12 m^3, 2.5 bar (800 kg)	Cryo Pump	30 × 1,000 bar cylinders	Dual 700/700	No	Yes
1 × 65 m^3, 2.5 bar (4,500 kg)	Cryo Pump	12 × 500 bar tubes	Single 350	No	Yes
1 × 65 m^3, 2.5 bar (4,500 kg)	Cryo Pump	18 × 500 bar tubes	Dual 350/350	No	Yes

Service and support every step of the way



Reaching beyond reliable gas supplies and state-of-the-art standardized fueling station systems, we also offer professional services to ensure the success of our customers' investments in hydrogen-powered mobility. Building on many decades of experience in this area, these extend from end-to-end project execution through maintenance and repairs to express spare parts deliveries. To ensure reliable operations, we also support customers with remote monitoring, and optimized service and maintenance concepts.

In addition, our consultants are more than happy to team up with our customers and help realize individual or special requests – whether that be for larger fueling capacities, combined fueling models or integration into existing fueling stations. Thanks to our global footprint, these services are available worldwide.

Greener future with H_2



Looking to the future, we are committed to advancing technologies that pave the way for widespread production, distribution and adoption of green hydrogen. In other words, hydrogen generated by using renewable energy such as wind or solar power to split water (electrolysis). Here we are focusing in particular on ways to efficiently liquefy H_2 so it can be efficiently transported from source to service, or be stored to buffer grid supplies. The higher energy density and more compact footprint of LH_2 bring compelling advantages to many applications – in particular to use cases with space constraints.

To synergize efforts in this area, we are an active member of many major advocacy groups committed to building out the hydrogen fueling infrastructure. These include H_2 Mobility Deutschland to build a nationwide H_2 retail network in Germany, the Hydrogen Council to accelerate the adoption of hydrogen technologies, Clean Energy Partnership (CEP) to advance hydrogen and fuel cell technologies, and numerous government-funded initiatives to support the realization of hydrogen as an energy carrier and a fuel.

At Energiepark Mainz, for instance, we are enabling the generation of hydrogen from renewable sources with the world's first power-to-X demo linking green H_2 with other industry sectors. We also delivered the technologies for Europe's largest H_2 bus fleet in Aberdeen, Scotland.

The **hydrogen**
future is here now.
Linde can **deliver it.**

Connecting the world of hydrogen – from source to service

Think Hydrogen. Think Linde.
The hydrogen future is here now. Linde can deliver it. Linde is the only company to cover every step in the hydrogen value chain from production and processing through distribution and storage to everyday industrial and consumer applications. Building on decades of research and countless real-world projects, Linde's hydrogen capabilities demonstrate its innovative power and proven expertise in delivering workable, economically viable hydrogen technologies suited to mass deployment.

Demand for these technologies is set to rise given that hydrogen is ideally positioned to accelerate the transition to more sustainable forms of energy while still supporting current energy models and regional variations. Hydrogen is a zero-emissions source of fuel for trains, buses and cars.

Do you want to get your hydrogen project off the ground quickly, safely and based on state of-the-art technology? Then you should team up right from the start with a partner who covers all areas of hydrogen expertise.

Get in touch with our team of experts:
www.linde-engineering.com/contact



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