

# Unique setup

Linde company profile



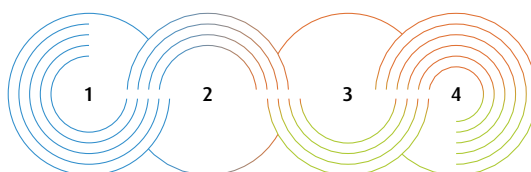
Leading.

  
THE LINDE GROUP



Linde company profile

# Unique setup



The Linde Group is a world-leading gases and engineering company with a history that stretches back over 135 years. The Group specialises in the planning, procurement, construction and operation of gas production and processing plants. In addition, Linde is a trusted gas supplier, serving customers of all sizes across almost all industries and trades, also supporting science, research and medicine.

An integrated business model puts Linde in a very strong position in the international gases and engineering space, based on a one-stop offering across the full product and service spectrum. The company's broad portfolio extends from gas production right up to delivery – in the supply mode best suited to individual needs. This is rounded off by an exceptionally deep industrial and medical gas application and service offering.

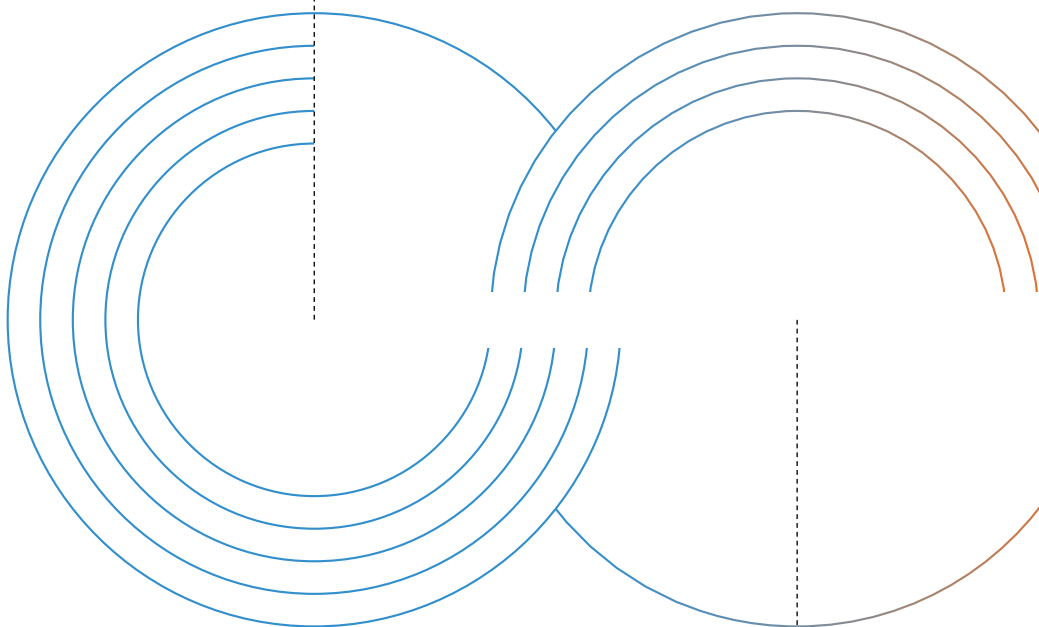
This unique profile has propelled Linde to the forefront of the gases market in over 50 countries around the globe. The company is also market leader in the cylinder and liquid gases business. In the field of healthcare, Linde is the number one provider of gases, therapies, consultation and supporting services for respiratory medicine.

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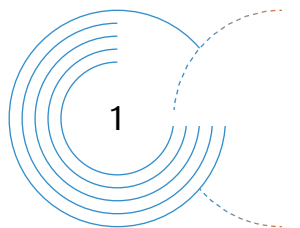
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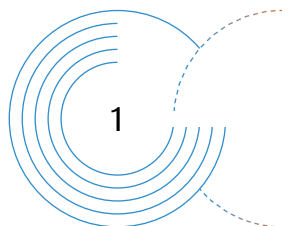
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## Engineering Producing gases

Linde is a leading technology partner for plant engineering and construction worldwide. The company focuses on particularly promising markets and can rely on its own extensive process engineering know-how in the planning, project management and construction of turnkey industrial plants. Its portfolio extends from air separation units for the production of air gases such as oxygen, nitrogen and noble gases through natural gas liquefaction and processing facilities to petrochemical plants that convert fossil fuels into base materials for the chemical industry. The company also offers plants capable of producing hydrogen, carbon monoxide, synthesis gas, ammonia and methanol – using both fossil feedstocks and renewable resources. Linde is the only provider worldwide that can build, deliver and operate these industrial facilities. The company holds over 1,000 patents in the field of process engineering and has built approximately 4,000 plants across the globe.



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## Air separation plants

# Fuel from Qatar

Linde has built around 3,000 air separation plants in 80 countries to date, making it the leading provider in this sector. Air separation units utilise a low-temperature rectification process to produce the industrial gases oxygen, nitrogen and argon. The noble gases krypton, xenon, helium and neon can also be produced using additional process steps. The largest facilities built today can now produce up to 5,500 tonnes of oxygen per day (t/d), or 160,000 standard cubic metres per hour (Nm<sup>3</sup>/h). These large-scale facilities are usually built on site to provide customers in sectors such as the steel industry with the gases they need, where and when they need them.







# 3,000

## air separation units

built by Linde.

# 5,500t

## oxygen

produced by largest single air separation units per day.

In recent years, the emergence of new processes capable of converting coal and natural gas into liquid fuel has opened up new markets for air separation units. These coal-to-liquids (CTL) and gas-to-liquids (GTL) processes require large amounts of oxygen, in some cases up to 30,000 t/d. Demand of this magnitude cannot be met by individual units. And so Linde offers cutting-edge, multi-train plant solutions capable of meeting the huge capacities required in this sector. In the Qatari desert, Linde has built a high-capacity eight-train air separation unit for the large-scale production of liquid fuels from natural gas.

In June 2011, Pearl GTL, the world's largest GTL plant at that time, went on stream after a construction period of several years. The extensive complex in Ras Laffan, Qatar, is still regarded as one of the most ambitious projects in the history of the oil and gas industry. 600,000 cubic metres of concrete and 120,000 tonnes of steel were used to build it – enough for 15 Eiffel Towers. Today, the energy company Shell produces 140,000 barrels of natural gas per day at the site. The feedstock is sourced from one of the world's largest reserves off the coast of the Emirates and transported by pipeline to the Pearl GTL facility.

By virtue of their sheer size, GTL units require enormous amounts of oxygen to convert natural gas into synthesis gas, which is then further refined using the Fischer-Tropsch process to create products such as kerosene jet fuel, clean diesel fuels for cars, waxes and other hydrocarbons. The train of eight identical air separation units therefore has a crucial role to play at Pearl GTL. Together, these units produce 860,000 Nm<sup>3</sup> of oxygen per hour from the surrounding air.

Weighing 470 tonnes each and towering 60 metres in height, the air separation units' eight coldboxes are the most distinctive structures at the Ras Laffan industrial hub and can be seen from miles away. Linde started planning their construction years ahead of the final contract award in 2006, leveraging a global network of suppliers to obtain the highest quality materials at the best possible prices. The coldboxes are where the low-temperature part of the air separation process takes place and therefore form the heart of the air separation units. They comprise a number of key components including aluminium plate-fin heat exchangers and rectifying columns. Linde sourced these key components from its sites in Germany and China. It also preassembled the coldboxes for Qatar into packaged units at these locations, eliminating the risk of a potentially complex and fault-prone assembly and construction process on site in Qatar, where temperatures can reach 50 degrees Celsius in the shade and where sand storms and dust would have made work extremely difficult for Linde's engineers. Prior to being shipped, the key plant components were subject to rigorous endurance tests lasting several weeks to ensure they met the requisite reliability standards. As general contractor, Linde was responsible for delivering the turnkey units on time at every step of the process chain. And in March 2012, the company was able to officially hand over the eight huge air separation units to Shell following the planned, step-by-step commissioning of the entire complex.

Taking stock, the Pearl GTL project has been a resounding success. The plant is producing innovative GTL fuel every hour, a less harmful and more environmentally sound fuel than conventional diesel obtained from mineral oil. Pearl GTL was also a key milestone for Linde. The company successfully executed the largest order ever placed in the history of air separation, ensuring that this global GTL lighthouse project never runs out of oxygen.

### The perfect fit

As the leading international contractor, Linde plans, builds and operates air separation plants of every size. Capacities range from small modularised units capable of producing up to 3,900 Nm<sup>3</sup>/h nitrogen through standard plants with capacities of up to 25,000 Nm<sup>3</sup>/h oxygen or 66,000 Nm<sup>3</sup>/h nitrogen and argon to world-scale facilities such as the Qatar project described above.

# 30%

of global energy demand met by natural gas.

# -162

degrees Celsius  
LNG transport temperature.

HIGH-TECH PLANT ON A POLAR CIRCLE: LINDE HAS ENGINEERED A WORLD-SCALE NATURAL GAS LIQUEFACTION FACILITY ON THE ISLAND OF MELKØYA, OFF HAMMERFEST IN NORTHERN NORWAY. GENERATING AROUND FOUR MILLION TONNES OF LIQUEFIED NATURAL GAS PER YEAR, THIS PIONEERING PROJECT SETS NEW STANDARDS FOR FUTURE FACILITIES ACROSS THE EXPANDING GLOBAL LNG MARKET.

## Natural gas plants

Natural gas is key to meeting the world's energy demand and already accounts for a sizeable 30 percent or so of the global energy mix. It is also a comparatively clean energy carrier, commonly used in the transport sector and for generating power in industry. It is generally pipelined to the point of use. Over the past two decades, liquefied natural gas (LNG) has become an increasingly important component in the global energy market.

Between the source and the point of use, however, natural gas has to undergo a number of important processing steps. Linde has the right technologies for the entire process chain. Heat exchangers, for example, form the heart of most natural gas treatment processes and Linde is the only manufacturer worldwide that offers both coil-wound and plate-fin heat exchangers.

Liquefied natural gas can be efficiently stored and transported over long distances without having to rely on pipeline networks. To do this, it must be cooled to temperatures of around minus 162 degrees Celsius. Linde has the technologies for this liquefaction process – and every other step of the entire LNG value chain. The company plans and builds natural gas liquefaction plants in a range of different sizes (small-, mid- and world-scale units) and can even construct entire LNG import terminals.



## Olefins

such as ethylene, propylene and butadiene are mainstays of the chemical industry.

850  
degrees Celsius  
heat applied to hydrocarbons  
in steam cracking.

## Petrochemical plants

Petrochemical plants provide the building blocks for many different industrial applications and products. These include olefins such as ethylene, propylene and butadiene as well as aromatics obtained from fossil fuels that are refined in downstream processing steps to create important base chemicals and plastics. The production plants that manufacture these highly versatile base materials are very complex.

As a leading technology contractor, Linde has the expertise to manufacture high-quality base materials via steam cracking, a process in which different hydrocarbons such as ethane or naphtha are subjected to pyrolysis at temperatures as high as 850 degrees Celsius. This produces olefins and other valuable by-products which are then separated and scrubbed in downstream process steps.

Linde is also committed to systematically developing alternative process chains for olefin production in order to expand and strengthen its product portfolio as it moves forward. For example, the company is working intensively on commercialising a process that manufactures ethylene directly from methane (natural gas).

Linde offers a broad scope of services that extends from the technical design of petrochemical facilities through the procurement of all components to the assembly and start-up of turn-key plants. Linde also provides customers with support on operational issues such as plant safety or energy optimisation. In addition, the company can undertake complete revamps of existing facilities.



ETHYLENE PLANT CONSTRUCTED BY LINDE FOR A PETROCHEMICAL CUSTOMER  
IN RUWAI, ABU DHABI.

## Hydrogen and synthesis gas plants

Linde is the leading international provider of hydrogen and synthesis gas (syngas) plants. The company designs, constructs and operates these plants using its own technologies, generating syngas which is then further broken down into hydrogen ( $H_2$ ), carbon monoxide (CO) and carbon dioxide ( $CO_2$ ). These products can be used to generate ammonia and methanol in downstream synthesis processes. Feedstocks include natural gas, liquefied natural gas, naphtha, residual oil and coal.

In addition to delivering new, turnkey facilities, Linde also helps industrial customers expand their existing capacities. The company covers the full competence chain with expertise in all processes for generating and treating syngas and  $H_2/CO$ , also specialising in large-scale production capacities for these gases.

Linde is also working intensively to establish hydrogen as an environmentally sound, widely used energy carrier. In addition to using natural gas as a feedstock, the company is focusing increasingly on sustainable production processes. The company's glycerine pyroreformer, for example, converts glycerine captured as a by-product of biodiesel manufacture into hydrogen that can then be used to power fuel-cell vehicles.

LINDE'S INTEGRATED PLANT FOR HYDROGEN AND SYNGAS PRODUCTION ON JURONG ISLAND IN SINGAPORE IS THE LARGEST AND MOST COMPLEX IN THE REGION.



1,000  
process technology  
patents.

4,000  
plants completed by  
Linde around the globe.



CRYOGENIC SYSTEM FOR HELIUM LIQUEFACTION: HEAT EXCHANGERS WITHIN THE COLDBOX (LEFT) COOL THE NOBLE GAS UNTIL IT LIQUEFIES.

## Other types of plants

Linde designs, builds and operates many other types of plants for its industrial partners, bringing its in-depth technological expertise and outstanding reliability to the table in every project. These plants include:

### Adsorption plants

Plants for separating and purifying process gases.

### Cryogenic plants

Plants that generate extremely low temperatures and can be used to liquefy helium and hydrogen.

### Biotechnology plants

Research, pilot and industrial-scale plants for customers in the biotechnology industry.

### CCS and CO<sub>2</sub> plants

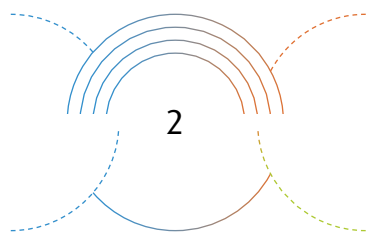
Plants for the removal and subsequent storage of CO<sub>2</sub> from flue gases in power plants (carbon capture and storage, CCS) and plants for generating carbon dioxide.

### Process and refinery furnaces and combustion plants

Furnaces for refineries and petrochemical plants; gas processing and steel manufacturing plants; and plants for environmental engineering industries.







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Removing nitrogen  
from natural gas → *page 20*

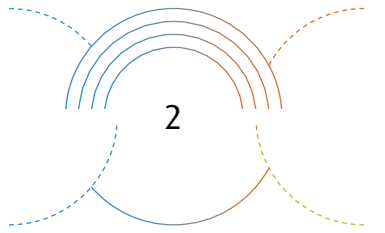
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## Engineering & Gases

# Processing gases

Natural resources such as natural gas and shale gas contain a range of chemical compounds that can be used to generate energy and manufacture chemical and petrochemical base products. Linde offers made-to-measure gas treatment processes based on adsorption, absorption and cryotechnology for this sector. Tailored to a diverse range of requirements and applications, these processes are used to efficiently separate individual components and remove impurities. The company also develops innovative technologies that remove unwanted nitrogen from natural gas streams and liquefy natural gas for transport by sea. In addition, Linde supplies tried-and-tested plants and process technologies for treating raw carbon dioxide from a wide range of industrial processes. These include pioneering solutions for capturing, cleaning and storing CO<sub>2</sub> contained in power plant flue gases.



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## Processing natural gas

# Creating base materials for the petrochemical industry

Linde has long-standing experience and in-depth process expertise across the entire natural gas value chain. The company offers a broad spectrum of technologies for separating natural gas components such as methane, ethane, propane and butane – all of which are crucial feedstocks for downstream industries. Linde also harnesses this extensive know-how to develop unconventional natural gas from shale reserves.





## Technologies for the entire natural gas value chain

The shale gas revolution is driven by innovative processes. And Linde's technologies are playing a defining role here. As a plant engineer and industrial gases specialist, the company covers the entire natural gas value chain, from exploration through processing right up to the point of use. In addition to providing gases such as nitrogen and carbon dioxide that help make fracking more efficient and environmentally friendly, Linde also supplies gases for enhanced oil and gas recovery (EOR/EGR). These gases maintain the pressure in existing conventional reservoirs and increase the amount of oil or gas that can be extracted. Linde also engineers plants that process natural gas and generate natural gas liquids (NGLs). These NGLs can then be processed further in crackers – which Linde also designs and builds – and used to produce olefins such as ethylene. Similarly, Linde technologies can be found in the liquefaction, storage, transport and use of natural gas. The Group offers a broad portfolio of liquefied natural gas (LNG) plants in all sizes along with LNG terminals and equipment for LNG tankers. The company's extensive offering includes end-to-end solutions that enable natural gas to be used as an environmentally sound source of energy in transport and marine applications. For example, Linde supplies complete LNG fuelling stations for ships and cars.

Natural gas is a valuable resource. Today, new drilling and exploration techniques are enabling companies to cost-effectively tap unconventional sources. In North America in particular, shale gas is gaining in importance – and not just as a source of energy, but also increasingly as a feedstock for chemical and petrochemical industries. This is because, in addition to methane, shale gas contains a number of valuable chemical compounds. And these components have to be extracted and purified efficiently before they can be refined into other products.

Shale gas can be either dry or wet. Dry shale has a high percentage of methane and is therefore more suitable as a source of energy. Wet shale gas, however, contains higher concentrations of valuable hydrocarbons known as natural gas liquids (NGLs). It is these components that make it such an interesting raw material for the chemical industry. The hydrocarbon ethane (C<sub>2</sub>), for example, can account for up to 45 percent of wet shale gas. Propane (C<sub>3</sub>) and butane (C<sub>4</sub>) are also present, together with other components with higher molecular weights. These hydrocarbons can be converted by petrochemical steam crackers into ethylene and propylene – two of the most important base chemicals in organic chemistry. Ethylene and propylene form the basis of the widely used plastics polyethylene and polypropylene, as well as of many other products used across a diverse range of industries.

Linde was quick to pre-empt changing market needs in the face of shale developments. The company's CRYO-PLUS™ technology was already well established and successfully deployed in many different refinery applications. Linde focused on adapting this proven solution for the extraction of high-quality hydrocarbons for chemical and petrochemical processes. The composition of unconventional natural gas reserves can vary widely and therefore requires specialist know-how and perfectly aligned processes. Wet shale gas, for example, often contains traces of mercury and hydrogen sulfide. These contaminants have to be reduced to the absolute minimum before ethane or propane can be fed into olefin plants. Linde also modified the gas pre-treatment process to cope with the higher concentrations of heavier hydrocarbons. In a further step, the company checked and optimised the hydraulic systems in its plants to enable them to operate more effectively with partial loads.

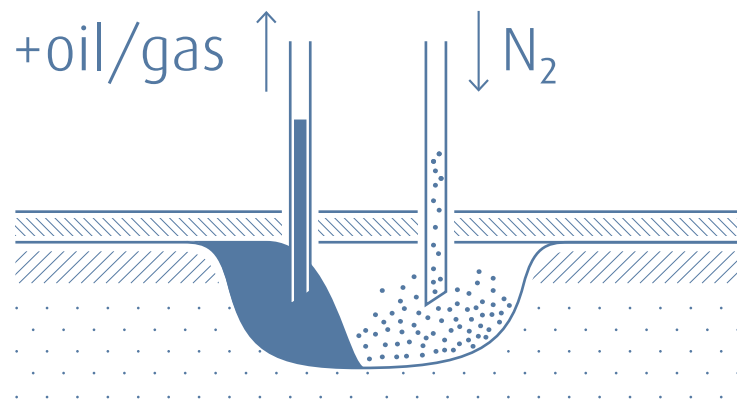
The enhanced CRYO-PLUS™ solution can be retrofitted to plants that previously separated only conventional raw gas into its constituent parts using compression and cryogenic cooling. Once the new technology is fitted, these plants can easily, flexibly and efficiently process wet shale gas. The modified system has been successfully deployed in over 20 refineries and petrochemical plants across the globe.

**-140/-180**  
degrees Celsius  
temperature range enabling  
near-complete separation  
of natural gas and nitrogen  
by rectifying columns.

## Removing nitrogen from natural gas

In oil and gas mining, nitrogen is injected into drill holes under high pressure to increase pressure and boost oil and gas yields. Depending on the geological make-up of each site, some of the nitrogen may mix with the natural gas during the course of this process. This nitrogen ballast can be removed using a nitrogen rejection unit (NRU). The NRU cools the nitrogen-rich gas stream until part of it has liquefied. The nitrogen is then separated almost entirely from the natural gas in rectifying columns at temperatures of between minus 140 and minus 180 degrees Celsius.

The NRU process is also used to remove nitrogen from naturally occurring gas streams if the nitrogen content exceeds the threshold value of downstream pipeline systems. Nitrogen reduces the calorific value of natural gas and compromises processing in the chemical industry. If the nitrogen content is too high, the natural gas will not meet trade and industry standards. Nitrogen content should also be below one percent if natural gas is to be cryogenically stored and transported in liquid form.



THE ENHANCED OIL AND GAS RECOVERY PROCESS INVOLVES HIGH-PRESSURE INJECTION OF GASES SUCH AS NITROGEN INTO THE DRILL HOLE TO RAISE RESERVOIR PRESSURE, WHICH CAN SIGNIFICANTLY INCREASE THE OIL OR GAS YIELD.

## Capturing boil-off gas

Natural gas can be transported around the globe in liquid form at a temperature of minus 162 degrees Celsius in specially designed LNG tankers. Although the storage tanks are extremely well insulated, a small amount of liquid natural gas will inevitably evaporate during transport. This boil-off gas (BOG) can be captured and reprocessed using technologies from Linde.

If the BOG remains below a certain temperature, it can be recompressed by two-stage compressors and used to power a dual-fuel marine engine. These types of engines can operate on a heavy oil/air mix or BOG and are often used to power LNG tankers.

However, boil-off gas can also reach temperatures of up to 40 degrees Celsius. At these temperatures, it can no longer be processed by two-stage compressors. Linde has developed a more powerful solution for processing warm BOG that harnesses proven centrifugal compressor technology. This four-stage system comprises several chambers and uses blades to gradually compress the warm gas, similar to aircraft turbines. The process does not require an intermediate cooling step and does not have to withstand changes in pressure. In addition, the four-stage centrifugal compressor technology is more compact, lighter and requires less maintenance than conventional piston compressors.

**40**  
degrees Celsius  
temperature sometimes  
reached by boil-off gas.

## 3% LNG

evaporates on a 20-day voyage without reliquefaction technology.

As another option, Linde has developed on-board reliquefaction units for capturing boil-off gas. This technology uses the Brayton refrigeration cycle, which relies on nitrogen as a refrigerant. Heat exchangers use the cold temperature of the nitrogen to cool the BOG, causing it to reliquefy so it can be fed back into the ship's storage tanks. The cooling process can be started quickly and is particularly useful during the period immediately after loading as a significant amount of BOG forms at this time. In comparison, tankers that are not equipped with reliquefaction technology can lose up to three percent of their LNG cargo through evaporation during a twenty-day voyage.



### Carbon dioxide for greenhouses

CO<sub>2</sub> can be used to boost plant growth. The Organic CO<sub>2</sub> for Assimilation in Plants (OCAP) project shows exactly how this is done.

Within the framework of this project, Linde supplies over 580 greenhouses in Holland with carbon dioxide sourced from Europe's largest Shell refinery and a bioethanol plant run by the Spanish company Abengoa. Linde processes the CO<sub>2</sub> emitted by these facilities and transports it to the greenhouses via an extensive pipeline network. Around 400,000 tonnes of gas per year are recycled in this way. And because the greenhouse operators no longer have to use fossil fuels to produce carbon dioxide for their plants, the project reduces CO<sub>2</sub> emissions by around 205,000 tonnes per year. This is the equivalent of the annual CO<sub>2</sub> output of a city in Western Europe with 150,000 inhabitants.

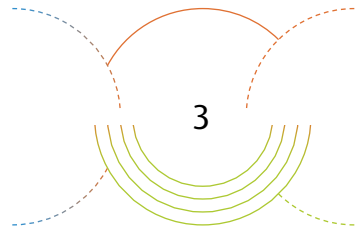
## Managing carbon dioxide

Linde designs and builds carbon dioxide (CO<sub>2</sub>) plants that cover every step in the processing chain from separation and scrubbing through liquefaction and storage to distribution. These plants can process raw CO<sub>2</sub> from a wide range of sectors, including exhaust gases from chemical and petrochemical processes, CO<sub>2</sub> from natural gas production and flue gases from power plants. Each unit is adapted according to the source of the CO<sub>2</sub> and its use further down the line.

Linde also develops and enhances technologies that efficiently capture and clean carbon dioxide from flue gas streams in power plants. The company offers solutions for pre-combustion, oxyfuel combustion and post-combustion (CO<sub>2</sub> scrubbing). These are the three most common ways of reducing CO<sub>2</sub> content in flue gases from power plants that burn fossil fuels such as oil and gas. Post-combustion is the only process that can be retrofitted to existing power plants. CO<sub>2</sub> scrubbing can remove over 90 percent of carbon dioxide from power plant flue gases, enabling it to be fed back into industrial processes. In fact, CO<sub>2</sub> from any source is suited to a huge range of industrial applications. It can be used to carbonate drinks in the food industry, for example, or cooled to minus 79 degrees Celsius to obtain dry ice for cleaning. In welding, CO<sub>2</sub> is a component of shielding gas. The oil and gas industry uses huge amounts of CO<sub>2</sub> in enhanced oil and gas recovery (EOR/EGR), while in the chemical sector, it helps to manufacture methanol and urea. Some target markets require CO<sub>2</sub> to meet specific purity standards; these include chemical synthesis and the food and drinks industry. Linde also offers plants capable of meeting these exacting requirements.







*Product portfolio:*

Diverse supply modes → *page 24*

Cylinder gases → *page 28*

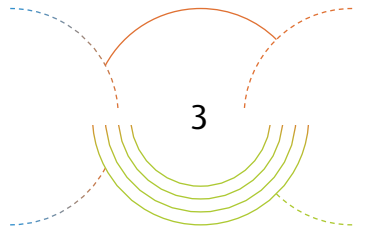
Gases in trailers and tanks → *page 29*

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## Gases & Healthcare

# Supplying gases

Gases are used in a wide range of manufacturing processes and industries across the globe. The volume of gases as well as the purity levels and delivery intervals can vary greatly depending on the actual processes they are used for. Linde deploys an integrated model to meet the diverse needs of its customers and is committed to continually improving and modernising its supply chain management for cylinder gases, liquefied gases and on-site systems. Backed by a dense production, sales and distribution infrastructure, Linde ensures that customers of all sizes always get the gas products they need – on time and in the right quantities and purities.



*Product portfolio:*

Diverse supply modes → *page 24*

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## Diverse supply modes

# Perfect fit

Industrial and medical gases can be transported to users in a number of different ways, for example in cylinders under very high pressure or in special vessels designed to hold cryogenically liquefied gases at extremely low temperatures. Gases can also be produced on site for customers with very high volume needs.



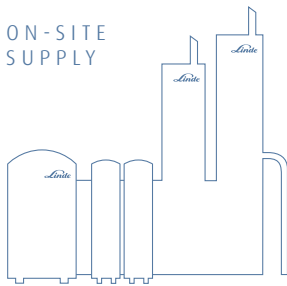


Pressure, volume and flow rate requirements are the three key factors that determine the most cost-effective supply mode for individual customer needs. To be delivered in cylinders, for example, gases usually have to be compressed at high pressure. Cylinders can only carry a limited amount of pure gases or gas mixtures but can be easily transported to the point of use.

Gases that liquefy at low temperatures can be supplied in small cryogenic containers or large tanks capable of holding up to several thousand litres of liquefied gas.

Linde also offers its customers a range of on-site supply systems for nitrogen, oxygen and hydrogen. These range from compact, standardised units (ECOVAR®) to tailor-made plants for companies that require very large volumes of industrial gases. Linde has developed a portfolio of high-performance products for this target group, capable of delivering atmospheric gases (air gases) and chemical gases in the requisite quantities and quality levels.

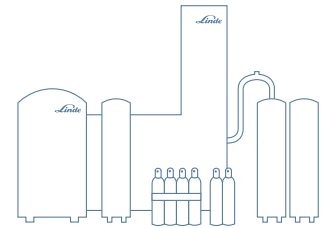
ON-SITE SUPPLY



1,000–  
2,000  
customers

450  
major air separation units and  
HyCO plants

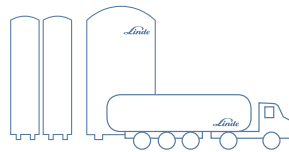
CYLINDER GASES



2 m  
customers

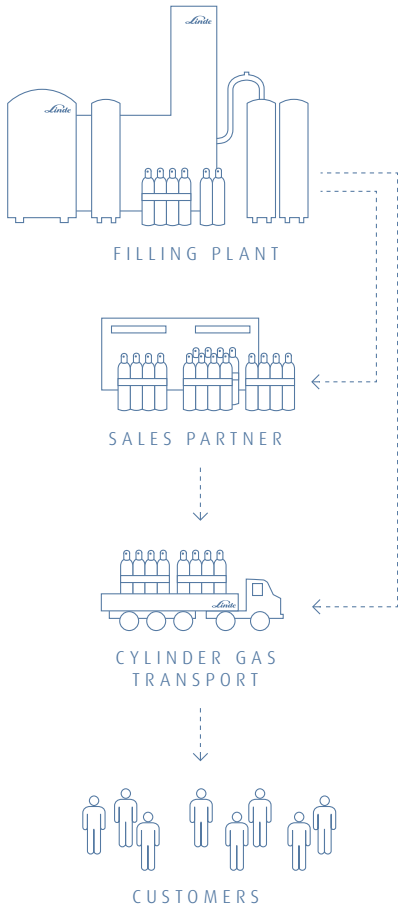
5 m  
deliveries

LIQUEFIED GASES



50,000  
customers

2 m  
deliveries



## Cylinder gases

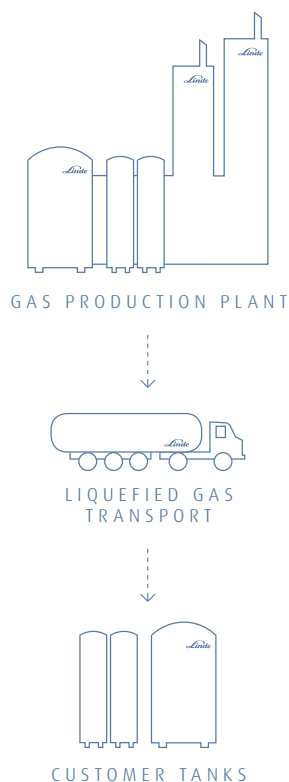
Linde is the market leader in the global cylinder gases business. The company operates over 430 filling plants worldwide, filling in excess of 25 million gas cylinders each year. Approximately 3,500 trucks make on average five million deliveries per year, supplying around two million customers with a diverse range of products. Linde’s sophisticated supply chain management system ensures that all gases are always delivered efficiently and safely in containers scaling in size from one-litre pressurised gas cylinders through interconnected cylinder bundles to trailer tanks for acetylene and hydrogen.



GASES SUCH AS OXYGEN, NITROGEN, ARGON, HYDROGEN OR HELIUM ARE EASILY COMPRESSED AND TRANSPORTED IN CYLINDERS WITH A FILLING PRESSURE OF UP TO 300 BAR.

Cylinder packages are usually made of high-strength steel or aluminium with a filling pressure of up to 300 bar. These cylinders are typically used for oxygen, nitrogen, argon, hydrogen or helium.

Linde has also launched a new generation of gas cylinders made of an innovative composite plastic. Highlights of the GENIE® family include ergonomic handles, transport wheels and a built-in digital display. Every cylinder is equipped with a valve that meets international standards for the gas and pressure in question. For even greater convenience, Linde offers cylinder valves with integrated pressure regulators developed in-house for different markets and applications.



## Helium – the global gas

Production and energy costs have a direct impact on the way gas is transported to customers. As a result, gases are classified as local, regional or global products. Nitrogen, for example, is a local gas. It has a very short supply chain. This is because it can be produced cost-effectively in large amounts, unlike noble gases such as argon. So a dense customer network near a local air separation unit that produces nitrogen will ensure ready availability. Argon, on the other hand, is a regional gas that can be easily transported over distances of 1,000 kilometres or more. Helium is even rarer still, and therefore classified as a global gas. There are only around a dozen helium sources worldwide to meet global demand. Regardless of how gases are supplied to customers, efficiency always plays a crucial role.

With over 50 helium filling plants in all key markets, Linde has the world's most reliable helium sales and distribution network. The company operates one of the largest helium production plants in the world in the US town of Otis. This is complemented by facilities at other sites around the globe including Algeria, Qatar and Australia. Linde supplies bulk liquid helium in insulated ISO containers and smaller volumes in dewars. Gaseous helium is transported in cylinders, multi-cylinder packs (bundles) and tube trailers.

## Gases in trailers and tanks

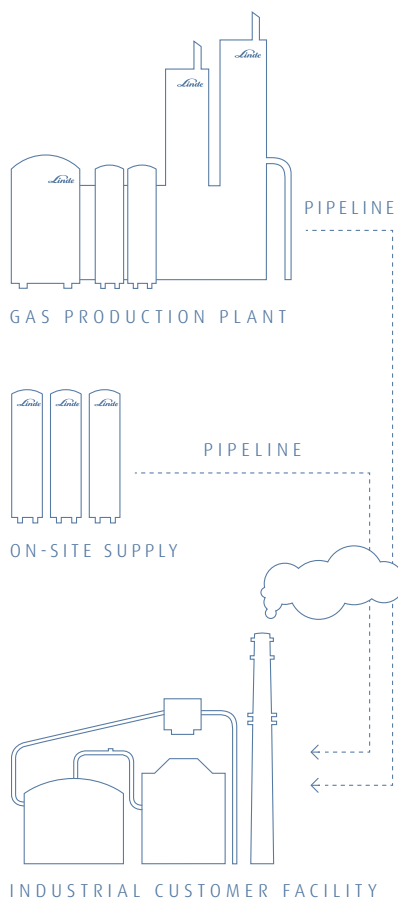
Linde is also the market leader in the supply of liquid gases. Every year, the company's 3,400 trailers deliver 18 million tonnes of cryogenic liquid gases to more than 50,000 customers. This corresponds to approximately two million deliveries and a distance of around 400 million kilometres. It requires a particularly flexible and efficient logistics and distribution infrastructure. Linde continually improves its liquid gas supply chain to ensure its customers always get the products they need – quickly, reliably and cost-efficiently.

The volume required by gases such as nitrogen, oxygen, hydrogen, argon and carbon dioxide shrinks 800-fold when they are converted from a gaseous state to liquid form. Delivering gases as cryogenic liquids is therefore a particularly efficient and environmentally sound supply option. Linde offers vacuum-insulated tanks with capacities ranging from 3,000 to 80,000 litres and installs these with the requisite distribution systems and peripherals at customer sites. Linde also delivers gaseous hydrogen in high-pressure tanks on request.

Linde's tanks usually come with telemetry systems for remote tank-level monitoring that communicate how much gas is left in the customer's tank. This allows Linde to automatically arrange deliveries and the customer is assured continuity of supply without having to worry about monitoring and placing orders.



SCALED SUPPLY: LINDE TANK INSTALLATIONS PROVIDE A CONVENIENT AND COST-EFFECTIVE SOLUTION FOR LARGE ENTERPRISES WITH COMPARATIVELY HIGH INDUSTRIAL GAS CONSUMPTION. THEY MEET THE LATEST TECHNICAL STANDARDS, ARE SIMPLE AND SAFE TO USE AND REQUIRE NO MAINTENANCE BY THE OPERATOR.



## Gases from on-site production plants

Linde rounds off its integrated supply model with on-site generation systems for customers who require very large volumes of gas. The company meets this demand by building production plants directly on site at the customer’s point of consumption. Linde operates around 450 major air separation units and hydrogen and synthesis gas (HyCO) plants for customers the world over. These systems can be remotely monitored and controlled from Linde’s eleven control centres located around the globe. The plants produce around eight million standard cubic metres of gas per hour for up to 2,000 major customers. In addition to these large-scale plants, Linde has installed over 1,000 modularised ECOVAR® units at customer sites worldwide.

### Supplying gases from large on-site plants via pipeline networks

Major customers in sectors such as the chemical and steel industries often require very large amounts of gases for a wide range of processes. These high volumes of oxygen, nitrogen, argon, hydrogen, carbon monoxide, carbon dioxide and synthesis gas are usually supplied via pipeline networks. One approach here is to build a production facility in direct proximity to a single customer. Alternatively, several gas production sites can be connected to a pipeline network which then supplies a number of different customers, for example in the same industrial complex or region.

Linde offers its on-site customers made-to-measure solutions that deliver the gas volumes at the purity levels they need. The company has extensive know-how in this field and many years of experience in the construction of air separation and HyCO plants. Its services range from consultation and concept creation through investment and construction to the operation of facilities and pipelines. Linde can also modernise and, in exceptional cases, take on full operational responsibility for existing facilities. The company has teams of experts in all key industrial regions and maintains close relationships with its customers to meet all of their on-site supply needs.







A LINDE AIR SEPARATION PLANT FOR ON-SITE SUPPLY OF AIR GASES INCLUDING OXYGEN, NITROGEN AND ARGON TO A MAJOR STEELWORKS IN RUSSIA.

#### **ECOVAR® standard on-site solutions**

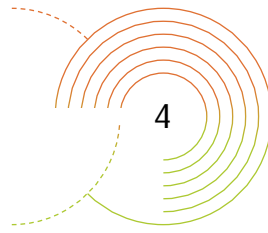
Linde's ECOVAR® product range is aimed at industrial customers looking for highly cost-effective, flexible and reliable on-site supply solutions.

The modular ECOVAR® programme comprises a standard plant and a back-up unit to ensure uninterrupted gas supplies. These systems are suitable for indoor and outdoor installation and can be adapted to fit existing space and utility requirements (energy, water and compressed air). Because they are built around standardised modules, ECOVAR® solutions are extremely cost-efficient and offer low development, construction, installation, operating and maintenance costs. They are usually mounted in cabinets, on skids or in containers and can therefore be rapidly assembled and deployed.

Automatic control systems track fluctuations in demand and activate the back-up unit to support the main plant during peaks in production. The back-up unit is also activated if the main plant comes to a standstill. Both the production plant and the back-up unit are normally monitored by the nearest Linde Gas Centre. ECOVAR® systems reduce transport volumes and energy consumption to a minimum, making them a much more environmentally sound option than conventional supply methods.

Linde's ECOVAR® offering includes a gas supply agreement and also extends to the planning, construction and operation of the standard plant and back-up unit by qualified Linde specialists. For comparatively low investment costs, customers can be sure of reliable gas supplies from state-of-the-art, cost-efficient plants – leaving them free to focus on their core business.





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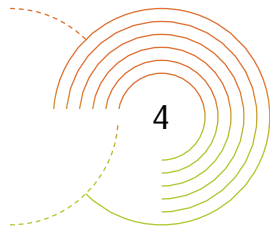
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## Gases & Healthcare

# Using gases

Linde gases are an integral part of our everyday lives – used for everything from joining, cutting, heating and cooling through protecting and preserving to testing and analysing. They are even helpful in patient treatments and therapies. Linde's gas applications and processes can be found in all key industries including food and beverages, chemicals and energy, metallurgy and glass, manufacturing and electronics. The products, hardware and services delivered by Linde enable manufacturers to increase the efficiency, cost-effectiveness, safety and environmental performance of their processes. They also improve the quality of end products.

In addition, Linde's medical gases, devices, therapies and supporting services play a vital role in the healthcare sector. Here Linde helps to keep patients healthy and improve their quality of life.



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## Food and beverages

# Improving quality and extending shelf-life

The food and drinks industry is extremely diverse. Equally varied, however, is the spectrum of gases used to bring food and beverages to the consumer. At every step of the value chain from production through processing to retailing, Linde's gases help reduce manufacturing costs, improve product quality and extend the shelf-life of food and drinks. Gases are also indispensable in drinking and wastewater treatment and in aquaculture.



**CRYOLINE®:****Made-to-measure freezing and cooling technology**

Today, cryogenic freezing and cooling is a proven technology to maintain quality levels in modern food production processes. Linde's CRYOLINE® family enables producers to streamline freezing processes even more, while increasing safety levels at low cost. Designed to meet the strictest hygiene standards, the CRYOLINE® family features new, improved technologies that reduce cleaning and maintenance downtime for maximum production flexibility. The programme includes different freezing and cooling models suitable for a wide range of foodstuffs including baked goods, meat and fish products, pasta, vegetables and ready-made meals.



## From field to fork

Cryogenic technologies and various gases play a key role along the entire food production chain. In fruit and vegetable cultivation, for instance, gases help plants to flourish by creating an optimum atmosphere. Carbon dioxide boosts growth rates in greenhouses, while ethylene enhances the ripening process of certain fruits. Cryogenic freezing and cooling technology is a well-established way of preserving the quality of sensitive food produce, harnessing the cooling power of cryogenic liquid gases. Optimising heat transfer is crucial here, so that the gas chills the product as effectively as possible. From ready-make meals to fillets of fish, Linde has the process know-how and cryogenic technologies to ensure optimum flash-freezing results, every time.

Gases are also essential in the processing of milk products, pastries, oils and fats – guaranteeing highly efficient production processes and extending the shelf lives of products. In addition, gases help preserve the flavour of different foods and drinks.

Linde develops special modified atmosphere mixtures that keep packaged products such as cheese, ready-mixed salads and minced meat fresh for longer. The company also develops innovative technologies that enable supermarkets and caterers to maintain uninterrupted cold chains – a “must-have” to deliver high-quality foods and drinks around the world.

Labs and testing institutes require high-purity specialty gases for the analysis and measurement instruments used to control quality in the food and drinks industry. Supporting the entire value chain from production and processing to quality control and consumption, Linde makes a valuable contribution to ensuring a fresh, safe and diverse selection of products on our supermarket shelves. Its family of food-grade gases for direct contact with edible products meets all international food safety standards.

## Producing and packaging drinks

Gases have many different applications in the drinks industry. The best known of these is carbonation – the process of injecting carbon dioxide into bottles of soft drinks, mineral waters and sparkling wines at high pressure. Injecting carbon dioxide also increases shelf life and prevents oxidation by eliminating the presence of oxygen. Nitrogen is another widely used gas in the drinks industry. In inerting processes, for example, nitrogen is used to displace unwanted oxygen from drinks such as fruit juices. This enables juices to retain their colour for longer while preserving valuable vitamins and flavour. Stabilising PET bottles is another key



THE DRINKS INDUSTRY NEEDS TO FILL AS MANY BOTTLES AS POSSIBLE WITHIN A SHORT TIME SPAN. GASES PLAY A CRUCIAL ROLE AT KEY POINTS THROUGHOUT THIS PROCESS.

## Regulating the pH value

and controlling limescale with carbon dioxide.

application of nitrogen. Here, a drop of liquid nitrogen is added to the contents of a bottle before it is sealed. As the nitrogen evaporates, pressure builds up inside the bottle, enabling it to withstand greater forces during transport and storage.

Gases are also used in the catering industry, for example in dispensing beers and soft drinks. Linde's dispense gas solutions consist of carbon dioxide or a mixture of nitrogen and carbon dioxide, depending on the target application. Linde's gases and cooling applications play a similarly important role in wine production. In cold maceration, for example, liquid carbon dioxide is used to cool the grape mash. The carbon dioxide also displaces oxygen, preserving the colour and important substances in the wine.

## Improving water quality

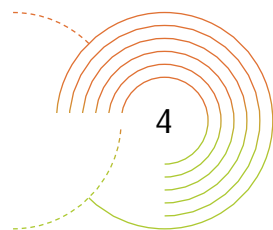
Water is the key to all life. Quality levels are continuously controlled and have to meet the highest standards, as set down by law. Linde gases have been successfully used to improve water quality for many years now. The company supplies a wide range of gases, equipment, services and technical solutions to companies that treat and process drinking water. Some of the most common applications in this sector include pH and limescale control with carbon dioxide and oxidation of unwanted impurities using oxygen.

Pure oxygen is also injected in large volumes into industrial wastewater treatment plants. Linde offers a broad portfolio of products for global waste management and recycling companies and for municipal water supply services. In addition, Linde's gas applications are used in seawater desalination to obtain drinking water, for example, to balance water chemistry.



LINDE OPERATES AN INNOVATION CENTRE FOR AQUACULTURE AND WATER TREATMENT IN ÅLESUND, NORWAY, WORKING WITH CUSTOMERS TO ADVANCE THE USE OF OXYGEN IN FISH FARMING.

Pure oxygen is an equally important resource in aquaculture. In fish farms, water in breeding basins must be saturated as far as possible with dissolved oxygen to provide optimum conditions for fish. Linde's experts continually develop these oxygen feed systems to ensure that this life-giving gas is distributed as precisely and energy-efficiently as possible.



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Chemicals, energy and the environment

## Focus on energy efficiency, safety and the environment

Companies in all areas of the chemical and energy sectors are under increasing pressure to adopt environmentally sound, climate-friendly production processes and use energy and resources as efficiently as possible. Linde's portfolio of industrial gases and cutting-edge applications supports this trend by making technological processes and plants more energy-efficient and safe. Linde technologies also help cut emissions resulting from its own and customer production processes and thus accelerate the move to greater sustainability and increased climate protection, while adding value to the entire production chain.





## Specialty gases for high-tech applications

Linde bundles its offering of high-purity specialty gases and specialty equipment for process instrumentation, quality control, laboratories and research institutes under its HiQ® brand. This rich portfolio of gases and supply systems supports the broadest application spectrum with, for instance, calibration gas mixtures for analytical instruments or high-purity gases for medical diagnosis, the production of pharmaceuticals and food testing. The HiQ® portfolio includes high-precision calibration and test gas mixtures for analytical instruments used in process control, emissions monitoring, environmental analysis and car emissions testing. Linde complements this offering with an extensive logistics network backed by a range of additional services such as consulting, safety training, accreditation and total gas management. The company also delivers a broad portfolio of analytical and technical services.



## Efficiently capturing nitrogen oxides

Linde's LoTox™ technology makes a valuable contribution to climate protection by enabling harmful nitrogen oxides to be removed from industrial flue gases. The process uses ozone as an oxidising agent and achieves efficiency levels of up to 95 percent, making it the leading commercially available solution for capturing nitrogen oxides. The LoTox™ process works at low temperatures and the ozone it uses can be produced directly on site. Linde delivers turnkey installations for this process technology.

## Processing fossil fuels and fine chemicals

Industrial gases from Linde play a key role in applications such as crude oil, natural gas and lubricant processing in the field of petrochemistry. Hydrogen, for example, is used to desulfurise fuels. It is also an important reactant in hydrotreating and hydrocracking processes, where it is used to convert hydrocarbon compounds with higher molecular weights into intermediate products for the manufacture of diesel, petrol and kerosene. Gases also play a crucial role in the Claus process, a downstream step in fuel desulfurisation. Enriching the air used in this process with oxygen significantly boosts the capacity and flexibility of Claus plants. In addition, gas-based processes from Linde streamline the production of fine chemicals, which are used to manufacture a huge range of products from pharmaceuticals through cleaning agents and adhesives to electronic products. On the environmental front, Linde offers a raft of innovative solutions that help companies in the chemical industry meet increasingly strict regulations. Gases such as nitrogen and carbon dioxide are used to inert oil and fuel pipelines, reactors and filling plants, thus limiting oxygen content – which could otherwise have a negative impact on many chemical processes. Linde also offers heating and cooling systems to control the temperature of reactors during chemical synthesis, as well as cryo-condensation units used to recover volatile organic compounds and solvents. In addition, the company develops and delivers efficient waste and wastewater treatment processes.

## Invisible helpers in pharmaceutical manufacture

Patient health and safety is the number-one priority in the pharmaceutical sector. Linde gases and gas technologies ensure that pharmaceuticals and active pharmaceutical ingredients (APIs) are produced safely and to the highest quality standards. The company offers solutions for every step of the pharmaceutical process chain, from research and development through processing and formulation to process monitoring and quality control. Linde works closely with its customers to ensure that all of its solutions meet the requisite quality requirements. Dedicated product lines help pharmaceutical and API manufacturers meet the applicable good manufacturing practices (GMP) governing batch uniformity and gas traceability, for instance. Linde also provides the pharmaceutical industry with cryogenic gases such as liquid nitrogen, liquid carbon dioxide and dry ice, all of which can be used as environmentally friendly alternatives to conventional cooling methods. In addition, cryogenic cooling solutions from Linde help improve pharmaceutical processes such as grinding, milling, mixing, granulating, freezing and freeze-drying. Gases are also used to preserve medical samples at low temperatures. Linde supplies liquid nitrogen for the safe storage and transport of a wide range of active ingredients and biologicals at temperatures as low as minus 196 degrees Celsius.

## Hydrogen and energy efficiency for more effective climate protection

Hydrogen (H<sub>2</sub>) has the potential to play a major role in the transition to environmentally sound mobility choices and climate-friendly sources of energy. It is, for example, the ideal environmentally friendly car fuel. Linde develops innovative technologies across the entire hydrogen value chain, from the production of H<sub>2</sub> using fossil and renewable energy sources through compression, liquefaction, storage and transport to vehicle fuelling. The company is working with a number of partners to continuously expand the H<sub>2</sub> infrastructure for fuel-cell cars, delivering turnkey H<sub>2</sub> fuelling stations the world over.

Solar and wind energy are two key – albeit fluctuating – success factors in the transition to a climate-friendly energy economy. Hydrogen has the potential to advance developments here



LEFT: A HYDROGEN FUELLING STATION BUILT BY LINDE AT BERLIN'S MAJOR NEW AIRPORT.



CENTRE: AN IONIC COMPRESSOR - THE CORE OF AN H<sub>2</sub> FILLING STATION.



RIGHT: REFUELLING A FUEL-CELL CAR WITH HIGH-PRESSURE HYDROGEN.

too. Power-to-gas technology, for example, uses electrolysis and regenerative electricity to convert water to hydrogen. This is a flexible and efficient way of storing energy for later use, for example to power fuel-cell cars. The hydrogen can also be fed into public natural gas pipelines, used for industrial supplies, reconverted to electricity by gas-fired power plants or converted into synthetic methane.

Linde is committed to reducing both its direct and indirect emissions and to conserving resources. To this end, the company continually increases the energy efficiency of its own air separation and synthesis gas production plants. As a result of its efforts here, Linde has developed a standardised, modularised design for air separation units. Building on the latest findings from basic research, the company continually develops new areas of application for its gases and works closely with customers to make production processes even more cost-effective and environmentally friendly. Key priorities here include the need to increase energy efficiency across processes and plants and cut the emissions released during production – by both Linde and its customers.

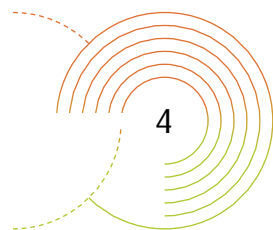
## Shaping the future with Clean Technology

Demand for energy is rising rapidly, fuelled by ongoing industrialisation in emerging markets and steady growth in the world's population. At the same time, resources are becoming increasingly scarce and climate change continues to advance. Linde offers innovative solutions for these challenges under the umbrella of its Clean Technology programme. The company is committed to continually exploring new ways of promoting sustainability. Linde technologies help increase environmental performance in coal-fired power plants across multiple process steps. The company also offers application technologies to recycle CO<sub>2</sub> or use it to generate biofuels, store renewable energies on an industrial scale and use natural gas or hydrogen as environmentally sound sources of energy. It rounds off its Clean Technology offering with innovative processes for the biotechnology and solar industries.

## Gases for pulp and paper production

Linde is a leading provider of industrial gases for the pulp and paper industry, working closely with customers to develop innovative applications that add value by optimising processes and protecting the environment. Gases offer significant optimisation potential in modern pulp production processes, in particular in pulp washing and bleaching of pulp suspension. Oxygen, for example, can be used in a wide range of process steps, including delignification, certain bleaching processes and ozone production. It also improves chemical recovery processes at the pulp mill. Carbon dioxide optimises pulp washing processes, decreasing the amount of water required. Reduced steam demand enables more efficient generation of green electricity. Using carbon dioxide for the production of crude tall oil can reduce sulfuric acid consumption by 30 to 50 percent, while improving the pulp mill's sulfur/sodium balance. In addition, CO<sub>2</sub> can be used to precipitate lignin, which can then be used as a biological raw material for carbon fibre or as an energy source.

Linde has also developed several CO<sub>2</sub>-based technologies for paper production. Each solution is tailored to individual customer needs and enables manufacturers to control and stabilise pH levels without increasing the hardness of process water. Possible benefits include reduced deposits, increased productivity, lower chemical demand, savings in energy and improved quality.



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## Metals and glass

# Producing metals and glass more efficiently and with lower emissions

Humans have been producing metals and glass for thousands of years. Yet these age-old industries continue to innovate and industrial gases play an enabling role in the technical advances we see here. Gases are an essential ingredient to increase energy efficiency, boost productivity, raise product quality, enable new material properties and decrease emissions. Linde helps glass and metal companies to realise these benefits through efficient gas supply solutions, backed by a vast portfolio of state-of-the-art application technologies.



## Oxygen boost for reheating furnaces

Steel must be reheated to around 1,200 degrees Celsius in a special furnace before each processing step in rolling mills or forges. This naturally consumes a lot of energy. So as part of its efforts to raise cost efficiency and reduce the environmental impact of steel production, Linde developed the REBOX<sup>®</sup> oxyfuel technology for reheating and annealing furnaces. This solution enriches the air with pure oxygen during combustion, significantly increasing furnace efficiency. The company's latest innovation in this area is REBOX<sup>®</sup> HLL (High Level Lancing) technology, which is particularly well suited to large reheating furnaces. Here, over 75 percent of the combustion air is replaced with oxygen. This cuts fuel consumption and more than halves exhaust gas emissions, while also increasing plant throughput.

## End-to-end offering for metal industries

Linde is not only the number-one supplier of industrial gases to the steel industry, but also a leading supplier to the cast iron, aluminium, copper, lead and precious material segments. For all of these sectors, Linde delivers the industrial gases and application technologies required along the entire value chain – from raw material processing through melting and refining to rolling and heat treatment.

Steel is the metal industry with the highest demand for industrial gases. Significant amounts of oxygen are required to decrease the carbon content in iron and ultimately create steel. Additionally, there are many other applications in the steel mill where gases offer far-reaching benefits. These include oxygen enrichment in blast furnaces and Cowper stoves for increased productivity, greater efficiency and lower emissions. Many operators also realise efficiency, productivity and emissions benefits through oxyfuel combustion and enrichment in reheating furnaces (REBOX<sup>®</sup>) and ladles (OXYGON<sup>®</sup>). In slab cutting, acetylene and oxygen are an effective way of boosting efficiency. And argon and nitrogen help limit chromium loss during stainless steel production in AOD converters.

These are not the only metal industries where Linde gases and application technologies are significant success factors. In iron foundries, for example, Linde's HIGHJET<sup>®</sup> solution for cupola furnaces increases the oxygen content in the blast. This helps operators reduce production costs, improve productivity and decrease emissions without compromising on quality or safety.

Looking at the aluminium industry, Linde's low-temperature oxyfuel (LTOF) solution optimises melting processes, for instance. This technology improves thermal efficiency and gas radiation without increasing the flame temperature. Benefits include productivity gains between 10 and 30 percent, fuel savings between 40 and 60 percent per tonne of aluminium and significant reductions in CO<sub>2</sub> and NO<sub>x</sub> formation without impacting dross formation or refractory wear.



ABOVE: BURNER AND GAS TECHNOLOGIES FROM LINDE INCREASE COST- AND ENERGY-EFFICIENCY IN ALUMINIUM PRODUCTION - WHILE CUTTING HARMFUL EMISSIONS.

RIGHT: LINDE'S FLAME-BASED SURFACE TREATMENT FOR GLASS CAN BE CUSTOMISED TO A MANUFACTURER'S SPECIFIC REQUIREMENTS.

## Heat treatment innovations for enhanced product properties

Heat treatment is an essential step in turning steel, aluminium and other metals into useful products for the automotive or aerospace industries, for example. This entails treating the metal parts for defined periods of time at set temperatures in specific gas atmospheres. The objective is to achieve the high-tech material properties required for these industries.

Nitrogen/hydrogen atmospheres create bright surfaces on sheet metal, for instance. Or carburisation entails raising carbon levels in the atmosphere to harden the surface of metal parts. Other heat treatment processes enabled by gases and application technologies supplied by Linde include furnace brazing, carbonitriding, nitriding, nitrocarburising, neutral hardening, sintering of powder metals and sub-zero treatment. Complementing the gases required for the heat treatment atmospheres, Linde also provides state-of-the-art atmosphere control and stirring equipment.

## Process technologies for the world of glass

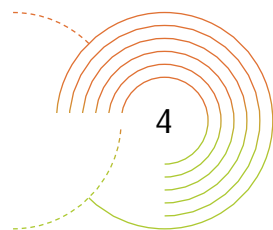
Glass production is extremely energy-intensive. The production of glass also results in significant emissions, mainly carbon dioxide (CO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>), but also sulfur dioxide (SO<sub>2</sub>) and carbon monoxide (CO). Legislation the world over is imposing tighter controls on these emissions. In addition to cost and emission pressures, glass manufacturers are challenged to secure their competitive position through the latest coating and insulating innovations. Demand is also rising for security and fire-rated glass, self-cleaning surfaces and smart capabilities.

Industrial gases are an extremely effective way of meeting today's glass production challenges. Linde offers a wide range of gas applications, process technologies and services to cover all glass melting, forming and processing needs. For instance, Linde's gas-enabled solutions can increase energy efficiency and productivity. They can also help reduce emissions and ensure legislative compliance. And – last but not least – Linde engineers have in-depth experience in many of today's leading process technologies. They can advise on the gases and supply modes best suited to helping operators achieve the high-tech surface finish or properties they require.

### High-shine finish for glass surfaces

Faced with growing cost and productivity pressures, many glass manufacturers are looking for ways to differentiate themselves from the competition through an enhanced, premium-quality finish. Ideally this should combine the speed of a machined finish with the finesse of handcrafted glass. This is especially true for items such as high-end wine glasses and perfume bottles, as well as in the specialty glass sector (e.g. oven doors). HYDROPOX®, Linde's flame-based glass surface treatment solution, is an effective way to address these challenges. It helps to increase brilliance, eliminates seams, and heals micro-cracks and imperfections early on. Depending on a manufacturer's specific needs, Linde offers both pre-mixing and surface-mixing burners, designed to run on either oxygen and hydrogen or oxygen and natural gas.





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## Manufacturing industry

# Quality and efficiency in materials processing

The manufacturing industry processes a variety of materials – including metals and plastics – to produce high-quality components for the widest range of target markets. This industry thus relies heavily on welding, cutting, heating and cooling processes. Applications range from simple joining techniques to high-tech laser treatments, and from spray coating to gas injection moulding. A wide range of application-specific hardware is required to support these processes. With its innovative range of processing solutions, Linde is a trusted partner for manufacturers across sectors as diverse as steel and mechanical engineering, construction, automotive and plant engineering.







### Innovative equipment for cylinder gases

Safe and precise operation of cylinder valves is a key safety factor when using gases. The cylinder valves in Linde's innovative EVOS™ family feature an ergonomic design that was specifically developed to reflect concrete customer needs. A built-in contents indicator shows the current pressure at a glance, while a quick-action ON/OFF lever means operators can start and stop the gas flow quickly, easily and safely. The lever also allows users to clearly see – even from a distance – whether the lever is in an open or closed position. An integrated safety interlock button gives added safety, eliminating the risk of the valve being opened inadvertently. In addition, EVOS™ comes with a specially designed guard with easy-grip arms that not only protects the valve against general damage, it also makes it easier to grasp, lift and move.

## Optimising arc welding performance

In the steel and mechanical engineering sector, the most important process for joining metals is gas-shielded welding. Depending on the type of component, this may entail various arc welding techniques, such as tungsten inert gas (TIG), metal active gas (MAG), metal inert gas (MIG) and plasma welding. Shielding gases from Linde play a key role here. On the one hand, these include inert gases such as argon and helium, and on the other, active agents such as oxygen and carbon dioxide or reducing agents such as hydrogen, which are mixed into the inert gas in small amounts. Tailored to specific materials and processes, the right gas mixture can improve welding performance and reduce manufacturing costs. Helium and hydrogen are particularly valuable, increasing the efficiency not only of the arc itself, but also of the heat transfer from arc to joint, thus accelerating the welding process. Selecting the exact composition of shielding gas to suit specific requirements also helps to improve the standard and quality of the weld. Linde further supports the metal fabrication industry with innovative technology and equipment, as well as customised gas supply concepts and services.



METAL INERT GAS WELDING ON AN ALUMINIUM PIPE.

## High-quality gases for laser applications

Gases are essential for laser-enabled materials processing applications. In laser welding, the choice of shielding and process gas has a direct impact on the cost-effectiveness of the process, potentially improving the welding speed and mechanical properties of the workpiece. Linde's offering here includes helium, argon and gas mixtures such as LASGON®.

Laser cutting also calls for the right gases. Linde's high-quality solutions for this segment extend from gases for CO<sub>2</sub> lasers, which can be used to cut a wide range of substances, to oxygen and nitrogen for efficient cutting of various steel materials and aluminium. Linde gases also enable laser-based surface treatment, for instance in hardening, spraying and alloying metal components.

High-purity gases are equally important in laser sintering processes to form three-dimensional structures. Complementing these gases, Linde delivers application know-how and comprehensive services in this area, increasing the safety, productivity and cost-effectiveness of materials processing with lasers. The company's product portfolio spans LASERMIX® gases for cutting and welding with CO<sub>2</sub> lasers, bespoke process gases for all laser techniques, and supply and application consulting across the entire spectrum – from large and complex laser systems for industrial use to small laser units in workshops.



### Burner system for individual applications

Some process challenges call for customised hardware solutions. Linde designed its LINDOFLAMM® range of acetylene burners specifically to provide adaptable answers to individual heating challenges. They ensure optimum heat transfer to the workpiece and minimise gas consumption. These LINDOFLAMM® burners provide tailored solutions for all flame straightening, pre- and post-heating, hot forming and flame hardening tasks. Linde offers its customers a one-stop, premium package, incorporating the best gas for the application in question, the appropriate equipment, dedicated services, security of gas supply and wide-ranging consulting expertise.

## Harnessing heat

Linde offers a variety of thermal process technologies for the metal fabrication industry. Components often need to be pre-heated prior to welding, for instance, to prevent subsequent cracking. And for high-strength steels, post-heating may also be required to reduce the hydrogen content of the weld. Flame straightening, on the other hand, is a thermal technique that uses an oxygen-acetylene flame to apply targeted heat to a workpiece and remove distortions. These powerful oxy-acetylene flames are also widely used in gas cutting – whether by hand or machine. Linde not only supplies the manufacturing industry with high-quality fuel gases and the accompanying supply infrastructure, but also with burner technologies, automated systems and complementary services to boost cost efficiency. When it comes to plasma cutting, for instance, the right gas mixture is crucial to success. So Linde provides specially adjusted argon and hydrogen mixtures to meet the demands of each application, as well as pure gases such as nitrogen and oxygen. Meanwhile, surface treatment and spraying processes are used to prolong the life of materials and components for plants and machinery. Thermal spraying is a good example here, protecting surfaces against wear and tear and improving corrosion resistance. This process can also cut costs, as engineers can achieve the desired surface properties through spraying and thus avoid expensive base materials. Here, again, Linde supports manufacturers with all the necessary technical equipment, supply systems and process expertise.

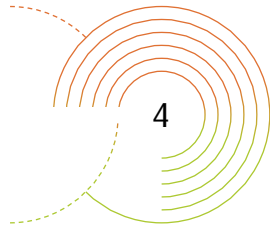
## Success at low temperatures and high pressure

Innovative cooling technologies can enhance process steps across a wide range of sectors. Dry ice blasting removes unwanted residues and impurities from machine components or materials, for instance. Here, Linde provides dedicated solutions for cleaning items such as tools, moulds and conveyor belts. The company's CRYOCLEAN® technology uses carbon dioxide cooled to around minus 78 degrees Celsius. Surfaces are then cleaned by blasting them with CO<sub>2</sub> dry ice pellets or 'snow' particles at high speed. This method can be used directly on the shop floor, so virtually eliminates downtime. And since dry ice blasting is gentle on surfaces, it minimises wear and tear too. This type of cleaning is also suitable for pre- and post-processing of welded parts, as well as preparing metals and plastics for paintwork. Linde's CRYOCLEAN® solution can easily be integrated into automated production workflows.

Linde also offers cooling applications to optimise production of moulded rubber components. The use of liquid nitrogen or carbon dioxide can speed up the removal of flash, for instance, which in turn raises the quality of rubber products. The company can also draw on decades of experience in cryogenic grinding, which is typically used for heat-sensitive, plastic or elastic products.

The plastics industry benefits from another innovative Linde process: gas injection moulding (GIM). Here, gaseous nitrogen or liquid carbon dioxide is forced into a plastic melt at high pressure. The gas or sublimating liquid displaces part of the material so that the plastic component is hollow inside after curing, thus saving weight. This method can nonetheless produce elements with high strength and stability. It thus has an important role to play in the automotive industry, which is using more and more plastic parts – in manufacturing door handles, for example, or casing for headlights and wing mirrors.

Cooling technologies are also invaluable in the construction industry. Liquid nitrogen is used for ground freezing, for instance, to enable tunnel work below unstable ground. And cooling concrete with liquid nitrogen prior to casting can avoid strains as it sets.



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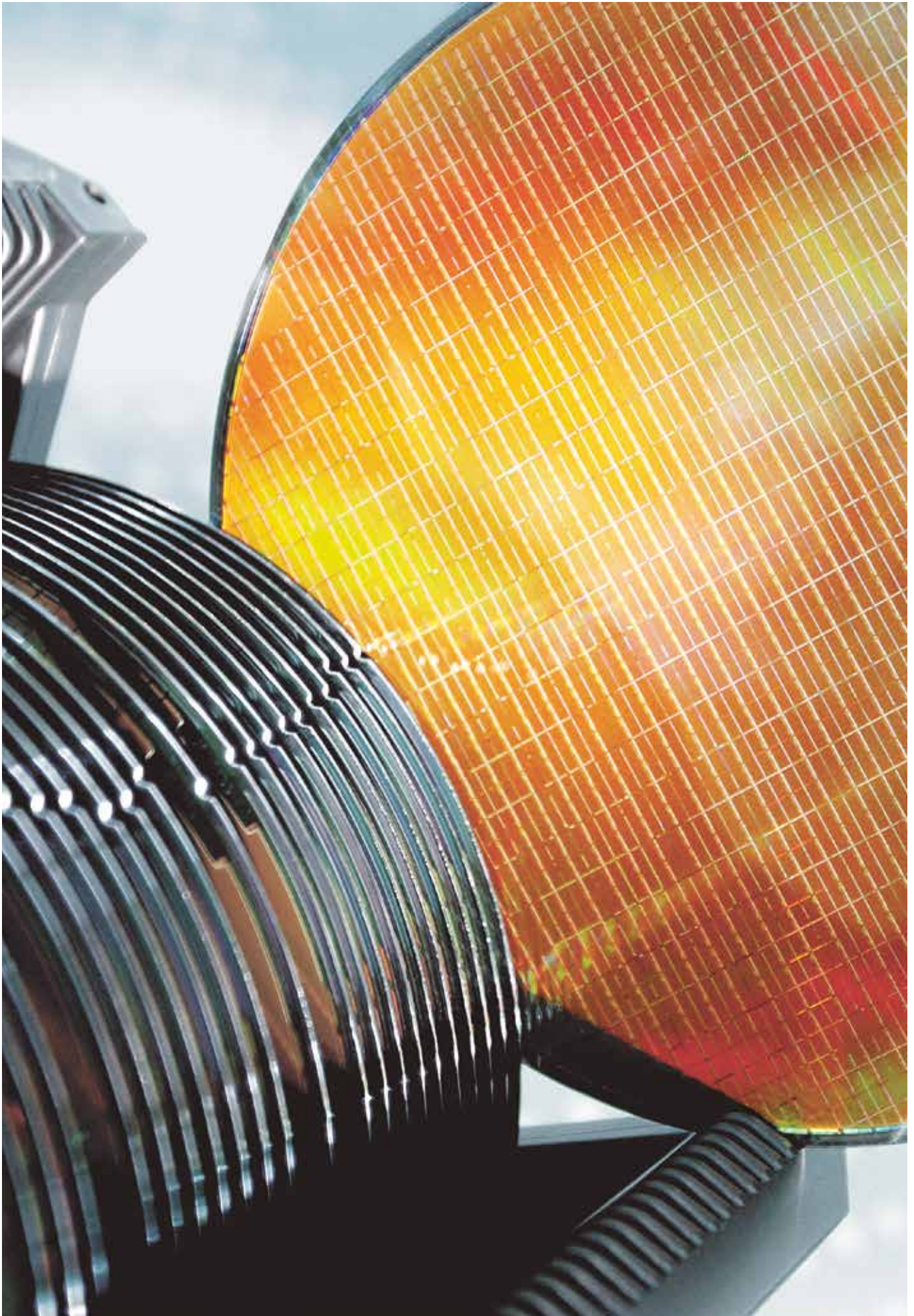
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## Electronics

# High-purity gases for high-tech applications

Manufacturers rely on high-purity gases to make high-tech products such as smartphone semiconductors, flatscreens and solar cells. The gases and chemicals required by semiconductor, display and solar companies have to meet some of the most stringent quality standards in the industry. The same applies to security of supply. Linde continually evolves its products and services to meet the exacting needs of its customers in the electronics industry. The company also meets individual specification demands, enabling its customers to comply with strict environmental regulations.



### Improving carbon balance with on-site F<sub>2</sub> generators

In the electronics industry, demand is growing for technologies that deliver higher etching rates and an improved carbon balance. Linde's Generation-F® generators produce climate-neutral fluorine (F<sub>2</sub>) on site. This effective, environmentally sound gas is used for cleaning process chambers during the production of displays and semiconductors. The fluorine replaces gases such as nitrogen trifluoride (NF<sub>3</sub>) and sulfur hexafluoride (SF<sub>6</sub>), which have a high global warming potential. F<sub>2</sub> shortens cleaning time by over 50 percent, reduces tool downtime and increases productivity by up to 10 percent. Linde also offers a process that captures residual post-cleaning SF<sub>6</sub> and feeds it back into the production process for reuse.

## Serving the semiconductor industry – worldwide

Linde has the global reach to supply every wafer fab in the world with ultra-pure gases and chemicals plus supporting services. Gas supply options scale from cylinders and tanks to on-site generation plants and pipeline deliveries. Linde's offering supports all semiconductor fabrication processes from deposition and doping through photolithography to etching. Innovative gas-enabled technologies allow semiconductor manufacturers to meet rising market demands, driven by trends such as chip miniaturisation, for instance.

Linde supplies the world's largest semiconductor manufacturers in cluster parks in Taiwan, the US and Korea via pipeline systems stretching over many kilometres. Core competencies in the electronics industry also include the production of laser gases, high-purity corrosive gases and isotope enrichment.



LINDE'S HIGH-PURITY SPECIALTY GASES PLAY A CRUCIAL ROLE IN MEETING THE GROWING CHALLENGES IN THE ELECTRONICS INDUSTRY.

## High-tech gases for displays

Huge amounts of high-purity purge gases and electronic special gases are required to produce screens for smartphones, tablets, laptops, computers and flatscreen televisions. Linde offers these gases in supply packages of all sizes. The company also helps customers improve their CO<sub>2</sub> balance in the process.

Next-generation semiconductor switches known as metal-oxide transistors are increasingly being used in ultra-high-definition (UHD) TV displays. High-purity gases such as nitrous oxide (N<sub>2</sub>O), also known as laughing gas, are needed to produce these new switching devices. Linde is a trusted and flexible gases partner to the electronics industry, helping fabricators to transition from silicon to metal-oxide transistors. Customers benefit from local delivery capabilities backed by a global supply chain. In addition, the company operates its own production plants for process gases in countries such as China, Taiwan and Korea, as well as a full tank supply infrastructure across Asia.



LINDE SUPPORTS THE SOLAR INDUSTRY WITH A GLOBAL SUPPLY CHAIN AND A BROAD PRODUCT PORTFOLIO.

## All-round solutions for the solar industry

Demand for silicon, wafers and solar cells for the solar industry is growing. Large volumes of argon, hydrogen and nitrogen as well as electronic special gases and chemicals are needed at all stages of the process chain – from the production of raw silicon right through to solar modules. All of these gases have to meet the highest purity, quality and consistency levels. At the same time, the industry is facing increasing cost pressures. To ensure long-term success in this competitive environment, manufacturers need to increase process efficiency and develop solar cells offering a higher yield. As a one-stop provider with in-depth process expertise, dedicated R&D programmes for cutting-edge technologies and highly qualified specialists, Linde is ideally positioned to help the solar industry meet these challenges. Backed by a global supply chain, the company offers a broad product portfolio that includes systems for argon recovery and innovative materials for high-performance solar cells.

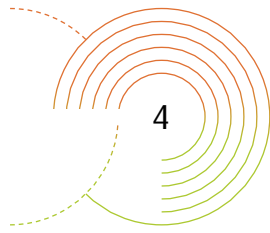
## Partner of choice for LED players

Solid-state light-emitting diodes (LEDs) are being used in more and more areas of everyday life to deliver high-quality lighting effects. This trend is primarily driven by applications such as backlit flatscreens and energy-saving lighting technologies. To meet this rising demand, LED manufacturers require large volumes of nitrogen, hydrogen and high-purity ammonia for their production processes. They also need a flexible supply partner with global reach that can help them increase capacity quickly and cost-effectively.

Linde has been a trusted partner to the LED industry for many years now, offering an all-inclusive portfolio of on-site generation systems, tank delivery options and specialty gases.

### Generating high-purity gases on site

Linde provides electronics manufacturers across various sectors with safe, stable supplies of high-purity gases. The company's offering includes cylinder and tank gases as well as systems for generating electronic gases on site: Linde's SPECTRA-N™ nitrogen generators are extremely energy efficient. They allow semiconductor and display manufacturers to produce large amounts of high-purity nitrogen while cutting costs and shrinking their CO<sub>2</sub> footprints. HYDROPRIME™ generators offer a flexible, highly cost-effective way for LED manufacturers to produce high-purity hydrogen.



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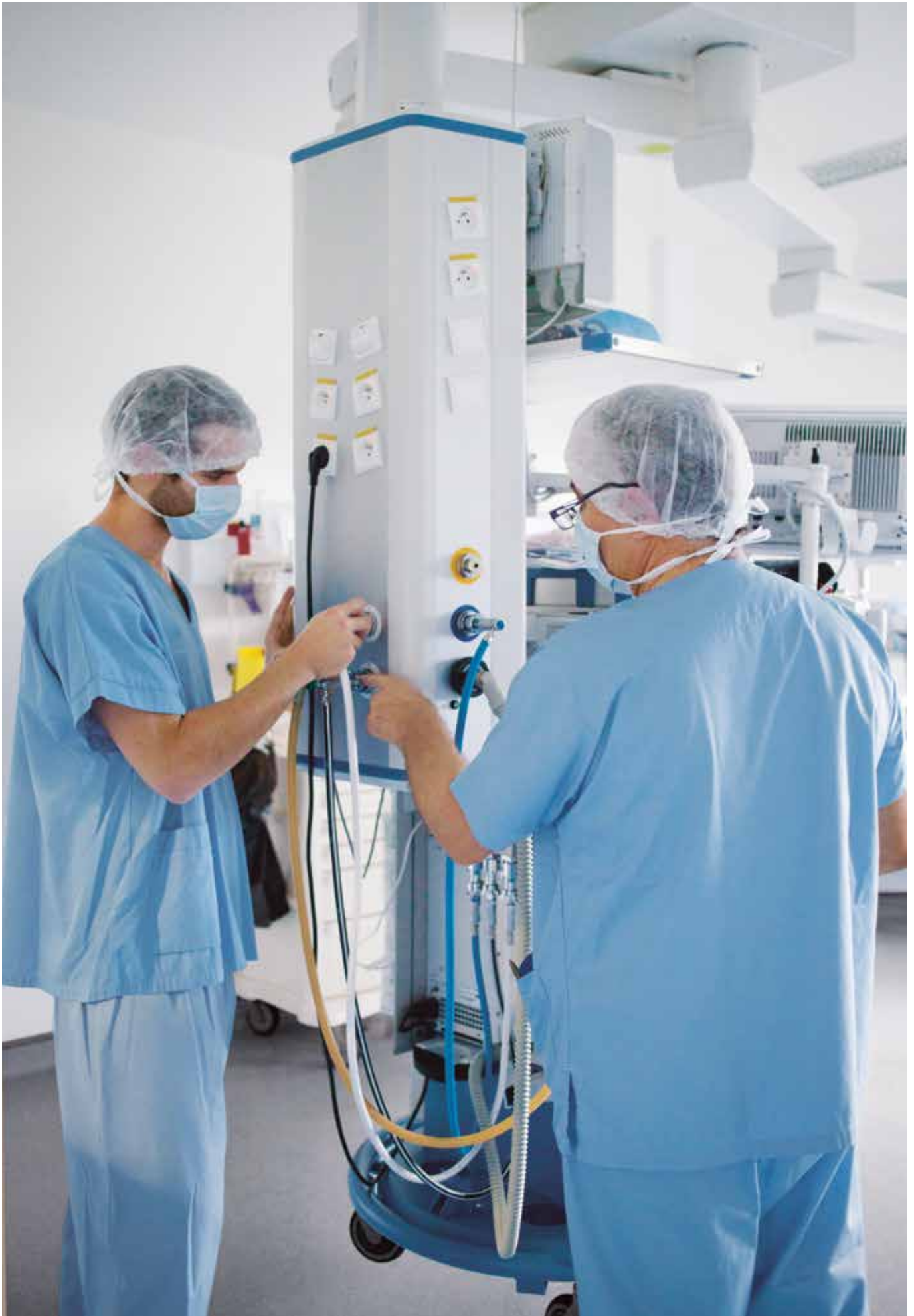
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## Healthcare

# Helping to improve patient care

Linde is one of the world's leading providers of medical gases, medical devices, clinical care, therapies and supporting services. The company makes a valuable contribution to the lives of patients, doctors, nursing staff and other healthcare professionals – supporting them along the entire care pathway. Linde's gases and therapies can be found almost everywhere – from ambulance services to GP and specialist practices and from intensive care units to rehabilitation clinics. They are also used in long-term homecare settings. The quality, purity and safe administration of medical gases is always a top priority for Linde.







### Medical valve with integrated pressure regulator

In an emergency, everything must run like clockwork. Linde developed the LIV® (Linde Integrated Valve) package to enable rapid, safe administration of life-saving mobile oxygen therapy. These cylinders feature a medical valve with an integrated pressure regulator which ensures quick and safe oxygen supply – both within hospitals and outside clinical settings. Eliminating the need for external regulators, LIV® is ready to use, with the active gauge on the valve always showing the pressure in the cylinder. Linde’s recently launched innovative LIV® IQ solution takes mobile oxygen therapy to the next level, replacing the typical mechanical gauge with an LCD screen showing pressure and remaining oxygen contents in the cylinder. LIV® IQ is simply clever, further enhancing safety and convenience with various alarm functions.

## Saving lives

When an accident happens, every second counts. Emergency medical attention using gases can save lives in those critical moments. Medical oxygen plays a particularly important role here, and is an indispensable component in any emergency kit. To ensure it can be administered rapidly and safely, Linde has developed an oxygen cylinder that is particularly light and easy for doctors and paramedics to handle. It is ideal for emergency and ambulance services, and is particularly popular among mobile medics who need lightweight, portable solutions that can be easily carried in emergency kits or motorbike backpacks.

In addition to oxygen, emergency services also rely on inhalable pain relief. Linde provides a gas mixture that is half nitrous oxide; half oxygen. Just a few breaths of this mixture will ease a patient’s discomfort and have a calming effect. This gas mixture is not only proving valuable in emergency care, but also during childbirth and smaller operational procedures, especially with children.



LINDE’S LIV® IQ SYSTEM IS USED TO DELIVER MOBILE GAS THERAPY AT HONG KONG BAPTIST HOSPITAL.

## Supporting clinics and patients

Today’s hospitals and outpatient surgeries depend on a reliable supply of medical gases. In addition to oxygen, Linde offers medical carbon dioxide for laparoscopic procedures, medical air, nitrous oxide as well as a nitrous oxide/oxygen mixture for pain relief, and nitric oxide for use in cardiology and newborn intensive care units.

The company also covers the entire medical gas supply system and all associated clinical processes. These are governed by strict safety regulations, so Linde’s comprehensive QI Medical Gas Services offering meets the high quality standards required in this area. Additionally, Linde experts are on hand to advise customers, exploring areas offering scope to further improve the safety, reliability or efficiency of their gas supply concept. Linde’s expertise extends along the entire supply chain – from design and construction through logistics and on-site management to end-to-end facility management. In addition, Linde’s service offerings can be tailored to the specific requirements of different hospital functions, from the emergency room through intensive care to the wards.



## Helping patients to return home

Demographic change means that the world's population is steadily ageing – and thus the number of patients with respiratory conditions is also on the rise. Linde's REMEO® concept offers an innovative and highly effective programme for long-term mechanically ventilated patients. REMEO® provides an integrated, evidence-based care path that bridges the gap between the intensive care unit of a hospital and a patient's own home with individualised treatment plans for weaning and rehabilitation.

The REMEO® programme offers the highest standards of care for long-term mechanically ventilated patients. All REMEO® healthcare staff undergo a strict training programme to become specialised in this area. In addition, REMEO® centres feature all medical equipment required to meet the patients' needs. Although REMEO® services are delivered in a clinical environment, patients and family members can enjoy the commodities and warm atmosphere of a home-like setting.



REMEO® CENTRE IN BRUCHSAL, GERMANY.

## Improving quality of life

Thanks to Linde's homecare offering, which includes advice on dietary habits and rehabilitation, an independent, self-sufficient life at home is now a reality for patients with long-term respiratory conditions such as chronic obstructive pulmonary disease (COPD) who are stable enough to be cared for at home. Tailored therapies along the patient pathway help to increase both quality of life and life expectancy for these patients. Homecare offerings from Linde comprise various technologies and services – including inhalation, ventilation and other respiratory therapy devices, oxygen delivery systems such as liquid oxygen for home use, plus stationary and mobile concentrators that deliver oxygen-enriched air. As a fundamental part of these offerings, Linde supports and trains patients and family members in the correct and safe usage of medical equipment.

In addition, Linde is actively helping to advance telehealth innovations. Here, monitoring equipment sends a patient's key medical data to doctors or specially trained medical staff via the Internet. A study conducted by Linde indicated that innovative telemonitoring technology can reduce the number of hospital stays required.

### A better night's sleep

People suffering from sleep apnoea experience regular interruptions to their breathing during the night, which can cause serious health problems. Linde has developed a special care concept for these patients too. The company offers comprehensive support for those affected – from diagnosis in Linde-owned sleep labs or at home, through treatment with the most appropriate and convenient devices, to follow-up, cardiovascular rehabilitation and long-term adherence checks.

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