The Linde Annual 2009.

Treasures of the Atmosphere.

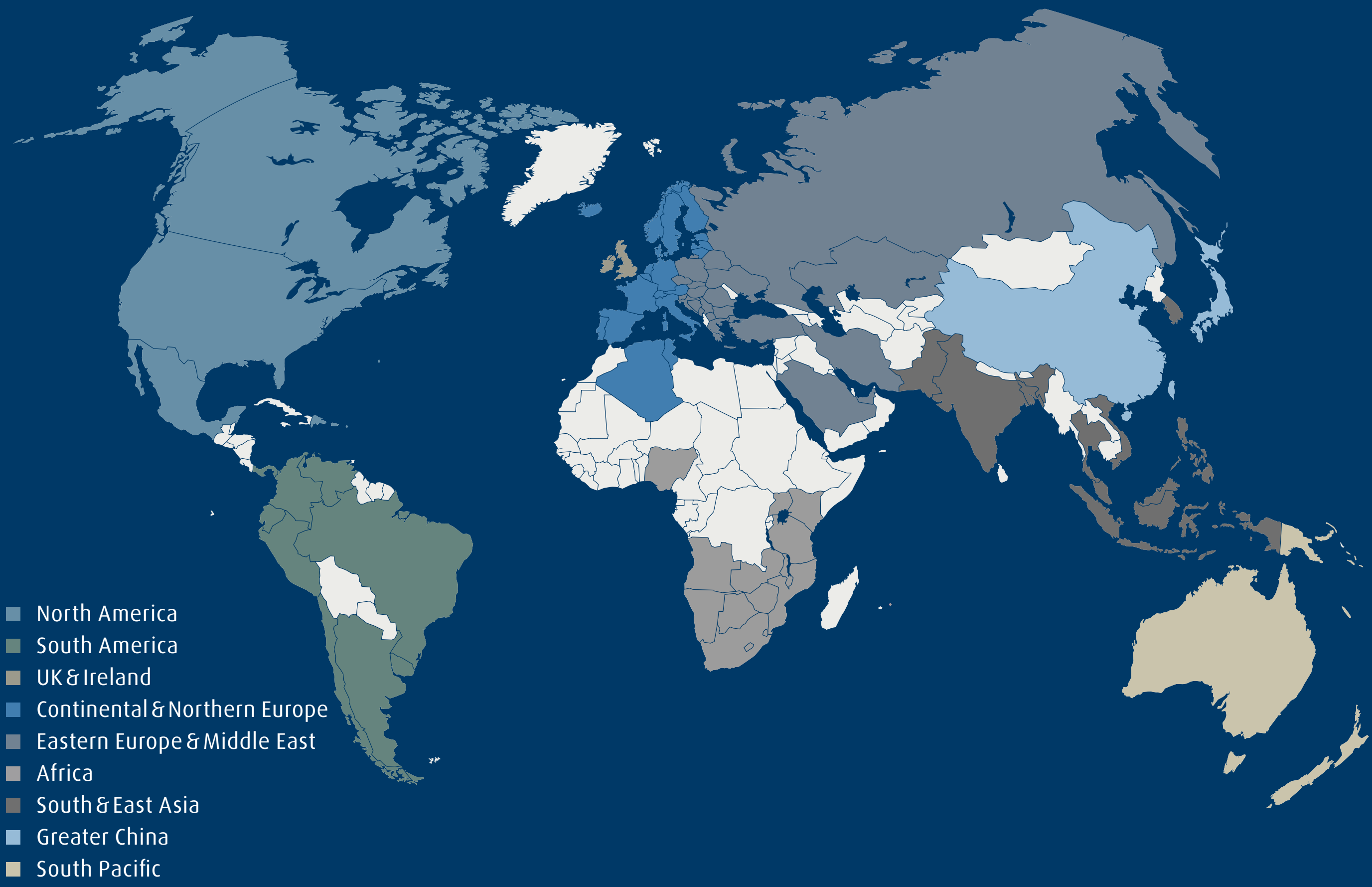
LeadIng.

THE LINDE GROUP

The Linde World

The Gases Division has four operating segments – Western Europe, the Americas, Asia & Eastern Europe, and South Pacific & Africa – which are subdivided into nine Regional Business Units (RBUs). The Gases Division also includes two Global Business Units (GBUs) – Healthcare (medical gases) and Tonnage (on-site) – and two Business Areas (BAs) – Merchant & Packaged Gases (liquefied and cylinder gases) and Electronics (electronic gases).

Specialised in olefin, natural gas, air separation, hydrogen and synthesis gas plants, our Engineering Division has a global footprint.



Customer segmentation within the Gases Division

Broad, well-balanced customer base ensures stability.

Food & beverages	Chemistry & energy	Metallurgy & glass	Manufacturing industry	Electronics	Healthcare	Others
Aquaculture & water	Energy	Glass & fibre optics	Aerospace	Solar industry	Hospital care	Education & research
Beverages	Fine & petrochemistry	Heat treatment	Automotive	Semiconductors	Homecare	Retail
Food	Pharma	Non-ferrous	Heavy constr. & machinery	Chip packaging		Distributors
Other F & B[1]	Other chemistry	Steel	Light metal fab. & prod.			
		Other M & G[2]	Other manufacturing			

[1] F & B: Food & beverages.
[2] M & G: Metallurgy & glass.

Corporate profile

The Linde Group
The Linde Group is a world leading gases and engineering company with almost 48,000 employees working in more than 100 countries worldwide. In the 2009 financial year it achieved sales of EUR 11.211 bn. The strategy of The Linde Group is geared towards sustainable earnings-based growth and focuses on the expansion of its international business with forward-looking products and services. Linde acts responsibly towards its shareholders, business partners, employees, society and the environment – in every one of its business areas, regions and locations across the globe. Linde is committed to technologies and products that unite the goals of customer value and sustainable development.

Organisation
The Group comprises three divisions: Gases and Engineering (the two core divisions) and Gist (logistics services). The largest division, Gases, has four operating segments, Western Europe, the Americas, Asia & Eastern Europe, and South Pacific & Africa, which are subdivided into nine Regional Business Units (RBUs). The Gases Division also includes the two Global Business Units (GBUs) – Healthcare (medical gases) and Tonnage (on-site) – and the two Business Areas (BAs) – Merchant & Packaged Gases (liquefied and cylinder gases) and Electronics (electronic gases).

Gases Division
The Linde Group is a world leader in the international gases market. We offer a wide range of compressed and liquefied gases as well as chemicals and we are therefore an important and reliable partner for a huge variety of industries. Our gases are used, for example, in the energy sector, in steel production, chemical processing, environmental protection, and welding, as well as in food processing, glass production and electronics. We are also investing in the expansion of our fast-growing Healthcare business, i.e. medical gases, and we are a leading global player in the development of environmentally friendly hydrogen technology.

Engineering Division
Our Engineering Division is successful throughout the world, with its focus on promising market segments such as olefin plants, natural gas plants and air separation plants, as well as hydrogen and synthesis gas plants. In contrast to virtually all our competitors, we are able to call on our own extensive process engineering know-how in the planning, project development and construction of turnkey industrial plants. Linde plants are used in a wide variety of fields: in the petrochemical and chemical industries, in refineries and fertiliser plants, to recover air gases, to produce hydrogen and synthesis gases (see glossary), to treat natural gas and in the pharmaceutical industry.

Linde financial highlights

in € million		January to December 2009	2008	Change in percent
Share				
Closing price	€	**84.16**	59.85	40.6
Year high	€	**87.95**	97.90	–10.2
Year low	€	**49.66**	46.51	6.8
Market capitalisation (at year-end closing price)		**14,215**	10,084	41.0
Adjusted earnings per share [1]	€	**4.58**	5.46	–16.1
Earnings per share – undiluted	€	**3.51**	4.27	–17.8
Number of shares outstanding (in 000s)		**168,907**	168,492	0.2
Sales		**11,211**	12,663	–11.5
Operating profit [2]		**2,385**	2,555	–6.7
EBIT before amortisation of fair value adjustments and non-recurring items		**1,460**	1,703	–14.3
Earnings after taxes on income		**653**	776	–15.9
Number of employees		**47,731**	51,908	–8.0
Gases Division				
Sales		**8,932**	9,515	–6.1
Operating profit		**2,378**	2,417	–1.6
Engineering Division				
Sales		**2,311**	3,016	–23.4
Operating profit		**210**	267	–21.3

[1] Adjusted for the effects of the purchase price allocation and non-recurring items.
[2] EBITDA before non-recurring items including share of income from associates and joint ventures.

Our company values

Passion to excel.

Innovating for customers.

Empowering people.

Thriving through diversity.

Our vision

We will be the leading global gases and engineering group, admired for our people, who provide innovative solutions that make a difference to the world.

Front cover fold-out:
C2: The Linde World/Customer segmentation, C3: Corporate profile/Linde financial highlights

Treasures of the atmosphere.

In a speech in 1907, Carl von Linde came up with a striking phrase to capture the special value of gases for modern civilisation: “treasures of the atmosphere”. This is how the founder of Linde AG described the elements of the air that – alongside gases from fossil sources – still form the cornerstones of our daily business today. These are the building blocks of our sustainable success as a company, enabling us to develop technologies and processes that improve the lives of people around the globe. With The Linde Annual 2009, we invite you to explore some of the wide-ranging applications of these treasures of the atmosphere.

01

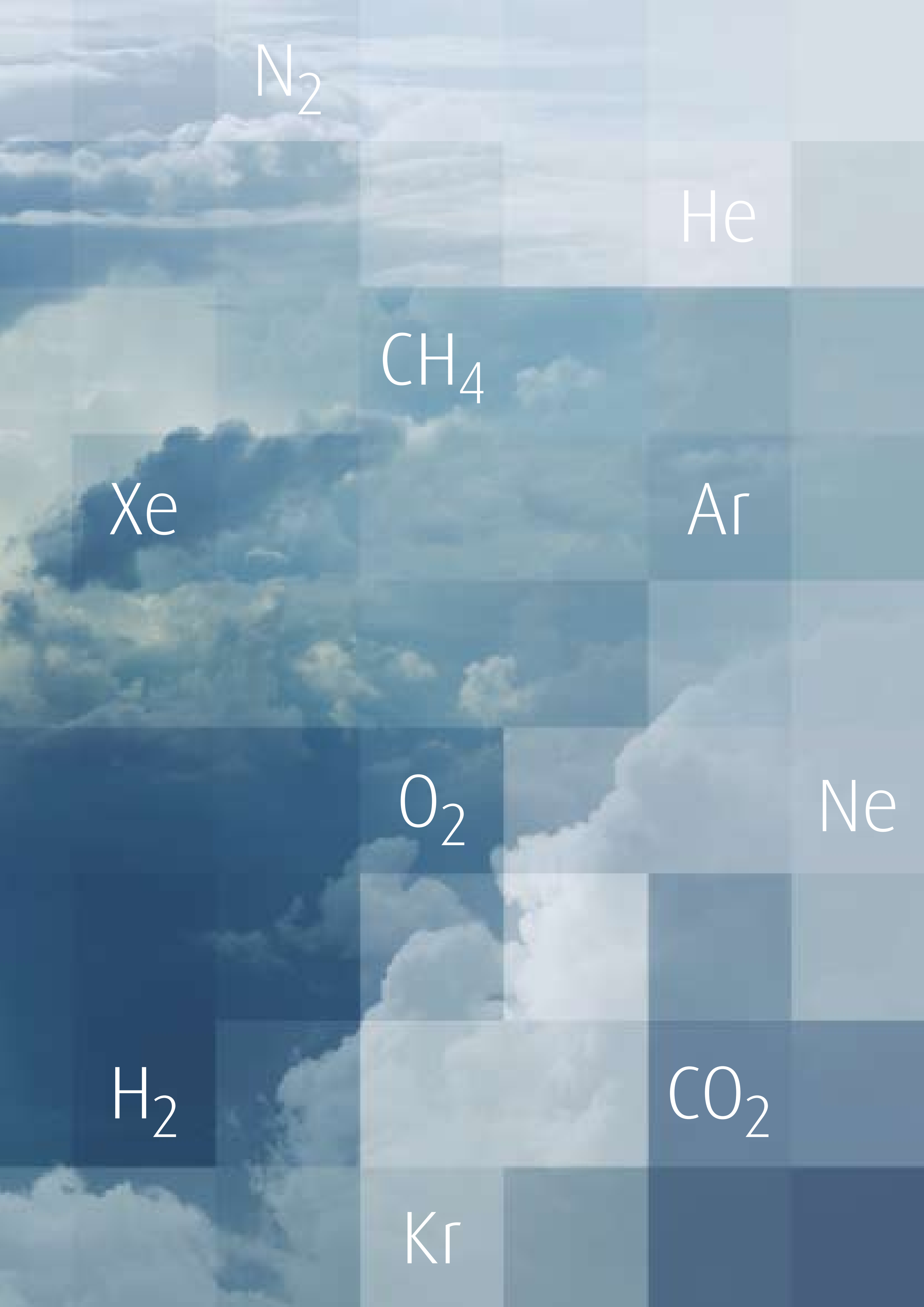
An idea.
Separating air.

"THE GIFTS OF THE ATMOSPHERE ARE PLENTIFUL, GIVING MANKIND NEW SOURCES OF PROSPERITY AND WELFARE. (...) EVEN IF THE ART OF ENGINEERING ACCOUNTS FOR BUT A SMALL SHARE IN THE OVERALL BOUNTY OF RICHES THE ATMOSPHERE HAS TO OFFER, THESE ADDITIONAL PRODUCTS MUST STILL BE EMBRACED AS THE NEW TREASURES OF THE ATMOSPHERE."

Carl von Linde, 17 December 1907

The foundations of our success go back to Carl von Linde's discovery that air could be separated. To him we owe our understanding of the treasures of the atmosphere, plus the values and achievements that have made us one of the leading gases and engineering companies in the world today. His pioneering spirit is both a source of inspiration and a challenge.


Securing our future with
the treasures of the atmosphere.

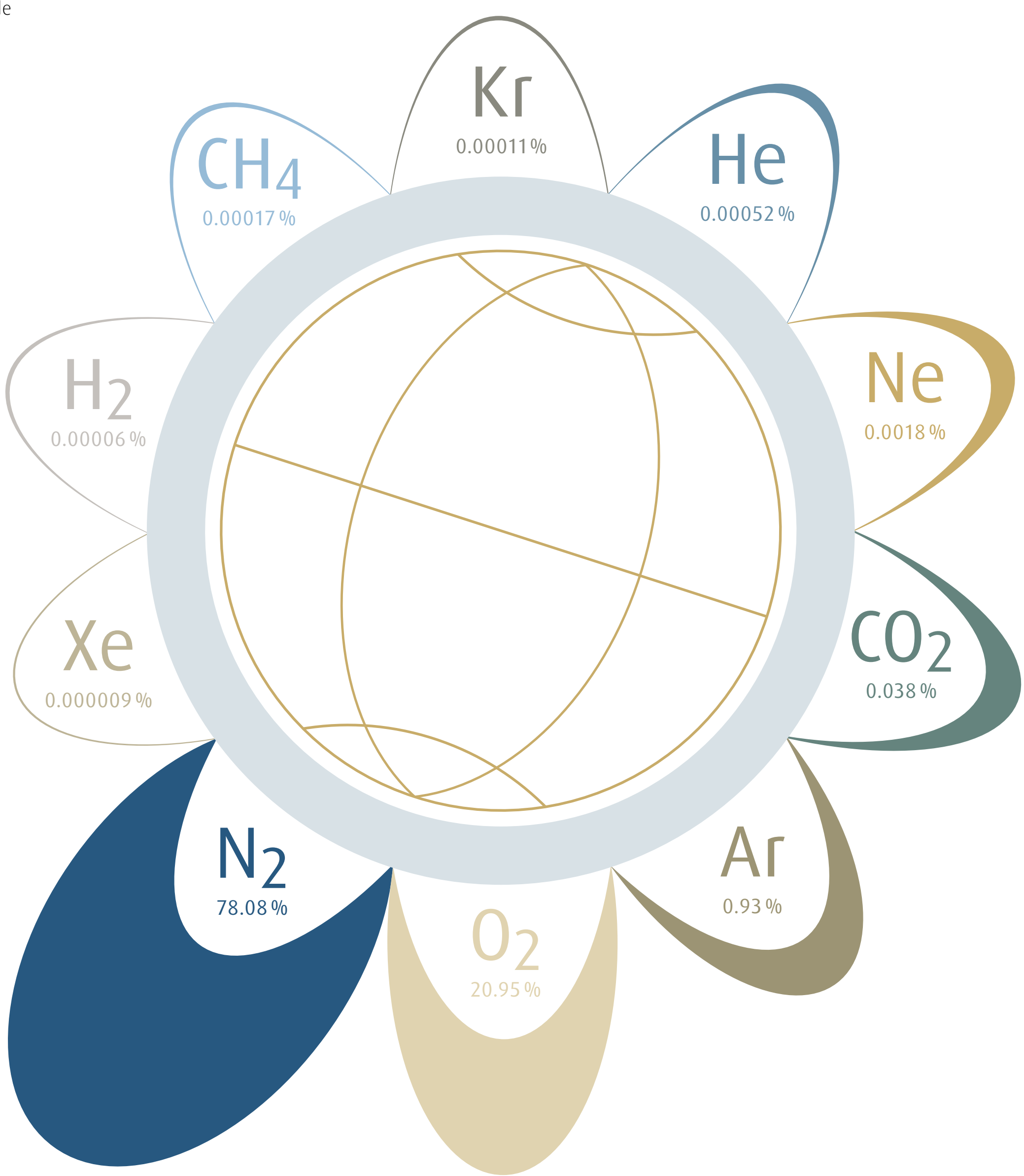

N_2
He
CH_4
Xe
Ar
O_2
Ne
H_2
CO_2
Kr


We separate the air and turn its components
into valuable resources for people.

All we need is air.

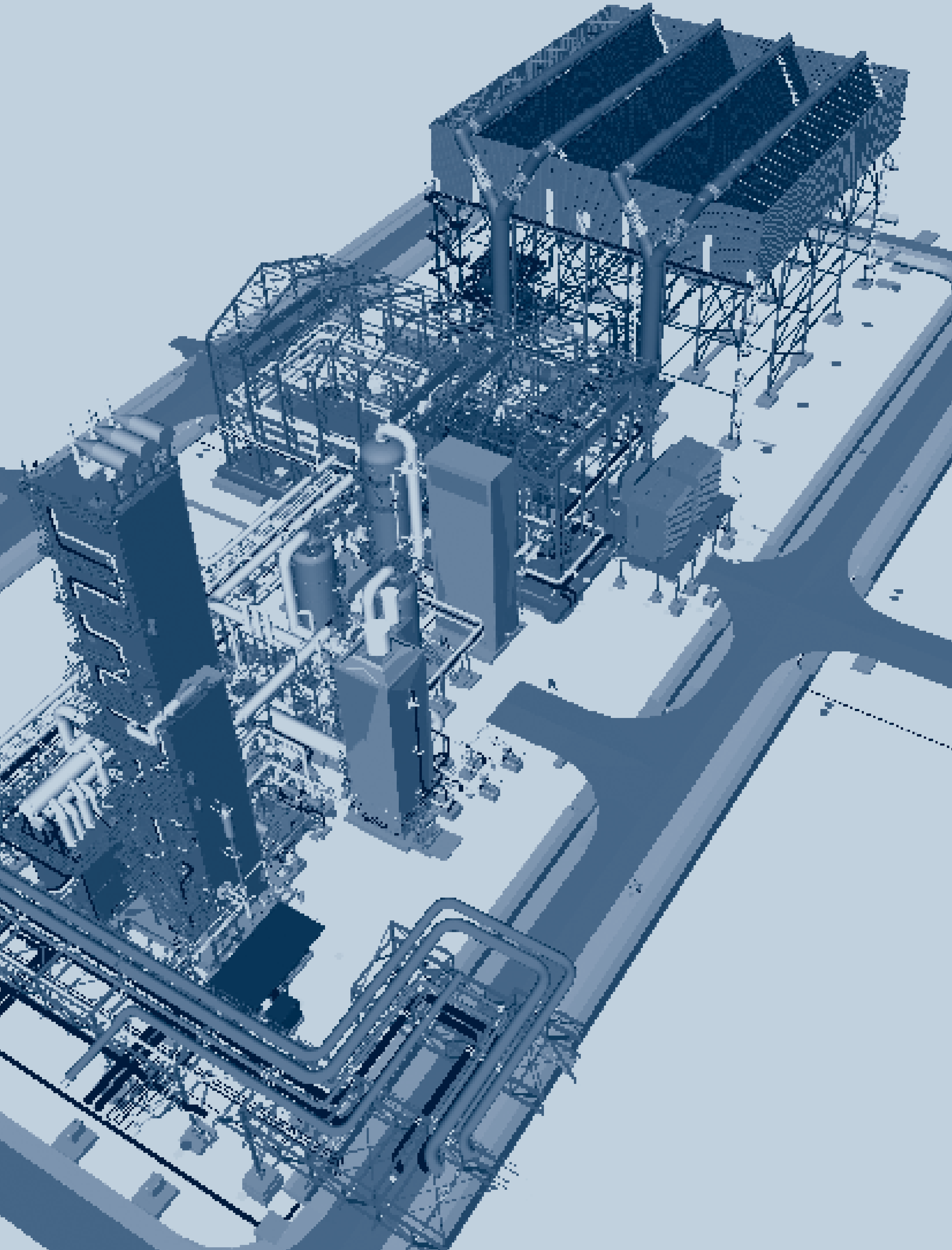
The elements of the air are essential to life on earth.

- Ar Argon
- He Helium
- CO_2 Carbon dioxide
- Kr Krypton
- CH_4 Methane
- Ne Neon
- O_2 Oxygen
- N_2 Nitrogen
- H_2 Hydrogen
- Xe Xenon



Elements of air

Until the end of the eighteenth century, the air was considered a pure substance. Only then was it discovered that it is actually a mixture of various elements. Today, each of these gases plays an important role, whether in everyday or unusual applications. Recently, human influence on the composition of the atmosphere has shifted centre stage among the research community.



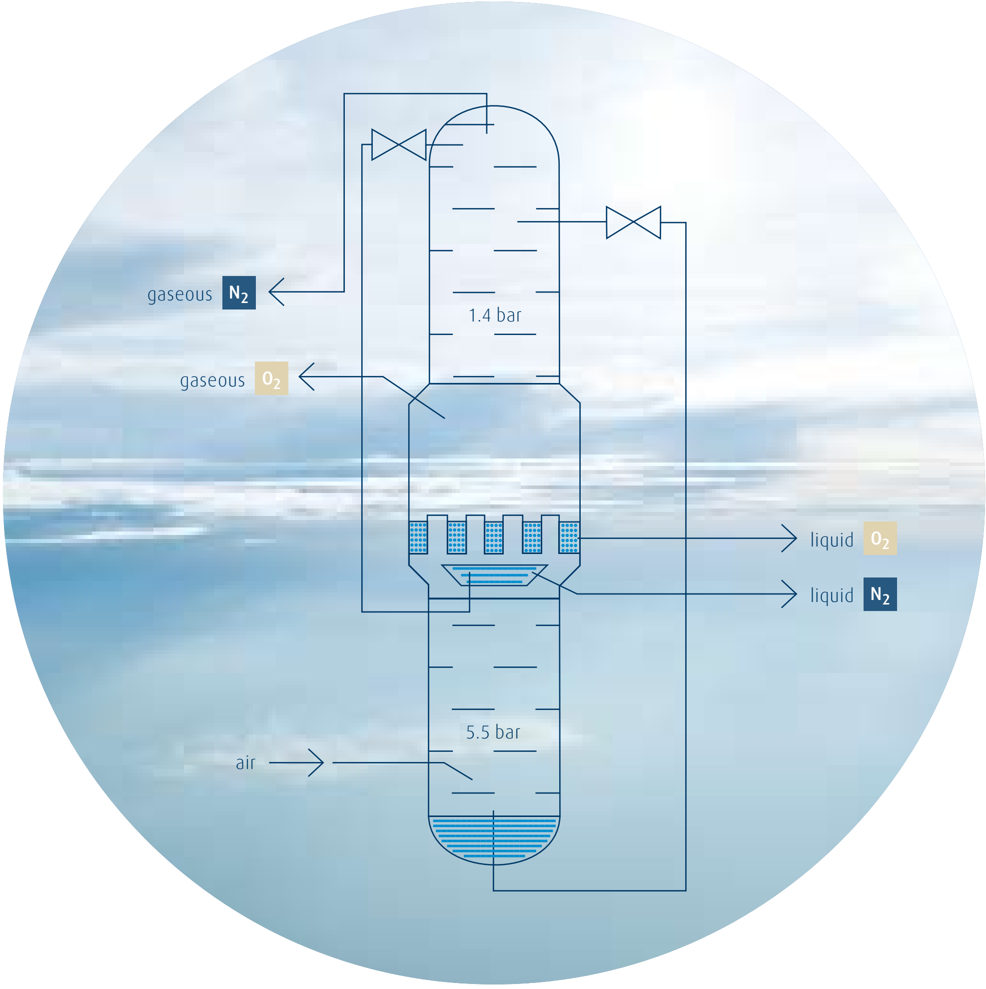
The air separation process.

The process developed by Carl von Linde around 1900 still lies at the heart of air separation today.

Diagram of a rectification column for air separation using the Linde process.

O_2 Oxygen

N_2 Nitrogen



Simple theory – complex design

The first air separation process, developed by Carl von Linde in 1895, used a cooling machine to harness the fact that gases warm up when compressed and cool down again when expanded. Separating liquid air into its components relies on their different boiling points, which allows the gases to be separated in a rectification process (see glossary). Linde has now constructed over 2,800 air separation units in 80 countries.

Linde is behind the world's largest air separation plant, currently being built in Qatar.

02

In practice.
Perfect fit – every time.

"IF THE NATURAL SCIENTIST'S CALLING IS TO WORK COMPLETELY LIBERATED FROM THE CONSTRAINTS OF PRACTICAL APPLICATIONS, THEN THE ENGINEER'S MISSION IS TO APPLY THOSE FINDINGS AND INSIGHTS TO A DIVERSE RANGE OF PRACTICAL SCENARIOS."

Carl von Linde

The Linde Group is now active in around 100 countries worldwide. Working closely together, our Gases and Engineering Divisions are constantly developing new products and technologies to bring maximum value to our customers.

02.1

Gases from the air.

By successfully separating atmospheric air into its main components of oxygen (O_2) and nitrogen (N_2) over 100 years ago, Carl von Linde tapped the vast market potential of these valuable natural resources. Over the decades, cryogenic air separation was further refined so that today, even the trace noble gases xenon, neon, argon and krypton can be produced in industrial-scale volumes. Air gases are deployed in a wide variety of applications to increase the quality of products and processes and make them more cost-efficient; they also make a significant contribution to climate protection by reducing harmful emissions.


N_2

02.1

Freshness you can rely on.

Air gases are increasingly deployed to meet rising quality and shelf-life expectations expressed by food buyers. Carbon dioxide, for example, inhibits bacterial growth, while oxygen ensures that meat retains its red muscle colour. In liquid form, nitrogen (N_2) is used for gentle, effective cryogenic freezing.

02.1

Clear quality boost for steel production.

On average, freshly cast steel has to be heated to between 1,000 and 1,200 °C twice so it can be further processed. Oxyfuel technology (see glossary), which uses oxygen (O_2) instead of air to heat the steel, enables manufacturers to cut energy levels, raise productivity and improve the quality of the cast steel.


O_2

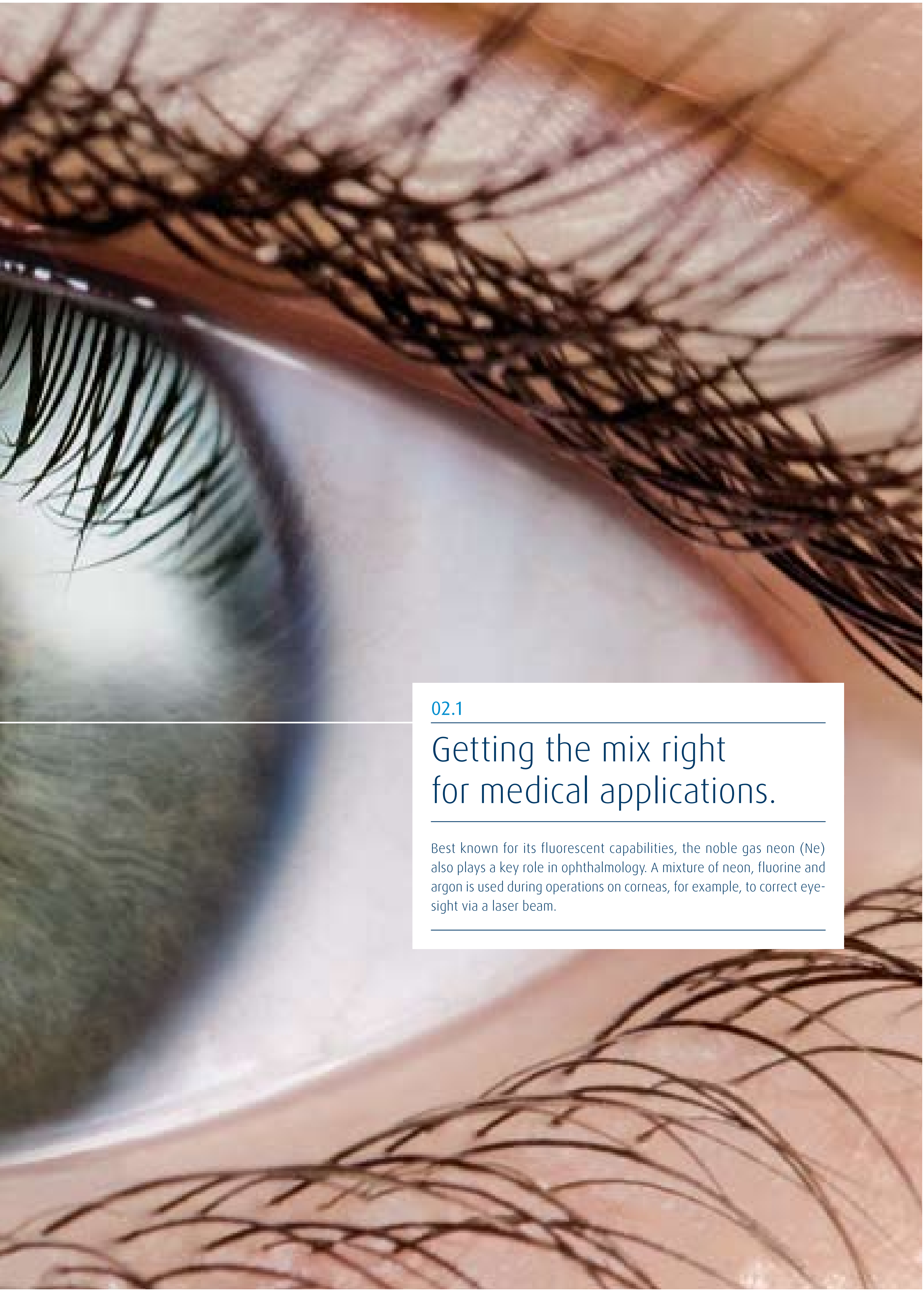

出发航班显示
Departures
Xe

02.1

Dazzling solutions for the electronics sector.

The extremely rare noble gas xenon (Xe) only accounts for 0.000009 percent of air. It is only used where lighter noble gases are not effective. This includes applications such as plasma screens and semiconductors as well as car headlights, camera flashes and anaesthetics.


Ne



02.1

Getting the mix right for medical applications.

Best known for its fluorescent capabilities, the noble gas neon (Ne) also plays a key role in ophthalmology. A mixture of neon, fluorine and argon is used during operations on corneas, for example, to correct eyesight via a laser beam.

02.1

Strong connections for automotive manufacturers.

Automatic arc welding (see glossary) with robots, frequently used in the automobile industry, would not be possible without the noble gas argon (Ar). Thanks to the high quality of argon-welded seams, this gas is also used to manufacture power generation equipment and fuel tanks for Ariane rockets.


Ar


Kr

02.1

Optimised energy balance in modern buildings.

Krypton (Kr) is a key success factor in energy-saving windows. It is used as a filler gas between insulated glass panes as its low thermal conductivity increases the effectiveness of insulation. 40 percent or more of all krypton produced worldwide is used for this purpose.

02.1

Gases from the air.

↳ (top) Thanks to special gas mixtures, which often include nitrogen, salad is still fresh when it reaches the consumer.

↳ (bottom) The use of oxygen, as here in energy-intensive aluminium production, reduces fuel consumption and emissions.

N_2

Nitrogen – a helping hand for the food industry

Nitrogen (N_2) makes up around 78 percent of air. Oxygen (O_2) accounts for just under 21 percent. The remaining one percent comprises more than a dozen trace gases, including the valuable noble gases xenon, neon, argon, krypton and helium.

Nitrogen has been deployed across a wide range of industrial applications since Carl von Linde first succeeded in separating nitrogen and oxygen by rectifying liquefied air in 1902. Its low boiling point of −196 °C and low reactivity make the colourless, odourless and flavourless gas ideal for use in the food industry, for instance. It is a gentle, non-chemical yet effective way of preserving the freshness and quality of meat, fish, vegetables, fruit and ready-made meals through applications such as modified atmosphere packaging and cryogenic freezing with liquid nitrogen.

The food and beverages industry is a stable market for the international gases business, even during economic downturns.

The right mix

Special gas mixtures used in modified atmosphere packaging (MAP) keep many types of food fresh, tasty and appealing to the eye. Nitrogen, carbon dioxide and oxygen are the main components here, although different mixtures are used for different products. Oxygen, for example, ensures that meat retains its red muscle colour. Carbon dioxide, on the other hand, inhibits bacterial growth. Nitrogen prevents caking, stabilises volume and prevents oxidation by displacing the surrounding atmospheric oxygen.

Linde provides the food and beverages industry with a broad portfolio of inert gases under its modified atmosphere MAPAX® brand.

Fast and efficient preservation

The trend in the food business is towards greater individualisation. Demand is rising for frozen convenience foods that can be stored without compromising quality, and mixed in individual portions on demand. These products therefore require the highest processing and preservation standards. Which can only be achieved with cryogenic media – in other words, liquid nitrogen or liquid carbon dioxide. By crystallising the water in and around the cells extremely quickly, cryogenic freezing produces tiny crystals, thus leaving the cells intact and preserving the freshness, taste and texture of the food.

Rising demand for portionable convenience food means that foodstuffs must be frozen individually so that consumers can serve the quantities they need and return the rest to the freezer. Linde not only offers cryogenic gases to manufacturers of these individually quick frozen (IQF) products, it also delivers an extensive line of CRYOLINE® freezer systems. Linde launched several of these food processing machines in North America during fiscal 2009.

Cooking up a cryogenic feast

Liquid nitrogen is an extremely versatile ingredient in the cryocooking movement, inspiring top chefs such as Ferran Adrià and Juan Amador to explore new ways of preparing food. Dipping a spoonful of mousse made from fruit and alcohol into liquid nitrogen (–196 °C), for example, produces a ball with a hard frozen exterior and a warm liquid centre. This same technique can be used to create a frozen coating over melted chocolate. The resulting jump in temperature from –80 °C to +20 °C ensures a delightful culinary surprise to unsuspecting diners.

Enhanced oil and gas recovery using nitrogen

Nitrogen is also playing an increasingly important role in the recovery of oil and natural gas. In a process known as enhanced oil and gas recovery (see glossary), engineers pump nitrogen below ground to increase the ease and efficiency of fossil fuel recovery.

In recent years, Linde has engineered and constructed some of the world's largest air separation plants to generate the enormous amounts of nitrogen required to recover crude oil and natural gas. Our air separation plant in Cantarell, Gulf of Mexico, is a prime reference project here.

Linde is currently building two major plants at Mirfa in the United Arab Emirates. The Group has been commissioned to construct these facilities by Elixier, a joint venture between Abu Dhabi National Oil Corporation (ADNOC) and Linde with 51 and 49 percent shares respectively. These plants will supply nitrogen to the Habshan oil and natural gas field via a 50-kilometre pipeline from 2011 onwards. At the field, the nitrogen will be pumped into the reservoirs to ensure a steady flow – above all of condensate – and to increase recovery rates.

The investment volume for the two air separation plants, which have a joint capacity of 670,000 standard cubic metres per hour (scm/h), amounts to around USD 800 m. They are almost identical in design to the Cantarell plants in Mexico, which has cut the delivery window to around two-and-a-half years.

Previously, natural gas was pumped into the gas field in Habshan to recover condensate and maintain consistent pressure. Once the new plants go on stream, this valuable raw material will be used instead to generate power in the fast-growing region.

Ground freezing with nitrogen

Liquid nitrogen is often used to freeze substrate in underground and tunnel construction projects as it is a fast, safe and above all environmentally sound way of securing unstable ground. In order to freeze soil, the exact amount of liquid nitrogen required is calculated and fed into the subsurface through pipes inserted into the ground. At a temperature of –196 °C, the nitrogen causes water in the soil to freeze, forming a solid wall of ice after around five to ten days. At which point, the ground is stable.

Ground freezing with liquid nitrogen was successfully deployed in tunnel construction projects in Leipzig and Budapest as well as during reconstruction of the Neues Museum on the Museumsinsel in Berlin, which re-opened its doors to the public on 19 October 2009.

O_2

Protecting the climate with oxygen

The drive to significantly reduce greenhouse gas emissions is gathering pace across the globe. Against this backdrop, oxygen is becoming an increasingly important enabler in a wide range of production processes, especially in energy-intensive sectors such as the steel and aluminium manufacturing industries.

Oxyfuel technology is deployed in the aluminium industry to raise productivity levels, increase cost efficiencies by cutting energy consumption and simultaneously reduce harmful emissions. The oxyfuel process uses oxygen instead of air during combustion, a technique that generally increases performance levels by 30 to 50 percent and cuts fuel consumption and emissions on average by around 50 percent. Linde has been at the forefront of oxyfuel technology in the aluminium industry for the past 20 years, installing this process in hundreds of plants.

Swedish company Stena Aluminium, a leading manufacturer of recycled aluminium, is also reaping the benefits of Linde's low-temperature oxyfuel technology after signing a supply contract with Linde for its aluminium plant in Älmhult, Sweden in spring 2009.

High demand from the steel industry

Steel production requires large amounts of oxygen, which is generated in air separation plants. As one of the world's leading constructors of these plants, Linde again won several contracts last year. Our agreement with the world's largest steel company ArcelorMittal, for example, includes the construction of a new air separation plant at the company's Galati location in Romania and modernisation of the existing air separation facilities there.

Linde is building a state-of-the-art air separation plant for Tata Steel Ltd in Jamshedpur, India. The plant is set to go on stream in 2012 and will be one of Linde's largest plants in Asia.

Right at the start of the last fiscal year, Linde received an order from the Indian steel industry. The Steel Authority of India Ltd. (SAIL) commissioned the Group to construct and operate two air separation plants for its Rourkela steelworks.

Linde is also a trusted partner of steel manufacturers in China. The third air separation plant built by Linde in the city of Ningbo's industrial park on the east coast of China also went on stream at the end of 2009. But China's steel industry is not the country's only major oxygen consumer. AkzoNobel, a world-leading supplier of paints, coatings and specialty chemicals, is building a chemical complex at Zhenhai Chemical Zone. Linde subsidiary Linde Gas Ningbo will supply a wide range of gases, including oxygen, nitrogen and hydrogen, to AkzoNobel by mid-2010. These gases will be delivered via a new oxygen pipeline connecting Linde's existing air separation plants in Beilun and Daxie with the complex. This supply contract brings the pipeline network infrastructure of Linde's largest integrated gas cluster in China close to completion.

The Chinese ship building sector also requires large amounts of oxygen. The country's largest shipyard, run by the China State Shipbuilding Corporation (CSSC), is located on the island of Changxing, just off the coast of mainland Shanghai. Linde has already established its own air separation plant here, producing and delivering 2,000 standard cubic metres of oxygen per hour. As part of plans to expand the shipyard, Linde concluded an agreement with CSSC in fiscal 2009 to construct a second plant. The on-site facility is scheduled to start operations in 2011, thus raising total capacity for CSSC to 4,000 scm/h.

Versatile all-rounder

Linde continuously develops and perfects new oxygen applications that help reduce costs, energy consumption and our carbon footprint. Last year, for example, saw the company launch a new technology for processing industrial wastewater. Known as AXENIS™, this highly efficient, biological procedure harnesses oxygen and air to treat industrial wastewater. The new technology can be used to recycle 70 percent of wastewater.

In fish farming, enriching water with pure oxygen raises productivity levels considerably. Increasing oxygen saturation from 90 to 100 percent can lead to a 30 percent rise in production levels. Adding ozone ensures the fish stay healthy by killing almost all germs. Linde has developed a range of processes for both local and centralised injection of oxygen in saltwater fish tanks, all of which can be modified to specific breeding methods as well as water and climate conditions.

Noble route to high-tech

The noble gases are only present in the air in trace amounts. Air contains just 0.93 percent argon, 0.0018 percent neon, 0.00011 percent krypton and 0.000009 percent xenon. Despite their high price tags, demand for these air gases is rising rapidly since numerous industries – ranging from electronics and glass fibre through lighting to aerospace – are increasingly harnessing the benefits of noble gases.

Similar to oxygen and nitrogen, the noble gases xenon, neon, argon and krypton are also obtained from air using cryogenic separation and purification. For several years now, Linde has been meeting rising demand for these gases by developing innovative plant concepts that boost the capture of noble gases from secondary streams in major air separation plants.

Xe

Xenon – the rarest noble gas

This extremely rare gas is used primarily in the lighting, plasma panel and aerospace industries. Beyond these three core applications, however, xenon is also used to manufacture semiconductors, in laser technology and as an anaesthetic gas.

The growing popularity of xenon headlights in cars coupled with regulations mandating energy-saving bulbs has sent demand for this gas skyrocketing. Brightness is not the only reason behind the automobile industry's move to xenon lights. Lower energy and fuel consumption was an equally appealing factor. Xenon bulbs can also be used in cinema projectors, light projectors and camera flashes.

↳ Modern lighting solutions would be unthinkable without noble gases xenon and krypton.

Xenon accounts for at least 5 percent of the gas mixture in plasma screens. It is used with neon to fill the many small cells between two glass plates. Every pixel is made up of three of these cells. To create a colour image, each cell is individually charged using a transistor, causing the gas to temporarily ionise and form plasma.

Xenon is also used in the aerospace industry for ion thrust propulsion, a technology that utilises ion beams to propel space rockets. Put simply, an ion beam is generated by initially ionising xenon and then using an electrical or magnetic field to accelerate the ions. The energy needed to generate the fields is usually sourced from solar cells.

Ne

Neon – keeping eyesight sharp

Ophthalmology is one of the most important applications of neon. Here, ophthalmologists use highly directional, intense beams of light to correct myopia (short sightedness), hyperopia (long sightedness) and to reshape the curvature of the cornea.

A mixture of neon, fluorine, argon and helium gases is used in today's standard cold laser treatments such as excimer lasing (see glossary). Up to 90 percent of the fluorine, argon and neon gas mixture produced at the Linde gases centre in Unterschleißheim near Munich goes to manufacturers of these kinds of eye laser devices. Linde serves the international ophthalmic excimer laser (see glossary) market via its US subsidiary.

Excimer lasers, however, are not limited to medicinal applications. They are also deployed in the electronics industry, for example, in microlithography processes (see glossary) for electronic circuits. Excimer lasers are also used to manufacture mobile phone displays and drill microscopic holes in the nozzles of inkjet printers.

Ar

Argon – perfect for high-quality materials

Argon is the most common noble gas in the earth's atmosphere. It is obtained from oxygen produced in air separation plants and used alone or in special mixtures as an inert gas (shielding gas) primarily for welding. It is particularly popular at the higher end of the quality spectrum, for materials such as high-grade steel, aluminium or titanium.

Argon not only acts as a shielding gas, protecting the workpiece against contact with the air, it also improves ionisation in arc plasma welding. Without it, arc welding with state-of-the-art robots, a process that is commonly used in car and wind turbine production, would not be possible.

↳ Xenon headlights improve vision for greater safety.

Due to its low level of reactivity, argon is also used to mix melts during steel production. This noble gas prevents oxidation, ensures that the melt is evenly heated and reduces chrome loss when manufacturing high-grade steel.

Kr

Krypton – keeping the warmth in and the cold out

Well-insulated windows are crucial in ensuring that new or renovated buildings meet increasingly strict energy rating regulations. The energy efficiency trend is driving demand for krypton, as this noble gas is used between insulated glass panes to help minimise thermal conductivity and significantly increase insulation effectiveness.

As with xenon, krypton is also becoming an increasingly important gas in the lighting sector. The car industry, for example, now offers headlights that work with krypton. This noble gas is also used as a filler gas in halogen bulbs, energy-saving bulbs and gas discharge tubes in illuminated billboards. Replacing nitrogen/argon with krypton in halogen energy-saving lamps and fluorescent lamps increases bulb life and produces more effective lighting.

02.1

"A strong competitive edge"

Gerhard Pompl, head of process engineering for air separation plants within Linde's Engineering Division, discusses Linde's key achievements and core competencies in this area.

↳ Gerhard Pompl has played a key role in developing and constructing air separation plants at Linde for over 30 years.

Mr. Pompl, Linde has been building air separation plants for more than 100 years. What developments have played a defining role over the last decades?

↳ In the midst of all the changes, there is one constant: our ongoing efforts to reduce energy consumption as far as possible. Since air costs nothing, energy is one of the main cost factors in generating air gases. So Linde engineers have always looked for new ways to operate air separation plants cost-effectively by saving energy.

Has this issue become more important against the backdrop of climate change?

↳ Yes, absolutely. After all, energy consumption is also responsible for generating CO_2. Our aim is to continue optimising energy efficiency so we can reduce CO_2 emissions. This has been a major driving force for us in recent years, particularly given that the integration of air separators in the energy chain will be an increasingly interesting market opportunity for Linde as we move forward.

And does the market reward these efforts?

↳ Not always, unfortunately. Every kilowatt-hour of electricity saved means greater investment in heated areas or pipelines. Some customers place higher priority on low initial outlay, in which case energy consumption becomes a secondary consideration.

Does that also apply to your main customer within the Linde Group – the Gases Division?

↳ Our colleagues here focus on both energy balance and investment costs. To harmonise both goals, we introduced our SCALE improvement programme. SCALE optimises lifecycle costs and explores potential areas of efficiency.

How did that turn out?

↳ Well, we identified which components could feasibly be omitted – and, of course, how we could further reduce energy consumption. We were ultimately able to reach our savings target here by significantly increasing standardisation as well as through modular construction.

The air separation plants Linde delivers are getting bigger and bigger. Why is that?

↳ It's certainly true that these plants are getting bigger all the time – in fact that's one of the most noticeable trends in our business. The first unit, built in 1902, produced one to two kilograms of oxygen per hour. 30 years ago, an air separator generating 10,000 cubic metres per hour was considered large. These days that is relatively small, since we're now looking at plant complexes with capacities in the region of one million cubic metres per hour.

Where are plants of this size constructed?

↳ The largest complexes currently include the nitrogen facility at Cantarell, Mexico, for enhanced oil recovery and the eight air separators we are constructing for Shell in Qatar. These will supply oxygen to the Pearl gas-to-liquids plant at a total capacity of 860,000 cubic metres per hour.

Plant size is also a factor in the secondary production of noble gases. Will the Qatar units also generate krypton and xenon?

↳ That would certainly be possible if we added the relevant components. However, our customer decided against it because obtaining liquid fuel from natural gas requires a steady, reliable process that could be disrupted by add-ons.

In general terms, now – which other technical developments have influenced the construction of air separation plants?

↳ When I started at Linde as a young engineer, over 30 years ago, we were still working with slide rules and logarithm tables. Then came the calculator, which was already a significant advance. And today, we all have PCs on our desks that put the whole world at our fingertips. Modern information technology has also made a huge difference to our processes in international plant engineering. The latest static and dynamic simulation tools, for example, allow designers to create technical solutions in a matter of minutes.

So communication has been one of the biggest areas of change?

↳ Yes, indeed. Previously you had to wait days for a reply to arrive by post or send a telegram if there was a plant malfunction. Now, a colleague on-site can film or photograph a defective pipeline, say, and I see it straight away here on my screen. But IT developments have also had an impact on plant design, too. In the past, every control function needed its own control box, which had to be designed and built separately. This type of functionality can now be implemented with ready-made software modules that run on a PC. That is what paved the way for fully automatic remote control.

Do all plant engineers have this level of expertise?

↳ At Linde, we have a strong competitive edge in automation technology for air separation plants, going back to the mid-1980s. Remote Operation Centres (ROC) are a good example of this, allowing us to monitor all the plants within a region or country – and perhaps soon an entire continent – and control production. Most faults are resolved from the ROC. A team of experts is only sent in if the fault cannot be repaired remotely.

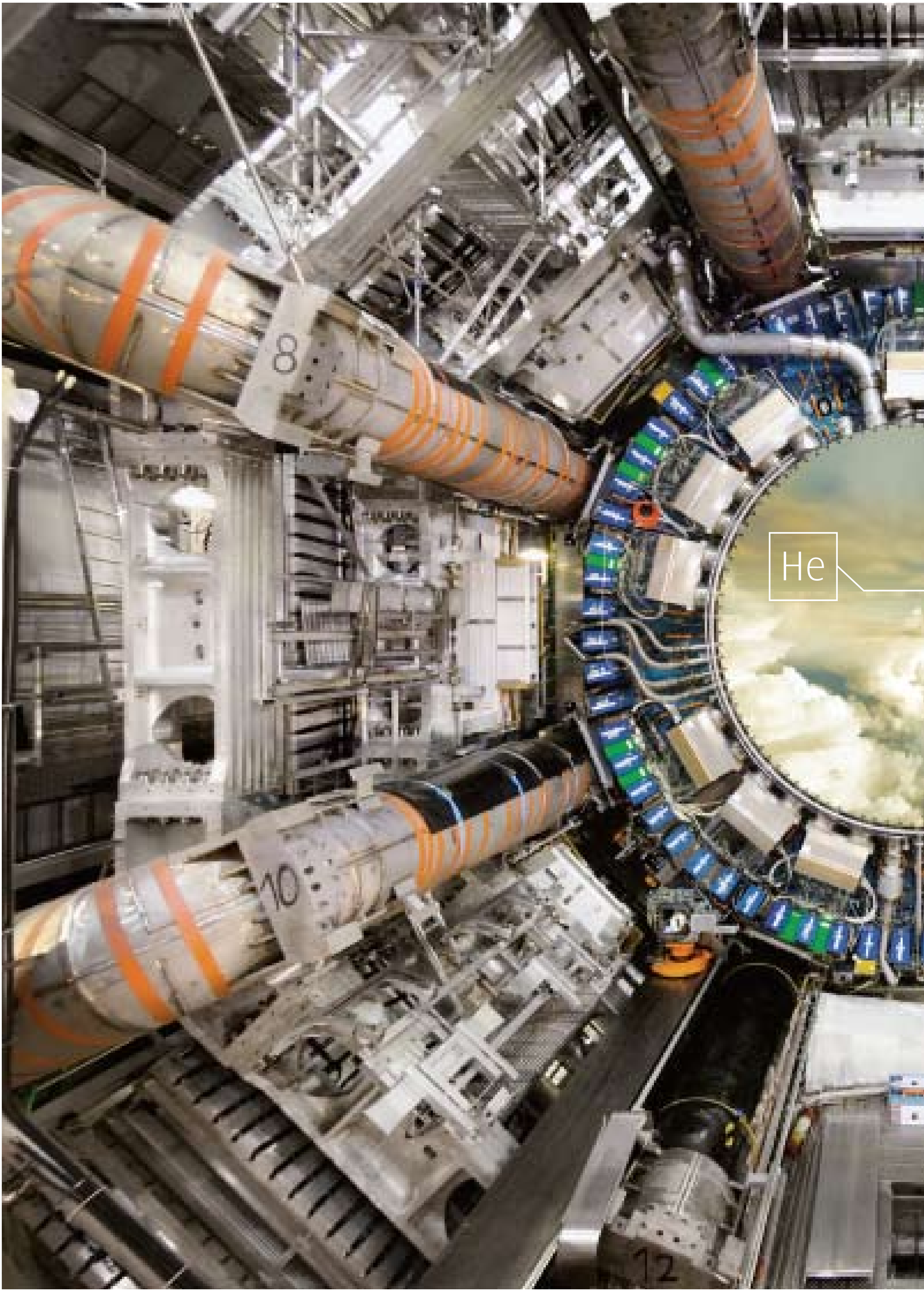
The basic components of an air separator have not seen major changes over the years, have they?

↳ Well, the air separation process itself is still the same. It relies on compressing and expanding gases to generate cooling energy. However, purification demands have changed over the years. To meet changing needs, we have managed to increase gas purity from 99 percent to 99.9999 percent over the last 40 years. And to secure our competitive position, we manufacture all critical core components ourselves. So altogether, looking back on overall developments and achievements, I would certainly say we are well equipped for the future.

02.2

Gases from the earth.

Fossil fuel fields are a rich source of valuable and versatile industrial gases. Natural gas can be directly extracted, for example, while other gases are generated as part of the oil and gas processing chain. These gases help reduce our environmental footprint. The role of hydrogen in desulphurising fuels is a prime example. Carbon dioxide, which is primarily released when fossil fuels are combusted and during various chemical processes, can also be used as an eco-friendly means to accelerate plant growth in greenhouses or clean electronic components. As a trusted partner for the petrochemical industry, Linde not only produces and delivers gases, but also specialises in the construction of ethylene plants to refine oil and gas into high-grade plastics.


He
8
10
12

02.2

Rock-bottom temperatures for world's largest machine.

The Large Hadron Collider (LHC) operated by the European Organisation for Nuclear Research (CERN) in Geneva is the world's largest particle accelerator with a circumference of 27 kilometres. The LHC simulates particle collisions just after the Big Bang. Extremely strong magnetic fields are required to keep the accelerating particle beams on course. Linde uses a special cryogenic solution based on Helium (He) to keep the magnetic coils close to absolute zero. Without these magnetic fields, we would not be able to deepen our insights into the origin and development of the universe.

02.2

Clear path to cleaner fuel.

To cut emissions from combustion engines, refineries desulphurise petrol and diesel. This is performed using hydrogen (H_2), which binds in a reactor with the sulphur in the feedstock to produce hydrogen sulphide. The sulphur is subsequently separated again and used for vulcanisation in the rubber industry or processed into fertiliser.


H_2

02.2

Green solution for accelerated growth.

Around 550 greenhouses in the Netherlands are now supplied with carbon dioxide (CO_2) which is a by-product from a refinery in Rotterdam. It's a win-win – operators can protect the environment while speeding up plant growth.


CO_2

02.2

Key component of light plastics.

Most plastics rely on olefins such as ethylene (C_2H_4). As one of the leading providers of olefin plants, Linde is active in petrochemical installations across many oil and gas-producing nations.


C_2H_4

02.2

Gases from the earth.

He

Helium – the universe's coldest element

Although helium is the universe's second most abundant element, after hydrogen, it is extremely rare on earth and also finite. In the earth's atmosphere, the concentration of helium by volume is only 0.0005 percent, so it cannot be obtained in significant quantities through air separation. Yet helium can reach concentrations of up to 7 percent in natural gas and can be extracted during gas processing at concentrations of 0.2 percent and above. Few gas reservoirs actually meet these conditions, however.

Helium is the least reactive of all gases, with the lowest boiling point (–269 °C), outstanding thermal conductivity and high diffusibility. These unique properties also account for the substantial increase in global helium demand. Whether as a cooling agent for super-conductive magnets and particle accelerators or as a lifting agent for airships and balloons, this versatile gas is indispensable in a number of fields. It is used for welding, cutting, fibreoptic cables, lasers and space systems, as well as being a key element of breathing mixes used in deep sea diving. It also has important applications in the semiconductor and photovoltaic industries.

Until a few years ago, around 90 percent of helium was obtained in the US, and that nation still accounts for the lion's share of global production. This was estimated at 180 million cubic metres. The remaining viable sources of helium are located in Russia, Poland, Qatar, Indonesia, Algeria and Australia.

Linde plays an active role not only in manufacturing helium liquefaction plants, but also in supplying the gas. Flanking Linde's long-standing production plant in the US and off-take arrangements elsewhere, the company has been delivering high-purity liquid helium to the European market since April 2007 from its source in Skikda, Algeria, through its joint venture Helison Production, in which Linde holds a 51-percent stake (the Algerian gas and oil company Sonatrach accounting for the other 49).

To date in Skikda, three LNG plants have been delivering the raw gas feedstock – a mixture of helium, nitrogen and methane – from which the helium is extracted at a purity of 99.999 percent. This is achieved using a cryogenic process in which the methane and nitrogen are separated in a cold box (see glossary), before final purification in a pressure swing adsorption plant (see glossary). Following purification, the helium is cooled down to –269 °C and thus liquefied for onward transport.

New source in Australia

To consolidate its position on the global helium market and secure long-term supplies for its customers, Linde also established a helium production facility in Darwin, Australia last fiscal year. The first in the southern hemisphere, this helium purification and liquefaction plant went on stream at the end of 2009. From here, Linde supplies not only the Australian market but also New Zealand and the Asia-Pacific region with this scarce gas.

Applications in medicine and science

Magnetic resonance imaging (MRI) is an important medical application of helium. MRI uses magnetic fields and radio waves to enable examination of internal body organs and tissues. To render the magnetic coils superconductive, they must be cooled to extremely low temperatures – a process requiring liquid helium.

Helium is also used to cool the magnets in the Large Hadron Collider (LHC) at CERN, near Geneva (Switzerland). Researchers across the globe anticipate that the scientific experiments conducted in this proton accelerator will lead to important new findings about physical processes during the Big Bang and deliver proof of exotic elementary particles whose existence is as yet unproven.

Above and beyond with helium

Space exploration would also be almost unthinkable without helium. Harnessing its expertise in helium-based cryogenic technology, Linde has participated in several space research projects over the past year. A notable date in this regard was 14 May 2009, when an Ariane 5 ECA launched from the European spaceport, Kourou, in French Guyana. On board were the Herschel and Planck space telescopes and cryogenic technology from Linde. During its orbit around the sun, Herschel is set to uncover new scientific insights into the formation and evolution of stars and galaxies thousands of millions of light-years away. Made of silicon carbide and 3.5 metres in diameter, its main mirror is protected from the sun's rays by a large metal shield, maintaining it at a temperature of –193 °C. However, the optical equipment has to be cooled still further using liquid helium. Reliable results are essential here, as even slight changes in temperature could cause significant interference to the sensitive measuring equipment. The cryogenic gas is stored in a 2,200-litre tank, from which around two milligrams of the –271 °C liquefied helium evaporate per second. A phase separator is used for highly accurate evaporation, ensuring the helium reserves last at least three years.

↳ (top) Around 1,600 litres of cryogenic liquid helium is required to cool the magnetic coils in MRI equipment.

↳ (bottom) Liquid hydrogen (LH_2) tanks at Linde's largest gases production centre in Leuna (Germany).

Its low density and non-combustibility also make helium the lifting agent of choice for airships and balloons. Aerospace organisations such as the National Aeronautics and Space Administration (NASA) use it for balloon research missions at high altitude, for instance. During the last year, Linde supplied helium for a series of uncrewed NASA research flights at an altitude of up to 43 kilometres. Launched in May and June 2009 from the Swedish Esrange Space Center, north of the Arctic Circle, these missions helped gather scientific data about the sun's magnetic field and the associated cosmic rays that can be dangerous to astronauts and pilots.

H_2

Protecting the environment with hydrogen

Molecular hydrogen (H_2) is produced on an industrial scale primarily by steam-reforming (see glossary) natural gas or naphtha. It also occurs in petrochemical processes such as ethylene production and coal gasification. Linde continues to explore sustainable ways of generating this colourless and odourless gas. Focus areas include landfill sites, biomass and blue-green algae (see page 71 onwards).

Although the lion's share of global hydrogen – around 600 billion cubic metres per year – is still generated from fossil fuels, the gas already contributes to environmental protection today. Alongside its many applications in metal fabrication and processing, as a cooling agent and in the chemical and food industries, it is also used in fuel desulphurisation.

To fulfil increasingly stringent environmental requirements, more and more fuel producers are equipping their refineries with hydrogen plants. This is welcome news for Linde. In 2009, for instance, the company was awarded a contract by Raffineria di Milazzo, Italy, for construction of a second turnkey hydrogen plant.

Linde is also delivering a hydrogen plant for the production of low-sulphur diesel fuel at the CITGO refinery in Lemont (Illinois, USA), due to open during 2010. The company has already been operating a hydrogen generator since 2003 for CITGO – part of the state-owned crude oil enterprise Petroleos de Venezuela S.A.

During the past fiscal year, Linde also signed a contract with the Shell Oil Company to deliver hydrogen to its Deer Park complex in Texas. Linde will supply the refinery via pipeline from its Houston facilities.

↳ Both gentle and cost-effective – CO2-based cleaning of premium surfaces.

Another valuable application of hydrogen is purifying oil sand. The north of the Canadian province of Alberta is home to oil sands spanning 194,000 square kilometres, which could theoretically produce 179 billion barrels of oil (1 barrel holds 159 litres). Even if only 10 percent of this was actually recoverable, it would still make the site the world's second-largest oil reserve after Saudi Arabia. Desulphurising the oil extracted from this tar sand means transporting it to refineries via pipeline and then treating it with hydrogen. Linde operates two facilities for BP and Sunoco in Toledo (Ohio, USA) for this purpose.

CO_2

The upside of carbon dioxide

The current media attention on greenhouse gases and their harmful impact on the climate tends to eclipse the fact that carbon dioxide (CO_2) is a natural component of the earth's atmosphere and possesses many useful properties. Without CO_2 there would be no plant life, since alongside light, plants require carbon dioxide for the photosynthesis essential to their growth.

This biological law forms the basis of the joint venture OCAP (Organic CO_2 for Assimilation by Plants), founded by Linde with Dutch construction company VolkerWessels. The Netherlands' many greenhouses use CO_2 to improve the growth of tomatoes, cucumbers and lettuces, previously generated by gas furnaces. But OCAP now supplies over 550 greenhouses with gas previously emitted into the atmosphere by a Shell refinery near Rotterdam. The company currently delivers around 356,000 tonnes of CO_2 to operations from Rotterdam to Amsterdam via an 85-kilometre pipeline linked to a 200-kilometre distribution network. This intelligent recycling solution prevents combustion of 105 million cubic metres of natural gas and avoids CO_2 emissions of 190,000 tonnes per annum (tpa).

Spurred on by the success of this project, Linde engineers in the Netherlands have also developed another innovative application for CO_2. C-grO_2w (pronounced "see grow") is a process to improve the growth and durability of grass on football pitches. A mobile tunnel tent is moved over the field, applying carbon dioxide, light and heat. This new, patent-pending system has already shown promising results during tests at the Dutch Groningen stadium.

Keeping food fresh with CO_2

Available in gas, liquid, solid and "snow" form, carbon dioxide is essential in the preparation of many foods and beverages. This gas is used to cool sensitive foodstuffs, create protective packaging atmospheres (see pages 30 and 31) and carbonate drinks, for instance. Its applications include meat processing and transport, ingredient cooling in bakeries, wine production and quality control in breweries.

Alongside natural sources, Linde primarily uses raw carbon dioxide to produce high-purity food-grade CO_2. This is generated by numerous chemical processes, for instance in ethylene oxide production. 70 percent of the CO_2 treated by Linde goes to the food industry.

To ensure reliable future supply for its customers, Linde began constructing a new CO_2 liquefaction plant at Gendorf (Germany) in November 2009, with operations due to commence in summer 2010. This facility will primarily supply food and beverage manufacturers.

The company also built a CO_2 plant at the Jurong Island chemical complex in Singapore. With a capacity of 100 tonnes per day (tpd), this will be Singapore's largest plant of this type and should increase Linde's market share in the region's cylinder gases business. The plant utilises the CO_2 by-product generated by a synthesis gas (see glossary) production process on site, thereby reducing its carbon footprint.

Another new facility is underway in Thailand for CO_2 purification and liquefaction. This facility will generate up to 300 tpd of liquid CO_2, again destined primarily for the food and beverages industry.

Eco-friendly textile cleaning

Linde operates a textile cleaning chain based on recycled CO_2 under the FRED BUTLER® brand. Alongside liquid CO_2, the specially developed cleaning machines only use biodegradable washing agents to completely remove grease, oil and other dirt particles from the fibres. According to the EU LIFE research project, cleaning with CO_2 not only brings ecological benefits, it also extends the life of clothing by up to 30 percent. FRED BUTLER® is also participating in the international EU project ACCEPT with this environmentally friendly process.

Dry ice for deep cleaning

Frozen carbon dioxide – dry ice and CO_2 snow – is an effective yet gentle way to remove impurities such as grease, glue, wax, oil or paint from sensitive surfaces. Cooled to −78 °C, the ice particles are blasted at the surface in question from special nozzles. Since the dry ice immediately converts to gas or sublimates, it removes impurities without leaving any residue (e.g. wastewater or sand used for blasting). With its CRYOCLEAN® technology, Linde ranks among the technological leaders in this area. The vast range of proven applications in the chemical, automotive, electronics, semiconductor, food, metal and restoration industries extends from cleaning welding and food-processing lines through post-fire restoration to cleaning moulds in the rubber and plastics industry and protecting against corrosion in ship-building.

In comparison with traditional, solvent-based cleaning methods, dry ice is both more cost-effective and better for the environment.

Linde's thermal spraying technology (see glossary) LINSPRAY® also uses CO_2 to cool materials faster and maintain them at the correct working temperature. The CO_2 prevents strains, tears and insufficient adhesion due to overheating during coating. In comparison with compressed air cooling, this coating process increases quality and productivity, as the evenly maintained temperature eliminates interruptions for after-cooling.

C_2H_4

Ethylene – key component in modern plastics

Many plastics have their origins in the fossil fuels crude oil and natural gas. Fractions of these raw materials like ethane, LPG and naphtha, are converted by steam cracking (see glossary) into ethylene, propylene and by-products. Polymerisation (see glossary) with the aid of catalysts then produces polyethylene and polypropylene, which are among the most widely used plastics worldwide and currently enjoy the highest growth rates.

Over 50 percent of global ethylene and propylene production is dedicated to generating these polyolefins. As a technology contractor, Linde's expertise covers every step involved in the chain from fossil fuel to polymer.

Linde's contribution to the petrochemical industry extends far beyond the supply of gases. Drawing on its comprehensive expertise in large-scale international contracting, the company also plays a leading role on the global market for ethylene plants and is involved in many important petrochemical projects worldwide.

A case in point is the industrial cluster now under construction in Ruwais near Abu Dhabi (UAE), whose first development phase is due for completion in 2013. Last fiscal year, Linde was contracted to construct the third ethane cracker at this location for Borouge, a leading provider of high-quality plastics, in a contract worth around USD 1.1 bn. Borouge is a joint venture of the Abu Dhabi National Oil Company (ADNOC), one of the world's largest oil and gas corporations, and Borealis, a leading chemicals and plastics provider headquartered in Vienna (Austria). Linde was awarded the contract as part of the Borouge 3 expansion programme, which aims to increase polyolefin production capacities in Ruwais to 4.5 million tpa by the end of 2013.

Autumn 2009 saw Linde hand over a polyethylene facility to its customer the Eastern Petrochemical Company (SHARQ) in Saudi Arabia. This double-line installation in Al-Jubail has a total capacity of 800,000 tpa. In addition, a new plant with an annual capacity of 150,000 tonnes of linear alpha olefins (LAO) successfully went on stream in Al-Jubail, based on an innovative process (known as the α SABLIN process) which Linde developed in collaboration with SABIC. Significant projects such as these have enabled Linde to underline its leading position as an engineering and gases partner in the Middle East.

Linde is also constructing the largest ethylene plant in India in consortium with Samsung Engineering (Korea). This will generate 1.1 million tpa ethylene, 400,000 tpa propylene, 150,000 tpa benzene and 115,000 tpa butadiene. This was awarded by the Indian company OPAL, a subsidiary of the state-owned ONGC (Oil and Natural Gas Corporation Ltd.).

↳ Part of an ethylene complex in Ningbo, China, supplied with oxygen and nitrogen by Linde.

02.2

"CO_2 doesn't deserve all the bad rap"

Stephen McCormick, responsible for the food and beverages sector within the Merchant & Packaged Gases Business Area, discusses eco-friendly applications of carbon dioxide (CO_2) with strong future potential.

At the Linde Application Centre near Munich, Germany, Stephen McCormick demonstrates just one of the practical benefits of CO_2 – a tunnel freezer for food in this case.

Mr. McCormick, CO_2 already plays an important role in the food and beverages industry when it comes to chilling and freezing fresh and convenience foods and carbonating soft drinks. What new avenues are there left to explore?

↳ Oh, we certainly still have a great deal to discover and the potential applications are varied. Over the last few years, we developed a complete CO_2-based system for the wine industry, for instance, which was successfully rolled out across several French vineyards in time for last year's grape harvest. Our aim here is to enhance the quality of wine by natural means.

How do you go about that?

↳ By protecting the entire winemaking process against oxidation – all the way from vine to wine. The first step is to cover the grapes with CO_2 "snow" or dry ice as soon as they have been harvested. This turns into gas which completely surrounds the grapes in the container and displaces the oxygen. We also use CO_2 to protect and cool grapes when they are transferred to maceration tanks, where flavours and aromas are extracted, and also to blanket them in the crusher. The cooling from CO_2 prevents the juice from fermenting prematurely. CO_2 is also employed to remove oxygen from the tanks and pipelines.

So CO_2 is a definite plus in the winemaking business?

↳ Yes, in both its protective and cooling functions, the gas contributes to a significant improvement in wine quality. And thanks to CO_2, winegrowers can significantly reduce the use of stabilising agents and preservatives such as sulphur dioxide, which is certainly in the interests of health-conscious consumers and connoisseurs. However, CO_2 also has numerous other effective applications within the food industry.

What applications are you currently focussing on here?

↳ Just now, we are in the process of launching a new range of tunnel freezers. These innovative products help reduce gas consumption in food-processing while significantly boosting cooling performance. They also cut freezing costs by around 10 percent for our customers. What's more, they release much less CO_2 into the atmosphere than standard freezers.

It would be best if this CO_2 could be reused directly, wouldn't it?

↳ Absolutely, which is why we are also working to recapture it after the freezing process. A recycling ratio of around 70 percent is technically feasible here. This would not only lessen the environmental footprint, but would also have a significant impact on overall process costs. So it's well worth continuing our efforts in that direction.

What other application areas are you pursuing at the moment?

↳ Treating drinking water is becoming increasingly important. In many regions with scarce freshwater reserves – North Africa, say, or the Middle East – drinking water has to be obtained in ever greater quantities from seawater desalination. However, this process produces pure H_2O, which is not suitable for drinking due to its complete lack of minerals. To enrich it with the mineral nutrients important for human consumption, its pH value must first be reduced.

And that's where CO_2 comes in?

↳ Exactly – this we achieve by adding CO_2. Calcium dissolves in water below a neutral pH of 7, rendering it drinkable. Our SOLVOCARB® product targets this simple but essential step in treating seawater for consumption. At a time when access to drinking water presents a major problem in many regions of the world, this application of CO_2 adds real value by improving quality of life for numerous people. CO_2 doesn't really deserve all the bad rap.

03

With potential.
Right on the megatrend.

“TACKLING GLOBAL WARMING WHILE MEETING GROWING ENERGY DEMANDS FROM EMERGING ECONOMIES IS ONE OF THE MOST COMPLEX TASKS SOCIETY FACES TODAY. AT THE SAME TIME, WE NEED TO PROVIDE MEDICAL CARE FOR AN AGEING POPULATION. WITH OUR TECHNOLOGIES, PRODUCTS AND SERVICES, WE ARE WORKING TO MEET THESE CHALLENGES HEAD ON.“

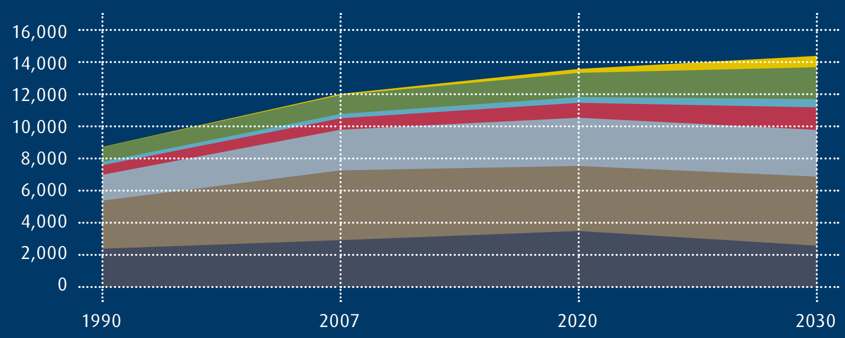
Professor Dr Wolfgang Reitzle

Whether by raising plant efficiency levels, reducing emissions or tapping energy resources in environmentally sound ways, a key focus of our research and development work lies on technologies that have the potential to reduce our carbon footprint – either today or in the near future.

03.1

Clean energy.

Balancing the growing global energy demand with the need to conserve natural resources is a major challenge. That is why Linde develops and harnesses innovative technologies for sustainable energy supplies.

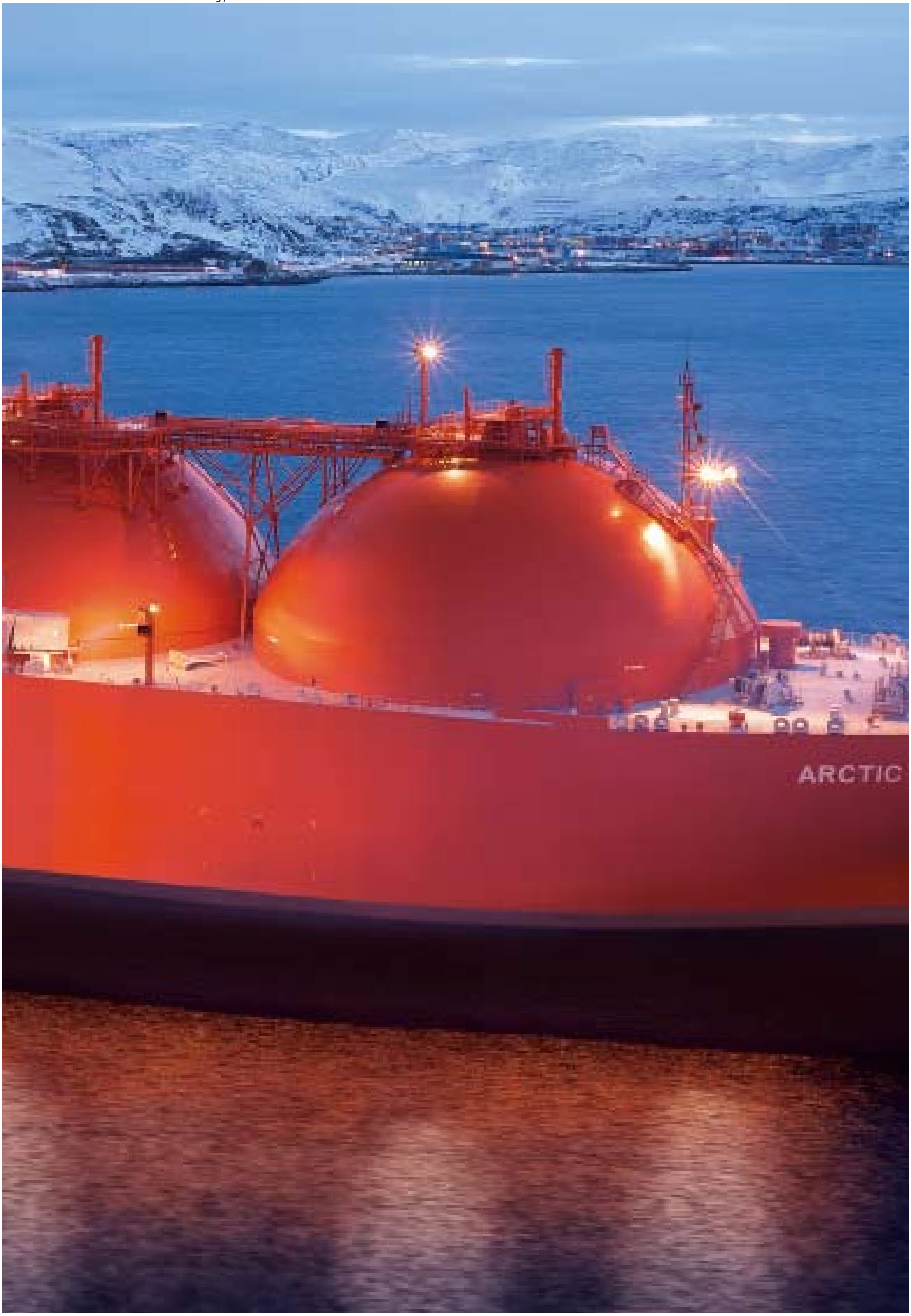


Global energy consumption in millions of tonnes of oil equivalent (Mtoe)

Coal Oil Gas Nuclear Hydro Biomass and waste Other renewables

Source: World Energy Outlook 2009 (International Energy Agency IEA)

One of the biggest dilemmas facing society today is the need to secure tomorrow's energy supplies without compromising the earth's climate or basic human living requirements. Linde develops and tests technologies and processes aimed at harnessing sustainable energy sources and making them economically viable. We also work on solutions that lower the ecological impact of fossil fuels, which remain indispensable in today's energy mix. Our portfolio of products and services is extremely broad, ranging from natural gas liquefaction through solar-cell production enhancements aimed at 'green parity' to the further development of alternative fuels.


ARCTIC

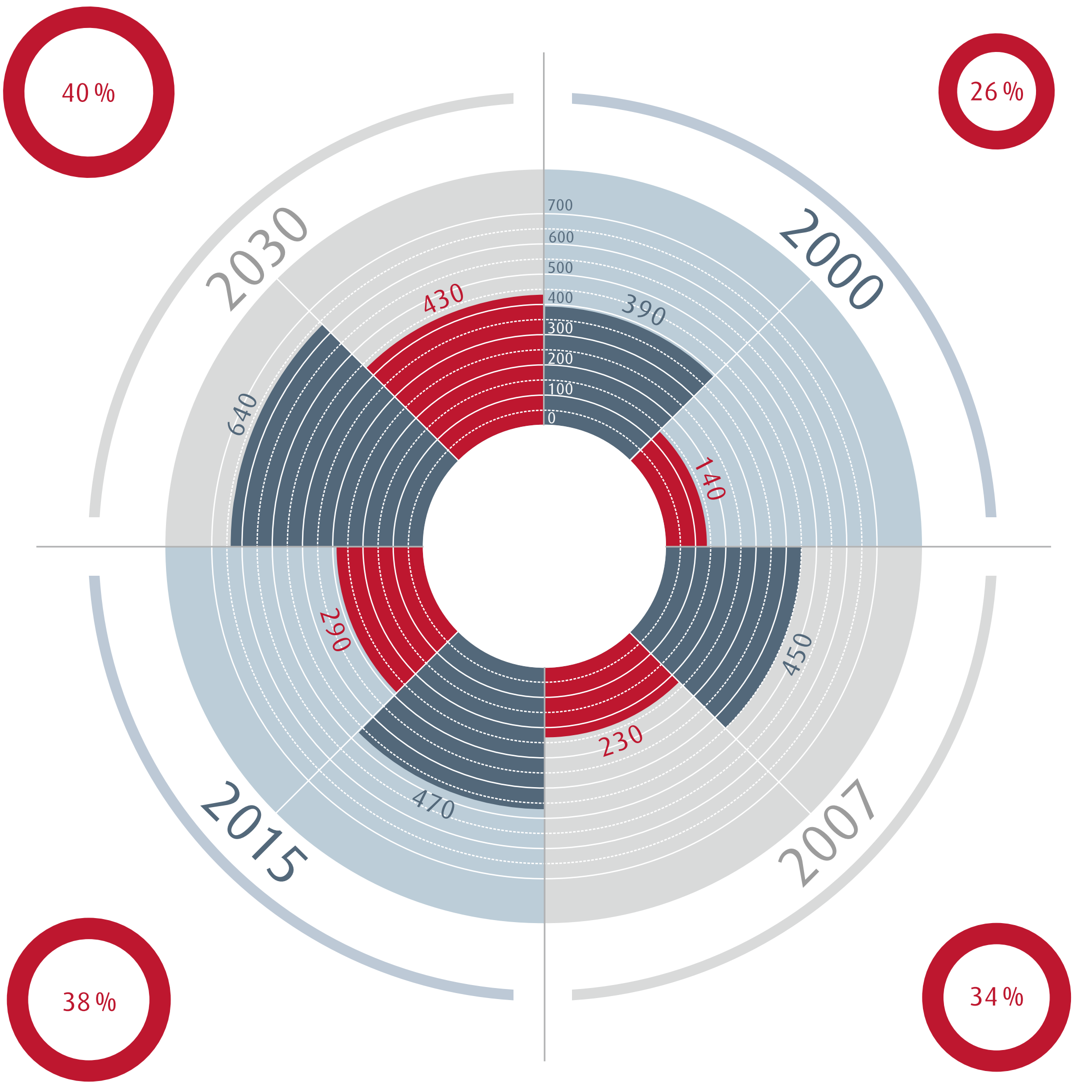
Liquefied natural gas (LNG). Fuel coming in from the cold.

LNG is gaining market share in the natural gas energy mix worldwide.

Global trade volumes in billion cubic metres:

- LNG (liquefied natural gas)
- Pipelines
- LNG share of total mix

Source: World Energy Outlook 2009

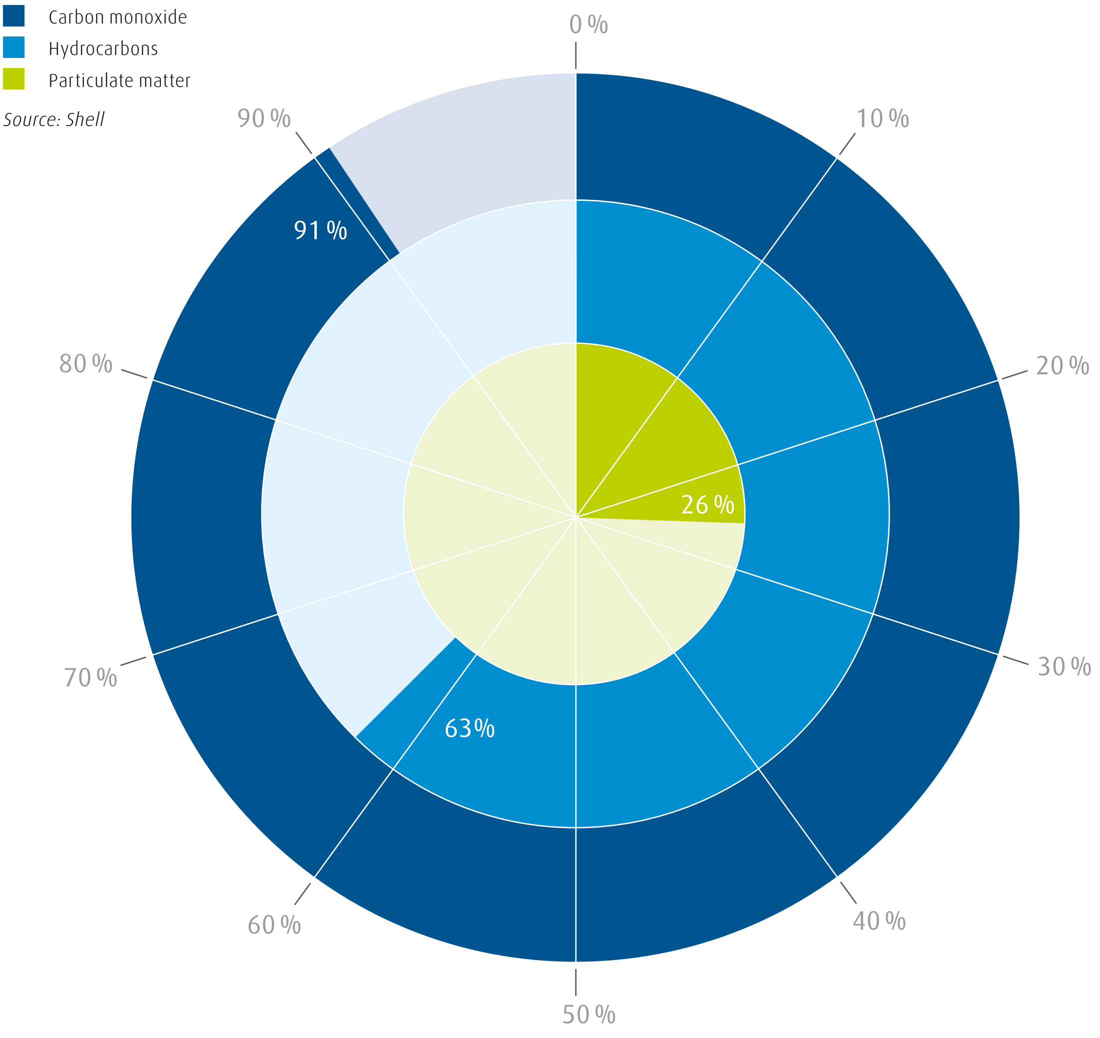


With the construction of Europe's largest natural gas liquefaction plant on Melkøya, an island near the town of Hammerfest in Norway, Linde has firmly established its position as a reliable partner to the energy industry. LNG (see glossary) can be transported over large distances by ship, reducing reliance on natural gas pipelines. This makes it an increasingly important pillar in today's energy mix. Furthermore, LNG has a high energy density and releases significantly less emissions than petrol and diesel.

Gas-to-liquids (GTL). Designer fuels taking the lead.

Impressive emissions balance for GTL diesel.

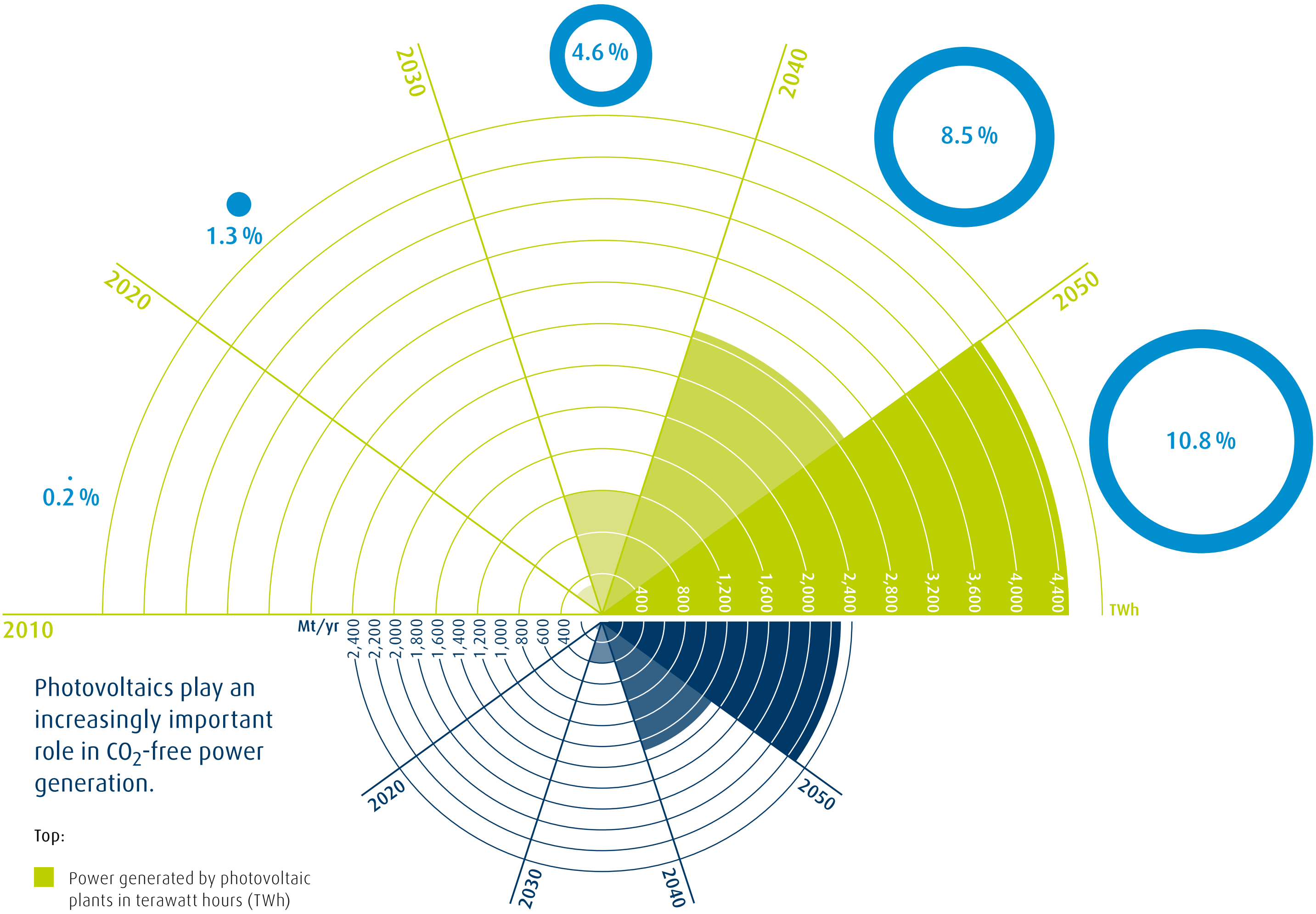
Reduction in selected emissions using GTL diesel instead of conventional diesel:



Source: Shell

Increasingly stringent environmental regulations mean that synthetic fuels are growing in popularity. Synthetic diesel or kerosene, for example, can be obtained from natural gas and oxygen using a multi-phase, gas-to-liquids process (GTL – see glossary). GTL diesel contains very little sulphur and no toxic aromatic substances such as benzene or nitrogen oxide. Its high centane number makes it an ideal additive to conventional diesel, helping improve air quality in city centres by ensuring cleaner combustion.

Solar energy. Using specialty gases to harness the sun's energy.



Photovoltaics play an increasingly important role in CO_2-free power generation.

Top:

- Power generated by photovoltaic plants in terawatt hours (TWh)
- Proportion of global power generation in %

Bottom:

- CO_2 emission reduction targets in megatonnes per year (Mt/yr)

Source: World Energy Outlook 2009

Enormous advances in technology combined with financial aid have pushed solar energy growth rates beyond those enjoyed by most other industries. New plants manufacturing large-scale thin-film photovoltaic modules (see glossary) are springing up in Europe, China and India. Linde supports these facilities by supplying specialty gases that help keep production processes as climate-neutral and cost-efficient as possible.

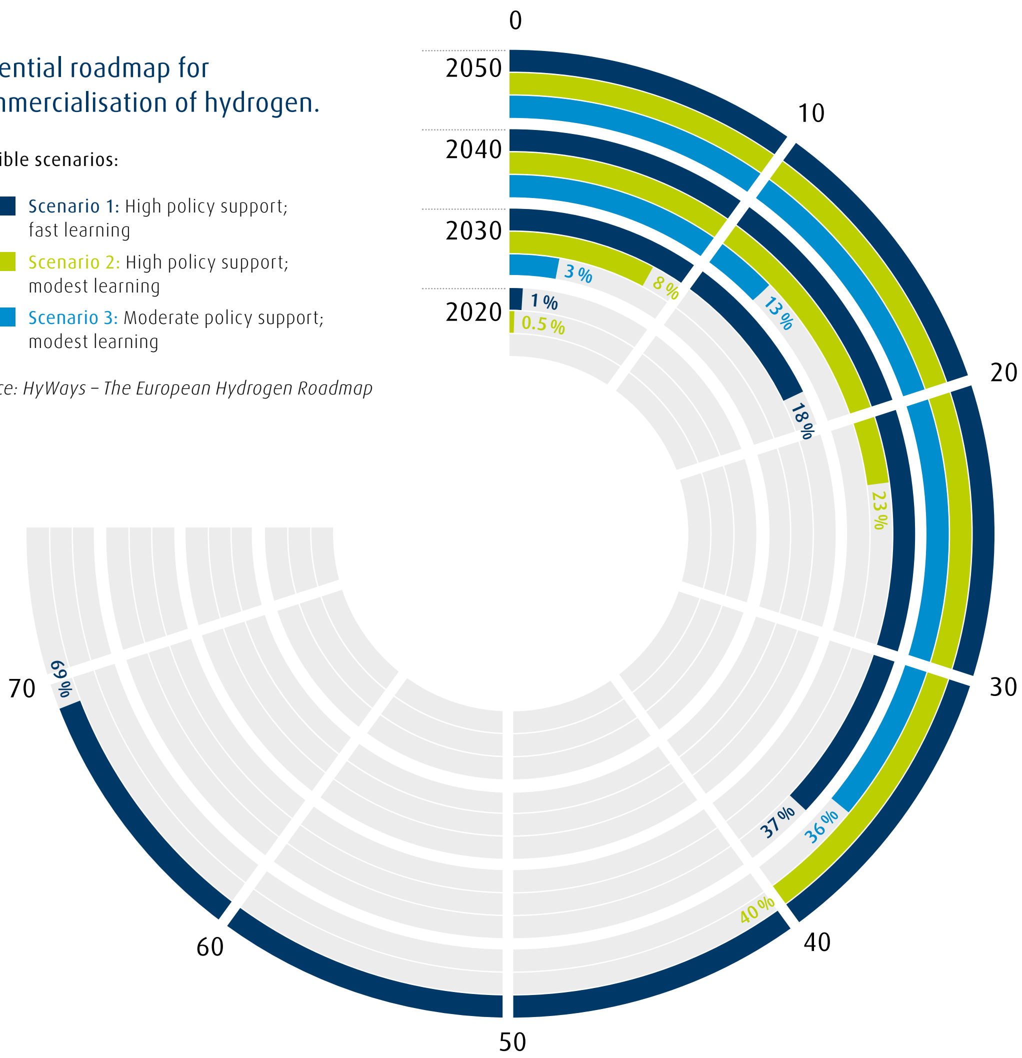
Hydrogen.
Energy carrier of the future.

Potential roadmap for commercialisation of hydrogen.

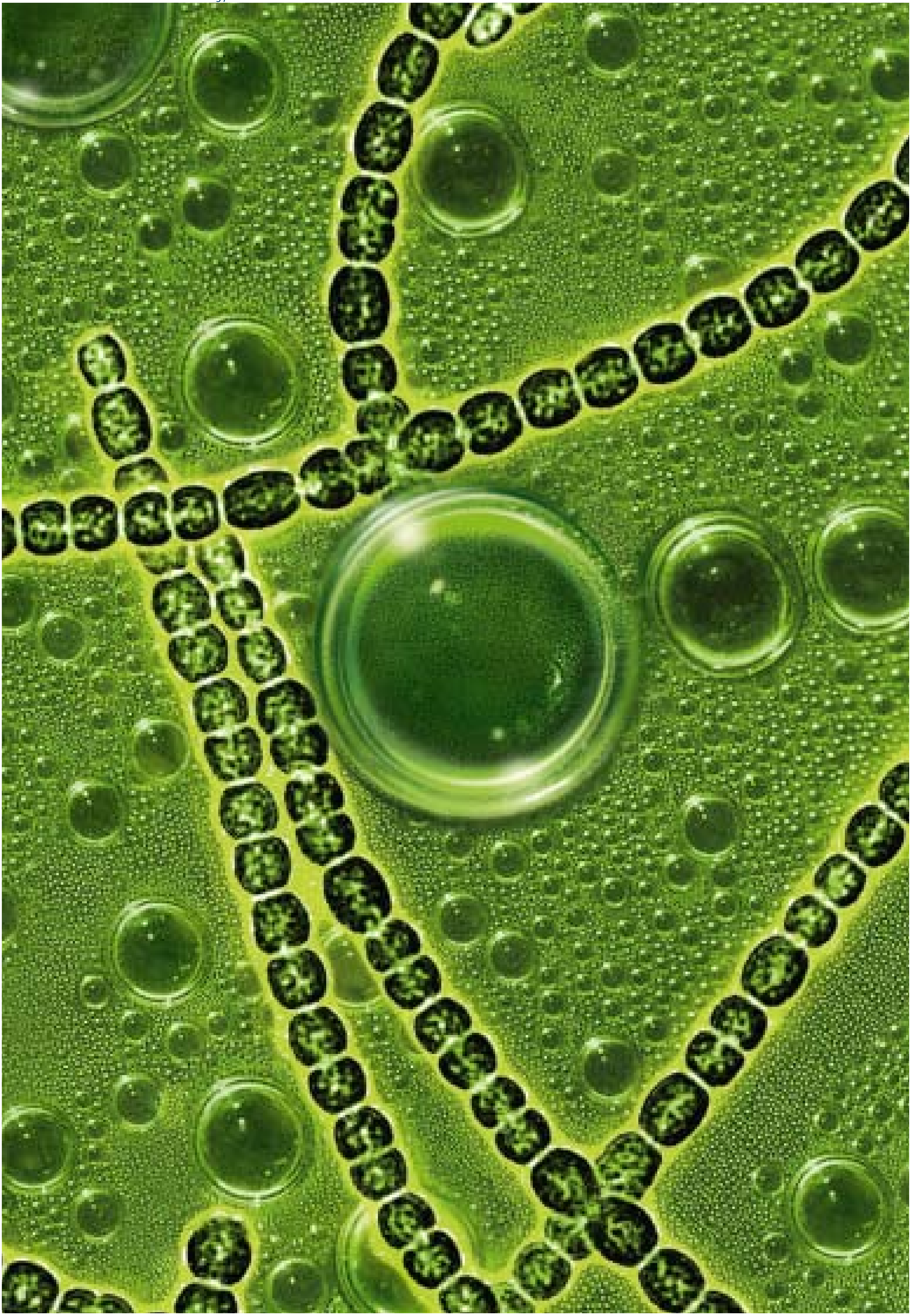
Possible scenarios:

- Scenario 1: High policy support; fast learning
- Scenario 2: High policy support; modest learning
- Scenario 3: Moderate policy support; modest learning

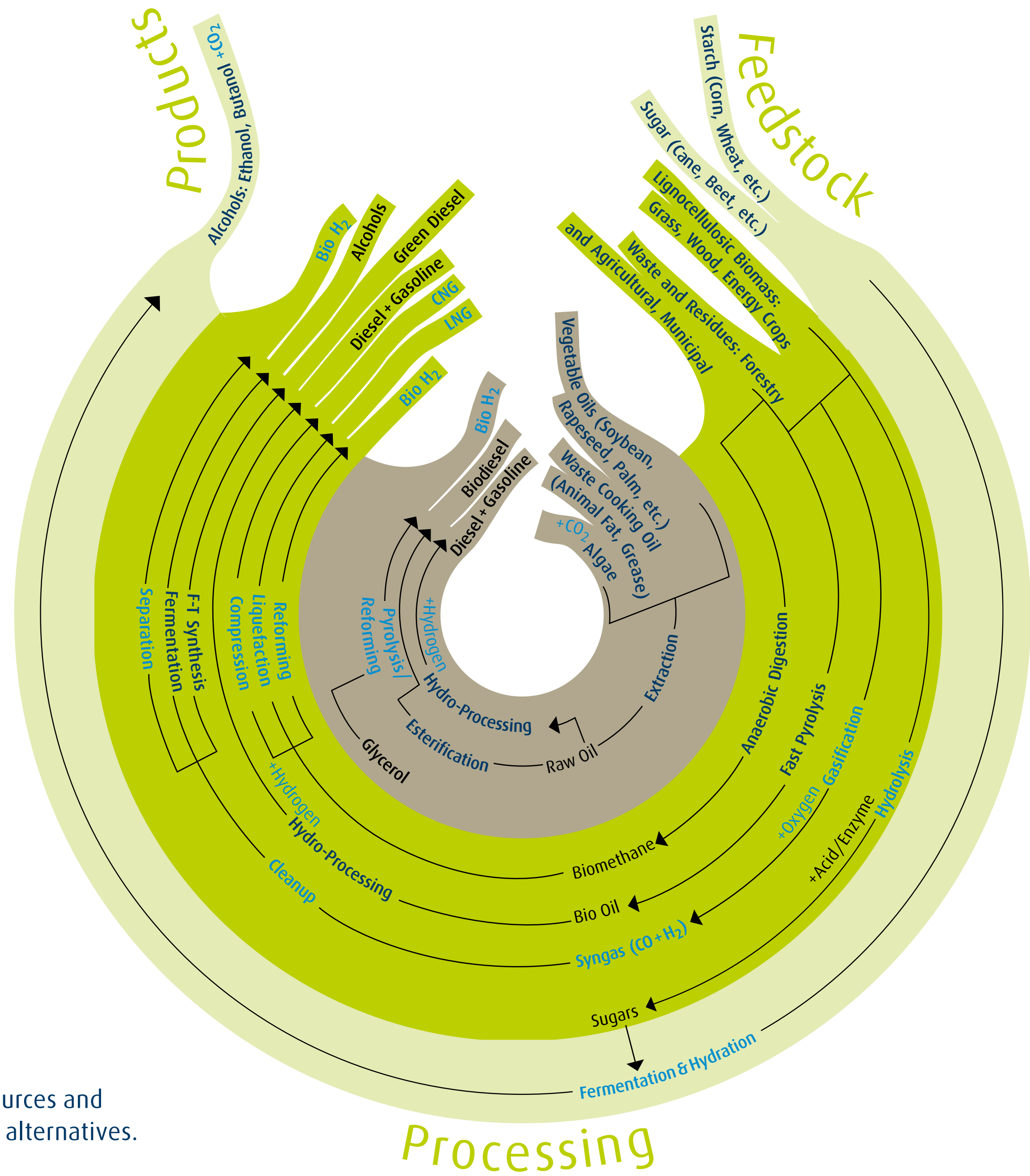
Source: HyWays – The European Hydrogen Roadmap



Linde is pioneering the advancement of state-of-the-art hydrogen technologies. From generation and liquefaction through transport solutions to vehicle fuelling, Linde covers the entire hydrogen value chain. The company is now looking to increase the regenerative share in the hydrogen mix. In addition, Linde is working closely with partners from the automotive and petroleum industries to establish a network of fuelling stations.



Biofuels. Energy feeding on nature's diversity.



Biomass sources and production alternatives.

Linde activities in cyan.

Source: The Linde Group

Second and third-generation biofuels – in other words fuels that do not conflict with food supplies – could play a key role in the sustainable energy landscape of the future. Lignocellulosic plant remains or algae that generate bioethanol directly from CO_2, saltwater and sunlight serve as feedstock for these new processes. Landfill gases can also be transformed into environmentally friendly fuel, as has been successfully demonstrated in California.

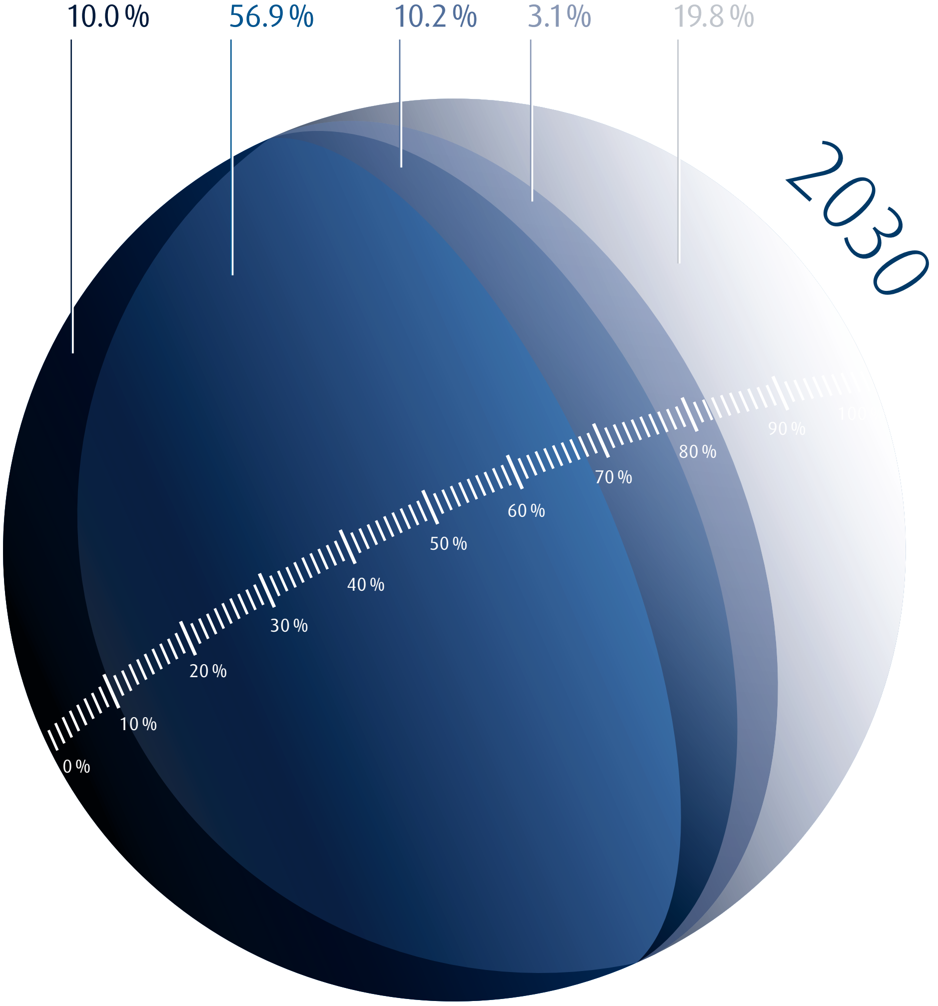
Avoiding CO_2 emissions. Combating global warming with climate-friendly technologies.

The right technology mix coupled with greater energy efficiency is the only way to achieve climate targets.

Breakdown of CO_2 reduction factors:

- Nuclear energy
- Energy efficiency
- CCS (Carbon Capture and Storage)
- Biofuels
- Renewable energies

Source: World Energy Outlook 2009



Rising CO_2 levels in the atmosphere are a major accelerator of global warming. Yet we will continue to rely on the earth's abundant coal reserves in the foreseeable future if we wish to secure energy supplies worldwide. Scientists and engineers are therefore focusing on technologies that capture carbon dioxide from the flue gases produced during coal combustion and store it deep underground under impervious layers of rock and clay (CCS = Carbon Capture and Storage – see glossary).

03.1

Clean energy.

Liquefied natural gas (LNG)

LNG – versatile and kind to the environment

Natural gas is becoming an increasingly important source of energy. It releases fewer harmful emissions than crude oil products when combusted to generate heat or power and is the most important feedstock for producing synthetic fuels and hydrogen.

Global demand for natural gas is on the rise. In addition, this energy carrier often needs to be transported over large distances. Yet the cost of transporting natural gas by pipeline increases with distance, which is why liquid natural gas (LNG) is becoming an increasingly popular alternative to pipelined compressed natural gas (CNG).

As a result, more and more natural gas sourced at remote locations is being liquefied and transported by special tank ships. Natural gas from the Norwegian gas field Snøhvit in the Barents Sea is liquefied on the island of Melkøya near Hammerfest and transported by tanker to customers in France, Spain and the US. The Linde-built liquefaction plant is the largest of its kind in Europe and went on stream in autumn 2007.

New LNG plants

The International Energy Agency (IEA) estimates that natural gas will meet a quarter of the world's energy needs by 2020. LNG's share of this is also set to rise – from the current 30 or so percent to 40 percent by 2030 – based on IEA forecasts. This organisation expects the overall volume of traded LNG to surge by 27 percent by 2015 and almost double by 2030. This development should also result in increased demand for liquefaction plants.

The experience gained by Linde in the planning, engineering and start-up of the Hammerfest plant is now being channelled into the process design plans for the new CIGMA LNG complex, commissioned by PDVSA, Venezuela's state-owned oil and gas company. This major project is part of PDVSA's plan to transport natural gas from numerous off-shore fields in north-eastern Venezuela to land, where it can then be processed, liquefied and exported to global markets.

Linde's Engineering Division is relying on its own technology innovations for this new plant. It will be powered exclusively by electric motors – an innovation that Linde pioneered at Hammerfest. Upon completion of the first construction phase, the CIGMA complex will deliver 9.4 million tons of LNG per year. The first deliveries are scheduled for 2014.

Natural gas liquefaction is scheduled to start in the second half of 2010 in the Western Australian town of Karratha. Here, natural gas from the off-shore gas field Pluto will be treated and liquefied. The incoming natural gas, transported via a 180-kilometre pipeline, is rich in nitrogen, which will have to be separated in order to lower the transport volume and increase the end product's calorific value. Linde is supplying its customer, Woodside Burrup Property Ltd, with the necessary separation facility, known as a nitrogen rejection unit (NRU).

The separation of nitrogen from natural gas is an increasingly important line of business for Linde. This is driven by the growing number of nitrogen-rich natural gas fields being developed and the increasing use of nitrogen itself to recover crude oil (enhanced oil recovery – see page 31).

Linde is currently constructing a medium-size LNG plant (300,000 tons per year) for Skangass AS in Stavanger (Norway). Following completion in autumn 2010, part of the liquefied natural gas will be shipped from the plant to Nynäshamn, south of Stockholm, where the Linde Engineering subsidiary CRYO AB is currently constructing an LNG import terminal. Linde's Swedish industrial gases company AGA AB is the owner and operator. Once the terminal is up and running, scheduled for 2011, part of the regasified LNG will be transported by pipeline to a refinery looking to lower emissions by switching from naphtha to natural gas. Stockholm Gas is another major customer also keen to change from naphtha to natural gas, and by doing so cut its CO_2 emissions by 51,000 tons.

The Chinese government is planning to construct around ten LNG terminals. Linde is also set to benefit from this economic action plan by supplying the state-owned oil and gas company PetroChina with six LNG vaporisers, a move that should give the Group a promising foothold in this fast-growing market.

Gas-to-liquids (GTL)

Major projects in the desert

Similar to natural gas liquefaction, gas-to-liquid (GTL) fuels are also experiencing an upturn. This is primarily driven by dwindling crude oil reserves, increasing oil prices and the lower emissions released during combustion of "designer" GTL diesel.

And nowhere is this trend currently more evident than in Qatar, where Pearl, the world's largest complex of this kind, is shortly due to be completed. And Linde has played a major role in Pearl by contributing a total of eight air separation plants. The oxygen generated there is required for a GTL process step, where natural gas is first converted to a synthesis gas (see glossary). The world's largest air separation hub is scheduled to be handed over turnkey to Shell GTL Ltd. in the first half of 2011. Linde has been leveraging its interna-

↳ (top) Special tankers carrying around 150,000 cubic metres of liquefied natural gas set sail from the LNG plant on the island of Melkøya near Hammerfest in Norway.

↳ (bottom) Workers on the construction site of what will be the world's largest GTL plant for Shell in Qatar.

tional production network to deliver this major project. The heart of the air separation plants, the cold boxes, were manufactured in Dalian (northern China). The fully assembled modules were then transported from there to Qatar.

Using natural gas as feedstock, the Pearl GTL plant is set to manufacture around 140,000 barrels of GTL products per day, including naphtha, paraffin, kerosene and lubricant oils. The complex will also produce approximately 120,000 barrels of condensate, natural gas liquids (NGL) and ethane per day. Pearl relies on Linde's air separation plants to ensure the high-volume oxygen stream required for this massive project – in other words, some 860,000 cubic metres an hour.

Solar power

Gases improve the carbon balance

Although it levelled off in 2009 as a result of the crisis, photovoltaics (generating electricity from solar cells) remains one of the most promising ways of securing our future energy needs without compromising the climate through harmful emissions. And yet we are nowhere close to realising the true technical and economic potential of this new technology. Productivity and efficiency gains are still necessary to achieve grid parity (see glossary) and – equally importantly – green parity, which refers to the environmentally friendly production of solar cells.

Linde's speciality gases and supporting processes not only help solar cell manufacturers ensure a reliable and economically viable power supply, they also play an important role in preventing harmful emissions.

In recent years, the company has further consolidated its position as a leading gases and chemicals supplier to both crystalline silicon and thin-film solar cell (see glossary) manufacturers in the key markets of Germany, Spain, Italy, China, Taiwan and India. Last year, Linde received major orders from a number of companies including Bosch Solar, which is building a new crystalline silicon solar cell factory in the German town of Arnstadt. Linde Nippon Sanso (LNS) has signed a long-term contract to supply the factory with high-purity nitrogen from an on-site air separation plant.

In May 2009, Linde was awarded an exclusive contract to supply the first Italian thin-film solar cell plant in Campofranco (Sicily) with high-purity gases. Within the framework of the agreement, Linde will install turnkey tank facilities and specialty gas supply systems for the Moncada Energy Group s. r. l.'s solar plant. It will also supply nitrogen, hydrogen, silane and chamber cleaning gases.

Last year saw Linde receive orders in Switzerland from the company Flexcell for the supply of speciality gases. Switzerland was also the location of a new thin-film photovoltaic manufacturing plant built by Italian group PRAMAC. Linde will also be supplying this production facility with speciality gases.

In addition, Linde signed a long-term supply agreement with Masdar PV GmbH to supply all the gases required for a thin-film photovoltaic module facility in the German city of Erfurt. The contract will see Linde provide an end-to-end gas storage and distribution system flanked by gas management services. The plant is to be equipped with Linde's fluorine-based process chamber cleaning technology (see page 70). Linde will also be responsible for supplying nitrogen, hydrogen, silane, argon and helium.

↳ (top) Specialty gases play a key role in reducing the environmental impact of photovoltaic module production.

↳ (bottom) T-Solar manufactures large-scale, state-of-the-art thin-film solar cells in Spain.

Solar projects in India

India plans to increase installed solar module capacity from zero to 20 GWp (gigawatt peak – see glossary) by 2020. As part of this production ramp-up, Linde signed long-term supply contracts with four major photovoltaic manufacturers in late autumn 2009. The manufacturers in question are Moser Baer, Euro Multivision, Solar Semiconductor and Indo Solar. Linde will be responsible for supplying these companies' new solar cell production facilities with the requisite speciality gases and delivering the full range of gas management services.

The Group's involvement here represents a major contribution to India's shift towards economically viable solar cell production.

Fluorine – climate-neutral cleaning gas

Linde achieved a breakthrough in the environmentally sound cleaning of process chambers in thin-film cell manufacturing facilities with the climate-neutral gas fluorine (F_2). This gas replaces the environmentally harmful nitrogen trifluoride (NF_3). It is also suitable for manufacturing semiconductors and LCD flat screens.

Following successful tests, Linde was awarded a contract to supply F_2 for photovoltaic module production to Malibu, a joint venture between energy group E.ON and the façade and roof company Schüco. The speciality gas is produced in a fluorine generator on the Malibu site in Magdeburg (Germany).

Silane – indispensable for thin-film solar cells

Silane is one of the most important gases in the production of silicon based thin-film solar cells. It is used to apply silicon to a substrate such as glass, metal or ceramic by chemical vapour deposition. Linde has joined forces with various silane producers and technology providers in Europe, the US and Asia to execute Linde's global silane programme. The aim of this programme is to secure silane supplies and cut silane costs per watt. In co-operation with technology providers in the US, Linde has successfully designed on-site silane production units to supply large-scale customers over-the-fence per pipeline. In Europe, Linde is working closely with Schmid Pilot Production GmbH (SPP), a technology provider currently set to go on stream with a pilot line for silane and polysilane targeted at thin-film silicon panels at Schwarze Pumpe (Germany) during 2010. As part of this co-operation, Linde constructed a silane filling station at the Schwarze Pumpe industrial park during the last fiscal year.

Hydrogen

Zero-emissions mobility within our reach

Linde has always been a pioneer in the evolution of hydrogen technologies and is committed to further advancing commercialisation of this environmentally sound energy carrier. To achieve our goals here, we work closely with the automotive industry and fuel companies within the framework of numerous national and international collaborative projects.

Linde is the only company in the world that masters the entire hydrogen technology chain "from well to wheel". Our expertise spans the entire process from H_2 production from fossil and renewable energy sources, through compression and liquefaction, storage and transport right up to fuelling vehicles with compressed (CGH_2) and liquefied hydrogen (LH_2).

Our goal – generating H_2 from renewable sources

Linde's long-term objective here is sustainability. In other words, it plans to generate hydrogen from renewable energy sources using ecologically sound processes. Although natural gas is the main hydrogen feedstock at present, experts are looking for green ways of producing this promising fuel. Biologists, for example, are focusing on cyanobacteria as a way of harnessing photosynthesis to generate hydrogen. Linde's hydrogen experts on the other hand have developed an innovative process for obtaining hydrogen from glycerine, a by-product of various processes including diesel refining.

Linde's innovative technology involves purifying glycerine and cracking it in a two-stage chemical/thermal process under high pressure and at temperatures of several hundred degrees Celsius. The resulting hydrogen gas undergoes a number of process steps before pure hydrogen is generated through pressure swing adsorption. Following successful lab trials, Linde is now constructing a demo plant at its Leuna site, which is scheduled to go on stream in mid-2010. This plant will process, pyrolise (see glossary) and reform the feedstock to create a hydrogen-rich gas, which will then be refined and liquefied in the tried-and-true Leuna II plant to create "green" hydrogen.

Expanding network of fuelling stations

H_2 fuelling stations are already in place in a number of major urban centres. The priority over the coming years is to establish an infrastructure capable of serving an increasing number of hydrogen-powered vehicles. To achieve this, Linde, Daimler, EnBW, OMV, Shell, Total, Vattenfall and the German organisation for hydrogen and fuel-cell technology (NOW GmbH) launched the H_2Mobility initiative in autumn 2009. This alliance brings leading companies together to advance the commercialisation of hydrogen and fuel-cell technologies, and position them as an integral part of our future mobility landscape.

During the first phase, this initiative will explore different options for establishing a Germany-wide network of hydrogen fuelling stations and investigate a joint, economically viable business concept. On successful completion of this process, phase two will see the partner companies roll out an action plan to put a nationwide network of H_2 fuelling stations in place by 2015. This infrastructure will then serve the needs of the rising number of fuel-cell vehicles expected on the roads by then.

This initiative will be flanked by the continued construction of individual, strategic hydrogen fuelling stations. Daimler, energy group OMV, Linde and the state of Baden-Württemberg opened the state's first public hydrogen fuelling station at Stuttgart airport in summer 2009. This fuelling point is one of the world's first stations to feature Linde's ionic compressor technology. This highly efficient H_2 fuelling innovation supports both 350 bar and 700 bar pressure. This increase in pressure doubles the range of fuel-cell cars, enabling distances of up to 400 kilometres. An entire tank can be refuelled with CGH_2 in just three minutes.

↳ The Linde Hydrogen Center in Unterschleißheim near Munich puts new hydrogen refuelling solutions through the paces.

Professor Dr Wolfgang Reitzle receives award for dedication to hydrogen technology

Chief Executive Officer of Linde AG Professor Dr Wolfgang Reitzle was awarded the "Gelber Engel 2010" (Yellow Angel) mobility prize in the category "personality" by the German automobile club ADAC. The award honours Reitzle's long-standing commitment to promoting hydrogen as an automotive fuel of the future. The award ceremony was held in January 2010 in Munich and was also attended by German President Horst Köhler.

Linde is also involved in the Clean Energy Partnership (CEP) in Berlin. This partnership also unites ADAC, Allianz, Coca-Cola, Hilton, Schindler, Axel Springer Verlag, Total and Veolia. Under the umbrella of this initiative, the car manufacturer Opel released ten HydroGen4 vehicles for testing in everyday conditions at the end of 2008. The vehicles are based on the Opel/Vauxhall Zafira A and powered by fourth-generation fuel cells. They have 100 hp engines and a range of around 320 kilometres. Three high-pressure tanks made of carbon fibre composite can hold 4.2 kilograms of hydrogen under 700 bar pressure. These cars refuel at Total stations set up by Linde under the CEP umbrella in Berlin. Probably as of April 2010, the latest addition to this network will dispense gaseous hydrogen as well as liquid hydrogen. Around 40 H_2 test cars are now on the road in the German capital as part of the CEP initiative.

Linde supplies liquid hydrogen from Germany's only industrial hydrogen liquefaction plant, based in Leuna. The liquid hydrogen is stored in a superinsulated tank designed by Linde and does not require subsequent cooling.

Linde is also involved in furthering hydrogen and fuel-cell technology in the US through membership of the California Fuel Cell Partnership (CaFCP), a project that aims to raise interest in these new technologies among drivers and promote consumer-friendly fuelling stations.

A new H_2 station at San Francisco's international airport is set to demonstrate that hydrogen stations are just as convenient and safe as conventional petrol stations. Over the course of this year, the station – designed and built by Linde – will represent a further milestone on the Californian hydrogen highway.

Hydrogen for forklifts

Originally planned as a trial project, the hydrogen-powered forklift trucks at a major Wal-Mart distribution centre in Ohio, USA, have long become an innovation benchmark. Following successful trials in 2006, the forklifts there have been running on hydrogen since 2008. And Linde has notched up over 12,000 fill-ups as part of a long-term agreement covering the supply of liquid hydrogen and fuelling technology. The fuel cells are delivered by project partner Plug Power. And the innovative technology doesn't just keep the air clean during fuelling and day-to-day operations, the hydrogen itself is CO_2-neutral, as it is manufactured using hydroelectric power.

Lighting the way with hydrogen

Another case study, this time in London, further highlights the versatility of hydrogen and fuel-cell technology. Trials aimed at an emissions-free source of power to light the city's underground network are proving to be a success. Linde has combined a H_2 fuel cell with hydrogen in a lightweight cylinder. The 150-watt fuel cell uses an LED floodlight to generate as much lighting as a conventional 750-watt light. This emissions-free lighting solution is ideal for use in enclosed spaces such as underground train tunnels, mines or building sites and is also suited to the IT sector.

Biofuels

Protecting the climate with regenerative raw materials

The European Commission and US Government are increasingly looking to biofuels as a way of further reducing fossil fuel consumption. However, generating green fuels from rapeseed, maize or wheat is also dogged by controversy, as oil- and starch-based agricultural feedstocks can also be used as food. Second-generation biofuels are seen as the solution to this food vs. fuel dilemma.

Linde experts have been collaborating with various experts including biotechnologists and chemists to develop a process that uses microorganisms to break down straw, wood and other plant matter into sugar molecules, which are then fermented to obtain bioethanol by adding yeast cells. Similar to brewing beer, the yeast converts the sugar to alcohol. The resulting second-generation (2G) biofuel does not conflict with food production. It also has a significantly better eco and energy balance than first-generation biofuels as the amount of CO_2 released by 2G ethanol during combustion corresponds to the same amount consumed by the original plant matter while it was growing.

Biogas for waste collection trucks

Inspired by the idea of turning waste into valuable fuel, the Northern American waste disposal company Waste Management Inc. and Linde formed a joint venture. The two companies have set up a plant at a landfill near the city of Livermore, California. The facility has been producing biofuel from the landfill site's gases since September 2009. Gases such as biomethane and carbon dioxide are generated by bacteria under the warm, moist anaerobic conditions at the site. Filter pipes are then used to extract the gas from the waste for compression and purification. The resulting purified biogas stream is cooled to −160 °C in a heat exchanger to produce liquefied biogas. The electrical energy powering this process is also sourced from landfill gas, which is burnt to generate steam that drives a generator. Linde supplied and now operates the biogas purification and liquefaction plant. The resulting 50,000 litres of CO_2-neutral biogas produced each day is used to fuel more than 300 of Waste Management's waste collection trucks, reducing CO_2 emissions by around 30,000 tonnes per year. And there is a lot of potential for expansion. There are more than 1,000 landfill sites in California alone and a single company such as Waste Management Inc. has a fleet of 25,000 waste collection trucks on the road. The project has also been recognised by the U.S. Environmental Protection Agency (EPA) and other government agencies.

An initial pilot plant that went online in April 2009 in Munich covers the entire integrated process chain for converting straw into bioethanol, albeit on a small scale. However, this plant places market-ready, industrial-scale plants for converting straw or other cellulose-based waste matter into 2G biofuels within our reach.

Linde is also collaborating with US company Algenol Biofuel LLC and other partners to develop third-generation biofuels. In other words, obtaining bioethanol as well as other biofuels and biochemicals from CO_2, salt water and algae. Here, Linde is focusing on developing the optimum carbon dioxide and oxygen management system for Algenol's algae photobioreactor technology.

Generally referred to as third-generation technology, this process delivers a number of benefits. Production facilities, for example, can be built on land that is not suitable for food production. In addition, no freshwater is required. Similarly, no costly process steps for treating or separating biomass are required. Finally, the algae consumes CO_2 from fossil sources and the requisite power is generated almost entirely from solar energy.

Avoiding CO_2 emissions

Clean coal

Despite the emergence of versatile, sophisticated technologies with the potential to open up green energy sources and gradually replace fossil energy carriers, coal is set to remain a major source of energy for a long time to come. In order to reduce or even eliminate harmful CO_2 emissions, experts from science and industry have initiated numerous, in some cases publicly funded, projects investigating new ways of capturing and sequestering carbon dioxide from exhaust and flue gases. Linde is taking an active role in many of these projects.

One example here is the company's collaboration with power plant operator RWE and chemical company BASF on the development of a process for retrofitting coal-fired power stations with CO_2 scrubbing technology (post-combustion capture – see glossary). This joint pilot project based at the lignite power plant in Niederaußem (Germany) went on stream in 2009. Flue gas is cooled and fed through an absorber at the Linde-built scrubbing plant, where a chemical scrubbing agent binds around 90 percent of the CO_2. Based on current estimations, existing power plants could be upgraded with this new technology from 2020 onwards.

The energy group Vattenfall has been running a carbon capture and storage (CCS) project since mid-2008 at a pilot plant in Brandenburg (Germany). The lignite plant is equipped with Linde's oxyfuel technology and generates process steam for plants at the Schwarze Pumpe industrial park. The carbon dioxide generated during combustion is liquefied and pumped below the earth's surface. Linde supplies the oxygen needed for the pilot plant and is responsible for scrubbing and liquefying the CO_2.

Last year, a demo study investigating the benefits of oxyfuel and post-combustion technology at Vattenfall's Jänschwalde plant in Germany was successfully completed.

Pilot projects for CO_2 sequestration

The research project CO_2SINK is currently investigating underground storage of CO_2 near the town of Ketzin, in the German state of Brandenburg. The carbon dioxide for Ketzin originates at the Leuna Chemical Site, where it occurs as a by-product of ammonia synthesis. Linde then purifies and liquefies it in a multi-step preparation process. The liquid CO_2 is then transported by road tanker to Ketzin, where it is gasified. Under pressure and at a temperature of +30 °C, the gas is pumped through arm-width pipes 700 metres underground into porous sandstone, which contains highly concentrated saltwater. Geologists believe that the layers of plaster and clay that cap the sandstone formation will keep the CO_2 – part of which is dissolved in water – under the earth's surface. The tests are scheduled to be completed by mid 2010.

When it comes to planning new coal-fired plants, many operators are deploying IGCC technology (integrated gasification combined cycle – see glossary). This process involves initially converting coal to combustible raw gas. This gas, primarily comprising carbon monoxide (CO) and hydrogen (H_2), is then purified. Steam is used to convert the carbon monoxide to CO_2 and more H_2. Following desulphurisation, the CO_2 is separated, compressed and stored underground. Linde has played a key role in developing this technology and RWE intends to implement it for the first time on an industrial scale in its planned Goldenberg lignite power plant in Hürth (Germany).

Low-CO_2 steelworking

Linde's REBOX® oxyfuel technology helped ArcelorMittal, the world's largest steel company, to garner the 2009 Energy Achievement Award from the Association for Iron and Steel Technology (AIST). The award is presented annually to an individual or organisation to recognise their deployment and use of innovative new technologies or practices that result in significant energy conservation improvements in steelmaking. ArcelorMittal asked Linde to convert a billet reheating operation at its seamless tube mill to flameless oxyfuel operation. The project reduced fuel consumption by 60 percent. In addition, over the last two years, REBOX® has reduced nitrogen oxide (NO_X) and carbon dioxide (CO_2) emissions by 92 percent and 60 percent respectively. Moreover, REBOX® has given the company the chance to increase material throughput by 25 percent.

Pressing need to cut CO_2 emissions in China

Coal accounts for around 70 percent of China's entire energy supply. This makes China the world's largest coal consumer. Given the continued rise in energy requirements, the Chinese government aims to significantly reduce CO_2 emissions from Chinese coal-fired power plants. And Linde is on hand to help with its new research and development centre in Shanghai. The company's collaboration with Tsinghua University is a case in point. A far-reaching R & D project will be focusing on carbon dioxide separation and absorption, and will involve Linde setting up a pilot plant at its site in Shanghai to investigate new CO_2 technologies.

↳ Waste collection trucks operated by Californian company Waste Management run on eco-friendly landfill gas generated in cooperation with Linde.

03.1

“Defining role from the start”

Krish Krishnamurthy, responsible for energy issues within the Innovation Management central function, discusses the potential of fuels obtained from biomass.

↳ Krish Krishnamurthy Ph. D., has been involved in the research and development of clean fuels since the late Eighties.

Mr. Krishnamurthy, in the field of alternative energy sources, Linde's activities include a series of projects to obtain fuels from biomass. Does this present an interesting business opportunity?

↳ Fossil fuel supplies will dwindle in the long term, while renewable energy will play an increasingly important role in the energy mix. To stay at the forefront of this development, we are pursuing a range of alternative production methods. Biofuels – including biohydrogen – open up many possibilities. As a leading hydrogen manufacturer and one of the pioneers of the future hydrogen infrastructure, we are collaborating intensively in this area with automotive companies and fuel-cell producers. Our aim is to generate hydrogen primarily from renewable energy sources in the future – and that at competitive costs.

It looks set to be many years before you reach that stage, however?

↳ Well, of course it will take time, but we are not starting from scratch. We already have a command of the necessary technologies thanks to our long-standing experience with natural gas and hydrogen. Now we need to find ways to transfer this expertise to commercial production of biofuels.

Which methods offer the best chances of success?

↳ That is difficult to predict at this stage. What is clear, though, is that the pilot projects we are involved in are showing great promise.

Such as?

↳ Such as the biogas plant we have set up in California in partnership with the US company, Waste Management. This treats and liquefies gas released at a landfill site to produce fuel. Using this method, we generate 50,000 litres of biofuel per day, which we use to supply around 300 waste trucks. As a next step, we are now looking at also generating hydrogen from the landfill gas.

And that isn't your only project to generate hydrogen from waste products, is it?

↳ No, that's right – at our Leuna site we are working on a method to obtain hydrogen from glycerol, which occurs as a by-product of biodiesel generation. The plant will open for operation some time this year.

And what about the use of plants as biomass for fuel production?

↳ We are making progress there too. We have designed and built a pilot plant that converts plant matter containing cellulose, such as wood cuttings and straw, into biofuels. An integrated biotechnological process first converts the raw material to sugar through enzymatic hydrolysis. The sugar is then fermented into bioethanol.

What obstacles still need to be overcome before we can talk about cost-efficient production?

↳ One major challenge is logistics. It is often not possible to bring enough biomass to a central location to generate fuel on a cost-effective commercial scale. And there still remains the general question as to whether sufficient renewable raw materials are available. In addition, pilot solutions have yet to be successfully mapped to industrial-scale production.

How could the logistics dilemma be resolved for example?

↳ One option would be to develop cost-efficient, smaller capacity biomass gasification plants that would covert syngas (see glossary) locally into the desired end product such as biohydrogen. Another option might be to link several small plants in a production network and transport the bio oil by tanker to a central unit for further processing. There it could be converted into synthesis gas, purified and finally processed into biohydrogen, bioalcohol or biodiesel. This would be achieved by means of separation, fermentation or Fischer-Tropsch synthesis (see glossary).

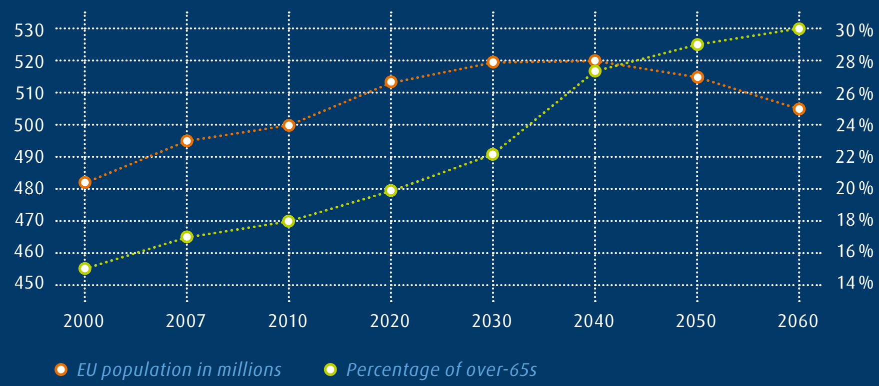
What go-to-market timeline are we looking at for these methods you are now testing?

↳ Most of these technologies are now in the pilot phase, with some already ready for demo. The majority could be market-ready in five to ten years. For us, the most important thing is to work closely with our technology partners and make sure we are on the frontline from the very outset. As ever, if you're not in – early – you can't win.

03.2

Growing healthcare market.

The rising average age of the population is posing new challenges for the medical and healthcare communities and many of the answers to these challenges are being found in the invisible yet effective shape of medical gases from Linde.



Source: United Nations, Population Division of the Department of Economic and Social Affairs

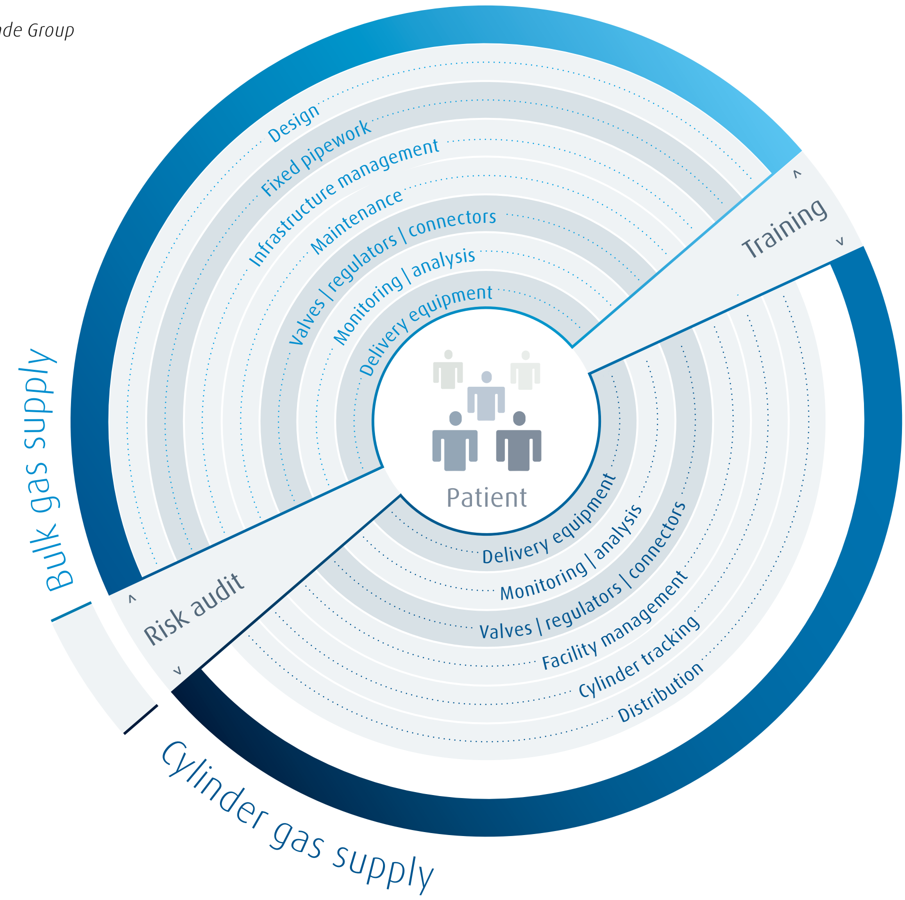
Life expectancy in most countries continues to rise. In Germany, for instance, the proportion of the overall population aged over 65 is set to increase from the current 18 percent to 30 percent by the year 2060. There will then be as many people over 80 as under 20 – a shift that will inevitably be accompanied by a rising need for nursing care. In Germany alone, the number of people requiring nursing care rose by over 230,000 between 1999 and 2009, hitting the 2.4-million mark. Many of these patients suffer from respiratory conditions. With its medical gases, services and easy-to-use equipment, Linde is helping to improve quality of life for many of these patients.

Serving hospitals. Reliable products and services.

Various services involved in delivering medical gases to hospital patients.

- Cylinder gases
- Bulk gases
- Hardware
- Services

Source: The Linde Group



Medical gases are essential in diagnosing and treating many illnesses. Every day, they prove invaluable across a wide range of processes in surgery, emergency services and intensive care. All of these applications call for consistently high standards of quality – not just in relation to the purity of the actual gases. All links in the gas, hardware and service chain must dovetail to perfection in order to effectively support doctors, surgeons and medical staff. Which is why Linde is now expanding its offering with a broad spectrum of complementary products and services. Extending from cylinder tracking to risk audits, these deliverables relieve pressure on hospitals and help to further improve the quality of patient care.

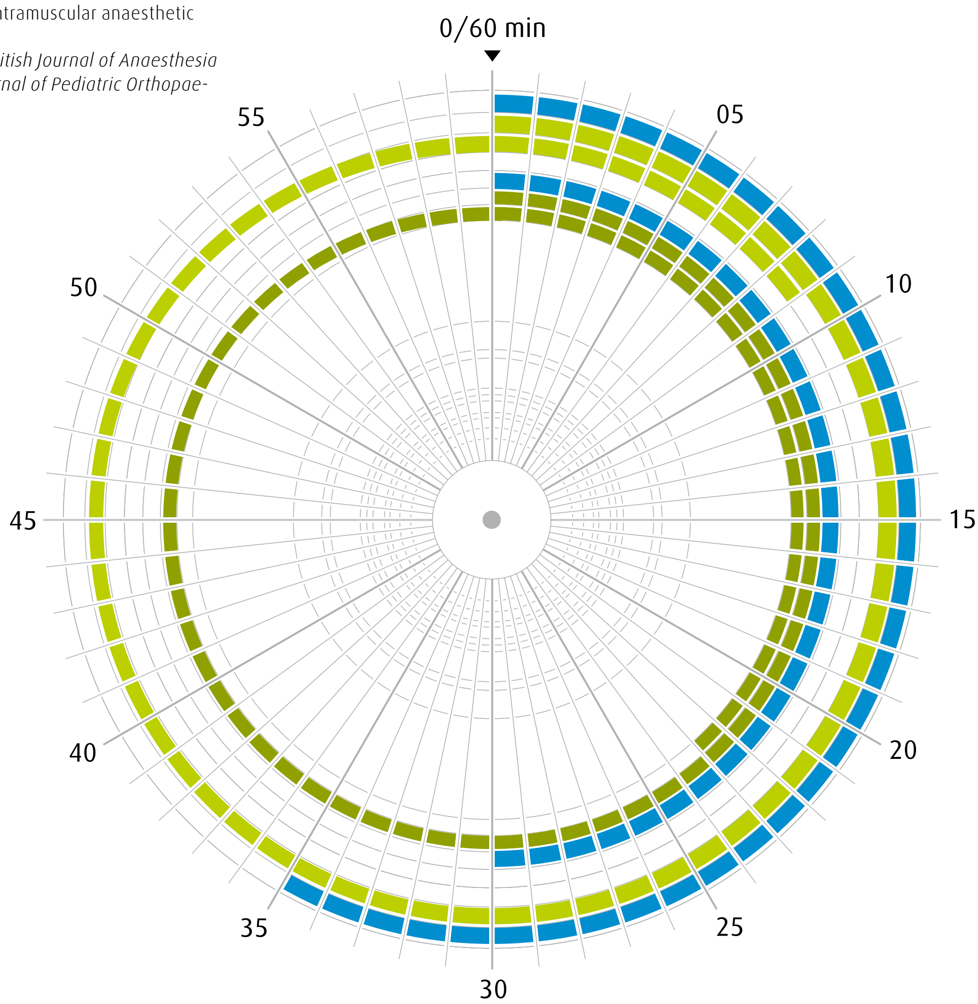
ENTONOX®/LIVOPAN®. Rapid, reliable pain relief.

Nitrous oxide reduces treatment times with minor interventions.

Chart comparing treatment times under various anaesthetics.

- Nitrous oxide/oxygen mixture
- Midazolam
- Intramuscular anaesthetic

Source: British Journal of Anaesthesia 2003; Journal of Pediatric Orthopaedics 1995



The ENTONOX®/LIVOPAN® gas mixture is inhaled for rapid relief from acute pain with minimal side effects. This mixture of half oxygen and half nitrous oxide has already been in successful use for years in childbirth, emergency medicine and, especially, paediatric care. Well established in Great Britain, France, Australia and Switzerland, Linde is now introducing the ENTONOX®/LIVOPAN® mixture in new markets across the globe.

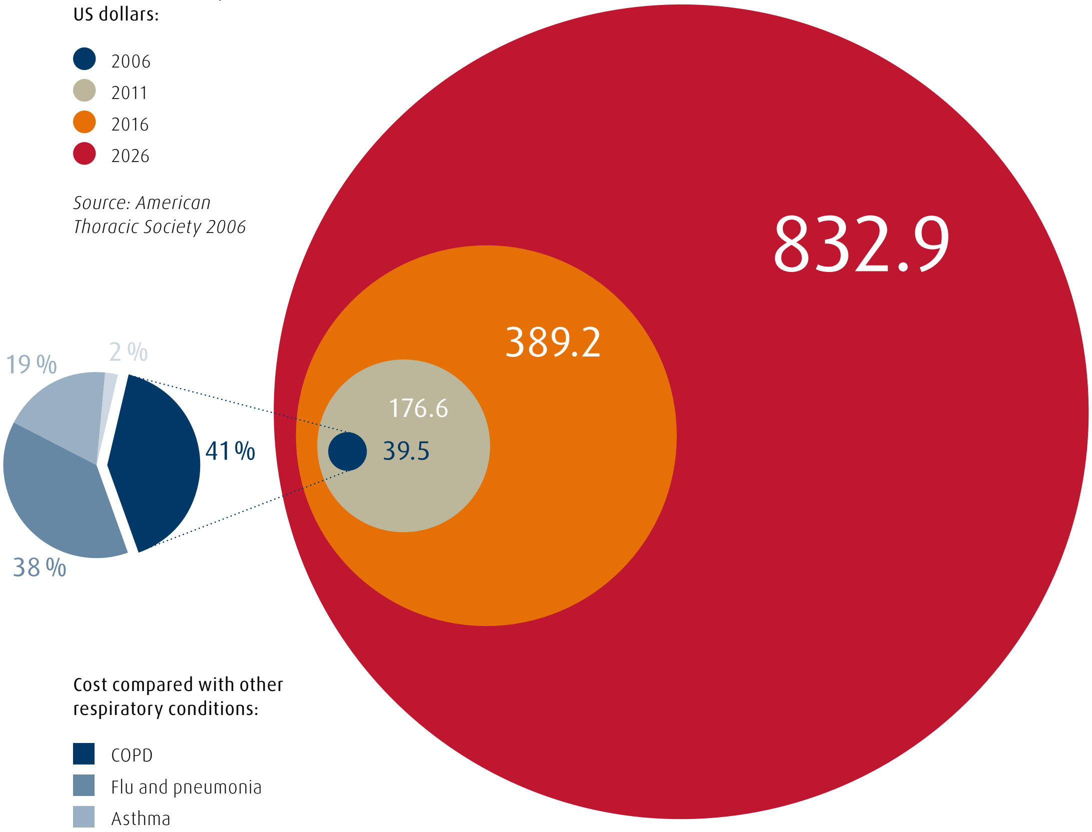
REMEO®. Bringing hospital care closer to home.

Medical costs are set to rise in coming years due to chronic respiratory disorders.

Cumulative cost of COPD (chronic obstructive pulmonary disorder) to the US economy in billions of US dollars:

- 2006
- 2011
- 2016
- 2026

Source: American Thoracic Society 2006



Cost compared with other respiratory conditions:

- COPD
- Flu and pneumonia
- Asthma
- RDS (respiratory distress syndrome)

Source: American Lung Association 2008

Linde's comprehensive REMEO® concept offers patients with chronic respiratory conditions dedicated care in long-term ventilation and gradual weaning. Rather than in hospital, this takes place in special treatment centres and at home. Highly qualified nursing staff and homely surroundings ensure a high level of patient comfort here. All parties involved in the healthcare system benefit from the resulting cost savings.

03.2

Growing healthcare market.

Serving hospitals

Medical gases, devices, service and support

Linde's activities in the healthcare segment primarily revolve around supplying medical-grade oxygen to hospitals and patients at home. As one of the world's leading providers in this field, we ensure our products fulfil all the requirements of the German Medicines Act (AMG) as well as equivalent directives for the European Union and other international markets.

Flanking our medical gases offering, our portfolio of supporting services is also growing in importance. We are steadily expanding this service line to meet the needs of many hospitals seeking expert support in the face of healthcare directives and increasingly tight safety regulations for handling pharmaceuticals. Practical services range from inspecting gas-supply equipment and specialised maintenance, through staff training on the correct application of various gases to complete management of the gas process chain.

Linde is well positioned to meet the varied needs of healthcare customers. We have developed a comprehensive service programme, which we offer hospital and healthcare managers under the brand name QI™ Medical Gas Services (QI pronounced "key"). Within this custom-designed concept, Linde specialists ensure prompt replenishment, rapid repairs and, if desired, end-to-end facility management.

Tank park for Munich's university hospital

A good example of the comprehensive range of deliverables Linde offers hospitals is the tank park for cryogenic liquid gases that we constructed last year as part of the extension and modernisation of Munich's Klinikum Großhadern university hospital (Germany). A total of eight new tank installations have been set up to meet the hospital's annual requirements, namely 600,000 cubic metres of medical-grade oxygen, 10,000 kilogrammes of medical-grade nitrous oxide, 20,000 kilogrammes of carbon dioxide and 150,000 cubic metres of nitrogen. To ensure reliable, top-quality supply, each unit is fitted with a dedicated management system. The tank levels and consumption data can be tracked online.

Asian expansion

Linde received permission from the relevant authorities in several provinces of China to deliver medical gases to hospitals last year. The first commercial successes followed swiftly. In Fujian, for instance, the Linde team secured a supply contract for the largest public hospital in the province.

In Shanghai, Linde agreed a three-year supply contract with the leading Huashan hospital for liquid medical-grade oxygen. This will also involve Linde installing the relevant storage and distribution system in the hospital.

Following acquisition of a local supplier in Guangzhou, Linde expanded its facilities to become the largest filling station for medical gases in the province. The company continues to expand in the eastern provinces of Jiangsu und Zhejiang from its base in Shanghai.

In South Korea, too, Linde has gained an important foothold by opening the first filling station for medical gases in Pohang. This will serve the burgeoning South Korean hospital market.

Fire protection during oxygen ventilation

Linde's US subsidiary LifeGas, one of the leading providers of medical gases and equipment for homecare, is offering its customers a new safety device: the FireSafe™ cannula valve. This protects against fire by immediately turning off the oxygen feed if a smoking patient's cigarette starts a fire. A sensible safety precaution, since the National Fire Protection Association estimates that around 30 percent of ventilation patients smoke while connected to oxygen supplies.

ENTONOX®/LIVOPAN®

Effective pain relief

Linde's medical gases are not only used to ventilate patients but also for pain relief, for example in paediatric care, emergency medicine and childbirth. Half nitrous oxide and half oxygen, the ENTONOX®/LIVOPAN® gas mixture combats pain quickly and effectively without the use of a needle.

This solution has long been successfully deployed in Great Britain, France, Australia and Switzerland under the brand name ENTONOX® or MEDIMIX®. In 2008, Linde launched a broad go-to-market campaign to extend its reach to Austria, Germany and Sweden (LIVOPAN®), with roll-out envisaged in more countries during 2010.

For many years now, ENTONOX®/LIVOPAN® has proven its worth as an inhalable analgesic, both in practical applications and in clinical studies. It is simple to use, works rapidly and has few adverse effects. Given these benefits, this treatment has become particularly well established in treating children. The Sheffield Children's Hospital (England) introduced ENTONOX® for short-term pain relief on its general wards and outpatient departments, for instance. The nursing staff only needed a two-hour induction. Once they tried ENTONOX®, the nurses praised it in particular for not only alleviating pain but also having a calming effect prior to infant procedures.

Ultra-light gas cylinders

Linde has launched an ultra-light one-litre gas cylinder to supply medical oxygen in the UK. Weighing in at just 1.55 kilogrammes, this is the lightest of its kind and therefore particularly suitable for children and older people using oxygen at home.

REMEO®

Ventilation centres relieve pressure on hospitals

Since 2006, Linde's REMEO® concept has been improving the health of patients in need of ventilatory support or undergoing weaning. The aim is to accomplish this in pleasant surroundings or at home, avoiding protracted stays in hospital intensive care units. The company has now established facilities or partnerships with hospitals in numerous different countries.

The REMEO® supply system combines clinical care with innovative medical technology. REMEO® offers a range of treatment models to meet individual requirements:

→ Full in-patient care at a REMEO® centre;
→ 24-hour homecare;
→ Regular home visits.

The REMEO® centres unite peace of mind on the medical front with the comfort and improved quality of life brought by rooms that can be personalised. Treatment in surroundings more similar to home helps patients to recover from a hospital stay. And once they are back in their own homes, they can continue to receive medical care from qualified staff.

Linde brought its REMEO® model to more countries over the last year. In May 2009, for instance, the company opened REMEO® 3 – its third centre in the US state of Tennessee (following REMEO® 1 in Knoxville and REMEO® 2 in Memphis). The new facility can provide 24-hour care for 16 residential patients. In September 2008, Linde acquired the US company Respiratory Support Service (RSS), gaining a foothold for the REMEO® concept in the US.

Another new REMEO® facility opened for operation in Bogotá (Columbia) in June 2009. This is the second centre established there by Linde within the last three years.

Sleep apnoea

An increasingly important application for medical-grade oxygen and supporting equipment is sleep apnoea syndrome. This is a breathing disorder that occurs during sleep, affecting 4 percent of all men and 2 percent of all women. It entails repeated interruptions to breathing that last several seconds. The ensuing lack of oxygen acts as a stimulus that wakes the affected person enough that they move and begin to breathe again. This means that sleep loses its restorative effect, leading to chronic sleep deprivation in the long term. This, in turn, can cause sufferers to fall asleep suddenly during the day – particularly dangerous for drivers, for instance, who may nod off at the wheel. According to scientific studies, 15 to 20 percent of all avoidable transport accidents are caused by this phenomenon.

Linde offers continuous positive airway pressure (CPAP) therapy for people suffering from sleep apnoea syndrome, providing equipment for assisted breathing alongside service and support to help improve the quality of life for these patients.

↳ Linde Healthcare is global leader in the supply of medical-grade oxygen to hospitals.

03.2

"We offer real added value"

Roel Kellenaers, responsible for Marketing, Sales and Business Development at Linde Healthcare discusses current healthcare trends and explains how Linde has carved out a competitive edge through quality, innovation and service.

↳ Roel Kellenaers explains why consulting and support are success factors in the market to supply hospitals with medical-grade oxygen.

Mr. Kellenaers, what are the current trends in the healthcare business?

↳ Several trends are currently shaping the healthcare market. We are looking at an ageing population not only in the West, but also in countries such as China, India and Japan. Furthermore, the cost of treatment and medical care is rising, as is the prevalence of chronic conditions. While patient requirements are steadily increasing, hospitals often face a lack of trained staff. Altogether, these factors exert enormous quality and cost pressures on the healthcare system, which represents both opportunities and threats.

What are the effects of this on the medical gases business?

↳ Well, first I'd like to note that the medical gases business, including technical equipment and supporting services, is a stable growth market. That said, against the backdrop of the cost squeeze I just outlined, the right product and service offering is crucial. At Linde, we have carved out a position defined by innovation, quality and added value for our customers.

What does that mean, in concrete terms?

↳ It means we don't just sell gas to hospitals, for instance. We deliver pharmaceutical products and hardware that meet all the appropriate safety and quality standards along with training and support. We offer patients, medical staff and hospitals real added value.

What kind of services does this include?

↳ We offer risk management services, for example, where we examine a hospital's entire gas infrastructure – from the tank through the pipeline to the point of use, i.e. the patient. We then deliver a detailed analysis, suggest improvements and flag up any safety issues.

And do you only offer these extended services to hospitals?

↳ No, value-added services also differentiate our homecare offering. Here we supply patients with high-grade technical equipment for use in their own homes and offer special nutritional products alongside medical gases, for instance. Doctors can rely on our monitoring systems to keep track of their patients' progress even remotely.

Linde has evolved into a pharmaceuticals provider through its Healthcare Global Business Unit – but how do you fit in with the existing pharma giants?

↳ It's true that Linde is a leading provider of gaseous medical products. Unlike other pharma players, however, we will continue to concentrate on medical gases. Products such as INOmax®, for example, medical nitric oxide for treating respiratory problems in premature and newborn babies, has already been established on the market for several years. And we are now working to gain widespread acceptance of our ENTONOX®/LIVOPAN® analgesic gas mixture in hospitals.

How are you going about that?

↳ We are establishing clinical sales teams in each country worldwide to explain Linde's offering to doctors, nurses and pharmacists. This calls for in-depth medical insights and plenty of patience, but we are confident we are on the right track as we have extremely effective products on offer.

Linde also operates REMEO® facilities for longer-term care outside hospitals. How is that going?

↳ Very well – we now run centres in six different countries and the trend is rising. This is a very interesting area for us, because it gives us a direct touchpoint between the patient and the full range of our products and services. Instead of an intensive care unit, we treat patients in an environment far more similar to home. This enables us to improve their quality of life, while significantly reducing the cost burden on the healthcare system.

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Contact information

Linde AG
Klosterhofstrasse 1
80331 Munich
Germany
Phone +49.89.35757-01
Fax +49.89.35757-1075
www.linde.com

Communications
Phone +49.89.35757-1321
Fax +49.89.35757-1398
E-Mail info@linde.com

Investor Relations
Phone +49.89.35757-1321
Fax +49.89.35757-1398
E-Mail investorrelations@linde.com

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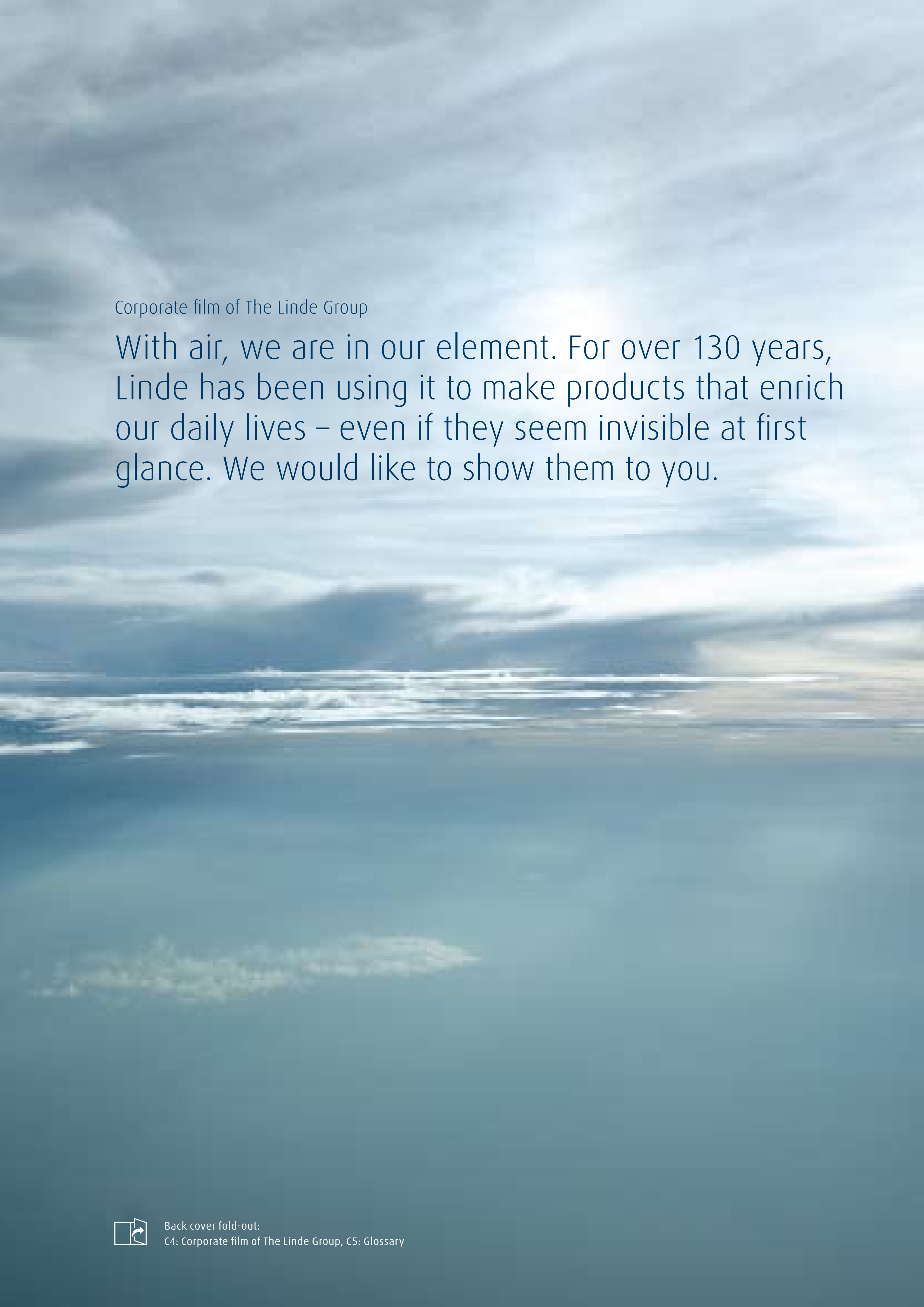
If you require any additional information about The Linde Group, please contact our Investor Relations department. Our staff would be delighted to send you anything you need free of charge.



Corporate film of The Linde Group

With air, we are in our element. For over 130 years, Linde has been using it to make products that enrich our daily lives – even if they seem invisible at first glance. We would like to show them to you.

Back cover fold-out:
C4: Corporate film of The Linde Group, C5: Glossary

CH_4 Ar

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→ Please remove the DVD with the sleeve.

N_2

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Kr O_2

CO_2 Ne

Glossary

→ Arc welding
During this welding process, an electrical arc is created between a consumable electrode (flux) and the workpiece. The requisite temperature is not generated by a chemical reaction but by an electric power supply.

→ Carbon Capture and Storage (CCS)
This process involves separating CO_2 from combustion flue gases and storing it, especially in underground sites. The aim here is to reduce the levels of CO_2 emitted into the atmosphere.

→ Cold box
Completely encased and fully equipped, ready-to-use unit comprising heat exchangers to separate gases at low temperatures.

→ Enhanced oil recovery (EOR)
Also known as tertiary recovery of crude oil, this procedure involves the use of steam, chemicals or gas such as nitrogen to extract the maximum amount of remaining reserves from an oil field.

→ Excimer laser
An ultraviolet gas laser used in surgery, for example, to correct short sightedness and in photolithography (microlithography).

→ Fischer-Tropsch synthesis
A process used to produce synthetic fuels. The raw material used for Fischer-Tropsch synthesis (FTS) is synthesis gas, a mixture of carbon monoxide and hydrogen. The synthesis gas can be produced from coal or natural gas (and also from oil fractions such as heavy oil). It is completely sulphur-free, although purification is sometimes required to achieve this. Consequently, the fuels produced by FTS are also completely free from impurities.

→ Gas-to-liquids (GTL)
GTL involves converting natural gas to synthesis gas by adding oxygen and steam and further transforming this to hydrocarbons using Fischer-Tropsch synthesis.

→ Gigawatt peak (GWp) (unit of measurement)
In photovoltaics, GWp refers to the rated electric output (nominal output) of a solar cell or a solar module. Nominal output is determined under standard test conditions. The amount of power generated in day-to-day operations depends on the actual amount of sunlight present.

→ Grid parity
This term from the energy industry refers to a situation whereby electricity from a solar plant or other renewable source reaches parity with grid electricity prices (from a coal-fired power plant, for example).

→ Integrated gasification combined cycle (IGCC) technology
IGCC is a combined cycle power plant with upstream fuel gasification. The primary fuel, such as coal or biomass, is converted to an energy-rich combustion gas in a gasifier, achieving thermal efficiency levels of 80 percent.

→ Liquefied natural gas (LNG)
LNG is regarded as a promising fuel of the future because of its high energy density, constant heat rating and high purity.

→ Microlithography
A process used to create extremely fine, microscopic, two-dimensional patterns in photoresist. It is used, for example, for highly integrated semiconductor chips and microscopic processes such as “drilling” extremely fine nozzles for inkjet printers.

→ Oxyfuel technology
In contrast to conventional combustion with air, oxyfuel uses almost pure oxygen, thus raising efficiency levels and ensuring a cleaner combustion process.

→ Polymerisation
A process whereby several monomer molecules react to form a larger molecule.

→ Post-combustion capture (CO_2 scrubbing)
Around 90 percent of the CO_2 in flue gas can be captured and bound to a CO_2 scrubbing agent at relatively low temperatures. The CO_2 is very pure and, following compression, can be transported and stored underground.

→ Pressure swing adsorption plant
During the gasification of biomass, these plants separate residual gases and pure hydrogen.

→ Pyrolysis
Pyrolysis uses heat to crack organic compounds. The high temperatures involved (500–900 °C) force the bonds in large molecules to break down.

→ Rectification
Also known as counter-flow distillation, this process uses repeated distillation steps to separate a mixture of several components.

→ Steam cracking
A petrochemical process; it uses steam and heat to crack liquid or gaseous hydrocarbons into olefins such as ethylene and propylene.

→ Steam reforming
A process for manufacturing synthesis gas, a mixture of carbon monoxide and hydrogen, from carbon fuels such as natural gas, benzene, methanol, biogas or biomass.

→ Synthesis gas (i.e. syngas)
A mixture of carbon monoxide (CO) and hydrogen (H_2); syngas serves as an intermediate for the production of synthetic fuels and other products such as hydrogen, ammonia and methanol. It can basically be made from a gaseous, liquid or solid feedstock.

→ Thermal spraying
A surface coating technology; for this, a gas flame, a laser beam or an electric arc melts metal or any other coating material, which is then accelerated towards the substrate (the surface to be coated) under high pressure generated by a stream of gas.

→ Thin-film photovoltaic modules
Solar cells made with extremely thin films of photovoltaic material, reducing production costs by decreasing reliance on expensive silicon wafers.

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Linde AG
Klosterhofstrasse 1
80331 Munich
Germany
Phone +49.89.35757-01
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