

→ H₂ as fuel

THE LINDE GROUP

Linde

The driving force.

Managing hydrogen projects with Linde.



Competence and customer focus for H₂.

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. With The Linde Group, you have a globally operating company at your side which is strongly committed to the consistent advancement of hydrogen technology and the expansion of corresponding infrastructures.



04 H₂ is everywhere

Discover the fascinating world of hydrogen and its eco-friendly application as an emission-free, flexible energy carrier.



06 Always the right solution

From production to storage to fuelling – we offer standardised as well as customised H₂ technologies for your applications.



08 Cutting-edge compression technology

With the ionic compressor and the cryo pump, Linde has set benchmarks for the operation of modern hydrogen fuelling stations and for the efficient fuelling of fuel-cell vehicles.



10 The one-stop shop for H₂ solutions

Our comprehensive expertise in hydrogen is based on our decades of experience with one of the most versatile gases.



12 Reference projects

All around the world, our company has successfully accomplished hydrogen projects. Just get in touch with us and we will find your solution.



Fully committed to less emissions. Linde and the passion for hydrogen.

The Linde Group is a globally active industry gases and engineering company with a history of more than 135 years of success. We are also the leading specialist for the production, storage and application of hydrogen (H_2). When used, this gas produces only water vapour instead of harmful emissions. It is therefore an ideal building block for the flexibilisation of our energy system and allows for the merging of today's power and gas markets. As a storage medium for electric power, hydrogen is an ideal energy carrier within a sustainable energy cycle. With this in mind, and knowing that fossil energy sources will only become scarcer and scarcer, we have been intensely engaged in the use of hydrogen as an emission-free fuel for over 25 years. Moreover, we have systematically strengthened our position as the technology leader for the eco-friendly application of hydrogen in the mobility sector.

Our cutting edge in this area is based on the development of innovative technologies, e.g. for the efficient compression and safe fuelling of hydrogen. This is what makes us an ideal partner for all who want to advance the use of hydrogen as a fuel – especially where the creation of a comprehensive H_2 fuelling station infrastructure for cars and buses is concerned. In addition, we offer an extensive technology portfolio for fuel-cell-powered material handling vehicles.

With support from Linde, hydrogen infrastructure projects can be implemented in a highly efficient, sustainable and professional manner: We are the one-stop shop for hydrogen solutions – offering everything you need, from reliable H_2 supply and cutting-edge fuelling station systems to customised services. Together, we plan, design and build high-performance plants, help you with commissioning, supply gaseous (CGH_2) or liquid hydrogen (LH_2) or produce it on site. And thanks to expert maintenance, we also ensure the highest levels of safety and reliability.

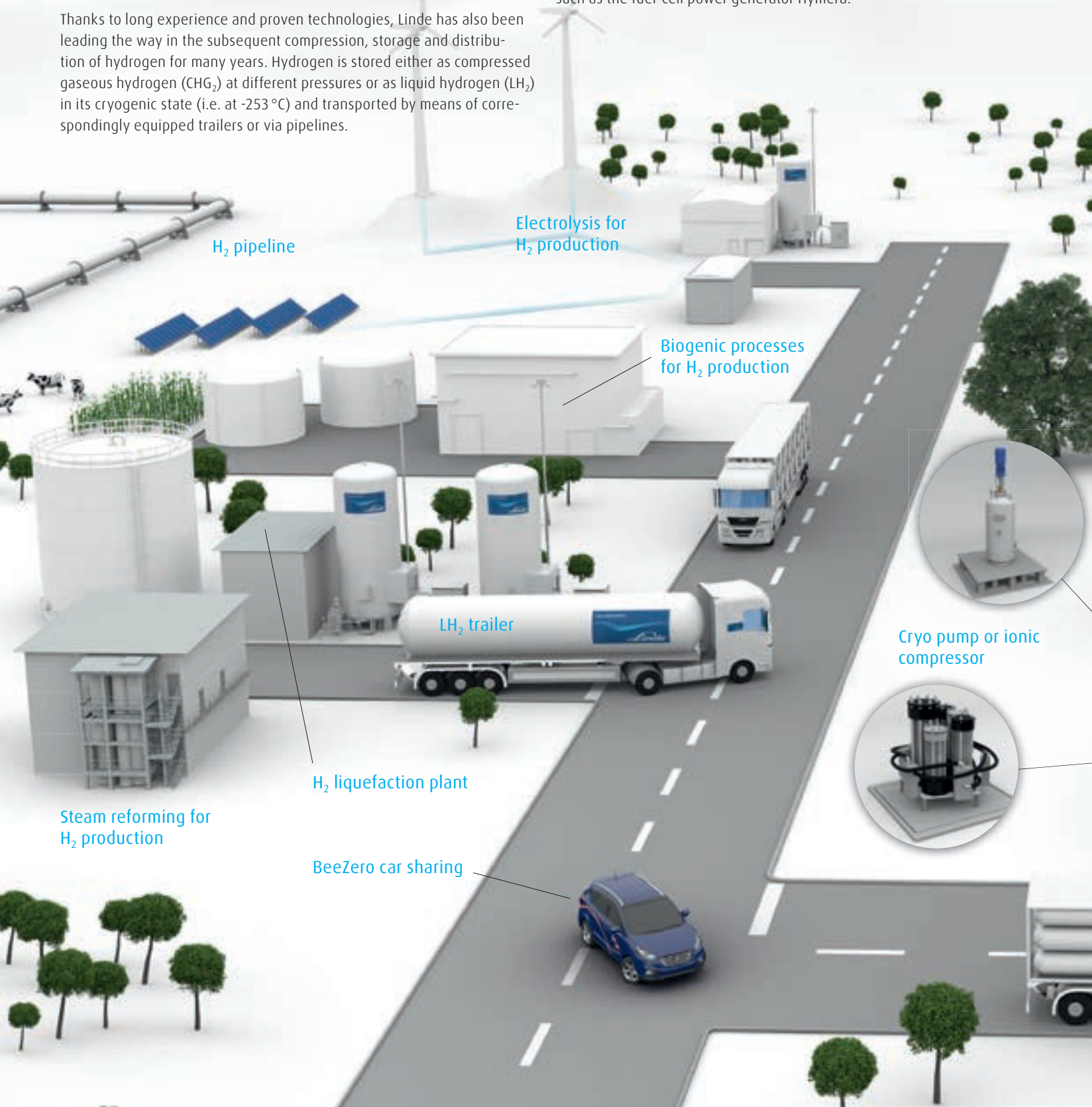
Linde is your partner – whether you are active, for example, in the areas of transportation, environment, energy or fuelling stations or are looking for reliable, high-quality, comprehensive support for your hydrogen project.

H₂ is everywhere. Linde's world of hydrogen.

Cutting-edge H₂ technologies from Linde are applied along the entire hydrogen value chain, beginning with the production – where, for example, the conventional steam reforming process (SMR = steam methane reforming) is used alongside “green” processes such as H₂ production from biogenic raw materials, which are currently being tested and advanced at Linde. At this stage, we can already supply our customers with 100% green hydrogen. The goal of our development work is to create an emission-free hydrogen energy cycle.

Thanks to long experience and proven technologies, Linde has also been leading the way in the subsequent compression, storage and distribution of hydrogen for many years. Hydrogen is stored either as compressed gaseous hydrogen (CHG₂) at different pressures or as liquid hydrogen (LH₂) in its cryogenic state (i.e. at -253 °C) and transported by means of correspondingly equipped trailers or via pipelines.

In addition to the development of applications, the equipment of hydrogen fuelling stations with the corresponding H₂ components is one of the key areas of our company's H₂ expertise. With our developments – e.g. with the ionic compressor and the cryo pump –, we have set new benchmarks in terms of safety, efficiency and reliability, and thus not only significantly increased the technical feasibility, but also society's general acceptance of hydrogen as a fuel for vehicles. Moreover, our portfolio includes H₂-fuel-cell-based technologies for self-contained power supply – such as the fuel-cell power generator Hymera.





Off-grid power supply



H₂ ship



H₂ material handling vehicles



H₂ e-bike



Storage in e.g.

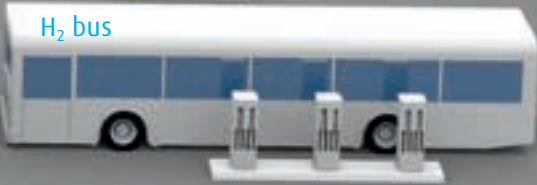
- CGH₂ tank
- LH₂ tank
- Cylinder bundle



H₂ car



H₂ bus



CGH₂ trailer



Always the right solution. Our hydrogen technologies for your applications.

Looking for a hydrogen-based mobility application?



H₂ cars

- Commercial market launch of fuel-cell vehicles from leading car manufacturers
- Usability like conventional diesel or gasoline-powered vehicles
- No local emissions (zero emissions along the complete value chain can be achieved with green hydrogen)
- Quick fuelling in 3 minutes
- Long travel distances (up to 800 km, according to manufacturers' information)

Over 80 fuelling stations worldwide are equipped with H₂ technology from Linde



H₂ buses

- First H₂ bus fleets are in daily operation worldwide
- Usability like conventional diesel buses
- No local emissions (zero emissions along the complete value chain can be achieved)
- Long travel distances and high flexibility (shift operation without fuelling possible)
- Quick fuelling in under 10 minutes
- Reduced noise emissions

Over 10 fuelling stations worldwide are equipped with H₂ technology from Linde



H₂ material handling vehicles

- Commercial market launch of entire fleets at production companies and distribution centres in the US (piloting in the EU)
- No loading times as with battery operation, no battery replacements, no space required for storage of replacement batteries
- Constant power level of the H₂ material handling vehicles
- No emissions in the storage/plant area, indoor and outdoor usability
- H₂ dispenser with very small footprint, for indoor or outdoor installation
- Quick fuelling in under 3 minutes

Over 700 material handling vehicles are already being fuelled with H₂ technology from Linde



Customised special-purpose H₂ solutions

- H₂ system solutions for industrial or research purposes
- Tailor-made solutions
- One-stop shop for plant design, engineering and project planning

We offer you the optimal fuelling concept for your application.

Our innovative solutions cover the entire range of H₂ fuelling technology – from the manufacturing of dispensers for H₂ material handling vehicles to complete fuelling stations for H₂ bus fleets or H₂ cars. Complemented by our wide range of services along the entire H₂ value chain, we are the one-stop shop for all hydrogen-related products and processes.

Over 90
fuelling stations with
Linde H₂ technologies

Over 1 million
fuellings with
Linde H₂ technologies



Production and distribution

On-site production or flexible delivery; Linde ensures your worldwide supply with H₂ – according to your preferences

- Over 200 production centres and a tight hydrogen distribution network
- Efficient distribution: Liquid or high-pressure hydrogen (up to 50 MPa) and a network of several hundred km of pipelines
- On-site electrolysis/steam reforming for independent production

Storage at the fuelling station

Appropriate, space-saving on-site storage options

- Gaseous:
 - 45-MPa upright tank (small footprint)
 - 20-MPa tubes (below-ground tank installation possible)
 - Storage tank sizes from 200–350 kg
- Liquid at -253 °C:
 - Storage tank sizes from 400–5,000 kg

Compression

The cryo pump and ionic compressor technologies are the core of the fuelling system

- Design of the optimal technology concept according to your requirements
- Powerful and energy-saving (10–120 kg/h possible)
- H₂ compression up to 90 MPa

Fuelling for your H₂ application

- Over 1,000,000 fuellings at stations with Linde technologies
- Gaseous fuelling for applications with 35-MPa or 70-MPa high-pressure tanks (cars: 70 MPa, buses and material handling vehicles: 35 MPa)
- Dispensers with familiar “touch and feel”
- Quick car fuelling in 3 minutes

→ Service and maintenance ←

Cutting-edge compression technology. The core of the hydrogen fuelling station.

The compressor unit is the key component of a hydrogen fuelling station because the fuelling is carried out using compressed gaseous H_2 at pressures from 35 to 70 MPa. Apart from the initial state – gaseous or liquid – the technology used for fuelling also depends on a range of other factors, as for example the throughput and the type of vehicle to be fuelled. Linde offers the suitable compression systems for the most varied requirements.

With the ionic compressor and the cryo pump, Linde has two cutting-edge, self-developed and patented technologies in its portfolio which impress with their outstanding reliability, their low amount of maintenance and their high energy efficiency. Both systems can be optimally tailored to meet your individual requirements. Furthermore, we have advanced our fuelling technology to a point where we are now the first company worldwide that can produce small series of H_2 fuelling technologies.

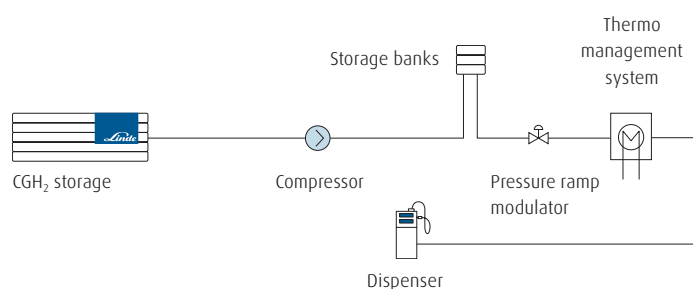
The ionic compressor.



In five steps, the ionic compressor compresses gaseous hydrogen up to 90 MPa. On its piston is the eponymous ionic liquid which, however, does not bond with the gas. This liquid acts both as a lubricant and coolant and thus significantly reduces wear, because the ionic compressor has a lot less moving parts than a classic piston compressor. On top of that, it increases the compressor's energy efficiency due to better cooling and the avoidance of dead spots during the compression process.

Because the ionic compressor helps to avoid the use of lubricants, there is also no contamination of the hydrogen's level of purity, which is required, for example, for fuel-cell applications.

Basic concept: Ionic compressor system



Our two technologies at a glance

Specifications

- Compact design (container construction): Space-saving at the fuelling station
- Standardised systems, technical specification individually adaptable
- Scalability: Small to large throughput – depending on hydrogen demand
- Technologies according to fuelling standard SAE J 2601 for H₂ fuelling stations

Advantages

- Low energy consumption
- Small footprint
- Energy-efficient compression
- Low maintenance requirements
- Low wear and long service life
- High reliability
- Low noise emissions

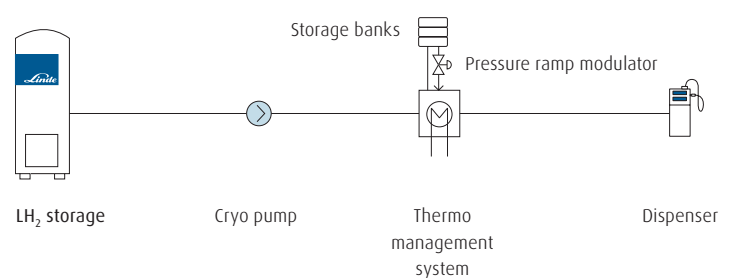
The cryo pump.



The cryo pump operates with liquid hydrogen (LH₂) at -253 °C. At this temperature, however, hydrogen cannot simply be suctioned in, which is why the pump uses a two-chamber system which is completely immersed in the cryogenic liquid. In the first chamber, LH₂ from the storage tank is compressed to 0.6 MPa. The compression to 90 MPa takes place in the second chamber. Subsequently, the temperature of the cryogenic gas is increased up to the fuelling temperature of -40 °C. During all of these process steps, the high purity level of the hydrogen remains unchanged.

In addition to its small footprint and very high capacity, the cryo pump system also minimises the energy consumption of the H₂ fuelling station. Due to the application of cryogenic LH₂, only 10–20 % of a gas compressor's energy are needed for compression and the cooling system within the thermo management is omitted. Furthermore, the low amount of maintenance ensures additional cost savings.

Basic concept: Cryo pump system



Hydrogen expertise from Linde.

Global presence, reliability and special knowledge in the areas of thermodynamics and cryogenic engineering: Our experience and know-how in hydrogen technology are based on these and other Linde core competencies. From production to service to maintenance, Linde offers you the complete H₂ performance portfolio from a single source, making our company a strong partner for your hydrogen project. With our long experience as a gases specialist, we help you implement your project while optimising it in terms of energy efficiency, cost-effectiveness, required space and availability.

Performance:

>300 % more*

More efficient energy consumption:

>40 % less*





































Footprint:

>50 % smaller*

*) In comparison with standard plants such as a conventional piston compressor

The one-stop shop for H₂ solutions. Our hydrogen fuelling portfolio.

Linde hydrogen fuelling portfolio

H ₂ application		H ₂ supply to the fuelling station				
		Product name	Storage tank	Storage tank	Storage tank	On-site production
		Operating pressure	4.5 MPa	20 MPa	0.25 MPa	Variable
		Gas type	CGH ₂	CGH ₂	LH ₂	CGH ₂
		Typical capacity per unit	350 kg	200 kg	400–4,000 kg	Variable
		Compression technology	–	–	–	–
Fuelling station	For H ₂ cars with 70-MPa vehicle tank		  **	  **	  **	  **
	For H ₂ cars with 35-MPa vehicle tank		  **	  **	  **	  **
	For H ₂ buses with 35-MPa vehicle tank		  **	  **	  **	  **
	For H ₂ material handling vehicles with 35-MPa vehicle tank		  **	  **	  **	  **
Mobile fuelling unit						
Industry and special-purpose applications						

● Recommended technology ● Optional
CGH₂: compressed hydrogen, CCH₂: cryo-compressed hydrogen, LH₂: liquid hydrogen

**) Supply and storage of hydrogen depending on space, amount and delivery situation on site

Reference projects. Hydrogen technology from Linde – all around the world.



BMW manufacture, Greer (SC), USA

- 14 H₂ dispensers for hydrogen-fuelled material handling vehicles
- Fuelling of more than 380 material handling vehicles
- Fuelling 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 fuelling station in the UK
- Fuelling of Europe's largest H₂ bus fleet
- More than 80 t H₂/year
- Alkaline water electrolyzers, hydrogen generation based on green electricity
- 35 MPa (2 x IC 90)



Ramos Oil Company, Sacramento (CA), USA

- Linde's first H₂ fuelling station in the US
- 11,000-litre LH₂ tank
- Ionic compressor IC 90
- 35/70 MPa



Energiepark Mainz, Germany

- Power to gas
- Production of green H₂ for mobility applications by electrolysis with renewable energies
- Storage capacity: 1,000 kg
- Ionic compressor



ATM, Milan, Italy

- Italy's first H₂ fuelling station for buses
- Fuelling of H₂ buses in daily operation
- H₂ production with on-site electrolyser
- 35 MPa

Please note:

The projects shown on this double-page spread represent only a small selection of examples (incl. a brief overview of key facts in each case). Around the globe, over **1,000,000** H₂ fuellings have been carried out at the more than 90 fuelling stations equipped with H₂ technology from Linde.



Arlanda Airport, Stockholm, Sweden

- Sweden's first public H₂ fuelling station
- Capacities for up to 180 fuellings per day
- 70 MPa



CEP/Vattenfall, Hamburg, Germany

- Capacities for a large fleet of up to 20 H₂ buses
- Integration of two electrolyzers for on-site H₂ production
- 35/70 MPa (2 x ionic compressor)



CEP/Total, Munich, Germany

- Public fuelling station
- Cryo pump with a capacity of 100 kg/h
- 70 MPa (30 MPa for cryo-compressed fuelling (CCH₂))



CEP/Shell at Sachsendamm, Berlin, Germany

- One of the world's most powerful H₂ fuelling stations with a capacity of up to 200 kg/h
- Below-ground installation of the storage tank and the compressor system (two cryo pumps)
- 50 % green H₂ from Linde
- 35/70 MPa



Iwatani, Amagasaki City, Japan

- Japan's first commercial H₂ fuelling station
- LH₂ tank
- Ionic compressor IC 90
- 35/70 MPa



OMV, Vienna, Austria

- Built in record time of less than 6 months
- Small footprint
- Austria's first public H₂ fuelling station
- 70 MPa (piston compressor MF 90)



Tongji, Shanghai Anting, China

- Shanghai's first H₂ fuelling station
- Hydrogen supply from Linde's SMR plant in Shanghai
- 35 MPa for cars and buses (diaphragm compression)



Linde. Your partner for hydrogen projects.

H₂ initiatives

Creating a sustainable hydrogen infrastructure is essential for the commercial use of this emission-free fuel. Within various initiatives, Linde, in cooperation with other companies and government organisations, is one of the main driving forces behind the advancement of the H₂ infrastructure. The common objective is to ensure that the vision of comprehensive hydrogen mobility is accomplished. Thanks to over 135 years of experience in the world of gases, including numerous patents and engineering solutions for the application of hydrogen, our company is optimally positioned to achieve this goal. On top of that, Linde is also involved in the development of industry standards for hydrogen technology such as, for example, SAE J 2601.

CaFCP – California Fuel Cell Partnership

The objective of the CaFCP, a consortium of vehicle manufacturers, electric energy providers, technology companies and government agencies, is the close coordination between the roll-out of fuel-cell vehicles, the build-up of an H₂ fuelling station infrastructure as well as government regulations in the State of California – the leading American state for sustainable mobility:

www.fuelcellpartnership.org

CEP – Clean Energy Partnership

The CEP initiative has taken up the task of testing the suitability of H₂ as a fuel for daily use in Germany. Since 2002, the CEP partners have been working on the roll-out of H₂ vehicles in Germany:

www.cleanenergypartnership.de

H₂ Mobility

The companies Air Liquide, Daimler, Linde, OMV, Shell and Total have joined hands to form the “H₂ Mobility” initiative. Their plan: 400 H₂ fuelling stations in Germany until 2023: www.h2-mobility.de

Our experience for your project

With Linde at your side, you choose a partner who has been consistently committed to the application of hydrogen as an energy carrier for over 25 years. Our expertise covers the entire H₂ value chain, from the production of the gas to tailored services, making us an optimally positioned solution provider for all customers who want to implement an H₂ project or who have already taken first steps in that direction. Based on our own research and development as well as numerous cutting-edge H₂ technologies, we can always offer you an optimal solution – even for special subdomains of your project.

We're ready. Now it's up to you: Let's do H₂.



www.linde-gas.com/hydrogen



Getting ahead through innovation.

With its innovative concepts, Linde is playing a pioneering role in the global market. As a technology leader, it is our task to constantly raise the bar. Traditionally driven by entrepreneurship, we are working steadily on new high-quality products and innovative processes.

Linde offers more. We create added value, clearly discernible competitive advantages, and greater profitability. Each concept is tailored specifically to meet our customers' requirements – offering standardised as well as customised solutions. This applies to all industries and all companies regardless of their size.

If you want to keep pace with tomorrow's competition, you need a partner by your side for whom top quality, process optimisation, and enhanced productivity are part of daily business. However, we define partnership not merely as being there for you but being with you. After all, joint activities form the core of commercial success.

Linde – ideas become solutions.

Linde AG

Linde Gases Division, Seitnerstrasse 70, 82049 Pullach, Germany
Phone +49.89.74 46-0, Fax +49.89.7446-12 30, www.linde.com

Linde LLC

575 Mountain Avenue, Murray Hill, NJ 07974 USA
Phone +1.216.908.464-81 00, Fax +1.216.908.771-47 75, www.linde.com

BOC (China) Holdings Co., Ltd.

Building No. 9, 27 Xinqiao Road
Pudong, 201206 Shanghai, People's Republic of China
Phone +86.216.105-98 88, Fax +86.216.105-97 77