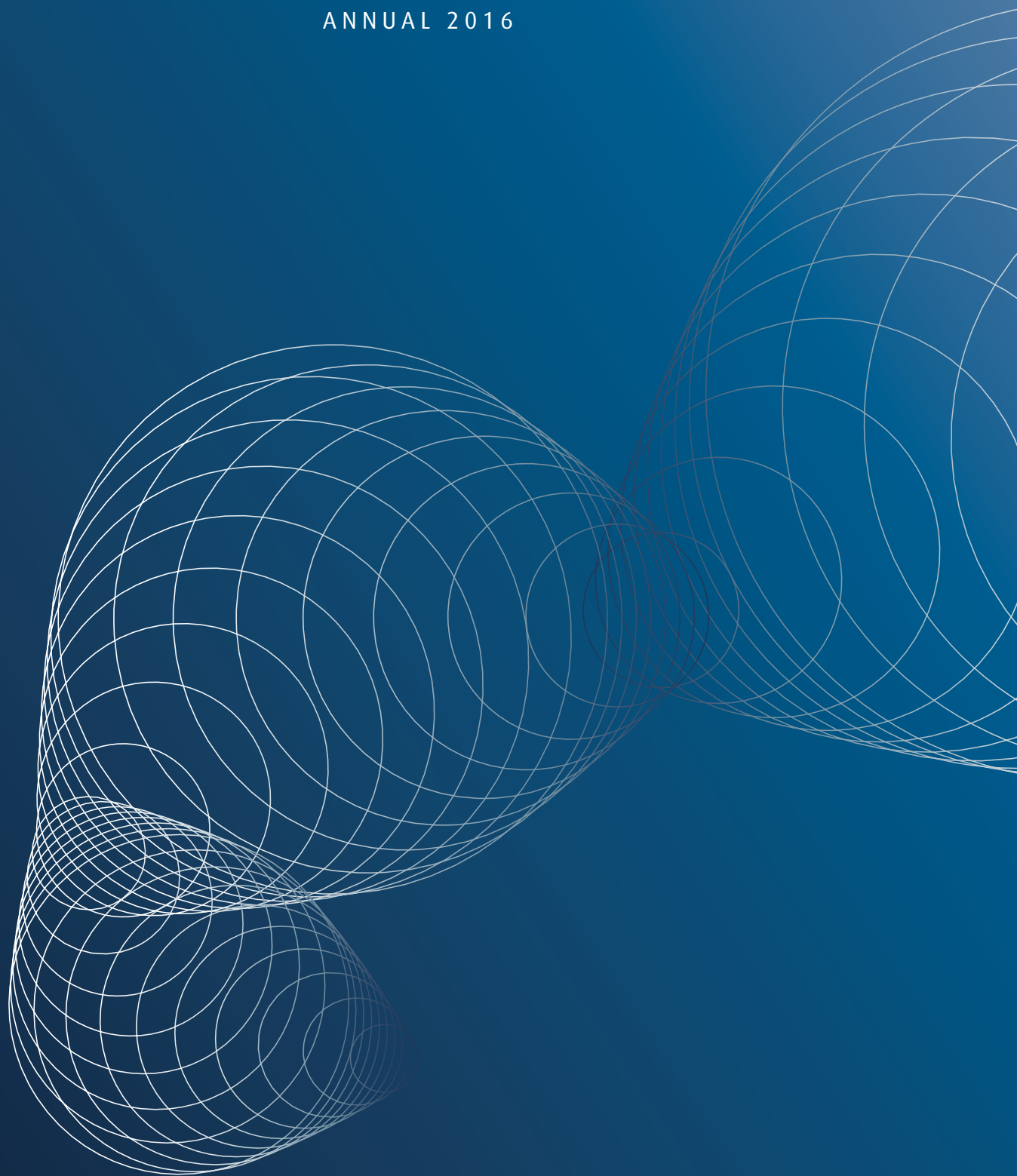


Leveraging Potential

ANNUAL 2016



Leading.


THE LINDE GROUP

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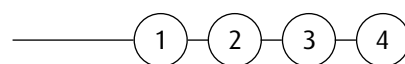
The global challenges of our time are all over the news – digitalisation, demographic change and demand for more renewable sources of energy. For Linde, these trends mean one thing above all: untapped potential. Because Linde has a lot more to offer than gas molecules.

Thanks to its broad portfolio, Linde is ideally positioned to systematically capitalise on new opportunities and leverage potential over time. You might be wondering “How?”

By researching new technologies, by optimising processes and by developing innovative applications.

All of which generates new growth at Linde. Which benefits customers, society at large and the environment. In other words: all of us.

CHAPTERS





Leveraging Potential: Technology

Linde is driven by the desire to constantly challenge the boundaries of technical feasibility. From the Siberian wilderness to a high-tech lab in Taiwan, Linde is already successfully optimising countless industrial processes in areas as diverse as gas purification and helium recovery. At the same time, the company is opening new horizons for the electronics industry by laying the foundation for the next generation of microchips.



THE RISE OF
HELIUM

4



GAME-CHANGER
IN AMUR

14



DIGITALISATION -
POWERED BY GAS

18



The Weil Group is using a new membrane technology to recover high-purity helium from Canada's Great Plains.

The rise of helium



The helium industry is making a comeback – partly due to dwindling reserves, and partly to a new method developed by Linde that is set to make efforts to exclusively recover this noble gas viable. The company's membrane technology completes the gas separation wishlist – there are now no limits to what Linde can offer its customers in this area.



Anyone driving through Saskatchewan in central Canada knows the true meaning of vast. The only points of reference in this flat, treeless expanse are the old wooden grain elevators. However, a new landmark has recently sprung up on the horizon of “big sky country”, as the locals also call their province. Shining brightly in the sun, the snow-white tarpaulin of the tent-like construction is located near the village of Mankota. But what makes this beacon in the prairie landscape so interesting is actually what is going on inside. Using a completely new gas separation process from Linde, US company the Weil Group is recovering a long-neglected local treasure from the ground: helium. Global supplies of this elusive gas are running out – yet demand is rising rapidly.

In demand the world over

Paradoxically, helium is the second-most-abundant element in the universe (after hydrogen). Yet it is a scarce commodity here on earth. The noble gas is extremely volatile and not even gravity can keep it

in its grasp. Once released, sooner or later it escapes from the atmosphere into space.

All of which would not be an issue if helium was just the stuff of party balloons. But the fact of the matter is that helium is a billion-dollar business – and reserves of this gas on earth are finite. A few years ago, research and industry were already warning of a global helium crisis. With this in mind, the US government delayed selling off the nation's stockpile several times in recent years. For decades, the US dominated this market, with the world power maintaining a near-monopoly on the gas. In a natural underground cavern near Amarillo, the nation stored up to one billion cubic metres of this valuable element. For a while, these Texan rock formations were thus home to around 30 percent of the world's accessible helium assets. But then storage grew too expensive and in 1995, Congress decided to sell off the stockpile entirely. This initially resulted in a veritable glut of helium. Meanwhile, though, growing demand has long since outpaced even this surplus supply. Indeed, the price of this noble gas continues to rise each year.



The helium is transported onwards for further processing.



Helium hero: Jeffrey Vogt, founder and CEO of the Weil Group.



The downstream membrane further increases the efficiency of Linde Engineering's pressure swing adsorption unit.



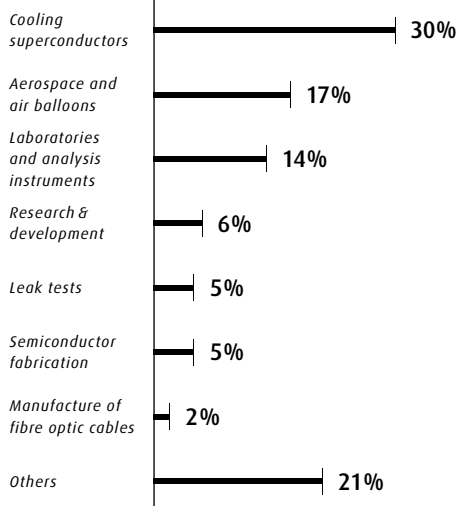
At least four more projects are planned in North America over the coming years.

APPLICATIONS

WHAT IS HELIUM USED FOR?

A free spirit among industrial gases, helium was formed within the earth's crust over billions of years through the radioactive decay of uranium and radium, accumulating primarily in natural gas reserves. It is extremely volatile and highly sought-after, since it possesses a number of exceptional properties. Helium has the lowest boiling point of any element (-268.9 degrees Celsius). It thus remains liquid even in the vicinity of absolute zero (-273.15 degrees Celsius), making it the cooling agent of choice – especially for superconducting magnets in research and medicine.

Both the world's most powerful particle accelerator, CERN's Large Hadron



Collider, and MEG equipment for imaging brain activity depend on helium as a refrigerant. It also quite literally keeps airship aviation afloat – the Hindenburg disaster of 1937 saw non-flammable helium replace hydrogen in the balloons.

In space travel, too, this gas is injected into rocket tanks to maintain a constant pressure. As an inert gas, helium is also useful in plasma welding. And in the semiconductor industry, this noble gas is used to detect leaks in the ultra-pure vacuum fabrication chambers. After repeated bottlenecks over the past few years, efforts to recycle this valuable element are now under way in many places.

Helium recovery is thus viable once again – even from smaller wells such as those beneath the Mankota grasslands. However, finding it in the first place is difficult and time-consuming. Up to now, it has often been discovered by chance, primarily in the course of natural gas exploration. But chance was something Jeffrey Vogt, founder and CEO of the Weil Group, was no longer content to rely on – particularly since the main producers, the US and Qatar, could scarcely keep up with demand. At the same time, further deposits – for instance in the East African Rift – were unconfirmed. Rarely had there been such a favourable climate to try out something new. “We were specifically aiming for helium – so we went to places where we know this gas resides,” explains Vogt. The entrepreneur and commodities expert, whose past activities include successfully drilling for nickel in the Philippines, was determined to go the extra mile. His teams spent months conducting meticulous underground investigations of Canada's Great Plains, delving deep into the earth. The presence of this noble gas in the area was first established in the 1960s but the reserves were not considered to be of further economic interest until the US released its grip on the helium market.

Operations began at the Weil Group's helium facility in June 2016. Since then, around 250,000 cubic metres of raw gas is extracted from the ground and processed each day. “This is not an enormous project – it certainly doesn't put us in the same playing field as the Exxons of this world – but the way we are obtaining the helium is a game-changer for the entire industry,” declares Vogt. In fact, his message to the wider world beyond the endless expanses of Saskatchewan can be distilled down to a single figure: 99.999 percent. That is the degree of purity ultimately produced from the nitrogen stream, which initially yields a 1–2 percent helium concentration. The result is a high-purity, industrial-grade product.

Winning combination

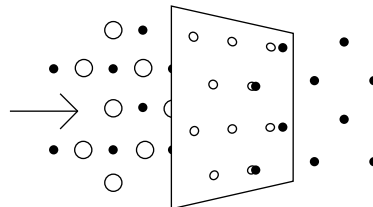
The key to this success lies in the process technology. Previously, large natural gas treatment plants generally distilled helium from the cryogenic nitrogen recovery stream. Now, though, Vogt and his team have a solution that bypasses this type of complex and, above all, expensive technology – thanks to an innovation by Linde Engineering that is set to revolutionise helium production. “Essentially

PARTNERSHIP

FORGING NEW PATHS TOGETHER

To succeed over time in business, you need to have the courage to venture into new territory. Fortunately, this is something the managers and staff of the Fibres, Membranes & Specialties product line at Evonik Industries have in abundance – as do managers at Linde's Engineering Division.

Evonik's core competence lies in innovative specialty chemicals, which are used to enhance the performance of countless consumer and industrial products. To date, however, Evonik has rarely worked with a partner to create a finished product. It is equally unusual for Linde Engineering to cooperate with other companies in its core areas of expertise – in this case,



gas separation. By forming an alliance, both companies are thus embarking on a promising new endeavour.

This partnership centres on Evonik's polymer-based membrane technology,

which is used in gas separation and treatment systems from Linde Engineering. The membrane enables gases such as methane, nitrogen, helium and hydrogen to be extremely efficiently separated in pure form from gas mixtures.

For Dr Axel Kobus, Head of Evonik's Fibres, Membranes & Specialties product line, the synergies arising from this collaboration are clear: "Creating a high-performance membrane product portfolio that unites Linde's plant engineering and gas separation expertise with our polymer and technology know-how establishes the best possible springboard for us to develop new markets together."

this is a hybrid process, which we are pioneering in Mankota in partnership with the Weil Group," is how Tobias Keller describes this world first. Keller is Head of the Adsorption and Membrane Plants Product Line at Linde's Engineering Division. His title says it all – this is a combination of two technologies, uniting two companies and leveraging their technology strengths. At its core is a highly selective membrane supplied by Evonik Industries. This is the new component that now makes helium recovery worthwhile even on a smaller scale. It is located upstream of the adsorption step, which means that the helium is first concentrated from the gas stream prior to the conventional gas separation and purification process. The membrane solution is thus a concentration technology. It pre-treats the gas so that all downstream technologies not only work (even) more cost-effectively, but can also be engineered on a smaller scale. This significantly reduces investment – and ultimately also operating – costs.

Summarising the benefits of this synergistic alliance for Linde's strategic path forward, Keller reports: "Evonik's high-selectivity membrane in combination with our other established gas separation technologies, such as our world-class adsorption

technology, allows us an extraordinary flexibility in the development and application of new and more efficient purification processes." Essentially, adding Evonik's membrane technology to the mix allows Linde to bundle all the relevant processes as a one-stop provider, strengthening its leadership in gas separation technologies. The move also opens up new opportunities in gas separation. The process to recover helium in Mankota could be applied to other sources of gases such as methane, nitrogen or hydrogen in the future.

While Jeffrey Vogt already has his eye on further helium projects in North America, the next chapter in the unfolding membrane story is about to begin in South Africa. In partnership with alternative and renewable energy specialist Renergen, Linde is planning to recover another cache of helium from 2018 onwards. The natural gas field in the central province of Free State boasts an unusually high helium content of up to 4 percent. In the end, even if these discoveries in Mankota and South Africa cannot stop helium escaping the earth at some point, they are certainly playing a key role in securing supplies of one of the rarest and most essential industrial gases of our time.

99.999%

*is the purity level of helium
recovered in Mankota.*



250,000

*cubic metres of raw gas is extracted
from the ground and processed every day.*



*Katja Baumgarten and her logistics team
brave the Siberian wilderness.*

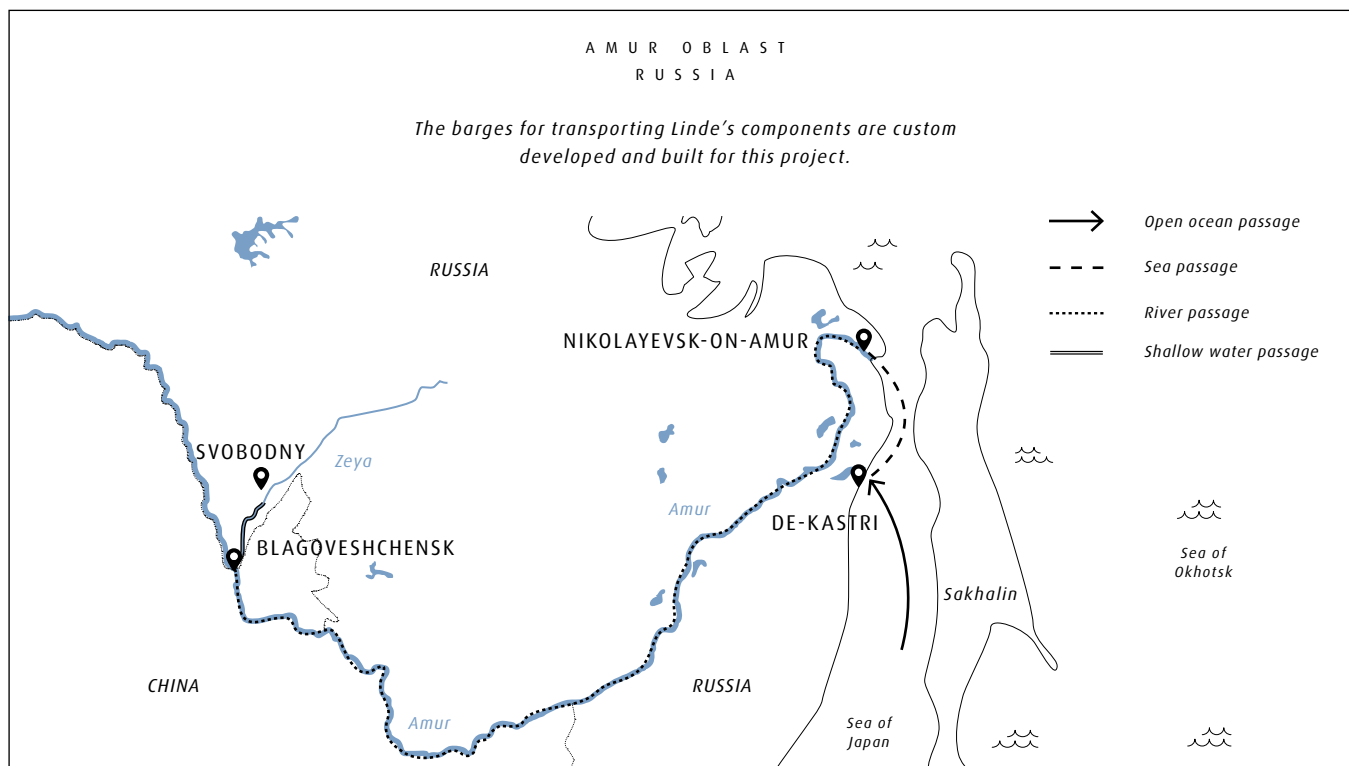


GAME-CHANGER IN AMUR

In the wilderness of eastern Russia's Amur region, near the border with China, a new chapter in natural gas history is being written. Gazprom is implementing one of the largest gas processing projects the world has ever seen – Amur GPP.

A new process technology developed by Linde will allow operators of the planned plant to eliminate an entire step.

At the same time, the complex is also set to redefine the global helium market.



Setting sail from Europe, the ships first cross around 20,000 kilometres of ocean, then navigate a further 1,500 kilometres or so up the Amur River – a waterway separating two world powers. The river marks the border between Russia and China and has retained much of its unspoilt character and charm. The last stretch of the journey runs along the Zeya mountain river, a tributary of the Amur, where water levels drop in places to 1.10 metres in summer. While this may sound like an adventure novel by Jules Verne, for Linde's Katja Baumgarten, it is cold, hard reality – made still chillier by the climatic conditions of the Russian Amur Oblast. This is a particular challenge in the winter months, when temperatures can fall below -30 degrees Celsius. However, this is nothing new to Baumgarten, who previously took on the extremes of Siberia with Linde Engineering's logistics team. That was near Tobolsk, where a large-scale polypropylene plant was built from the ground up. The new Amur project is set to push the boundaries of technical feasibility once again.

Around 8,000 kilometres east of Moscow, industry giant Gazprom is overseeing construction of one of the largest natural gas processing facilities in the world. When completed, the Amur Gas Processing Plant (GPP) will have a capacity of up to 49 billion cubic metres of natural gas every year. And Linde is delivering the enabling technologies. The only question is how: "There aren't any roads or ports there yet; there is no infrastructure capable of withstanding the heavy loads we need to transport," Baumgarten

explains. She is undoubtedly referring in particular to massive components such as the 90-metre separation column, weighing in at around 1,000 tonnes. "As a transport route, the Amur is our best option."

Linde paves the way

December 2015 marked the start of this mission for Baumgarten and her team, with Gazprom and Linde entering into a far-reaching cooperation agreement. Linde has undertaken to engineer and supply units for ethane and natural gas liquid (NGL) extraction and for nitrogen rejection. The contract also includes a helium recovery and liquefaction plant. Construction will take place in five stages, running until 2024. Once finished, the complex will be an important part of the Power of Siberia pipeline project, connecting the natural gas fields of eastern Siberia with northeast China. The plan is ambitious and its impact enormous – due both to the sheer size of the project and to the remarkable role played by Linde technology.

Eliminating an entire process step

Natural gas is a valuable resource because its components are so versatile. At the Amur GPP, the first step involves extracting ethane and higher hydrocarbons – all of which play an important role in the petrochemical industry. In the second step, the remaining gas mixture is processed into the product we are all familiar with: a source of energy to generate heat and power.

And it is this second step where things get tricky. In the past, a time-consuming and cost-intensive process was required before the remaining gas, which is mainly methane, could be piped to its final destination. This step is necessary to remove nitrogen and thus increase the quality of the resulting gas as a fuel. A nitrogen rejection unit (NRU) is used for this purpose, operating at temperatures of between –100 and –155 degrees Celsius. The problem here is the carbon dioxide (CO₂), which is also still present. Starting at temperatures of –57 degrees Celsius and lower, depending on the CO₂ concentration, this turns into dry ice – and clogs the system. In the past, preventing this has meant using a process known as amine scrubbing to separate CO₂ from the natural gas stream.

Now, though, thanks to an innovation from Linde, this scrubbing step is no longer required. The secret lies in keeping the carbon dioxide away from the coldest part of the system by means of a partition in the NRU. As long as the surrounding temperature is –100 degrees Celsius or warmer, CO₂ can remain in the gas at concentrations of up to 5,000 ppm (0.5 percent) without causing damage by forming dry ice. Since the natural gas stream in the Amur plant will contain just 3,000 ppm, this is an effective solution here.

This CO₂-tolerant design eliminates the need to invest in amine scrubbing, saving Amur more than 10 percent of total costs – a significant gain on a multi-billion-euro project. And, given its positive impact on the value chain, the market potential of this new plant type is huge.

The world's largest helium production plant

What is more, the Amur project will also herald another development of global proportions. Once all the expansion phases are complete, a total of two helium purification and six liquefaction trains supplied by Linde Engineering will recover enough of this highly prized noble gas to meet around 30 percent of current global demand each year. This roughly corresponds to the present annual consumption of the world's largest helium market to date – the US. As it stands, the US is also still the leading producer, but is facing dwindling reserves. Meanwhile, other countries are entering the market. For a long time, Russia struggled with helium extraction but that is now changing with the development of remote natural gas deposits in eastern Siberia. Natural gas is generally the key source of helium recovery – and the gas to be processed by the Amur plant is particularly rich in this elusive element. In the medium term, then, Russia looks set to redefine the market and become one of the world's biggest helium producers.

INTERVIEW

THREE QUESTIONS FOR MANFRED FISCHEDICK

NEW ENERGY AGE

As the world stands on the threshold of a new energy age, Professor Manfred Fischedick of Germany's Wuppertal Institute for Climate, Environment and Energy explains the growing focus on natural gas as a bridge to a more sustainable post-fossil energy economy.

What are the benefits of natural gas relative to other fossil fuels?

M.F. The major benefit of natural gas is that it releases lower levels of greenhouse gases and other pollutants when it is combusted. A second advantage lies in its versatility: it can be used to generate electricity and heat and can power vehicles. And a third is that gas-fired power plants are significantly more efficient than their coal-based counterparts.

Do you think we can achieve our climate aims with the help of natural gas?

M.F. By just switching to natural gas – certainly not. But neither is it enough to focus solely on expanding renewables. We also need to use

our energy more efficiently, also by leveraging intelligent technologies. But thanks to its specific properties, natural gas will certainly play an important role and act as a key bridging function in achieving these goals.

Russia is set to supply China with 38 billion cubic metres of natural gas per year from 2019. What does this gas mega-deal mean for global efforts to transform the energy economy?

M.F. China is now at a turning point and the country is working to diversify its energy mix. This involves greater use of renewable energy carriers, but also of natural gas as a bridge. If this dual strategy pays off, China will be making a major contribution to climate protection.

Digitalisation – powered by gas



Linde's electronics lab in Taichung (Taiwan) is setting new standards for the production of electronic components such as semiconductors.

In Taiwan, Linde has opened a modern research and development centre for microelectronics. At the Taichung electronics lab, the company's experts are working alongside researchers and customers to explore the next generation of specialty gases for the electronics industry – and their findings are opening up new horizons in chip fabrication.

The inventors might well have thought that champagne would have been a more fitting celebratory consignment, but in fact it was 'just' 50,000 cans of beer that went down in history as the first commercial consignment delivered by a self-driving truck. The vehicle covered around 200 kilometres of highway through the US state of Colorado last October with no driver at the wheel. The enabling hardware and software were supplied by start-up company Otto, which specialises in autonomous driving systems for cars and trucks. Headquartered in San Francisco, Otto was acquired by ride-sharing company Uber in summer 2016. And perhaps that is the real story behind the beer delivery: autonomous driving is no longer restricted to isolated test routes, but is now within reach of all road users. The ability of non-automotive players, such as Google and Uber, to disrupt the automotive market is largely due to dramatic advances in semiconductor and processor performance. These microsystems are now clearing hurdles that were still insurmountable just a few years ago – partly thanks to materials research and development work by Linde.

335

**BILLION
US DOLLARS**

*is the value of the global
semiconductor market.*

80%

**OF LINDE'S
FUTURE ELECTRONICS
BUSINESS**

is expected to stem from Asia.

A bright future for Asia

The heart of the electronics industry beats in Asia, with around a quarter of all chips produced worldwide originating from fabrication facilities in Taiwan. Neighbouring China is now investing billions in building up its domestic semiconductor industry, having previously been mostly a buyer on the 335-billion-dollar global market. Indeed, Chinese chip imports now outvalue oil imports – a state of affairs this massive country is determined to change through its own production facilities. As such, it is no surprise that around 80 percent of Linde's future electronics business will be based in Asia. The company supplies the gases and chemicals essential for the production of electronics components. Without these specialty gases and chemicals, the microelectronic and mechanical marvels inside mobile phones, computers, cars, displays, games consoles and medical equipment would simply not be possible.

As it is, this sector stands for unlimited possibilities – for a world where massive streams of data fly around the globe in fractions of a second and people from far-flung countries can take part in virtual meetings without ever catching a flight. Yet physical proximity to partners remains a key success factor in today's business. The semiconductor market is fiercely competitive and survival calls for a lot more than the ability to exchange electronic data. Companies aiming for global leadership must engage directly with customers and partners, and share visions and ideas. The smaller the chip circuits, the higher the requirements, necessitating ever-closer collaboration between the various players. Both business and conceptual drivers inspired Linde to open its most advanced research and development centre in Taiwan last year. The Taichung electronics lab is a type of Starship Enterprise. On board, alongside the Linde crew, are experts from the Taiwanese Industrial Technology Research Institute (ITRI) and, of course, representatives of the various industry sectors. Together, they are venturing into uncharted territory across the semiconductor galaxy.

One of the key research areas focuses on the reproducibility of structures that are now in the nanometre (millionths of a millimetre) range. This is a universe invisible to the naked eye, made up of components and logic structures so tiny that a human hair looks like a giant tree trunk in comparison. Today's most advanced chips entail over one thousand process steps – most of which require very special substances. Specialty gases are used to dope the semiconductor crystal with different atoms, making targeted modifications to its conductivity. And others build up thin layers by depositing material from the gas phase and etching these layers into intricate structures. Specialty gases are even used to clean the process chambers afterwards.

Analysis and synthesis

Gas purity is a recurring theme in this field: “The tiniest changes in gas composition can have serious repercussions,” explains Jeff Chiou, Director of the new lab in Taiwan. “Take plasma etching, for instance: even 0.0001 percent – which corresponds to 1 part per million or ppm – impurity inhibits the effectiveness of the fluorinated gas used. Among other consequences, this can mean that the trenches isolating the individual circuits on the semiconductor material are not deep enough – rendering the chip useless.” The technologies are evolving so quickly that established findings reach their sell-by date faster than ever. Thresholds valid for one generation are already obsolete by the next. Taking LEDs as an example, 50 parts per billion (ppb) oxygen and moisture content was previously just about acceptable in the process gas ammonia, while anything above that would affect performance, dimming the brightness of the diode. Now, though, when producing the new generation of light-emitting semiconductor elements, impurities of just 20 ppb are tolerated.

At the newly established lab, Linde’s experts and their industry partners are striving to eliminate this chemical variability. Alongside analytical processes, the focus is also on new formulations – so developing new gas products that enable the semiconductor industry to make further improvements to manufacturing or even take off in completely new directions. Organic light-emitting diodes (OLEDs) are a case in point here, promising even more vibrant images on ever-thinner screens. Key to this development are smaller, more powerful transistors consisting of new semiconducting materials such as metal oxides. Up to ten different gases are used in the production of a single transistor, with nitrous oxide, otherwise known as laughing gas, playing a particularly important role.



Lab Director Jeff Chiou (centre), YS Hwang (left) and Cheng-Han Lin are enabling development of the next generation of microchips.

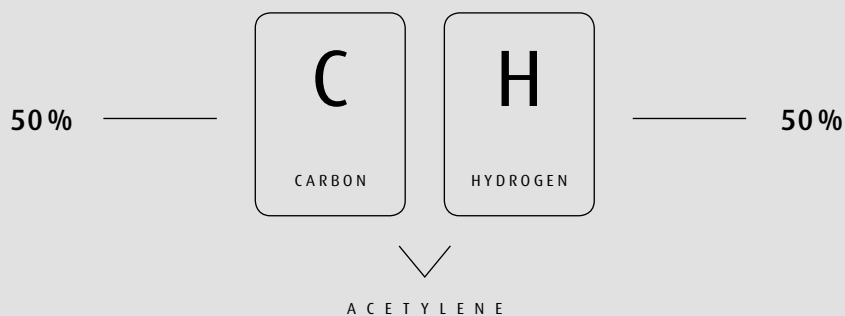
Onwards and upwards

The semiconductor industry is now facing major change and the search is on for new growth drivers. Previous contributors, particularly smartphones and PCs, still have a role to play but the signs of saturation are evident. Lab Director Jeff Chiou views autonomous driving and medical applications as the areas of greatest potential, while demand for LEDs and displays also shows promise. And then there is the massive call for the king of chips: NAND flash memory components. Since space is at a premium on the surface of today’s processors, chip architects now stack transistors on top of each other to create three-dimensional structures – skyscrapers with billions of transistors on each storey. 3D NAND flash chips are already used in smartphones, tablets and computers, and with requirements steadily growing, their skyline will continue to evolve. We only need consider the complex processing essential for autonomous driving, with sensors and cameras having to anticipate situations before they even happen. Or perhaps next-generation mobile phones, with data speeds a hundred times faster than before. Or even artificial intelligence. Yet none of these milestones would be possible without electronics specialty gases supplied by Linde.

L I N D O F L A M M ®

THE PRE-HEATING ADVANTAGE

*Linde has been shaping the evolution of welding technologies for several decades.
The company's ability to continually innovate traditional welding
processes gives its customers both an economical and technical lead, but also
realises potential that benefits the environment and society at large.*



**Doing more with less – that is the best way to summarise
demands around the latest high-grade steels, which are unleashing their
full potential with welding technologies from Linde.**

Steel is one of the most important framing materials used by modern society. But there is more than one type of steel. These metal alloys are sometimes exposed to extreme conditions, as in the case of monopiles – the foundations of offshore wind farms. As engineers venture into ever deeper waters, these gigantic support structures have to withstand more and more strain.

Steel grade S355 is currently heralded as one of today's high-performance heroes. It is stronger than standard structural steels while reducing weight by a third. Provided, of course, that this high-strength steel is pre- and post-heated as part of the welding process. Linde's LINDOFLAMM® solution is particularly effective for these heating applications. Metals may become damaged during the actual welding process unless the working zone has been heat-treated using acetylene burners. Consequently, welding would not produce a reliable joint. The steel temperature also needs to be maintained after welding, or the weld seam is susceptible to embrittlement and fine cracks then form.

As Technical Director at EEW Special Pipe Constructions (SPC), one of the world's leading monopile producers headquartered in Rostock (Germany), Tobias Hintz is familiar with the challenges in this sector – and knows the benefits of LINDOFLAMM®. Just last year, Linde installed a large, fully automated pre-heating station for EEW SPC affiliate Offshore Structures Britain. As Hintz concludes: "For SPC, using LINDOFLAMM® means we are ideally positioned to play a leading role in the rapidly growing and technically demanding monopile market. As the size of offshore wind turbines continues to increase and their locations become ever more challenging, we have to deliver higher-performance monopiles. And we are able to do that thanks to flame technologies from Linde."

DIGITALISATION

ACCURA®



Message in a bottle – but in real time! Last year, Linde launched a cloud-based version of its cylinder inventory intelligence service, ACCURA®. The internet-based system allows users to track the content and location of every single gas cylinder. Scanning a barcode on each cylinder uploads the data to the ACCURA® cloud. The captured information is then used to monitor and trace cylinder stock levels, movements and usage in real time. Customers can access this data via a mobile app for smartphones and tablets or a regular web browser. This dynamic management system makes it easier to comply with reporting requirements in sectors that demand a high degree of transparency such as pharma and the food and beverage business.

COMPANY
HISTORY

CARL VON LINDE

Working with his son, Friedrich – a doctor of theoretical physics, Carl von Linde developed the first air liquefaction system in 1895 using ambient air as the refrigerant. The machine sucked air in, cooled it in a countercurrent apparatus and then collected it in cryogenic form. This invention laid the cornerstone for an entire industry.

INNOVATION

3D PRINTING
COMES OF AGE

Linde technology is helping to advance 3D printing from infancy to a mature, industry-ready manufacturing process.

Already used to produce furniture, dental crowns, car parts and aircraft components, and even gaining a foothold in fashion – 3D printing has now made its way into the production lines of many different industries.

As additive manufacturing (AM) – to use the more technical term – morphs into an important economic driver and the dust begins to settle after the initial excitement, new fundamental questions are emerging along the entire process chain. One of the biggest challenges involves gaining a better understanding of the production specifics. Manufacturers are looking to expand their know-how, ensure reproducibility and assure quality – and industrial gases play a key role here. Their composition and purity have an impact on the metallurgical properties of the resulting materials and have a decisive influence on the quality of AM parts.

One of the success factors in 3D printing involves maintaining the right atmosphere

during the manufacturing process. The end product will only possess the desired properties if this atmosphere is precisely tailored to the type of material and process in use. To achieve this, Linde's Gases Division developed ADDvance™ O₂ precision – the first gas management system that precisely measures, analyses and controls oxygen (O₂) and humidity levels in AM chambers that apply metal powders. Inspired by the concrete needs of aerospace company Airbus Group Innovations, this new system can measure O₂ concentrations as low as 10 parts per million (ppm) within the AM chamber. The presence of too much oxygen or humidity can negatively impact the quality and performance of the 3D printing process. So, if required, the system can also modify the gas composition by adjusting argon or nitrogen levels.

With its new ADDvance™ family, Linde is bringing additive manufacturing to maturity. Its gases and applications support the entire process chain – from powder production and storage to the actual printing process.

ADDVANCE™ PORTFOLIO



Linde is set to play an even bigger role in the manufacture of 3D powders in future.

Linde's ADDvance™ portfolio ensures optimum storage conditions for printing powders.

Linde's gases are already used in 3D printing processes, where they enable the atmosphere in the AM chamber to be precisely controlled.

INTERVIEW

THREE QUESTIONS FOR
GERD WITTTAILORING PROPERTIES
THROUGH GAS

Professor Gerd Witt from the University of Duisburg-Essen has been active in the field of additive manufacturing technology for 18 years. His department is one of Germany's leading research institutes in this area. In this interview, Witt explains why Linde is the partner of choice for companies looking to explore the fascinating opportunities in the emerging world of additive manufacturing.

Why is there now such a focus on industrial gases in additive manufacturing – was their importance not clear before?

G.W. Well, we already knew we needed a controlled atmosphere consisting of various inert gases. However, their application was largely based on rough values gleaned from previous experience – so essentially a “wait and see what happens” approach. However, the technology has matured since then and the influence of these gases on production is being systematically examined. Users need to know what they can accomplish with each different gas – that’s the only way to ensure reproducibility. Welding is the same in that respect, with specific shielding gases suited to specific processes and materials.

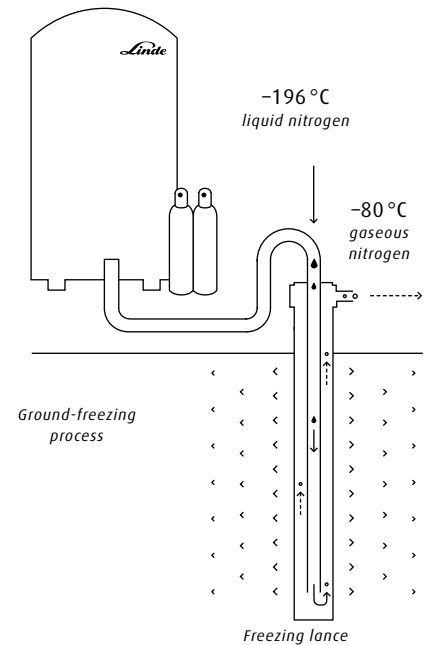
Welding is practically part of Linde’s DNA. Would you say additive manufacturing holds the same potential for Linde and its customers?

G.W. Yes, Linde has always been a major player in welding, not only distributing gases but also advising and supporting its customers in how to use them. I now see the same opportunity in additive manufacturing – Linde has the expertise to accompany users along this new path and offer valuable assistance.

Will every process and production line need its own gas mixture in future?

G.W. That remains to be seen. Whether a dedicated gas is really required for every part – or perhaps more for each type of material or application scenario. Material requirements for medical applications might be quite different, after all. Or certain properties might not be as relevant as they are in aircraft construction or the automotive industry. Basically, though, if you use the right gas, you have a greater certainty of achieving the desired properties. Ultimately that also has an impact on costs, since it increases efficiency in production.

URBANISATION

GROUND
FREEZING

The German city of Munich is planning a second main transport artery for its suburban railway (S-Bahn) system, running underground beneath its centre. This entails digging two tunnels below a densely built-up area. In addition, the Bavarian capital lies on a gigantic gravel plain. Linde’s proven ground-freezing technology would be an effective way to prevent this loose sediment from trickling down like sand into holes on a beach.

In this process, liquid nitrogen circulates through copper pipes, also known as freezing lances, sunk into the ground, where they extract heat energy from the surrounding soil. This gradually forms a frozen wall, which acts like a type of local anaesthetic on unfavourable geological conditions by stabilising the substrate. Particularly against the backdrop of increasing urbanisation and underground infrastructure, ground freezing is growing in importance. Linde recently enhanced its method further to enable the lances to be removed from the frozen ground so that tunnelling equipment is not damaged.



Leveraging Potential: Efficiency

Any integrated industrial gases enterprise that wishes to remain at the forefront of the global market must always be ready to forge new, entrepreneurial paths. Here at Linde, that means offering a lot more than “just” gas molecules. In the on-site business, for instance, the company is extending its value chain to reach promising new market segments through alliances with other companies.

At the same time, Linde is constantly leveraging new potential both for its own benefit and for that of its partners – building, for example, on the latest digitalisation technologies or on game-changing solutions to get even closer to its customers.



CREATING AND
SHARING VALUE

26

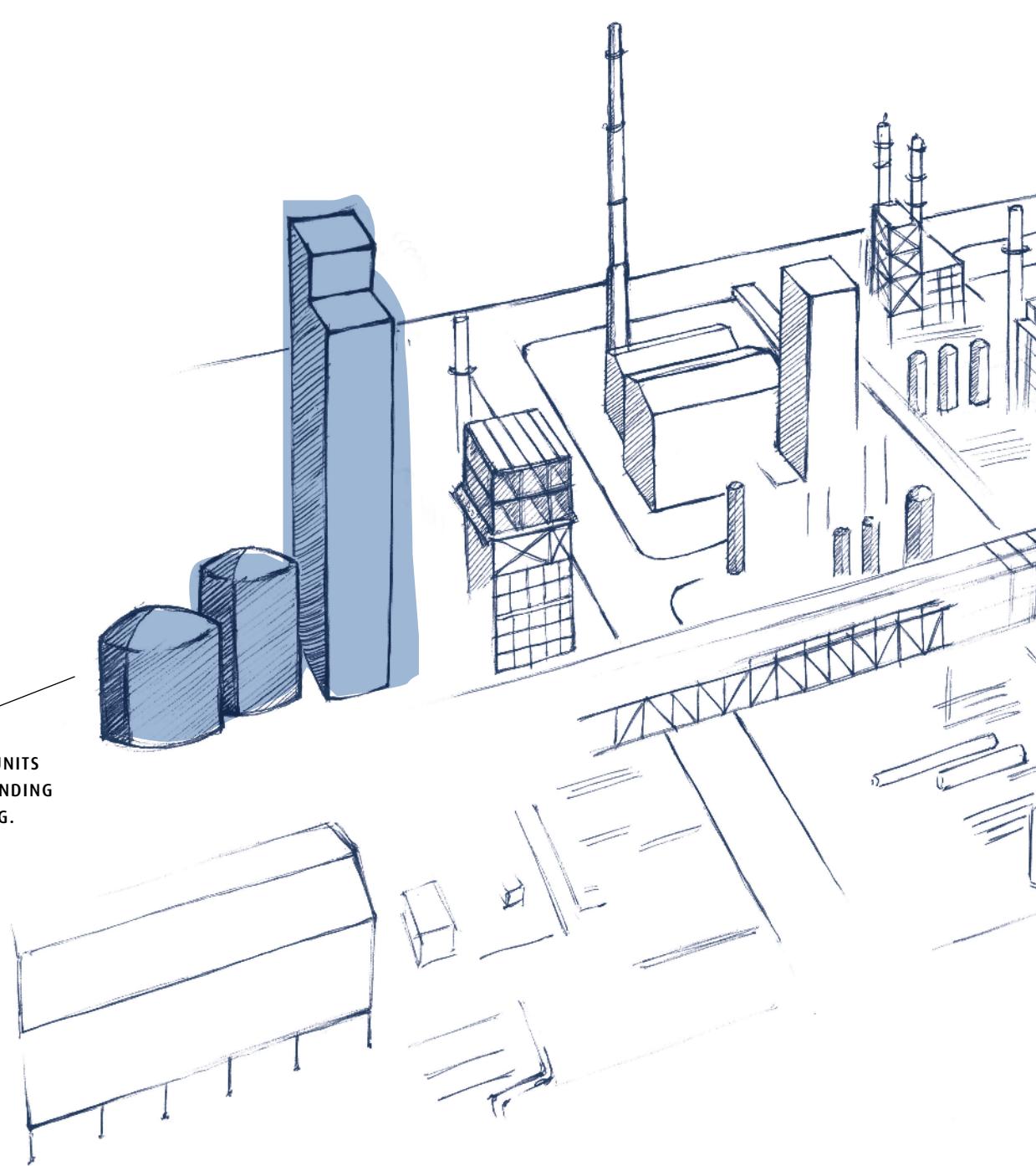


NEW WAYS TO
REACH THE CUSTOMER

34

Creating and sharing value

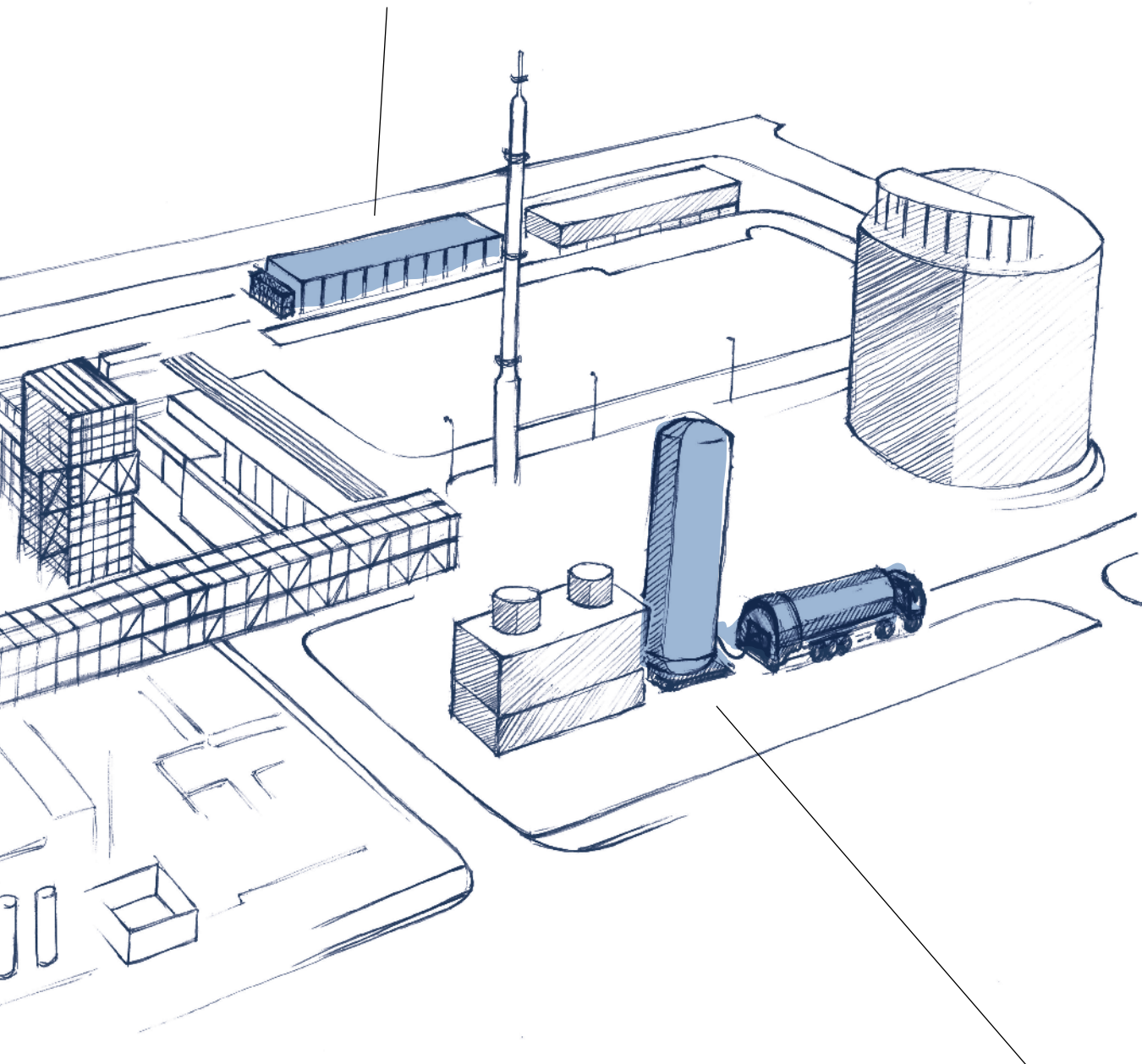
The on-site supply of industrial gases offers a number of compelling advantages to customers. This business model also benefits Linde – and not only because it favours long-term relationships.



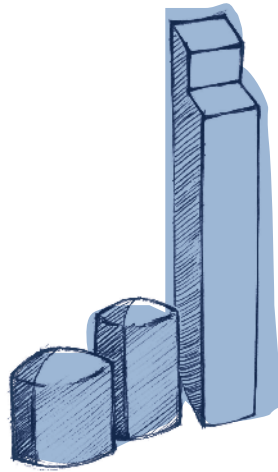
AIR SEPARATION UNITS
TO SUPPLY SURROUNDING
CUSTOMERS, E.G.
WITH OXYGEN

Overview of an on-site facility maximising distribution potential.

**GAS CYLINDER FILLING
STATION FOR SMALL AND
MEDIUM-SIZED COMPANIES**

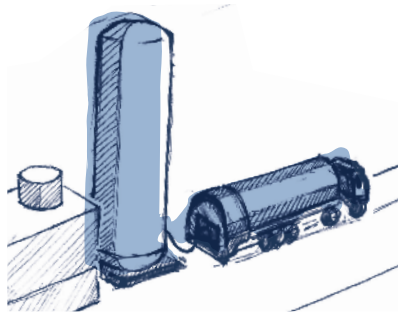
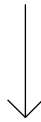


**TANKER FILLING FOR BULK
DELIVERIES TO MAJOR CUSTOMERS NOT
CONNECTED BY PIPELINE**



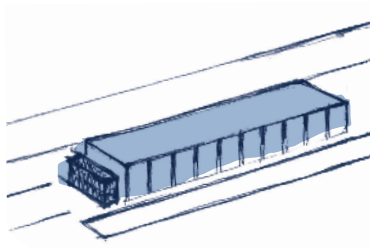
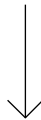
ON-SITE

Linde systems play an essential role in major industrial parks – and open up other lucrative business fields.



BULK

Linde sells some of the surplus gas generated by on-site systems to major customers outside the industrial park.



CYLINDER

On-site facilities are so cost-effective that Linde can develop the cylinder business even in highly competitive markets.

The recent joint venture between Linde and PETRONAS Gas Berhad is a shining example of the power of the on-site business. The common goal: the construction of a 150-million-euro state-of-the-art gas production plant in Johor, Malaysia. This on-site cooperation creates immediate benefits for both parties in the short term but also presents the potential to achieve sustained benefits in the future. In fact, for Linde, therein lies the key: establishing a large-scale on-site production facility to supply bulk customers, thus creating value for customers and realising economies of scale.

Two towering giants join forces

The PETRONAS Twin Towers, interconnected by their double decker sky bridge, dominate the skyline of Kuala Lumpur's Central Business District. In equal standing on a business scale is the company from which they take their name. The state-owned, petrochemical giant governs the entirety of Malaysia's oil and gas resources and its subsidiary – PETRONAS Gas Berhad – is Malaysia's leading gas infrastructure and utilities company.

In September 2016, it was announced that PETRONAS Gas Berhad would team up with Linde Malaysia Sdn Bhd to form Pengerang Gas Solution Sdn Bhd. The joint venture company will build a state-of-the-art industrial air gas facility including two large air separation units (ASU) and associated gas facilities that will produce gaseous oxygen and nitrogen to supply the needs of PETRONAS' world-scale Refinery and Petrochemicals Integrated Complex (RAPID).

Just to put this complex in perspective: on completion in 2019, RAPID will be one of the biggest facilities in the world, boasting a 300,000 barrels-per-day refinery, a naphtha steam cracker and an integrated petrochemical complex including an ethylene oxide/ethylene glycol plant. The highly specialised chemical products from such a plant are the building blocks for many consumer products such as plastics and synthetic rubbers. You can thank them for everything from de-icing fluid through shoe polish to that glorious 'new car' smell.

More than just business as usual

The on-site business has been, is currently and always will be the backbone of The Linde Group's business. Historically, it has been built on the solid foundations of the steel industry with its immense oxygen demands. It continues to be a stable source of revenue characterised by long-serving contracts. However, that is not to say Linde can rest on its laurels. On-site must evolve as the demands of the modern world change: new raw materials mean a need for different gases, namely hydrogen, nitrogen, ammonia and carbon monoxide. As a result, on-site

business is no longer only synonymous with ASUs but with Hydrogen and Carbon Monoxide (HyCO) and synthesis gases (Syngas) plants too. A greater range of products means more customers can benefit. But it doesn't end there.

In a move reflective of the strategic direction the business is taking, the PETRONAS partnership deviated somewhat from the typical on-site project tender process. While traditional deals would go to tender to win the immediate installation of an ASU and gas supply, this joint venture involved a long period of development after the tender process. Two years were spent developing a perfectly tailored, integrated concept in cooperation with PETRONAS – as Stefano Innocenzi, Senior Vice President Investment Projects for the Asia-Pacific region, explains:

“IT REALLY
DEVELOPED FROM A TENDER
TO A PARTNERSHIP –
A COOPERATION BASED ON
MUTUAL TRUST.”

The obvious question however, is: Why? Why the joint venture? Why are large companies teaming up with Linde rather than taking this on themselves? That is to say: why can we be sure our on-site business will continue to be a pillar?

Symbiosis in business

It all comes down to a time-proven success recipe borrowed from nature: symbiosis. This describes the interaction between two different organisms in close proximity to the advantage of both. Similarly, in business, the on-site model is all about mutual benefits. In entering a partnership with Linde, customers are leveraging the knowledge of experienced experts in the gas business – and that expertise manifests in a number of benefits. Where solutions have a high degree of complexity, it becomes most evident – as was the case with PETRONAS:

“LINDE IS VERY GOOD
WHEN THE SOLUTIONS ARE VERY
COMPLEX. AND THIS PROJECT
WAS VERY COMPLEX. SO THIS WAS
ONE OF OUR STRENGTHS.”

The complexity lay in the sheer number of off-takers from the plant – as Innocenzi goes on to explain: “With so many different off-takers, you have to optimise the plant to be able to operate efficiently in various modes, so you have to be very flexible. This is something only an industrial gas company can offer.”

Reliability was another factor. When a plant is the sole supplier of gas – like in the PETRONAS case – reliability becomes a must. Linde draws on extensive experience to design such solutions – something a customer might not have. No matter what the project, Linde offers design that fits the purpose and by joining forces, the customer can be sure that the plant is specified to their profile.

But that’s only one half of the symbiotic relationship so far: what exactly is Linde gaining from it? As mentioned, on-site projects in general present several obvious benefits: the technical and execution expertise of Linde’s Engineering Division can be leveraged for the design and construction of the sites. Beyond that, Linde ensures stable revenue by supplying the gases in question for the duration of what is usually a relatively long period of time. PETRONAS was no different: Linde secured long-term agreements for the supply of oxygen and nitrogen to the complex, but what this partnership illustrates so well are the strategic opportunities that on-site projects can provide for value creation down the line. For starters, the plant will produce a significant amount of argon and Linde holds the exclusive right to monetise all of it. But on a bigger scale, it’s all about location, location, location.

A foot in the door ...

Asia is a key growth market for The Linde Group and Johor is, in fact, the most southern point of the Asian continental mainland. It is separated from the Republic of Singapore by the Straits of Johor. Indeed, the major petrochemical and oil trading hub in the region is but a hop, skip and a jump away: something the Malaysian government are capitalising on. All of the parts of the infrastructure puzzle that have to come together to develop a new petrochemical hub across the water are appearing. There is already natural gas and a power plant supplying both the complex and the whole national network. And lest we forget, Johor is perfectly situated for a deep sea harbour. And why is this significant? Remember, the on-site business represents a foot in the door for higher yielding bulk or cylinder businesses as more and more potential customers flock to the emerging hub. Bottom line: the PETRONAS investment is only a small piece of what is yet to come and Linde will be perfectly positioned to further elevate potential.

Value shared is value added

What has not been mentioned so far is capital expenditure. Investment costs are so often the driver for customers when contemplating whether to enter this type of symbiotic relationship. The fact is by working with Linde and developing the solution together, that cost is reduced significantly. Linde creates value by bringing the capital expenditure to the right level by investing where it’s needed and saving where it’s not. Innocenzi sums it up nicely:

“WE HAVE TO CREATE VALUE
AND IF WE CREATE VALUE,
THERE IS VALUE TO SHARE,
THAT’S THE TRICK HERE.”

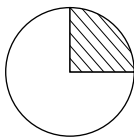
The outcome: a more efficient, reliable solution for a lower cost than had the customer taken it on themselves. At the end of the day, that answers the ‘why’ question: why symbiosis makes sense in business and why Linde’s on-site business is as relevant now as it has ever been.

INDUSTRIAL GASES BUSINESS MODELS

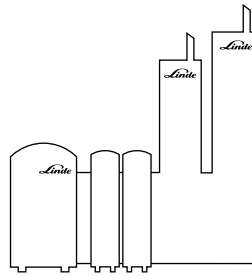
Business models in the gases industry are defined by the distribution method – on-site, bulk or cylinder – and customer size. Linde's integrated approach leverages the full potential across all three business fields.

By volume, the cylinder business accounts for just a fraction of the gas generated at the various facilities. Yet cylinders generate the most sales and have the highest margins.

PERCENT OF SALES

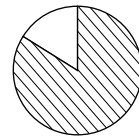


25%

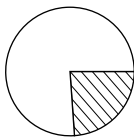


ON-SITE

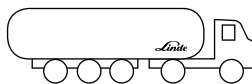
DISTRIBUTION VOLUME



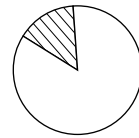
84%



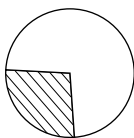
24%



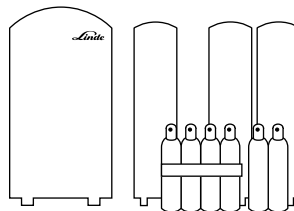
LIQUID GAS TRANSPORT (BULK)



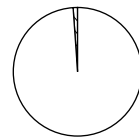
15%



27%



CYLINDER



1%

The Healthcare segment accounts for the remaining 24 percent.

ON - SITE INSIGHTS



LA PORTE

TEXAS
U S

SYNGAS
ON A WORLD SCALE

o

Natural gas has been playing a much greater role in the energy market in recent years due to the shale gas revolution. Lower prices, particularly in the US, have seen more growth opportunities for the petrochemical industry.

o

To better serve a growing demand, Linde has invested more than 250 million dollars over the past two years to build a large, state-of-the-art ASU as well as the world's largest complex based on natural gas for the generation and processing of syngas.

o

The plant converts natural gas into syngas and constituent products such as carbon monoxide, hydrogen and carbon dioxide. These are shipped by pipeline to a key customer on site where they can be used to produce methanol, downstream chemicals and cleaner transportation fuels.

ON - SITE INSIGHTS



TOGLIATTI

SAMARA
RUSSIA

DELIVERING
SUPER - HIGH EFFICIENCY

o

Leading Russian corporations are increasingly keen to bring in know-how from Linde to deliver solutions with specific requirements such as high efficiency – something customers can't always achieve themselves.

o

In a joint venture with JSC KuibyshevAzot, Linde constructed an ammonia plant which produces some 1,340 tonnes of ammonia per day. Both companies have a fifty percent stake in "Linde Nitrogen Togliatti". The project has seen a 275 million euro investment to date.

o

JSC KuibyshevAzot requires a rising stream of ammonia to support the plans to expand Togliatti production capacity for caprolactam – a precursor of polyamide plastics – and nitrogen fertilizers. This project strengthens Linde's position as the leading gases and engineering company in a fast-growing Russian market.

ON - SITE INSIGHTS



SADARA

AL JUBAIL
SAUDI ARABIAHYCO IN A
HIGH - POTENTIAL REGION

o

Back in 2012, The Linde Group and Sadara Chemical Company signed a long-term contract to invest, construct and operate a 380-million-dollar HyCO and ammonia facility in the Jubail 2 petrochemical cluster – the largest chemical complex ever built in a single phase.

o

As well as a two-stream HyCO plant and single-stream liquid ammonia unit, Linde also installed a large ammonia storage tank, resulting in a sophisticated supply concept which will enable the plant to run smoothly and reliably at all times. Sadara plans to use the carbon monoxide, hydrogen and ammonia primarily for MDI and TDI production – used in the production of polyurethanes.

o

The petrochemical industry is expanding rapidly in Saudi Arabia and there is growing opportunity for firms like The Linde Group to leverage its technology and operational excellence to take the region's industrial gases play to the next level.

THE ECOVAR® CONCEPT



ECOVAR®

ONE SIZE FITS ALL

o

Numerous industries depend on a reliable supply of high-quality gases. However, many companies need more adaptability than that required by the petrochemical giants – and their volume requirements are often also significantly lower. Linde's modular ECOVAR® portfolio is the ideal choice for these customers.

o

For instance, Linde delivered two ECOVAR® systems for on-site supplies of nitrogen and oxygen to Finnish paper and pulp specialists CP Kelco and Metsä Fibre. Oxygen plays a key role in modern pulp production and so paper companies need a solution that can guarantee an uninterrupted flow. In addition, the modular, standardised design of ECOVAR® significantly reduces development, construction, operation and maintenance costs.

o

In short, ECOVAR® customers enjoy almost the same benefits as large-scale on-site customers. They can look forward to the highest quality and reliability standards with the added bonus of lower investment and operating costs. Linde has already installed more than 1,000 ECOVAR® plants worldwide.

New ways to reach the customer

In Asia, reaching customers can be quite a challenge.
With mobile demo centres for product presentations and training,
Linde is bringing its technology to its customers' doorsteps.



Linde demo truck on its way to the next customer session in Bangkok.

*Mobile demonstration centre up and running
in just 20 minutes.*





Multimedia tools support live demonstrations.

Customers gain fascinating insights into latest welding techniques.



"A demo is always the best way to seal a deal," declares Olof Kallgren, Head of the Application Technology Hub in Shanghai. "And if the customer can't come to our Application Technology Centre, the Centre will just have to go to the customer." Given the geographical expanses of Asia, it is not always easy to hold live technology demonstrations showing how theory translates into real-world practice. "Our customers want to understand the effectiveness of introducing gases technology into their manufacturing processes," explains Rob Hughes, Linde's Managing Director for Region South Asia and ASEAN. "The mobile demonstration centres are an innovative way to showcase how our technology can add value to their business." That is precisely what the market needs. Construction, for instance, is booming across the entire region. And the right cutting and welding technologies are essential in the construction business. As a full-line supplier specialised in industrial gases, Linde supports its customers across the entire process landscape – from arc welding through laser cutting to the increasingly specialist application technologies needed to handle the growing variety of steel grades and alloys. To remain efficient and productive in this increasingly diverse environment, construction companies need to provide their staff with regular training. And that is what inspired Linde to go the extra mile.



Three Linde demo trucks are currently on the road in Asia. Two are focused on the latest welding technologies and the third on freezing and cooling.

ALWAYS AIMING HIGHER

I N D I A

**KRISHNAMOORTHY
MANIKANDAN**

Ashok Leyland Limited

*Indian commercial vehicle manufacturer
Ashok Leyland came across Linde's
expertise in welding through a consultant.*

*Discussions with Linde experts
soon followed – and they flagged up huge
potential for improvements. Also
involving its suppliers, Ashok Leyland thus*

**"WITH THE HELP OF LINDE,
THE REJECTION RATE
OF THE SHEET METAL
PARTS HAS COME DOWN BY
ALMOST 95 PERCENT."**

*entered into an alliance with Linde as its
technology partner. As Krishnamoorthy
Manikandan from Ashok Leyland recalls:*

*"We understood what Linde can do and
we saw the advantage of their technology.
I just had to open the door to our suppliers –
and Linde did the rest!"*

Know-how hits the road

Since the start of 2016, this region has had three 20-foot customised containers on standby, two for welding and one for food freezing demonstrations. All three units are fully equipped, including multimedia facilities for demonstrations and training. Each Mobile Demo Centre (MDC) can be easily transported by truck or ship and is ready for use within minutes of arrival. Within just a few months, they have already proved a major asset, giving the local application engineers and sales teams the ideal tool to share application know-how, strengthen dialogue with customers and drive sales. In the words of Olof Kallgren: "Set up either directly at the customer site or at one of our locations, the MDCs enable us to demonstrate all our processes and visualise the full range of benefits. So a customer can see, for example, how they would benefit from switching from CO₂ to another gas mixture, a step that adds real value by increasing return on investment by a factor of four or five."

Building trust on the ground

The compact containers use the latest presentation technologies to showcase the highlights of Linde's welding and industrial gas offering. Two 55-inch screens are a real eye-catcher; one showing the processes in high-speed sequences with slow-motion effects and the other focusing on the penetration and arc stability benefits. The containers also feature product samples, info panels and display cases. Due to its high relevance for Asia, arc welding is one of the core topics here.

One MDC is primarily in use at Linde locations in China to support open-house meetings. Held over several days, these involve Linde experts sharing their knowledge about the latest technologies and applications – both with external participants and with Linde staff. This MDC was also on site for the opening of Linde's new filling plant in Ningbo. And two months later, in June 2016, it proved a major attraction for visitors to the 21st Beijing Essen Welding and Cutting Fair.

Another MDC is travelling along the Chinese coast, demonstrating Linde's cryogenic freezing solutions for the food industry. Its first stops were the port cities of Zhoushan and Yantai, also calling into the international seafood trade show in Tsingtao at the start of November. There, it got an eager reception in front of the exhibition hall – a Linde team had installed a CRYOLINE® tunnel freezer within the roughly six-metre container and gave visitors a live demo of the workings of this innovative solution.



LEE YONG HANG

Senior Operation Manager Huatraco

"DIFFERENT STEELS NEED
DIFFERENT WELDING TECHNIQUES.
AND THAT IS WHY LINDE IS OUR
TECHNOLOGY PARTNER - WE MUST
NEVER STOP LEARNING."



Increasing efficiency by building know-how - Lee Yong Hang is enthusiastic about training with the Linde demo truck.



Cutting edge of application know-how

The third MDC is on a roadshow in Southeast Asia, travelling on a flatbed trailer. In the middle of last year, this unit went on tour in Malaysia, before heading to Thailand. One of the first companies it visited was Huatraco PTE. LTD., a scaffolding and formwork manufacturer that had recently relocated one of its plants. This was obviously not the best time for Huatraco to send staff to external product demos or training courses. But thanks to Linde's MDC, the company was able to expand its application know-how with the aim of increasing efficiency – while keeping everyone on site. Lee Yong Hang, Senior Operation Manager at Huatraco, was certainly impressed: "We were able to see the benefits of the various applications immediately."

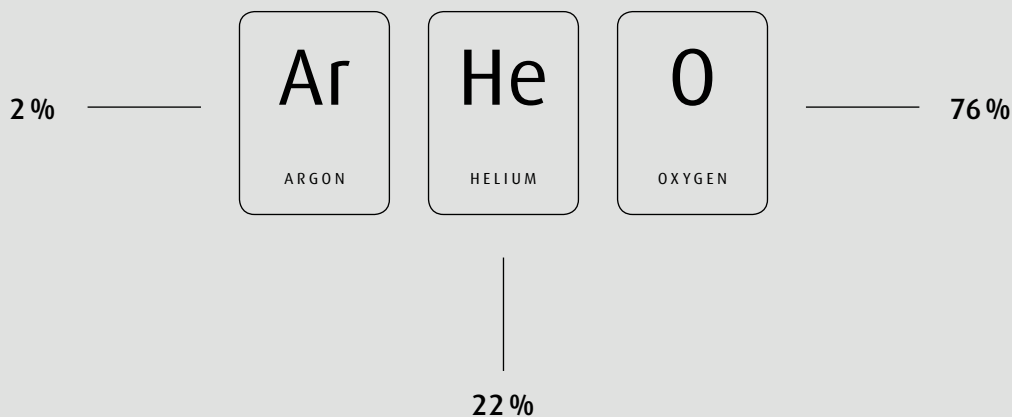
Within just a short time, the MDCs have proven to be an ideal platform for knowledge transfer between Linde and its customers. They have already had a huge impact – also prompting Linde to develop further innovative solutions to bring the company even closer to its customers. A virtual demo unit went online in China in autumn 2016. This micro-site for welding technology provides users with demo videos and webinars, is closely connected to the social media channel WeChat and helps funnel qualified leads. The initial results speak for themselves: accessed over five million times, the service has already generated hundreds of new prospects.

L A S G O N®

OPTIMISING LASER WELDING

Linde has been shaping the evolution of welding technologies for several decades.

The company's ability to continually innovate traditional welding processes gives its customers both an economical and technical lead, but also realises potential that benefits the environment and society at large.



The LASGON® series of process gases makes laser welding particularly cost-effective, also extending the benefits of laser welding to new types of material.

The high-tech boom is presenting a series of new challenges for welding technologies. Roaring flames to manipulate materials is a thing of the past. While the trade still – more than ever – requires a high level of general skill and expertise, welding itself is becoming ever more specialised. The depth and breadth of applications is growing, and with it the choice of innovative techniques, such as laser welding. In comparison with conventional methods, this offers more targeted heat transfer, less warping and higher welding speeds.

Linde created the LASGON® family to capitalise in full on the benefits of laser welding. For years now, the company has been developing new process gases within this series, catering for the most varied of tasks and materials. These bespoke gas mixtures help improve laser welding outcomes – whether in automotive or plant engineering, equipment construction or steel fabrication.

CUSTOMER SERVICE

REPAIRS IN RECORD TIME

The start of October 2016 came as a major relief for Unipetrol, with the company's steam cracker in Litvinov (Czech Republic) gradually going back on stream. Just 13 months previously, in mid-August 2015, an explosion had caused severe damage to the plant. Leaking oil ignited and a serious fire destroyed key components including four cracking furnaces, the main pipe rack and around 350 kilometres of cabling. This presented Unipetrol, the Czech affiliate of PKN Orlen – one of Eastern Europe's largest crude oil refiners – with a major problem, since the incident also took several downstream plants out of production.

Thanks to revamp work in 2007, Linde Engineering was already familiar with the operator and polyethylene plant affected and immediately offered assistance, with the first experts reaching the scene just three days after the event. After a detailed review of all repair options, Linde was appointed to manage the decommissioning and reconstruction project. An extremely careful approach was required even for the clean-up, due to the risk of the damaged furnaces spontaneously collapsing. The peak phase saw up to 1,000 specialists from different companies working on the site. Thanks to Linde's extensive engineering, procurement and construction experience and its strong focus on smooth coordination across all repair steps, Unipetrol was able to resume operations at the plant two months earlier than planned.

3

DAYS

*after the incident the first
Linde experts were on the scene.*

13

MONTHS

*after the event the plant
started up again.*

2

MONTHS

*earlier than planned,
operations at the plant
could resume.*

INNOVATION

PREDICTIVE ANALYTICS

Operators of industrial plants around the world generally rely on fixed preventive maintenance schedules. Predictive maintenance goes a step further, triggering the right maintenance action, at the right time, by analysing the growing stream of data from industrial plants to predict potential component failures with even greater precision. Every day, Linde's

Remote Operating Centres (ROCs) receive huge volumes of sensor data from the plants they monitor. Synergising digitalisation and engineering know-how, Linde's predictive maintenance team of experts transform this data into valuable, actionable insights – using intelligent algorithms specially developed and programmed on the basis of the ROC data feeds.

COMPANY
HISTORY

CARL VON LINDE

Although three types of refrigeration system already existed by the time Carl von Linde developed his process, his cooling technology marked an economic breakthrough. The other approaches at the time were all very limited in their effectiveness.

Carl von Linde first devised a theory to calculate cost efficiency and then published a paper in 1870 describing his findings: "Mechanical Methods for Extracting Heat at Low Temperature".

1870

PAPER ON
MECHANICAL REFRIGERATION

1873

BREAKTHROUGH IN
MECHANICAL COOLING

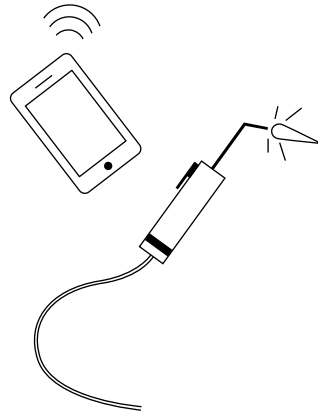
Three years later, in 1873, he succeeded in proving that the direct transfer of artificially generated cooling was more cost-effective than the natural ice method in widespread use at the time. Construction of his first commercial refrigeration machine soon followed. It provided a predictable, reliable and constant supply of cooling power, which enabled brewers to continue producing beer throughout the whole year for the first time. Spaten-Bräu, Heineken and Carlsberg were among the first customers, having rapidly recognised the financial potential of mechanical cooling.

DIGITALISATION

WELDING ENTERS THE CLOUD

The EU mandates uniform standards in structural steel processing. For fabricators, this means gathering and documenting a host of welding-relevant data. Linde introduced AVANTO™ to help them meet these needs – quickly and cost-effectively.

AVANTO™ brings the benefits of digitalisation to the world of welding. It is a cloud-based process management system that covers every step in the welding workflow, from job planning through execution to evaluation of results. All data required for a job can be called up at any time on a PC or mobile device. The



database also displays welders' qualifications, ensuring the right expert is always assigned to each job, no matter how specific the requirements may be. And if the job is particularly tricky, the operator can check welding procedure specifications stored in the cloud or ask a supervisor for support in real time.

AVANTO™ provides the transparency required in the increasingly complex metal fabrication industry. The system delivers an effective response to the challenges in the structural steel market resulting from the implementation of EU regulation EN 1090.

DIGITALISATION

DRIVING INTELLIGENCE INTO HOSPITAL PROCESSES

3

HOURS

*saved every day
with Hospital IQ.*

"We always knew what we delivered and what we got back – but not what was going on with the gas cylinders in the meantime," reflects Peter Senior, Head of Hospital Care Marketing. Now, though, the Bluetooth-enabled Hospital IQ data platform is set to change that. Linde Healthcare is closing the last gap in medical gas cylinder management – and initial outcomes from the US market have the potential to revolutionise hospital logistics around the globe.

Hospital IQ is an evolution of the LIV® IQ intelligent oxygen cylinder system. Melissa Owen, contract sourcing specialist at the Henry Ford Allegiance Hospital in Jackson, Michigan (US), is convinced that the digital alliance with Linde is already a huge success: "Prior to having LIV® IQ, our staff members were

making avoidable oxygen rounds. Now, they can easily check real-time contents on the Hospital IQ app – eliminating unnecessary tasks and maximising efficiency." This also benefits patients, since eliminating these rounds leaves more time for their care. Plus it dramatically reduces costs. In 2016, the Michigan hospital's cylinder procurement costs were down more than 22 percent on the previous year thanks to more efficient usage.

For Linde Healthcare, Hospital IQ marks an important shift from pure gas supplier to trusted partner supporting all logistics processes. As Peter Senior emphasises, cylinder management is just the beginning: "And a very exciting development, because it allows Linde and hospitals to work together to improve process efficiency."

36%

REDUCTION

in gas wastage.



Leveraging Potential: Ecology

Hydrogen-based mobility is a perfect example of how the need for cost efficiency can dovetail with ecological interests. Linde's pioneering role in this area is making hydrogen technology an everyday reality.

The company is equally committed to sustainability in its offering for industries such as petrochemicals or steel, helping to turn what used to be considered waste products into valuable resources. To advance developments in this area, Linde supports new recycling methods and participates in research initiatives.



THE FUTURE UNFOLDS -
IN SOUTH TYROL

46



PUTTING OLD OIL
TO GOOD USE

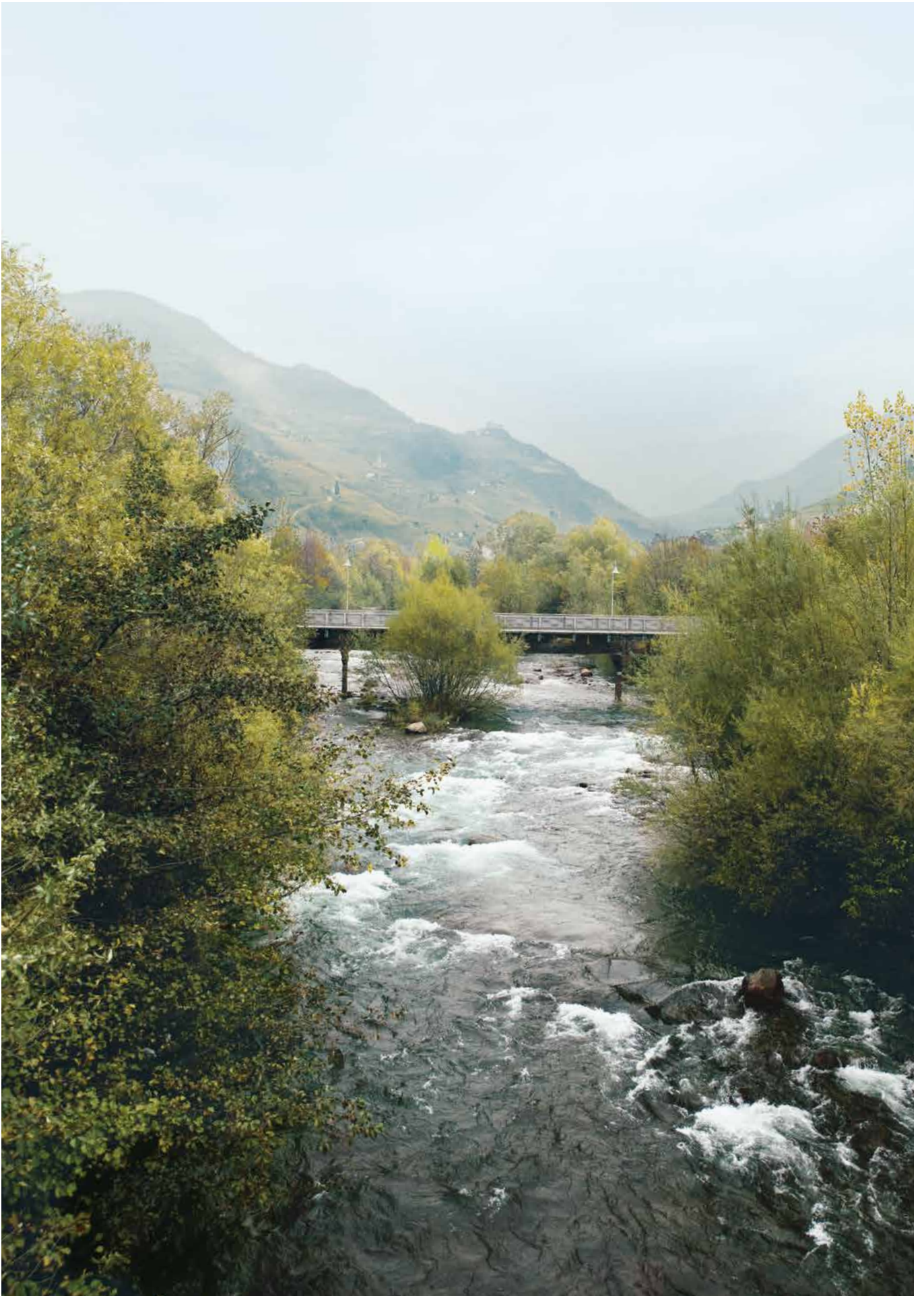
52

The future unfolds – in South Tyrol

Hydrogen-powered drivetrains are enhancing the quality of daily life for the citizens of Bolzano. All fuel for the hydrogen buses is generated from green sources.



One of five fuel-cell buses leaves the fuelling station at the depot.



Most of the green hydrogen is generated from hydroelectric power.

Sometimes progress is silent – but that doesn't make it any less impressive! Anyone boarding one of the new fuel-cell buses in Bolzano is stepping into the future of mobility. Since 2010, 5 of the 96 city buses in the capital city of South Tyrol have been running on hydrogen (H₂). Not every passenger even notices straight away, with some asking curiously: "Is the engine even running?" Bus driver Alessandro Petris gives a telling smile. It has long since been clear to him: "These are the best buses we've ever had in Bolzano. They are quiet, comfortable – and clean."

Spotlight on public transport

In a bid to reduce noise and air pollution, numerous European cities are now stepping up their quest for alternative drive technologies for local public transport. The focus here is increasingly on hydrogen technology in combination with a fuel-cell drive system. Urban traffic services require short refueling windows and long ranges, which is where an electric drivetrain really comes into its own. The need for non-stop service and central supply stations adds to the appeal of electric mobility.

Behind one of the South Tyrol buses, its motor running, stands service technician Roman Oberrauch – all smiles. He points up at the exhaust pipe above the rear window. Nothing to see. Really? Not quite – if you tilt your head backwards, a delicate cloud becomes evident against the dark roof behind. Which you could inhale without another thought, since it consists of pure water vapour. No nitrous oxide, no carbon dioxide, no soot. "Since we introduced this technology in 2010, we've seen major changes. Our work is so much cleaner and more pleasant now. Once you've tried a fuel-cell bus, you'll never want to touch anything else!" he declares with conviction. Not to mention a note of pride – the pride that comes with venturing into new terrain, which is now paying off for all concerned.

Potential for other transport services

The international commercial vehicle industry also sees the opportunities of fuel-cell drives. Refuse collection trucks, construction equipment and other special-purpose vehicles cover planned-out routes and usually have a central supply station – all of which simplifies setting up a communal hydrogen infrastructure. Experts calculate that every fuel-cell truck replacing a diesel truck leads to a reduction in carbon dioxide (CO₂) emissions of around 70 to 80 tonnes per year. Trains also travel predictable routes within the rail network – and the first 2 of a total of 14 zero-emission hydrogen trains are set to begin serving North German stations in 2017, each able to travel up to 600 kilometres on a single tank. Even aircraft manufacturers now sense an end to

ROMAN OBERRAUCH

Service technician

"WHEN WE
INTRODUCED THIS TECHNOLOGY
BACK IN 2010, I KNEW
IMMEDIATELY THAT I WANTED
TO BE PART OF IT.

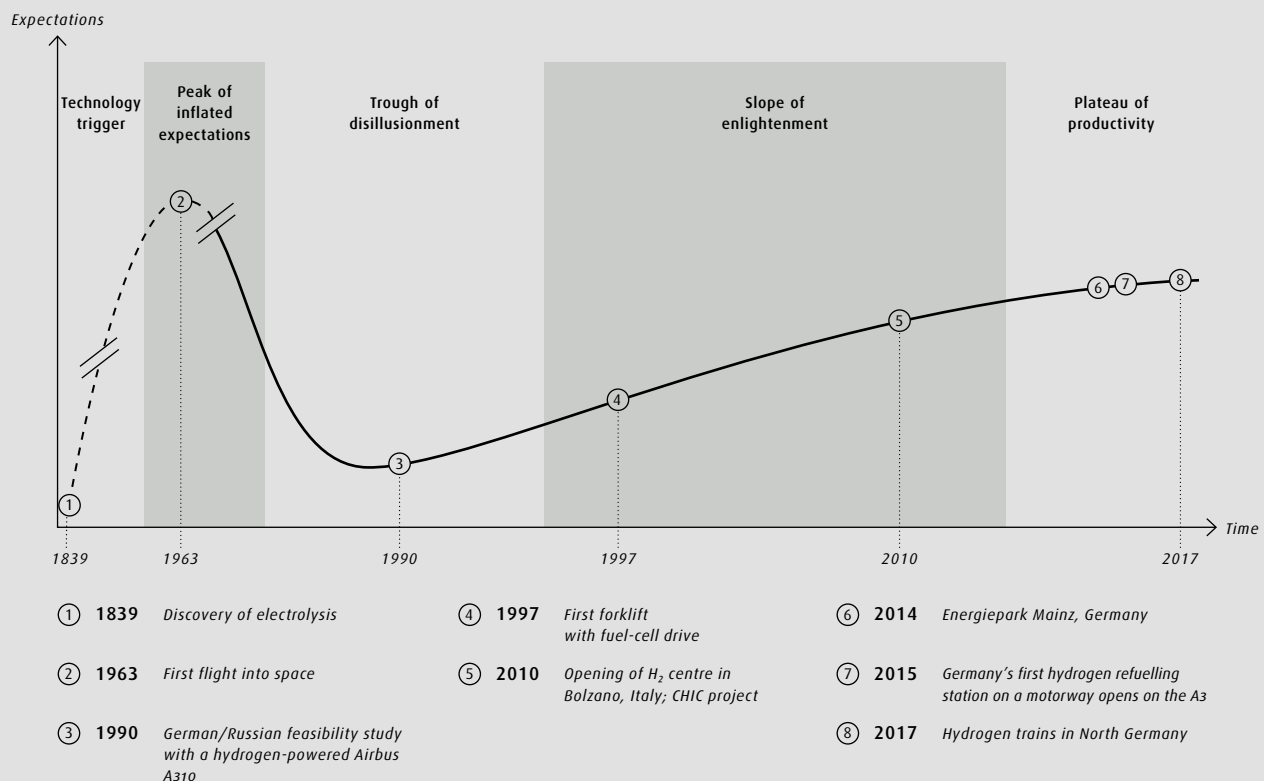
ONCE YOU'VE TRIED A
FUEL-CELL BUS, YOU'LL NEVER WANT
TO TOUCH ANYTHING ELSE!"

Service technician Roman Oberrauch rates in particular the fact that fuel-cell engines are so clean.



HYDROGEN HYPE CYCLE

US research and advisory company Gartner developed the hype cycle to visualise the maturity, acceptance and business application stages of emerging technologies. Hydrogen technology has also passed through the various phases of this cycle.



the oil age, with the first hydrogen-powered four-seater plane taking off in September 2016 – developed by the German Aerospace Centre (DLR).

Proof of concept – day in, day out

Hydrogen-based electromobility is already part of daily life in Bolzano. During the day, the custom-built H₂ fuelling station is fairly quiet. In the evening, though, the fuel-cell buses return from their daytime travels with around 200 kilometres on the clock – and then it is time to refuel. Within just a few minutes, fresh gaseous hydrogen flows into the tanks at 350 bar, leaving the buses all ready to set off again the next morning. Project manager Marlene Rinner from South Tyrol's transport company, Südtiroler Transportstrukturen AG (STA), has the facts: "It's all running very smoothly. And at 90 percent, we have the same high availability as with diesel buses." This pilot proves the everyday usability of hydrogen based mobility while establishing a ground-breaking ecology balance: five fuel-cell buses, 200 kilometres per day, six days per week and zero emissions since 2010. That all adds up to a saving of 750 tonnes of

CO₂ emissions to date. Which is great news for the air, both in Bolzano and across South Tyrol.

The call to rethink mobility choices is also gaining traction in political circles. A ban on vehicles with combustion engines is on the agenda – although whether from 2025 or 2030 is not yet certain. But there is certainly a growing consensus on this topic, since the problems with conventional technologies are pervasive. Stuttgart, for years now the German city with the highest levels of particulate pollution, has long been threatening to impose driving bans if the limits are exceeded. Paris has already taken this step several times due to smog, with the city centre periodically restricted to either vehicles with an even or with an uneven number at the end of their registration plates. Bucharest, Milan, Rome, Oslo and other European cities are also struggling with air quality, while urban areas of Asia face smog problems of an even greater magnitude. While the mobility sector is not the only culprit here, the health risks are clearly dramatic and demand a rapid response. According to a current study by the World Health Organization (WHO), over six million people worldwide die from the effects of air pollution each year.

ALESSANDRO PETRIS

Bus driver

"THEY ARE SIMPLY THE BEST
BUSES WE HAVE EVER
HAD HERE IN BOLZANO – QUIET,
COMFORTABLE AND CLEAN."

*Alessandro Petris prefers to
drive hydrogen buses.*



Clean Hydrogen in European Cities (CHIC) project

Along with four other European cities, Bolzano has benefited from public funding aimed at lowering the entry barrier to the alternative drivetrain market caused by high investment costs for the buses. The CHIC project provided almost 26 million euros to help integrate 26 fuel-cell buses in daily operations on regular bus routes across five European cities. The transport authorities of Aargau (Switzerland), Bolzano (Italy), London (UK), Milan (Italy) and Oslo (Norway) worked in close collaboration on this project from 2010 to 2016. However, Bolzano was the region that showed the strongest commitment to putting an end-to-end hydrogen value chain in place, extending from energy generation through storage to flexible usage. And now South Tyrol is taking its next strides forward – which include adding twelve more fuel-cell buses to its fleet. As soon as other cities follow suit and place joint orders, fuel-cell technology will be propelled towards series production, significantly cutting the costs per vehicle. Meanwhile, closely linking the energy supply and transport sectors has proven so successful that South Tyrol has decided to roll out this model across the wider province.

Linde has been the driving force behind hydrogen technology advancement for decades now, having made a huge contribution to widespread commercialisation in the mobility sector. Several partnerships with vehicle manufacturers have seen visions turn into market-ready solutions. However, the technology is complex and demands a high level of expertise – which also contributed to a certain element of deflation following the initial hype. For a time, Linde was one of the few manufacturers still investing in hydrogen technology. Since then, though, hopes for the mobility sector have been reviving around the world. Hydrogen is an ideal energy carrier for other applications too, capable of storing surplus electricity and stabilising the grid as more and more renewable energy sources with fluctuating feed rates are coming on stream.

Flagship location

The overall environmental footprint of hydrogen also depends on how it is produced. In answer to this, the attendant at the Bolzano fuelling station just gestures over his shoulder. Behind a motorway slip road, in the middle of a traffic intersection, lies the beating heart of South Tyrol's electromobility. Here, in the hydrogen centre in Bolzano, green electricity is turned into green hydrogen. As the only supplier to meet all the requirements, Linde won the contract to build the infrastructure, whose core consists of three electrolysis systems and several ionic compressors. This pilot plant is another part of the region's H₂ success story, quickly proving a

viable model for everyday use and now acting as a powerful magnet for both national and international delegations.

Linde is currently involved in pioneering hydrogen projects in many regions around the world, focusing in particular on local public transport. Several electrolysis plants with refuelling stations for hydrogen buses have already been installed – including in South and North Germany (Stuttgart, Hamburg), Italy (Milan), Scotland (Aberdeen) and California (San Francisco). By mid-2017, Germany alone should have a network of around 100 refuelling stations.

GREEN HYDROGEN FROM GREEN ELECTRICITY

Hydrogen is an ideal medium to store energy generated by renewable sources, which are subject to strong fluctuations in the amount of electricity they produce. And it is precisely the availability of green electricity – which South Tyrol has in abundance – that makes Bolzano such a perfect hydrogen hub.

965

HYDROELECTRIC PLANTS
and numerous photovoltaic installations in Bolzano.

The region's first hydroelectric power station opened as far back as 1895 and today it has over 965 of them, as well as numerous photovoltaic installations. Once this power is converted into hydrogen via electrolysis, it can then be stored. This relieves pressure on the grid, helps save costs and ensures on-demand availability of electricity.



For Lisa Aberer, the main attraction lies in the low levels of environmental pollution.

LISA ABERER
Student, aged 21

**"I THINK YOU REALLY
NOTICE THE DIFFERENCE.**

**THE HYDROGEN BUSES ARE
MUCH QUIETER PLUS
THEY VIBRATE LESS – IT'S JUST
A NICER WAY TO TRAVEL."**



Putting old oil to good use

Located south of the city of Leipzig, central Germany's chemical triangle is home to the world's first and only refinery to process used oils into base oil products. The key to this recycling process is hydrogen – supplied by Linde.



The Puraglobe refinery helps to avoid CO₂ emissions that would otherwise be released when used oils are burnt.

Keen to increase efficiency and improve their ecological footprint overall, many industrial companies are looking for ways to use raw materials more intelligently. One of Linde's long-standing customers is firmly committed to this strategy, and has advanced from pioneer in used oil recycling to global market leader. Based around 40 kilometres south of Leipzig at the Zeitz chemical and industrial park, Puraglobe GmbH, a German subsidiary of Puraglobe Inc., now provides the best-quality base oils in the world that are produced from waste oil. These are then used as engine oil, for instance.

Hydrogen plays a key role in the treatment process here – heavy metals and other chemical impurities are removed by vaporising the oil with hot hydrogen. A complex purification process, known as catalytic hydrogenation, turns waste engine and machine oils into high-quality base oils for the automotive and metal industries. These "recycled" base oils match the key performance characteristics of newly manufactured oils. So, for instance, they have a neutral odour, a low sulfur level and the same viscosity index.

Sole supplier worldwide

To achieve this, Puraglobe uses patented UOP-Hylube technology, fine-tuned over several years. The Zeitz production facility is one of the most advanced refineries of its kind. It consists of five reactors and 17 different catalysers – including one made of platinum, so even more costly than gold. High-pressure process technology is used to inject the hydrogen. As Alexander Stubinitzky, Head of On-Site Account Management at Linde, explains: "We have been working closely with Puraglobe for several years now and – through our hydrogen supply scheme – have made a valuable contribution to the overall cost efficiency of the plant." A pipeline connection ensures hydrogen deliveries are also completely carbon-neutral.

Focus on environmental aspects

Treating around 150,000 tonnes of used oil per year now represents annual savings of around 130,000 tonnes of carbon dioxide (CO₂) – as independent institutes confirm. And the market outlook is even more impressive: Germany alone generates around half a million tonnes of used oil each year. "Used oil is a valuable raw material for us," confirms Andreas Schüppel, CEO of Puraglobe GmbH. "And we are proud that our process enables such a significant reduction in CO₂ emissions."

The majority of recycled base oils are currently classified as Group II or Group II+. From mid-2017, the company intends to start production of Group III oils, developing a further market segment.

Group III oils are suitable for newer engines that run on synthetic oil, allowing up to 30,000 kilometres of travel before an oil change is required. Two factors improve the ecology balance still further: on the one hand, these oils can be used for longer, so overall market consumption is lower, and on the other, they reduce engine friction, cutting CO₂ emissions with each kilometre. For certified disposal specialist Puraglobe, base oils with this high classification will play a decisive role in finally capturing the high-volume global market.

ANDREAS SCHÜPPEL

CEO of Puraglobe GmbH

“WE SEE USED OIL AS
A VALUABLE RAW MATERIAL –
AND SUSTAINABILITY
AS A KEY SUCCESS FACTOR
FOR GROWTH.”

Updated framework required

At present, used oil is still classified as waste in Germany and procedures for handling it are set out in the country's recycling laws. The relevant legislation does stipulate that recycling should be prioritised over thermal use. However, while undoubtedly well-intentioned, this phrasing is unfortunately not effective in encouraging environmentally aware practices in the marketplace. Indeed, old oil is still widely used by the cement and steel industries as a cheap fuel to generate process heat – producing yet more carbon emissions.

Following the example of other industries, the market will, however, increasingly acknowledge that burning used oil makes neither economical nor ecological sense. The Puraglobe business model is also a good example of the huge range of industrial applications that hydrogen supports as a process gas. Across the full application spectrum from oil purification to environmental compliance, Linde is an innovative and reliable partner with long-standing experience in the production, storage and distribution of hydrogen.

1 TONNE OF RECYCLED OIL SAVES 1.3 TONNES OF CO₂

Treating used oil has a major ecological impact. Working independently of one another, two respected institutes – the IFEU (Institute for Energy and Environmental Research, Heidelberg, Germany) and the NSF (National Science Foundation, Arlington, Virginia, US) – both came to almost exactly the same conclusion: every tonne of base oil recycled from used oil saves 1.3 tonnes of CO₂.

1.3

TONNES OF CO₂

*are saved with every tonne
of oil that is recycled.*

38

**MILLION TONNES
OF LUBRICANT**

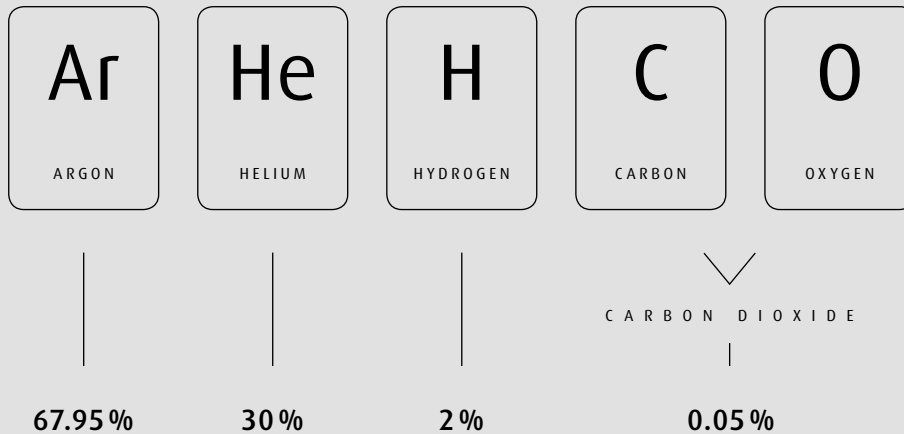
are used worldwide every year.

The potential is huge, since around 38 million tonnes of lubricant are used around the world every year. Recycling all used oils could save as much CO₂ as a country the size of Ireland emits each year.

C R O N I G O N[®] N I 1 0

HIGH EFFICIENCY, LOW EMISSIONS

*Linde has been shaping the evolution of welding technologies for several decades.
The company's ability to continually innovate traditional welding
processes gives its customers both an economical and technical lead, but also
realises potential that benefits the environment and society at large.*



**Linde's shielding gases for welding enable
power plants to operate extremely efficiently thus helping
to reduce emissions that affect climate.**

Modern steam and gas-fired power stations, such as those in Irsching (Bavaria) and Düsseldorf, recently made headlines around the world. These plants are achieving over 60 percent efficiency – partly thanks to higher combustion temperatures. However, this places greater stress on core plant components such as turbines; stress they can only withstand if the steel parts are equipped with a type of heat shield. Linde's CRONIGON[®] N110 shielding gas, for instance, can be used to evenly apply a corrosion-resistant material – usually a nickel-based alloy – to a steel body.

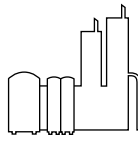
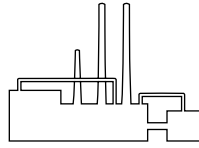
This type of overlay welding for protection against corrosion is also used in waste incinerators and biomass power plants, for example, as well as in the petrochemical industry. Anywhere, in fact, where critical components such as pipes and boilers are exposed to extreme temperatures.

Welding with CRONIGON[®] N110 offers a further benefit. The high combustion temperatures reduce emissions of flue gases that affect climate – especially carbon dioxide. The fuel burns more cleanly, helping to achieve climate protection goals, the success of which depends heavily on ongoing advances in power plant technologies.

INNOVATION

FROM CLIMATE KILLER TO VALUABLE RAW MATERIAL

Climate protection and a globally competitive steel industry – two goals traditionally considered to be mutually exclusive. Now, though, an industry and science consortium is set to change that with the Carbon2Chem project. The idea is to turn blast furnace emissions into chemical products instead of releasing them into the atmosphere and contributing to climate change. The partners hope to achieve a closed carbon dioxide (CO₂) cycle, similar to photosynthesis – except that the output here will not be sugar, but a base product for fuels, plastics and fertilizers. In the future, more than 50 million tonnes of CO₂ from the German steel industry could become a valuable industrial resource thanks to this process. First, though, these gas by-products must be pre-purified and then separated. Linde is responsible for this



>50

MILLION TONNES OF CO₂
could be used.

subproject, advancing its hydrogen (H₂) pressure swing adsorption (PSA) technology to recover reusable hydrogen and valuable synthesis gas from the emissions.

Experimental tests are scheduled to launch in 2018 at a plant in Europe's biggest steel hub in the German city of Duisburg, potentially paving the way for a harmonious balance between conflicting interests. Or, as Johanna Wanka, Germany's Federal Minister of Education and Research, put it when announcing the project: "Moving forward, industrial production must go hand in hand with a strong commitment to climate protection. With Carbon2Chem, we are showing how this can be achieved in the real world, and bringing the Paris Agreement to life in the process."

COMPANY HISTORY



CARL VON LINDE

Renewable energy was hardly a burning issue for Carl von Linde when he opened his production site in Hoellriegelskreuth (Pullach) just south of Munich back in 1901.

More to the point, he needed on-demand access to a heavy-duty supply of electricity.

For production and process technology experiments, he needed as much as 150 HP on any given day. The nearby hydroelectric power station run at the time by Isarwerke GmbH was able to deliver this power, whereas the weaker



150

HP FROM
HYDROELECTRIC SOURCES
powered production and
experiments at Linde.

grid available at the former location in Munich's Nymphenburg district had not been able to do so.

Which is why von Linde decided to look for a new company premises. The benefits of Hoellriegelskreuth included what we would now term sustainable energy management, plenty of space and the knowledge that he could set up operations without either disturbing neighbouring communities or being disturbed. The company also bought the site, now home to the company's largest premises, from the supplier of the three-phase current it needed, Isarwerke GmbH.

S U S T A I N A B I L I T Y

HYDROGEN IN POLE POSITION

WORLDWIDE



445

TEAMS

*bringing together around
3,500 students from around
the world to compete.*

E U R O P E

200

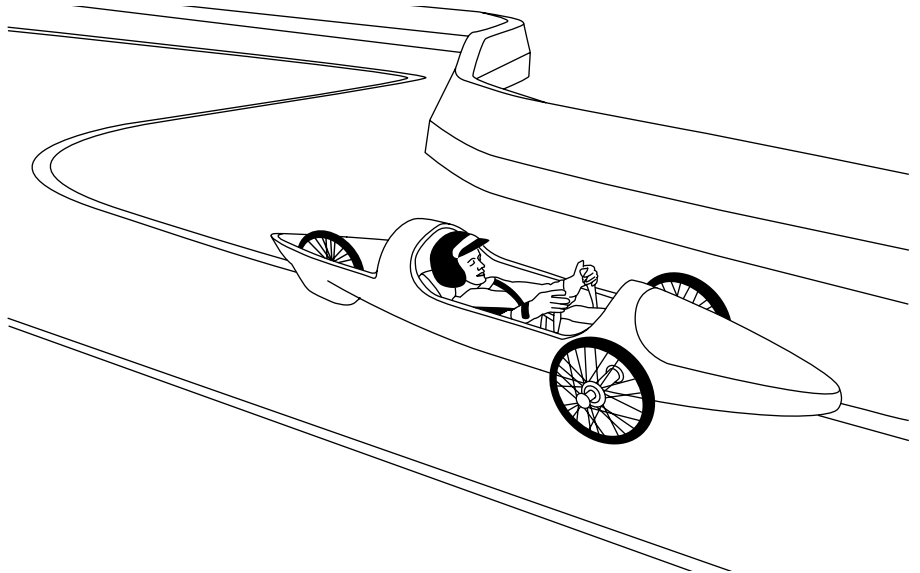
TEAMS
from

29

COUNTRIES
including

14

FROM GERMANY
*took part in
the 2016 European event.*



Powered by innovation, eco-friendly mobility is really gaining traction. The Shell Eco-marathon is the world's biggest energy-efficiency competition, challenging students and trainees around the globe to publicly showcase their ideas and inventions around sustainable drive-train technologies. Who can design, build and drive the most energy-efficient car? And who can travel furthest on the least amount of fuel?

Competition events are held each year in Asia, the Americas and Europe. In 2016, over 440 teams from more than 50 countries took part in various events around the world. 14 teams from Germany took their place at the starting line of the European Eco-marathon in London.

After a year of preparation, the young engineers were ready to step on the gas in vehicles they built themselves – with Linde providing technical advice and support. As an official partner, the company supplied ready-to-install hydrogen cylinders to all teams entering fuel-cell vehicles. Experienced engineers were on hand to give the students technical support in changing the hydrogen cylinders in the cars, checking for potential leaks in the H₂ system and monitoring driving performance. This gave participants a valuable opportunity to gain practical experience. Each year, the

competition sets new efficiency records for distance travelled – and gives fresh impetus to the training and development of young technicians enthusiastic about new, eco-friendly solutions in the process. As patron of the European Shell Eco-marathon, Johanna Wanka, Germany's Federal Minister of Education and Research, opened the London event with an address emphasising the importance and impact of pioneering research for our everyday lives.

Linde has been a driving force in researching and developing hydrogen infrastructure technologies for several decades now. The company's offering in this area thus includes innovative solutions at every link in the value chain of hydrogen-powered mobility – from production and storage to distribution and refuelling systems. Linde is also innovation leader in green hydrogen, generated for instance from surplus electricity from renewable sources such as solar, wind and hydropower, and has equipped over 150 fuelling stations in more than 15 countries with hydrogen refuelling technology to date.

The Linde Group thus plays a pivotal role in shaping a more efficient and sustainable future for mobility.



Leveraging Potential: Society

Business success cannot come at the expense of society. Which is why Linde prioritises technologies that balance business interests with a sense of responsibility towards society. The company steps up to its duties in this area through innovations that help improve patient care while relieving the burden on healthcare systems. And by balancing quality of life with the need for efficiency, the company is also helping to secure supplies of one of the world's most valuable resources: clean water.



THERE'S NO PLACE
LIKE HOME

60



SECURING WATER
SUPPLIES

70

THERE'S NO PLACE LIKE HOME

Healthcare spending in the US is at nearly 3 trillion dollars annually. That equates to more than 17 percent of its Gross Domestic Product. With that figure expected to reach 20 percent by 2022, there is an ever-increasing need to find more cost-efficient ways of delivering quality care. Lincare – a US Linde subsidiary – is doing exactly that: containing costs while at the same time improving the quality of life for its patients. How? By bringing healthcare to the home.



Equipped with his mobile oxygen concentrator, Robert Lohr is free to get out and about – despite his chronic lung condition.



*Reliable oxygen supply in his own home
is hugely important for Robert Lohr.*



ROBERT LOHR
Patient

"I CAN'T ENGAGE IN ANY STRENUOUS ACTIVITY
BECAUSE I JUST RUN OUT OF BREATH SO I HAVE TO BE
CAREFUL WHAT I DO AND WHEN I DO IT."



"I just enjoy life for what it is," says Robert, in a voice so sprightly it belies his 89 years.

Robert Lohr, like more than 11 million other Americans, has been diagnosed with Chronic Obstructive Pulmonary Disease (COPD) – a progressive life-threatening lung disease that causes breathlessness and predisposes to exacerbations and accompanying illnesses.

Robert's treatment facility? His home in Florida. Here, licensed clinicians and service representatives from Lincare visit him on a regular basis and support him in many ways – not least by providing the oxygen and breathing apparatus that he depends on at night and most of the day. This includes the stationary oxygen concentrator as well as his battery-powered 'portable' which can even be plugged into his car's cigarette lighter. But although Robert still has the freedom to get out and about, he is well aware of his limitations:

"I can't engage in any strenuous activity because I just run out of breath so I have to be careful what I do and when I do it," he explains.

Robert's diagnosis confirms his condition, yet more often than not, people suffer COPD unknowingly. In 2013, the American Lung Association estimated that a further 24 million cases in the US went undiagnosed. And that's only one part of the story.

Robert Lohr and his wife Faye are amongst 46 million seniors (65 and over) in the US today. They also represent an increasing number of seniors living well into their mid-80s. Indeed, life expectancy is projected to gradually increase, with men living, on average, to age 87 and women to age 89 by 2060. We have modern medicine to thank for that. But the same modern medicine must now treat the rising rate of chronic disease that is part and parcel of an ageing population. Respiratory conditions like COPD for example are becoming more and more prevalent: a 4 percent compounded annual growth rate is expected in the US from 2014 to 2020.

And in the end what do all of these statistics amount to? Unsustainable costs of healthcare. COPD cannot be cured. Yet the 11 million diagnosed COPD patients must be treated, putting enormous strain on the system. Healthcare cost solutions are required: cost-efficient options for delivering quality care to a growing market. One such solution is homecare – and that's where Lincare comes in.

Thanks to oxygen therapy in the home, respiratory patients can continue to enjoy familiar surroundings with home comforts and loved ones at hand.





Shifting the point of care

Lincare is the leading US provider of oxygen and other respiratory therapy services to patients in the home. It provides homecare services and equipment to 1.2 million patients like Robert operating from over 1,000 locations in 48 US states and Canada. Lincare's core business is home oxygen therapy with a focus on respiratory care for patients, including those with COPD, sleep apnoea and the need for ventilation services.

"Our mission is to set the standard for how care is delivered in the home. We want to make homecare an easy, accessible, relevant part of the healthcare continuum," explains Kristen Hoefer, CEO of Lincare – part of The Linde Group.

Considering that healthcare continuum: by far the least cost-efficient way to treat a patient is when they're in crisis. A trip to the emergency room to treat an exacerbation for example can cost on average around 2,000 dollars. Should they then have to be admitted to hospital, the average cost can become about 4,000 dollars per day. What homecare does is move the point of care along that continuum to where it becomes the most cost-efficient: to the home of the patient. Depending on a patient's location, the average cost to Medicare – the US federal health insurance programme for people who are 65 or older – for providing stationary oxygen in the home is a relatively modest 2.35 dollars per day.

In the current climate, healthcare providers in the US are increasingly asked to demonstrate how the care products or services they provide help contain costs while delivering positive outcomes for the patient. The cost aspect of homecare is clear, but what about positive outcomes for the patient?

1.2

MILLION LINCARE PATIENTS
IN THE US
AND CANADA.

4,000

US DOLLARS
IS THE COST PER DAY
OF IN-PATIENT
HOSPITAL TREATMENT.

2.35

US DOLLARS
IS THE COST PER DAY
OF STATIONARY OXYGEN
SUPPLIES AT HOME.

20%

OF THE 13,000 LINCARE
STAFF MEMBERS ARE
MEDICAL PROFESSIONALS.

Home comforts

"When am I getting home?" goes the familiar plea of most hospital patients. It speaks to the inherent desire to be at home, in familiar surroundings with home comforts and loved ones at hand. That's where homecare has an invaluable advantage. It improves health outcomes, is cost-effective, but most importantly, it improves patients' quality of life – as Hoefer states:

"When you have COPD, it's a progressive disease – it doesn't go away. So we're not trying to cure patients, we're trying to enable them to live productively with their disease."

In moving away from the safety net of the hospital or other around-the-clock care facilities, however, the idea of help being on hand must be maintained. Patients want home comforts, but they also need peace of mind that they can 100 percent depend on Lincare. As well as helping them remain engaged in life, an important part of the Lincare vision and strategy is the 'peace of mind' concept which Hoefer goes on to describe:

"Think for a minute if you didn't have the oxygen you needed to breathe and the fear that this instills – not knowing if you can take your next breath. It's extremely nerve-racking. Patients need to be able to rely on us to not only provide that oxygen, but ensure that they never run out – wherever they may be."

The strong, personal relationships between patients and the Lincare clinicians who see them in their homes give patients the reassurance they need. Lincare's deep clinical expertise is a compelling and differentiating advantage, with clinicians representing about 20 percent of its 13,000 strong workforce. The company also has an experienced team of service representatives who serve patients. Robert Lohr is the first to sing the praises of Scott Rogan – the service representative who works closely with him:

"I have nothing but praise for Scott – the man who takes care of me. He has been super to me. When I need him he's always available and that means an awful lot."





A partner in care

Adopting such a 'clinical model' not only means building trusting relationships with patients but with prescribing physicians too. In that respect, Lincare strives to be more than just a supplier but rather a partner in care. This means communicating with prescribing physicians to help them stay informed, intervene earlier and effectively manage the patient's condition.

Lincare's patients come to them through physician referrals. Dr Hugh Rutledge is one of those doctors. Based in Florida and a specialist in geriatric medicine with decades of experience in treating COPD and sleep patients, he knows the importance of good communication:

"As I've always said, as a physician, I'm only as good as the person I send you to. If I send you to a bad homecare provider, I'm bad. We are very specific about who we use because we need clinicians out there who are smart, who can recognise an issue and who can communicate well. Lincare has those."

He also knows the importance of quality care during the transition period of becoming dependent on breathing apparatus, for example. In this sense, physicians rely on Lincare to smooth the transition from traditional care to homecare:

"When dealing with these respiratory conditions, you really need someone who can hold the hand of the patients as they get used to these devices – Lincare does a good job with that."

Lincare has firmly established itself as the industry leader in homecare. Patients, physicians and insurance companies alike recognise it as a strong, stable company that will be around for years to come. The backing of Linde means it will continue to grow to serve more patients more effectively. The recent acquisition of American HomePatient, a major US provider of home healthcare products and services, illustrates the strategic approach to growth and scale perfectly.



Kristen Hoefer is responsible for the wellbeing of 1.2 million Lincare patients.



KRISTEN HOEFER
CEO of Lincare

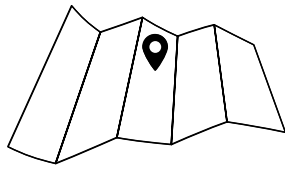
"WHEN YOU HAVE COPD, IT'S A PROGRESSIVE DISEASE - IT DOESN'T GO AWAY. SO WE'RE NOT TRYING TO CURE PATIENTS, WE'RE TRYING TO ENABLE THEM TO LIVE PRODUCTIVELY WITH THEIR DISEASE."

*Monica was always a passionate traveller –
and she still is thanks to mobile oxygen therapy.*



MONICA AND HERBERT VOLKER
Patient and her father

**"THANKS TO LINCARE, WE CAN SPEND
OUR WINTERS IN FLORIDA."**



1,000

EXISTING LINCARE
LOCATIONS.



200

AMERICAN
HOMEPATIENT
LOCATIONS.

Looking to the future

In February 2016, Lincare completed their largest acquisition to date, acquiring Tennessee-based American HomePatient with over 2,000 staff. This represents two important strategic steps. The first is growing the core business: American HomePatient was also focused on respiratory care – primarily sleep therapy. The second is increasing Lincare’s density in markets, allowing them to take advantage of economies of scale, as Hoefer points out:

“With the American HomePatient acquisition, we added around 200 locations, primarily located in the Eastern and Central states. Growth and market density are essential to our success. Our expanded footprint allows Lincare to serve more patients, more cost-effectively.”

While Lincare clearly has a tremendous business and an expanding market that will support profitable growth, it also has a calling: to make life better for patients and the people who care for them. As Dr Rutledge says:

“Staying at home means everything to these patients. Even the nicest care facilities will never be home, so we do everything in our power to keep them there.”

As long as that is the case, Linde will play an increasingly important role in healthcare – and patients like Robert Lohr will continue to do the little things that bring them true happiness:

“I took my wife to a ballet last week,” he says proudly. “We sat through it for two hours with no problem at all.”

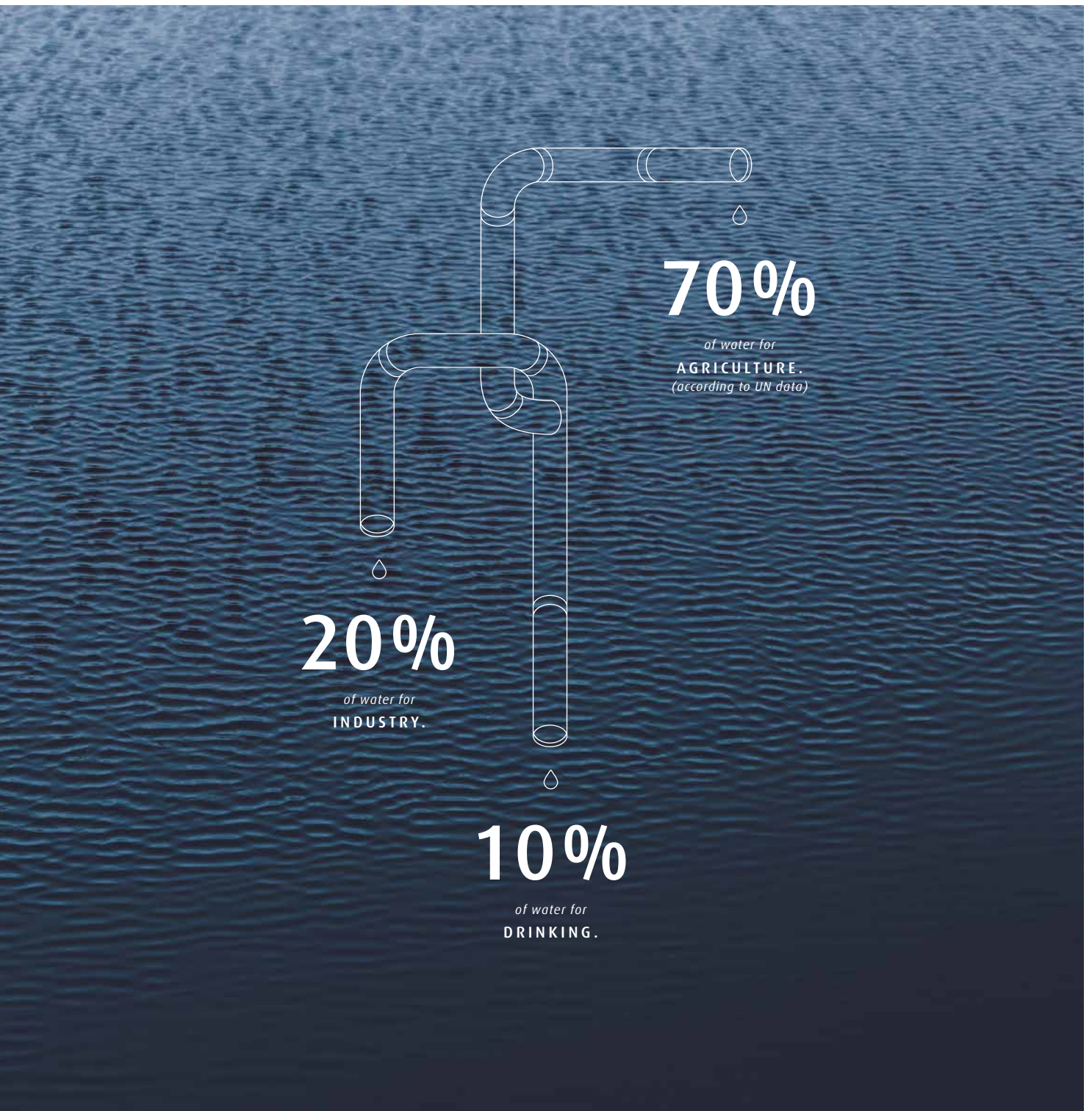
SECURING WATER SUPPLIES

Water scarcity is one of the most pressing problems of our time, with agriculture, industry and private homes all competing for this valuable commodity. Over the years, Linde has developed a water treatment system that not only alleviates this conflict of interests but also supports conservation efforts – SOLVOCARB®.

In Israel, every drop counts. Just a few years ago, the country was almost at breaking point due to chronic water shortages. Population growth, rising living standards and climate change were considered the main causes of this predicament. But that changed when Israel took a closer look at how it is using water and explored untapped potential. Today, Israel is a shining example of water efficiency. A conservationist strategy is now flanked by state-of-the-art technologies, such as desalination plants, to protect this valuable resource.

The water cycle does not waste water. So although freshwater is clearly unevenly distributed around the world and reserves will continue to fluctuate depending on local weather conditions, shortages are often the result of careless use. Recycling is thus the key to security of supply.

Balanced water chemistry is at the heart of all water treatment processes. If the pH value is too high, water becomes undrinkable. And not only



that – water with high alkalinity can also affect infrastructure, causing corrosion damage to pipe-work or making it impossible to manufacture industrial goods, for instance. That is why Linde developed the SOLVOCARB® system – a reliable, eco-friendly way to neutralise the alkaline pH value of water using carbon dioxide (CO₂). Reliability and ecology are particularly important when obtaining drinking water from the ocean, for instance.

Quenching our thirst with seawater

Around 40 percent of the global population lives less than 40 kilometres away from the coast – and that figure is set to rise. In these regions, seawater treatment offers a means of reducing pressure on freshwater reserves in the future.

“Everything is pointing towards desalination,” confirms Darren Gurney from the Linde Global Development Centre. Gurney is a water treatment expert who has seen countless desalination plants go on

stream in the last few years – due in no small part to Linde’s SOLVOCARB® system. After adding important substances such as calcium compounds to enrich the seawater (known as re-mineralisation), the pH value is then corrected to place it in the range required by the customer. This is achieved by adding CO₂.

“The costs per cubic metre of treating water have dropped significantly in the last 15 years,” reports Gurney, adding that this has less to do with energy prices and more to do with technology and continued innovation. Linde already has Singapore’s next major plant on its order books for 2017. This will be the island state’s second desalination facility, using SOLVOCARB® to recover several hundred million litres of drinking water from the sea each day. Over time, SOLVOCARB® has become more and more efficient, opening up new opportunities and expanding the application spectrum. As a result, companies are increasingly also turning to CO₂ to treat water for industrial purposes.

To the good health of the environment

Pilsner Urquell is famous around the globe. This Czech brewery is benefiting from the current beer boom – of all alcoholic drinks, beer is the most popular worldwide. The other side of the coin is high water consumption, with around 2.4 litres required to produce one litre of beer. Before the process water can be piped to the public infrastructure for treatment and discharge, the pH must be brought to an acceptable level. Stipulations vary from one country to another here. In the Czech Republic, the target pH for companies falls between 5 and 10. By comparison, aquatic ecosystems ideally require a value between 6 and 8.

To reduce the pH, Pilsner Urquell previously mixed its high-alkalinity rinsewater with the remaining, more acidic, wastewater. Ultimately, though, that was not sufficient to neutralise the alkaline

BENEFITS OF THE CO₂ METHOD

In contrast with conventional methods using hydrochloric or sulfuric acid, neutralising the pH value with CO₂ is a far more eco-friendly, natural approach. Indeed, this effect can also be observed naturally in freshwater. With SOLVOCARB®, gaseous CO₂ reacts with water to form carbonic acid. This is a weak acid with a high buffering capacity, meaning that the pH value of the water barely changes, even if acids or bases are then added.


pH 7
*is ideal
for ecosystems.*

Stabilisation with sulfuric acid, on the other hand, is much more complex and laborious, since even a slight overdose can result in a dramatic reduction in pH – particularly if the water is only mildly alkaline, i.e. with a pH value close to neutral (pH 7).

effect. As a result, the brewery turned to Linde’s SOLVOCARB® D technology. This variant uses a nozzle to inject CO₂ into the plant’s own wastewater system. This makes it easier to balance the pH – which both benefits nature and eases the burden on downstream treatment facilities.

Smaller water footprint

The CO₂ method of neutralising pH is rapid, precise and effective. “When CO₂ is added to the water, it controls the pH, hardness and alkalinity, making the water quality more consistent,” confirms Paul Bradford of Kimberly Clark, one of the world’s largest manufacturers of personal care products. Bradford is a process engineer at Kimberly Clark in South-East England, where toilet paper is produced. Manufacturing this everyday item requires 150 cubic metres of water per hour – around as much as a four-person household in Germany consumes per year. In view of these volumes, Bradford’s company began to look into ways of using process water more efficiently. The breakthrough came in 2014, with Linde’s SOLVOCARB® solution. Since then, around 70 percent of the water is recycled in-house and reused in further processes. Not only does this save the company substantial wastewater costs and reduce the pressure on public infrastructure, it also shrinks the environmental water footprint.

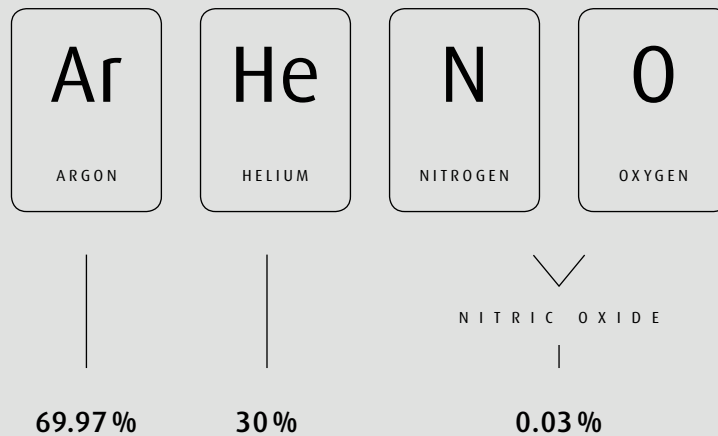
By 2050, 40 percent of the population will live in regions where water is scarce. At the same time, demand for water is rising. While SOLVOCARB® alone will not be able to redress the balance, the Linde system is certainly part of the solution. Not just because it secures drinking water supplies, but also because it enables industry to make more efficient and responsible use of this valuable resource – without either limiting industrial processes or squeezing supplies to other areas.

M I S O N®

HEALTHIER WORKING ENVIRONMENT FOR WELDERS

Linde has been shaping the evolution of welding technologies for several decades.

The company's ability to continually innovate traditional welding processes gives its customers both an economical and technical lead, but also realises potential that benefits the environment and society at large.



Shielding gases from Linde are shining a new light on welding – also providing an excellent foundation for improving the working environment of welders.

A hull in a shipyard: towering steel walls, blasted by large welding torches in the hands of even larger welders, sweat dripping from grimy faces, surrounded by noise and smoke. Needless to say, this archaic imagery is a far cry from reality today – dirty, dark and dangerous has long since been replaced by cool, clever and clean in today's welding profession. A transition that is partly attributable to the development of shielding gases such as Linde's MISON® range. These gases dramatically reduce the formation of hazardous substances during welding.

Take ozone, for instance – one of the most harmful gases of all for humans. Depending on the material, but particularly when welding aluminium, ultraviolet radiation generated by the welding arc reacts with oxygen in the surrounding air to form ozone. However, MISON® gets rid of this gas immediately. Shielding gases like MISON® play a key role in meeting and even exceeding occupational safety standards, thus ensuring a secure future for welding.

HEALTHCARE

REMEO® CARE CENTRES – OPENING DOORS FOR PATIENTS AND ATTRACTING NEW TALENT

Rehabilitation therapy is essential for patients on long-term mechanical ventilation who wish to return to their home environment. Thanks to Linde Remeo® Deutschland GmbH, these patients now have a slightly wider and richer set of choices with options along a clinical care path outside the acute care setting. In Germany, seven specialized nursing homes have already been established.

However, REMEO® centres are not just opening up new opportunities for patients. For the last three years, these dedicated units have also been training geriatric caregivers in an effort to attract and develop new talent in the sector. Germany is already lacking around 44,000 clinical personnel and as the majority of baby boomers reach old age, demand is increasing. Against this backdrop, Linde Healthcare is combining the latest technologies with clinical excellence and a personal commitment to talent development. Frank Stotko, HR Manager at Linde REMEO® Deutschland GmbH, sees this as a crucial aspect: "Whether clinical personnel or engineers, in the end it's always the people themselves that make the difference."

7

LOCATIONS

in Germany.



FRANK STOTKO

HR Manager at Linde REMEO® Deutschland GmbH

"WHETHER CLINICAL PERSONNEL
OR ENGINEERS, IN THE END
IT'S ALWAYS THE
PEOPLE THEMSELVES THAT
MAKE THE DIFFERENCE."

COMPANY
HISTORY

CARL VON LINDE

FOUNDED "GESELLSCHAFT
FÜR MARKT- UND KÜHLHALLEN"

Preserving foods by cooling was already a well-established practice before Carl von Linde's day. However, the development of industrial cooling units opened up new possibilities of entirely new dimensions. In 1890, von Linde thus founded "Gesellschaft für Markt- und Kühlhallen" (market halls and cold storage company) in the German city of Hamburg. Numerous applications developed at the time demonstrate the appeal of this business proposition, including refrigerating milk, freezing meat and even a method for freezing asparagus. The decision to move beyond the pure cooling and storage business to include the actual processing of food with gases and freezing technologies was a key milestone in the company's history. To this day, the food and beverages segment is a key pillar in the company's business model, built on the fact that Linde can preserve and protect frozen goods for today's consumer with its gases and processes.

SOCIAL ENGAGEMENT

PATRON OF THE DEUTSCHES MUSEUM

The fascinating world of science and technology is an essential part of any modern society. Carl von Linde was well aware of this, which is why in 1903, he founded the German Museum of Masterpieces of Science and Technology (Deutsches Museum von Meisterwerken der Naturwissenschaft und Technik) in Munich along with Oskar von Miller and other peers. In 2016, his company still ranked as one of the museum's keenest supporters. After all, technology breakthroughs are a lot more likely to succeed in a climate that actively fosters interest, acceptance and technical understanding.

With over 1.5 million visitors each year, the Deutsches Museum is one of Germany's most popular museums today. The building, however, is in urgent need of modernisation and many permanent displays with complex and valuable exhibits require reconditioning.

To secure the museum's position as a leading international exhibitor of science and technology, the Deutsches Museum initiative for the future (Zukunftsinitiative Deutsches Museum) was launched. Linde is one of the founding members of this initiative and is

supporting the extensive renovation efforts with a donation of five million euros.

Modernisation work is already progressing fast, with the first revamped section set to reopen in 2019. The world's largest science and technology museum will be ready to reveal its fully renovated splendour in time for the building's hundredth anniversary in 2025.

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