ANNUAL

2017

Compelling Perspectives

LeadIng.

THE LINDE GROUP

Today's headlines are a steady drumbeat of the global challenges of our time – digitalisation, demographic shifts, climate change ... Whether these bring opportunities or risks ultimately depends on each stakeholder's sense of empowerment. Since Linde was founded in 1879, the company has intuitively anticipated and actively shaped the major developments of the day. Because a company can only offer its customers, employees and investors compelling perspectives for the future if it can identify megatrends, channel them into evolutionary technologies and bring concrete solutions to market.

ECONOMIC PERSPECTIVES

Automation is having a far-reaching impact on our working lives. At the same time, Industry 4.0 is creating huge potential for cost and efficiency gains. At this dynamic interface between humans and machines, collaboration is the key to success.

PAGE 04

"IN THE PAST, YOU HAD TO GET BEHIND THE WHEEL OF A FORKLIFT TRUCK – NOW, ALL YOU NEED TO DO IS TAP YOUR TABLET AND AN AGV WHIZZES UP."

RALF WORRECH
DEPUTY PLANT MANAGER, MARL

TECHNOLOGICAL PERSPECTIVES

Technology lies at the heart of everything we do, with digitalisation unleashing a wealth of new possibilities. Yet Linde does not believe in jumping on every bandwagon, instead preferring to selectively roll out new technologies in use cases that create real customer value.

PAGE 26

"WE CAN USE VIRTUAL REALITY TO TRAIN OPERATORS IN PLANTS THAT HAVE NOT YET EVEN BEEN COMPLETED. SO WORKERS KNOW 'WHAT, WHERE AND HOW' ON THEIR VERY FIRST DAY ON THE JOB."

NANNA THIELE,
PROGRAMME MANAGER
DIGITALISATION, PULLACH

ECOLOGICAL PERSPECTIVES

Creating value doesn't have to be at the expense of the environment. The world's largest petrochemical plant in Saudi Arabia is proof positive – turning waste CO_2 gas into a valuable commodity.

PAGE 46

"THE CUSTOMER WAS VERY CLEAR ABOUT THE NEED TO BALANCE ECOLOGY WITH ECONOMY – THIS WAS NEVER GOING TO BE 'EITHER OR'."

MUHAMMAD MUHAMMADIEH, MANAGING DIRECTOR OF LINDE ENGINEERING SAUDI ARABIA

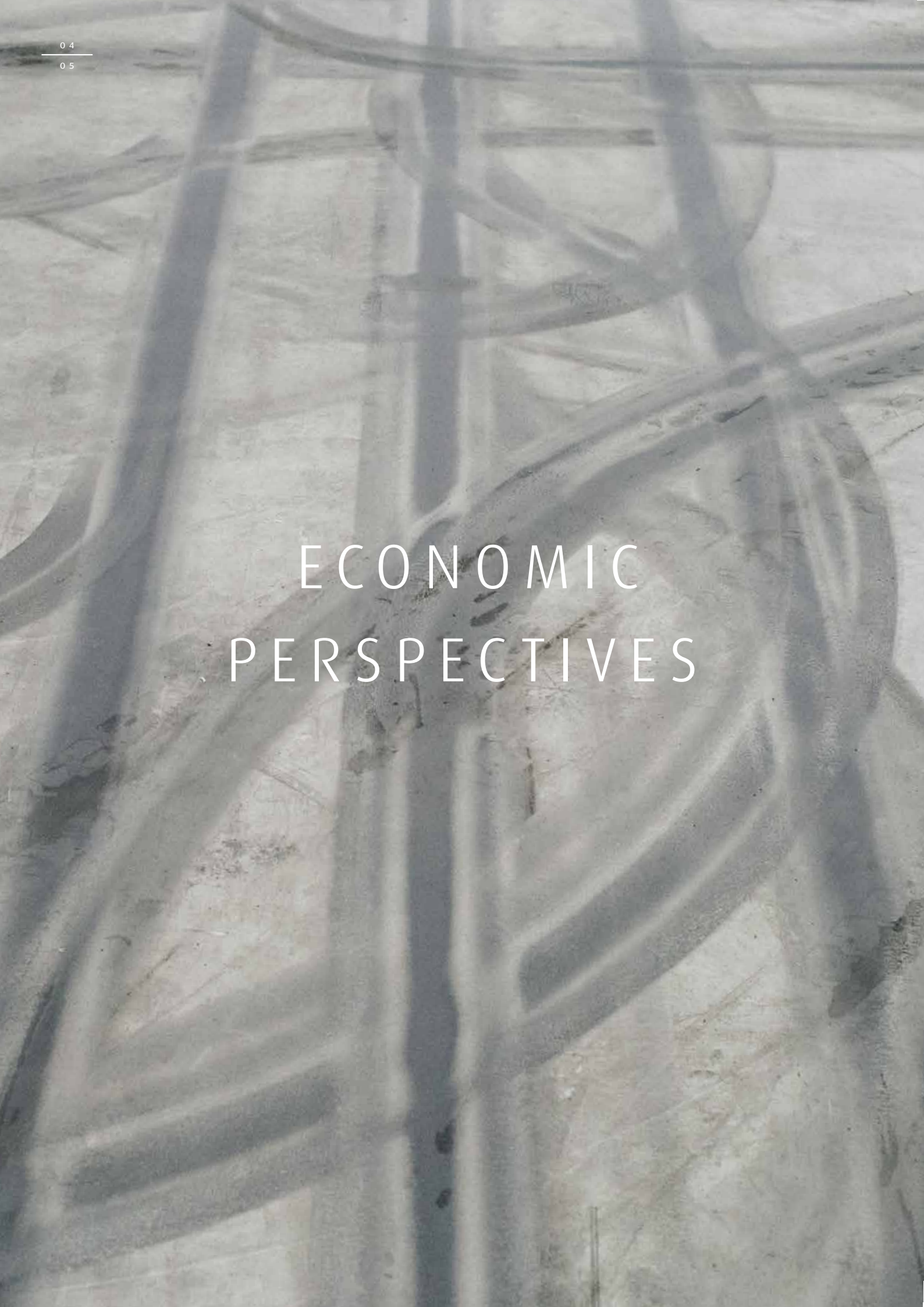
SOCIAL PERSPECTIVES

One of the downsides of globalisation is the massive air pollution caused by commercial shipping. This is placing the spotlight on marine fuel. Our solutions here offer promising perspectives for the shipping industry – and for society as a whole.

PAGE 60

"EFFORTS TO REGULATE SHIPPING EMISSIONS LAG BEHIND THE AUTOMOTIVE INDUSTRY BY AT LEAST TEN YEARS – SOME WOULD EVEN SAY THIRTY."

JOHAN MELLQVIST, CHALMERS UNIVERSITY OF TECHNOLOGY, GOTHENBURG



ECONOMIC PERSPECTIVES

Robots are replacing human muscle power – a key step in the pressing quest for greater efficiency. Still more importantly, they are opening up new opportunities for both Linde's customers and its employees. The wheels of change are also turning at Linde's gas filling plants, powering a carefully balanced transition to automated technologies in close alignment with regional social and economic dynamics.


+CR11
CIMCORP

THE AUTOMATED PLANT FAMILY

It's full speed ahead for Linde on the journey to automate its gas filling plants – a move motivated both by financial considerations and by the key trends of our time. This carefully engineered technology transformation journey will ultimately benefit both employees and customers.

Emma Lejonberg smiles enthusiastically when asked whether automation already plays a role in her personal life: "Indeed it does! We recently moved into our new home near Enköping, and I must say, it's a pretty intelligent house. We can now control lighting, heating and various other things with a smart app." As Cylinder Operations Manager at Linde, the Swedish 36-year-old is no stranger to robotics and automation. Until recently, she worked for power and automation technology group ABB, joining Linde's Swedish Group member AGA in November 2017 – "because here I have an opportunity to create something new."

Located in Northern Europe, around 80 kilometres northwest of Stockholm, Enköping will also soon be home to one of the world's most advanced gas filling plants. The plant is currently under construction and Lejonberg has been involved from her very first day at Linde. Not only is she helping to get her company fit for the future; she is also co-pioneering the transition to the Second Machine Age.

COMPLEMENTING – AND NOT REPLACING – HUMANS

While the prospect of a digital era creates a vague sense of uncertainty among many employees, companies in leading industrialised countries are busy preparing to harness the new opportunities it promises. Both optimism and scepticism are flanked by shifts in social and economic life that further increase the relevance of digital technologies. These include cost pressures, rising demand for specialised products and the need for greater flexibility. At the same time, companies face steadily ageing workforces and

Filling carousel, Riihimäki, Finland: The fully automated gas filling station was brought to maturity here. The Finnish site serves as the automation hotbed for cylinder filling.

difficulty filling vacancies for trainees. Digitalisation offers a solution to these conflicting demands, favouring brain over brawn. But does this mean that algorithms will replace human intuition? And that automation will replace human workers? Or is it the key to greater productivity and prosperity?

As a process and technology expert for filling plants around the globe, Rob Wark is one of the people playing a key role in shaping the new working world at Linde. "We don't intend to automate every single plant – only the ones where it makes sound business sense. And even then, it won't necessarily extend to every workflow."

GEARING UP FOR THE FUTURE

Wark comes from Canada – a country renowned for its open-mindedness and strong sense of community. And this spirit of solidarity also underpins the Linde expert's strategic planning. Wark is responsible for overseeing the global transformation of the Group's gas filling plants. His mission began five years ago, when senior management decided to review the future viability of Linde's 400 or so filling plants, obviously taking regional and market-specific requirements into account. "We set out to find a modular, scalable solution – and not a universal blueprint," Wark explains. This was not a one-size-fits-all project – the aim was to align the degree of automation with local dynamics such as the competitive landscape, customer demands and labour costs.

THE DEGREE OF AUTOMATION IS ALIGNED WITH LOCAL DYNAMICS SUCH AS COMPETITION, CUSTOMERS AND WAGE LEVELS.

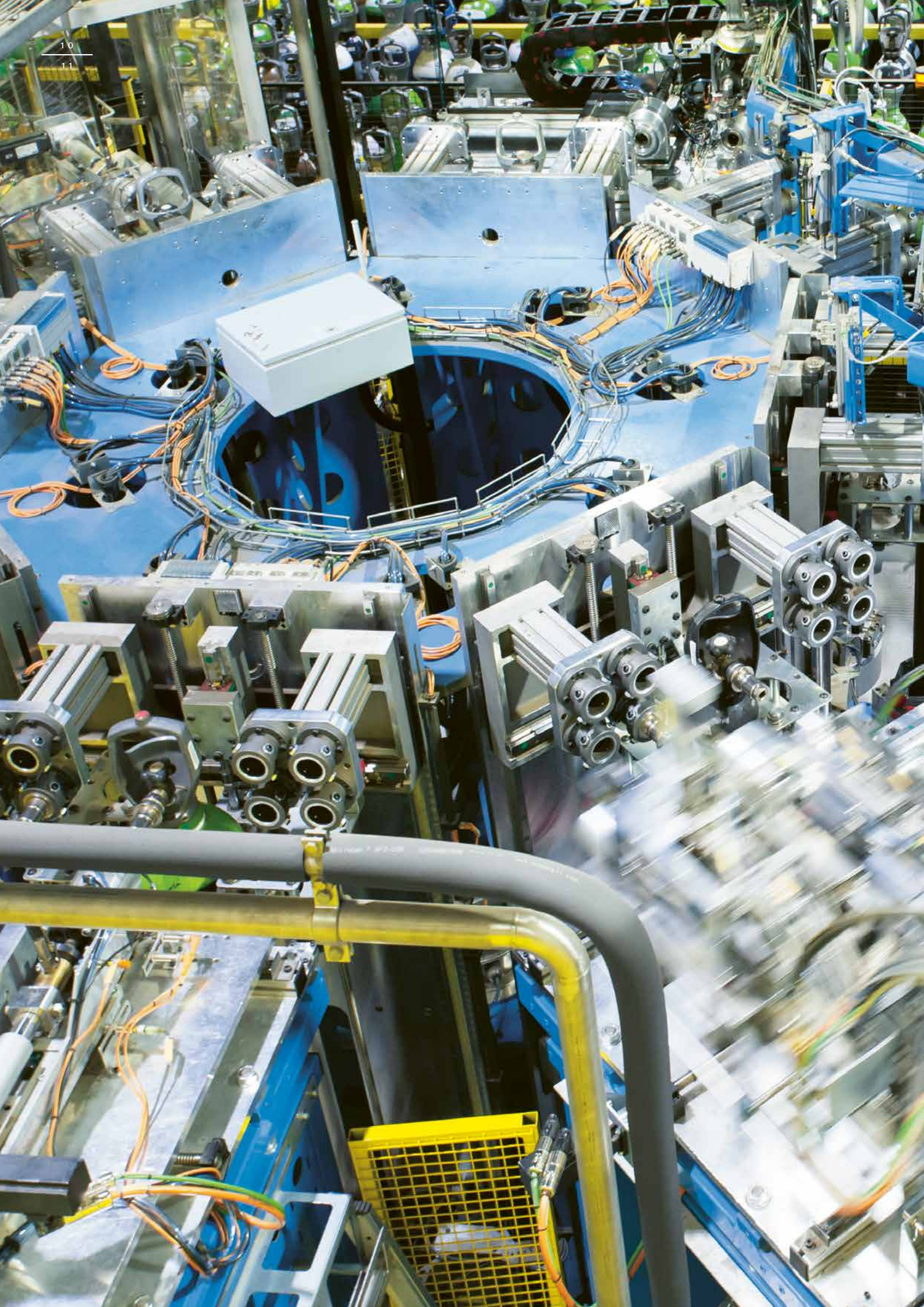
Needless to say, this plan has meant a great deal of extra travel for Wark over the intervening five years. One trip took him to Riihimäki, in Finland – to a site that functions as the automation hotbed for Linde's filling plants. Automated processes were first introduced in Riihimäki as far back as 20 years ago. Since the last complete overhaul, no-one here is surprised to encounter driverless forklifts – also known as automated guided vehicles (AGVs) – or gantry robots as they transport cylinders from A to B and remove them from their pallets. The site also deploys automated optical inspection capabilities to check cylinders for damage before reuse. However, the most recent automation highlights are the sort & pick and the filling carousel modules, which have been sorting and then filling empty cylinders here since June 2017.

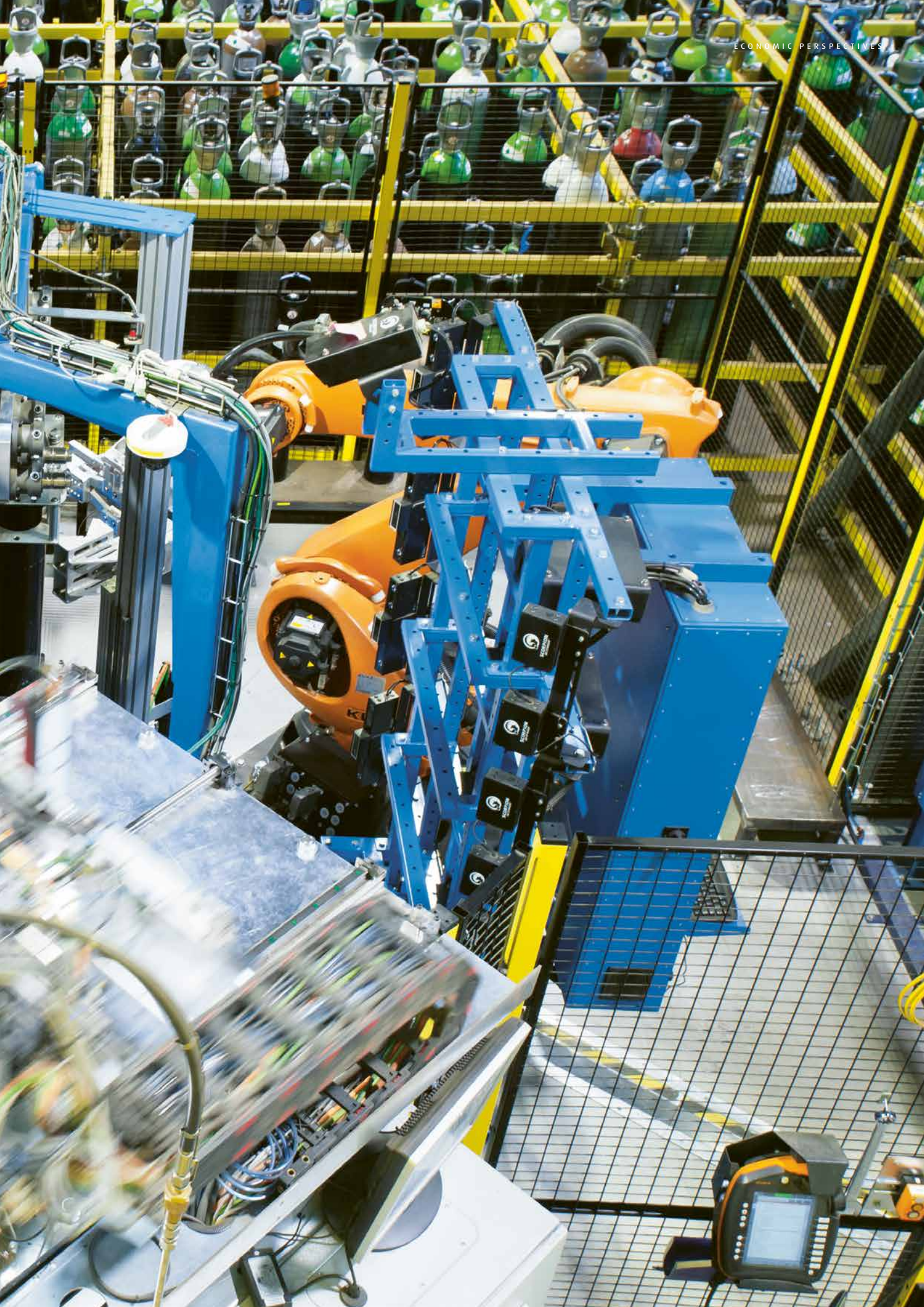
This pioneering plant has since inspired further flagship projects across four countries, which Wark affectionately refers to as the "plant family". Each family member focuses on optimising one step in the automation process flow.

Next page: Filling carousel, Riihimäki, Finland: The new technology, live since June 2017, speeds up the filling process significantly.

"MODERNISING THE ENKÖPING PLANT GIVES ME AN OPPORTUNITY TO CREATE SOMETHING NEW."

EMMA LEJONBERG,
CYLINDER OPERATIONS MANAGER, ENKÖPING





At the Marl plant in Germany's northern Ruhr area, for instance, the Manufacturing Execution System (MES) takes centre stage. This is like the nerve centre of the plant – connecting all the individual components and enabling them to interact. The MES coordinates the entire material flow and planning process within a plant. "Previously, an forklift was required for every production step and staff spent a lot of time dragging cylinders around. Now an operator taps their tablet and an AGV whizzes straight up to deliver the cylinders to the filling station or take them to the high-bay warehouse for storage. It's all completed in a flash."

SYSTEM CALLS THE SHOTS

Unlike his colleagues in Finland, Ralf Worrech, Deputy Plant Manager at Marl, is still in awe of these seemingly magical changes. Although he has been with Linde for 31 years now, he says that the revamped Marl plant "tops everything I have experienced in my work thus far". However, for Worrech and other long-serving colleagues, the biggest change of all is actually invisible. Behind the scenes, the MES now calls the shots. Previously, it was the plant workers who planned the process flow and knew which step came next. They took the lead and the technology followed. Now it's the other way round.

For Linde's customers, this will mean greater transparency, better quality and – above all – more flexibility in the long run. Plus a wider range of gases to choose from. And, most importantly, customers can order them in smaller volumes too. Thanks to the MES, it could take as little as 40 minutes for a single gas cylinder to travel from the truck's loading platform to the filling station and back in future. Previously, manual sorting at the loading bay, filling and order picking might have taken several days. The new workflow enables a more individualised customer service. Never before have people and machines worked side by side in such a productive way.

"Automation is creating new job profiles," emphasises Tina Olbrich, responsible for Linde's filling plants in Germany. She doesn't associate automation with scenarios such as robots seizing control, people-free factories and so on. Quite the opposite, in fact: "We need people on the ground who understand the technology and can take immediate action if systems are not running as well as they should." At the same time, workers will be increasingly relieved of physically strenuous, routine tasks. Olbrich does not see automation as a threat, but rather as a promising opportunity to shape an entirely new level of collaboration between humans and machines.

A recent report from the McKinsey global management consulting firm underlines the importance of this collaboration for the future, predicting that Germany's workforce will decline by three million people by 2030. Other studies estimate even bigger drops, signalling the growing risk of skill and labour shortages in the most rapidly ageing societies. According to the authors of this report, productivity gains will thus only be possible if people engage with and embrace advances in technology.

NEW CAREER PROSPECTS

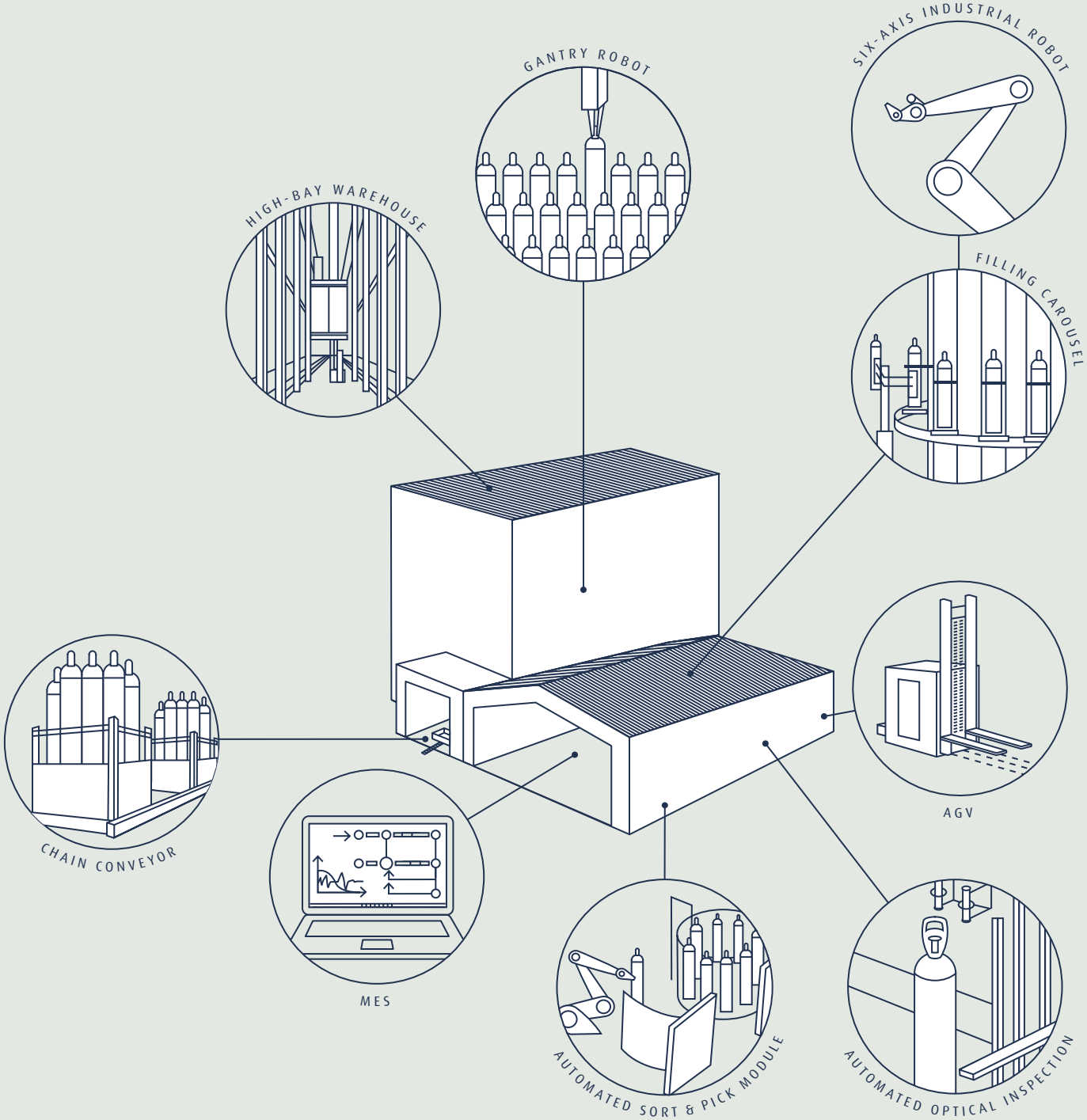
Sooner or later, this new form of collaboration is bound to entail fundamental changes in the workplace – as Ian Maher is already well aware. However, as an electrical engineer, he had a head start in adapting to the new processes – automation and control software are not entirely new terrain for someone who specialises in circuitry. The 42-year-old has been with BOC Australia since 1996 and, like his colleague Lejonberg in Sweden, feels that the winds of change are already blowing. "I'm happy to be part of this evolution. It presents opportunities for my own professional development." On the ground, the future has already started for Maher, who supervised the electrical installation of new pumps as well as the electrical infrastructure for the three sort & pick cells.

400
FILLING PLANTS
OPERATED BY LINDE WORLDWIDE

High-bay warehouse, Marl, Germany: Staff members and machines always know where every single cylinder is located. Cylinders that are not moving through the process flow have designated spots in the automated high-bay warehouse.

FILLING PLANT OF THE FUTURE

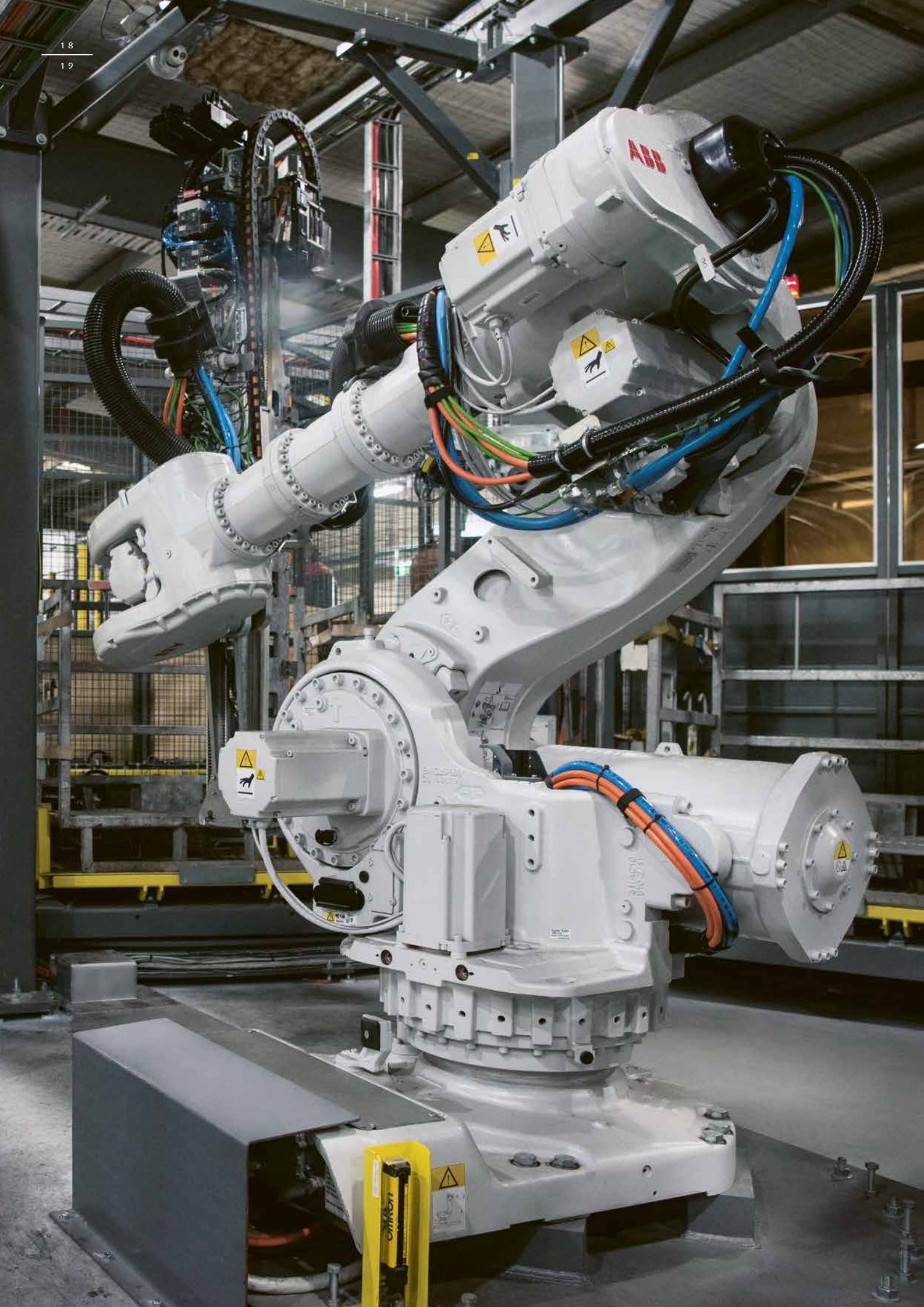
An overview of the process steps and technologies currently on trial worldwide. These can be implemented in various combinations to suit regional dynamics.



"IN THE PAST, YOU HAD TO GET BEHIND THE WHEEL OF A FORKLIFT TRUCK – NOW, ALL YOU NEED TO DO IS TAP YOUR TABLET AND AN AGV WHIZZES UP."

RALF WORRECH
DEPUTY PLANT MANAGER, MARL

Automated guided vehicle (AGV), Marl, Germany: The number of forklift incidents has halved since AGVs were first introduced.



ABB

Sort & pick is to Sydney, Australia, what MES is to Marl. Here, again, the backstory begins in Finland. The reason Scandinavia has been using robotic arms to carry cylinders around for years is specific to that region, since only there do cylinder caps feature a type of loop that makes it easy for gantry robots to grasp them. The challenge thus lay in finding an alternative gripping solution that would work in all other regions. The answer presented itself in the form of a robot that grasps cylinders from the side. And this is the system now being trialled in Sydney – a global first. As soon as an AGV delivers a pallet of empty cylinders, the robots get to work, sorting cylinders by their contents and condition, hauling them off to be filled and then transporting them either back to the warehouse or directly on to order picking, where they end up repackaged on pallets and shipped out to the customer again.

"One of our main aims was to reduce the number of manual handling steps at the stations," explains Peter Dunn, Manager Regional Engineering at BOC Australia. He adds: that "The heavy labour takes its toll on our workers – especially those who have been doing it over time." With gas cylinders weighing in at 30 to 50 kilos, hauling them about is certainly not ideal for the shoulders, elbows, wrists or feet. "By automating various process steps, we are significantly reducing the risk of incidents." In other words, automation takes people out of the picture at physically strenuous and hazardous points – and internal incident statistics are already starting to reflect this. Forklifts and pedestrians, in particular, have an unfortunate tendency to cross paths. While there were 150 of these incidents worldwide in 2013, the number of forklift-related accidents in 2017 was down by half – in part thanks to the use of AGVs. Like Tesla cars, the forklifts are equipped with a host of high-tech features, including sensors to prevent collisions. Their predictable driving behaviour is another benefit – the on-board computer never has a "bad" driving day.

THE MODULAR UNITS CAN BE EASILY INTEGRATED INTO THE EXISTING FILLING PLANT STRUCTURE

MODERNISED PLANT CREATES 50 NEW JOBS

In Enköping, too, the focus is on safety. And on a lot more besides – on everything, in fact, given that the latest member of the plant family is the current showcase. "This is where all building blocks will come together for the first time," Jonas Nyström is proud to point out. With gantry robots, a filling carousel, automated optical inspection, AGVs, automated high-bay storage facilities, an MES and a dedicated area for handling medical gases, Enköping is positioned at the forefront of the filling plant automation journey. This also means hiring up to 50 new staff. As Head of Cylinder Production Platforms for Northern Europe, Nyström certainly has a clear appreciation of the benefits of modernisation. In winter, temperatures here regularly drop below minus 20 degrees Celsius – which increases the risk of staff slipping, tripping and falling on icy ground. Automation is helping to reduce the risk of injury – also by moving staff indoors to do their work.

Six-axis industrial robot, Sydney, Australia: The highly flexible gripper assists the sort & pick module.

WINNING ARGUMENT IN PUBLIC TENDERS

Not only does automation protect workers against these harsh temperatures, it also takes transparency to a whole new level. An individual report is generated for every cylinder filled, with up to 200 data points ranging from filling pressure to valve thread condition. The resulting data streams are growing in importance in public tenders, with customers paying special attention to sustainability performance, according to Nyström. In addition, automation can further boost cost efficiency. In fact, the plant in Enköping will be so efficient that the company will be able to close three other sites in the vicinity.

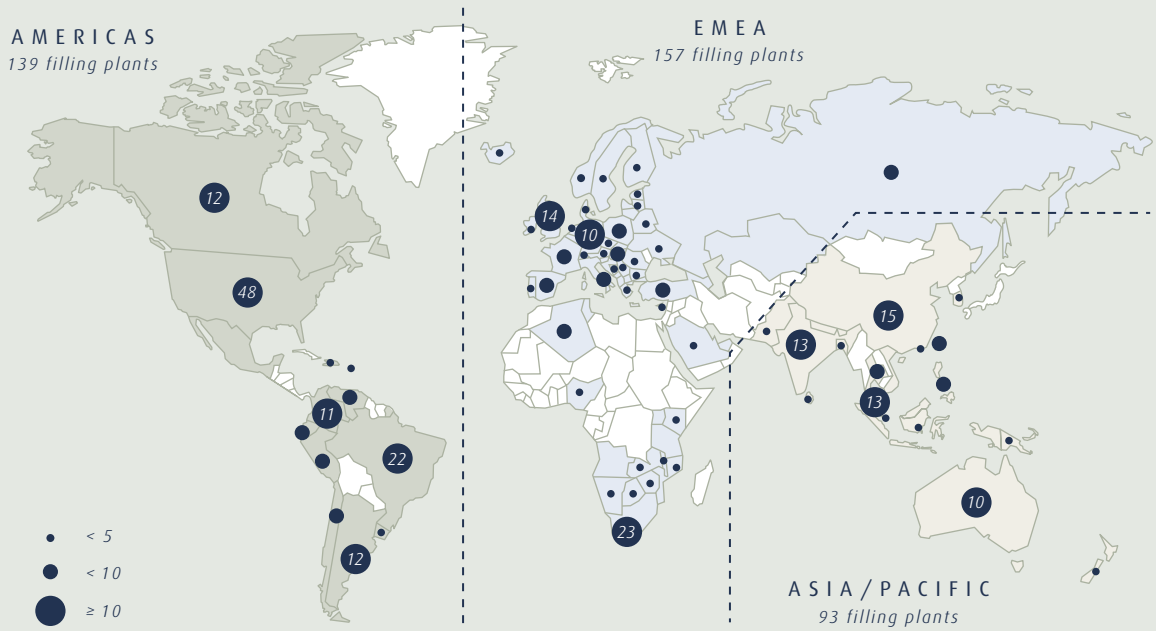
All the modules currently being brought to maturity in Finland, Germany and Australia will thus come together in Enköping to synergise a raft of compelling benefits that were a lot harder to achieve prior to automation, as Ylva Kallin confirms. The 53-year-old Plant Manager has been with Linde for ten years now and will take the helm alongside Emma Lejonberg. The latter's in-depth knowledge of automation technology will thus be complemented by Kallin's long-standing experience in the cylinder gases business. And Kallin knows just how important it is for Linde to meet its customers' quality expectations – she is confident that automation can support efforts here. "The biggest challenge now will be to ensure processes dovetail to perfection and are seamlessly documented from the get-go," she explains. Pausing only briefly, she adds: "But I'm sure we'll get there – and succeed in making this filling plant one of the most advanced in the world." Customers will be able to experience it firsthand from autumn 2018 onwards.

200

DATA POINTS

PER CYLINDER: FROM FILLING PRESSURE TO VALVE CONDITION

LINDE FILLING PLANTS WORLDWIDE



"BY AUTOMATING VARIOUS PROCESS STEPS, WE ARE SIGNIFICANTLY REDUCING THE RISK OF INCIDENTS."

PETER DUNN,
MANAGER REGIONAL ENGINEERING, SYDNEY

Automated sort & pick module, Sydney, Australia: This station gathers various cylinders and prepares them for transport to the customer.

Sustainable success with industrial gases

Carl von Linde and his colleagues worked tirelessly for years on end before they managed to produce oxygen in sufficiently high volumes and – above all – in a commercially viable format. The turning point came at the beginning of the 20th century in the shape of two crucial developments: the invention of autogenous cutting and welding, and the adaptation of the rectification process by Linde. The new cutting and welding technique required liquid oxygen in higher purities than those available at the time – and Linde's innovative rectification process was able to meet those demands. These two developments marked the birth of a major new industry: the production of industrial gases.

At the outset, however, the potential of these gases was limited by the underlying logistics. Although gases are all around us, they do not tend to travel well once they have been separated and confined to containers. Ultimately, this also had an impact on profits – particularly in the early days, when oxygen was still transported in pouches or cast-iron cylinders.

Quite apart from the fact that the gas in these metal containers could not be compressed effectively, handling these early storage mediums was a risky business. People were frequently injured or killed by gas containers exploding. In short, the costs involved in the challenging and hazardous process of filling and dispatching the gas far exceeded the value of the product itself. As a result, major purchasers of oxygen often ended up building their own facilities.

This trend did not escape the attention of Rudolf Wucherer – Carl von Linde's son-in-law, who took over the company's own oxygen and acetylene plants in 1914. Over the following years, Wucherer systematically expanded this area of the business. He set out to increase efficiency by improving the gas cylinders and, above all, reducing delivery distances. Proximity to the customer became an increasingly important factor. Between 1914 and 1925, Wucherer arranged for 25 new air separation plants to be constructed at 14 locations across Germany. And success was quick to follow, with oxygen production increasing fivefold in the course of that decade. Acetylene sales rose fourfold over the same period. With Linde also establishing regional monopolies in the cylinder business, Wucherer certainly made his mark on the company and is now considered the real founder of its gases business. Today, revenue from the Gases Division, which includes earnings from around 400 filling plants worldwide, continues to form the company's financial backbone.

CONSTRUCTION OF
AIR SEPARATION UNITS

+
147 %

17
BETWEEN 1903 AND 1914

25
BETWEEN 1914 AND 1925

DEVELOPMENT OF
ACETYLENE SALES

+
286 %

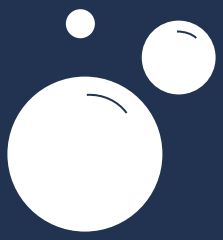
175,000 m^3
(1913)

675,000 m^3
(1925)

EVOLUTION OF
OXYGEN PRODUCTION

+
400 %

650 m^3/h
(1913)



3,250 m^3/h
(1925)

Digitalisation is not just revolutionising our lifestyles, it is also transforming and disrupting industry as it opens up previously inconceivable opportunities. Framed by an evolutionary strategy, Linde is carefully engineering new digital products and services that ultimately turn big data into smart data – to the benefit of both Linde and its customers.

TECHNOLOGICAL PERSPECTIVES

A MEETING OF MINDS AND MACHINES

Digital technologies are having a massive impact on almost every aspect of our lives. With computers increasingly outsmarting humans, the ability to embrace digital change is more important than ever. Linde has mapped out its own path forward, leveraging its employees' expertise and building on digital technologies to extend its offering.

The relationship between humans and machines is being redefined. Computers already beat chess grandmasters and champions of Go – the world's most complex board game. Increasingly, machines are now also outsmarting people in their personal and professional lives. Facebook, for instance, needs only 300 'likes' to gauge a user's preferences better than their partner can. And since Tesla Autopilots drive better than humans overall, insurance companies actually offer discounts for drivers who use this feature. Meanwhile, artificial intelligence can surpass medical specialists when it comes to diagnosing cancer. Computers are obviously ideally suited to analytical tasks such as these. But the hands-on business of caring for patients will always be reliant on the human touch. Which is why digital visionary Christoph Keese predicts that "Nurses could even end up earning more than doctors in the future." He maintains that this digital transformation will impact every industry and every profession.

For technology groups such as Linde, a concept referred to as Industry 4.0 is at the heart of this transformation process. In other words, the fourth industrial revolution, following in the footsteps of the inventions that sparked the three industrial revolutions that shaped the past three centuries. The first was triggered by the steam engine in the 18th century, the second by electricity in the 19th and the third by microelectronics in the 20th. And now, in the 21st century, we are witnessing the fourth transformation with consequences that – according to many observers – will eclipse anything we have experienced thus far.

The reason for this lies in the growing convergence and cross-fertilization between trending technologies in key areas such as robotics, 3D printing, artificial intelligence and the Internet of Things. Advances in these technologies are also being driven by the explosion in cloud computing power and new big data structures. Harvard economist Michael E. Porter, one of the world's leading management theorists, maintains that a carefully engineered digitalisation strategy has the potential to unlock far-reaching opportunities.

A CEO survey among the top 500 US companies undertaken by Singularity University, a Silicon Valley think tank, demonstrates the scale of the challenges ahead: 80 percent of respondents expect that exponential technologies will transform and disrupt their industry within the next two years.

Of course, this trend also affects Linde. According to German engineering association VDMA and management consultancy maexpartners, 68 percent of managers of industrial-scale engineering companies expect competition to intensify significantly over the next three years. That is almost three times more managers than those who made the same prediction back in 2014.

Germany, however, got off to a slow start in this race. According to the digitalisation indicator used by German industry group BDI and acatech, the German Academy of Science and Engineering, the country only ranks 17 among the 35 nations analysed. The report attributes this mainly to Germany's comparatively low numbers of patent applications, lack of digitalisation in the government sector and sluggish network expansion.

Two leading German commentators have outlined a solution to this predicament, however. Network economist Holger Schmidt and business IT professor Tobias Kollmann have created a 25-step plan to build a successful "Germany 4.0". In a nutshell, companies should hire technology scouts, universities should train entrepreneurs, the authorities should expand their digital service offering and data networks, and leading lights from all sectors should show more enthusiasm for digitalisation.

Linde has also mapped out a clear path forward here. Nowadays, digital sensors on the company's gas cylinders simplify hospital logistics. At the same time, virtual reality headsets mean future operators of large-scale industrial plants can train while the plant is still being constructed. And 500,000 sensors in industrial facilities around the world are feeding data to predictive maintenance algorithms. This proactive approach to maintenance focuses on detecting faults before a malfunction even has a chance to occur. Linde is thus fully embracing the smart revolution with digital innovations that are rapidly helping to take the "competition" out of human/machine interaction and replace it with "cooperation".

INSTANT INSIGHTS

Internet of Things: Whether oxygen cylinder, ventilator or infusion pump – if the right equipment is not available at the right time, the patient faces inconvenience and delays. Linde is helping hospitals to solve this challenge by connecting these devices over the Internet of Things and bundling all of this intelligence on its digital platform, Cobalt*.

At the St. Josef Caritas hospital in the German city of Regensburg, the colour yellow used to mean one thing above all for nursing staff: stress. When patients are moved from one department to another, the hospital uses mobile cylinders to ensure uninterrupted oxygen therapy. Previously, the contents gauge on these cylinders was divided into three zones: green, yellow and red. Green meant that the cylinder was full, while red stood for empty. But yellow? Something in between. "When a cylinder was in the yellow zone, we often just replaced it with a new one," recalls Alexandra Stich, Ward Manager at St. Josef. "We can't risk a patient suddenly running out of oxygen."

This often meant returning half-full cylinders. Now that has changed – ever since the hospital introduced Linde's smart cylinder system, LIV® IQ. These days, a digital display shows the current contents level in the compressed gas cylinder and indicates how much longer the reserves will last – to the nearest minute. "This is a huge weight off our minds," reports Stich.

PARTNERING TO CAPITALISE ON DIGITAL CHANGE

While the impact of digitalisation on medical and patient care has been modest thus far, new technologies are nonetheless enabling small but decisive improvements – so more of a gradual evolution than a radical transformation. Reflecting this trend, Linde expanded its LIV® IQ offering in 2016 to create the Hospital IQ data platform. This central system collects all cylinder data, providing an instant overview of each cylinder's location and contents.

** internal project name*

"COBALT LIFTS
A HUGE WEIGHT
OFF OUR MINDS."

ALEXANDRA STICH,
WARD MANAGER,
ST. JOSEF CARITAS
HOSPITAL

2013

LIV® IQ

DIGITAL DISPLAY ON THE VALVE SHOWS CONTENTS LEVEL AND HOW LONG THE GAS WILL LAST

2016

HOSPITAL IQ

DATA PLATFORM ALLOWS STAFF TO TRACK CYLINDERS AND CHECK HOW MUCH GAS THEY STILL HOLD

2017

HOSPITAL IQ COBALT*

IN ADDITION TO LINDE OXYGEN CYLINDERS, COBALT ALSO SUPPORTS CYLINDERS WITH OTHER GASES AND ADDITIONAL MEDICAL DEVICES, MAKING IT THE IDEAL PLATFORM FOR MANAGING ALL ASSETS IN FUTURE.

The digital transformation is not stopping at hospital doors – mobile ventilators, infusion pumps and oxygen cylinders can now communicate with hospital staff thanks to technology from Linde.

** internal project name*

"IF AN IDEA HOLDS REAL POTENTIAL, WE CONTINUE TO DEVELOP IT AND LOOK AT WAYS OF EXTENDING THAT NON-STOP MOMENTUM TO OTHER AREAS."

HELMUT FRANZ,
GLOBAL BUSINESS MANAGER
MEDICAL GAS PACKAGING

The software can also order new oxygen cylinders automatically – an additional task that previously fell to managers such as Stich. The time this saves can prove invaluable for patient care. In addition, Hospital IQ automatically optimises inventory levels, avoiding costly overstocking.

MISSING EQUIPMENT WASTES TIME

Through its close working relationships with customers in the healthcare sector, Linde was also able to identify another – previously overlooked – area of inefficiency offering huge scope for improvement. It may seem like a routine, straightforward task at first glance, but transporting patients within a clinic can be an incredibly time-consuming undertaking. Say a patient needs to go to the operating theatre, for instance. Stich and her staff then need to check whether the necessary equipment is in place – which means not only oxygen cylinders, but also ventilators and infusion devices.

In larger hospitals, this quickly becomes complicated. Infusion pumps, for instance, could be dotted all over the building – essentially everywhere except the place they are needed. The result is stressed-out staff having to go on equipment hunts instead of caring for patients – and anxious patients whose transport is then delayed. Not to mention a surgical team on standby, unable to start the operation on time.

COST EFFICIENCY KEY TO SURVIVAL

Digitalisation offers hospitals the opportunity to optimise these processes, reduce stress and cut costs. In particular, cost efficiency has become an absolute must if hospitals are to remain financially viable, since reforms mean that many of them now receive fixed reimbursements for specific procedures – regardless of the actual outlay. The average patient stay simply has to be reduced to meet these pressures. In large hospitals, this means that many small steps must dovetail to perfection. And where processes are delayed – for instance because a missing infusion pump holds up transport to the operating theatre – expenses quickly start to add up for the hospital. Over the course of a year, many minor delays thus result in significant extra costs.

GIANT STEP INTO THE INTERNET OF THINGS

This is where Cobalt comes in – Linde's enhanced version of its digital Hospital IQ platform. Building on oxygen cylinder intelligence, Cobalt will also integrate medical devices in future. Fitted with sensors, medical devices will be able to communicate with Cobalt – thus propelling them into the Internet of Things. Staff can then track the location and movements of all devices, at all times. "Staff need to be sure that the equipment they need will be in the right place, at the right time," emphasises Helmut Franz, Global Business Manager Medical Gas Packaging at Linde.

To ensure it is, Linde is now applying digitalisation innovations it developed for its own products to third-party devices. "If an idea holds real potential, we continue to develop it and look at ways of extending that non-stop momentum to other areas," declares Franz.

Cobalt will initially be deployed in several trial scenarios from 2018 onwards. For Ward Manager Alexandra Stich, the system would be a huge bonus for her work. Indeed, any hospital stands to gain if staff spend a lot less time phoning and mailing to organise full oxygen cylinders or other devices for patients. Cobalt would make this time-consuming activity a thing of the past, creating a win-win for everyone involved: the hospital, the staff and – of course – the patients.

INSIDE-OUT ANALYTICS

Big data: Linde engineers used data analytics capabilities to develop an algorithm allowing them to look into the inner workings of air separation units – long before they need to be dismantled for maintenance.

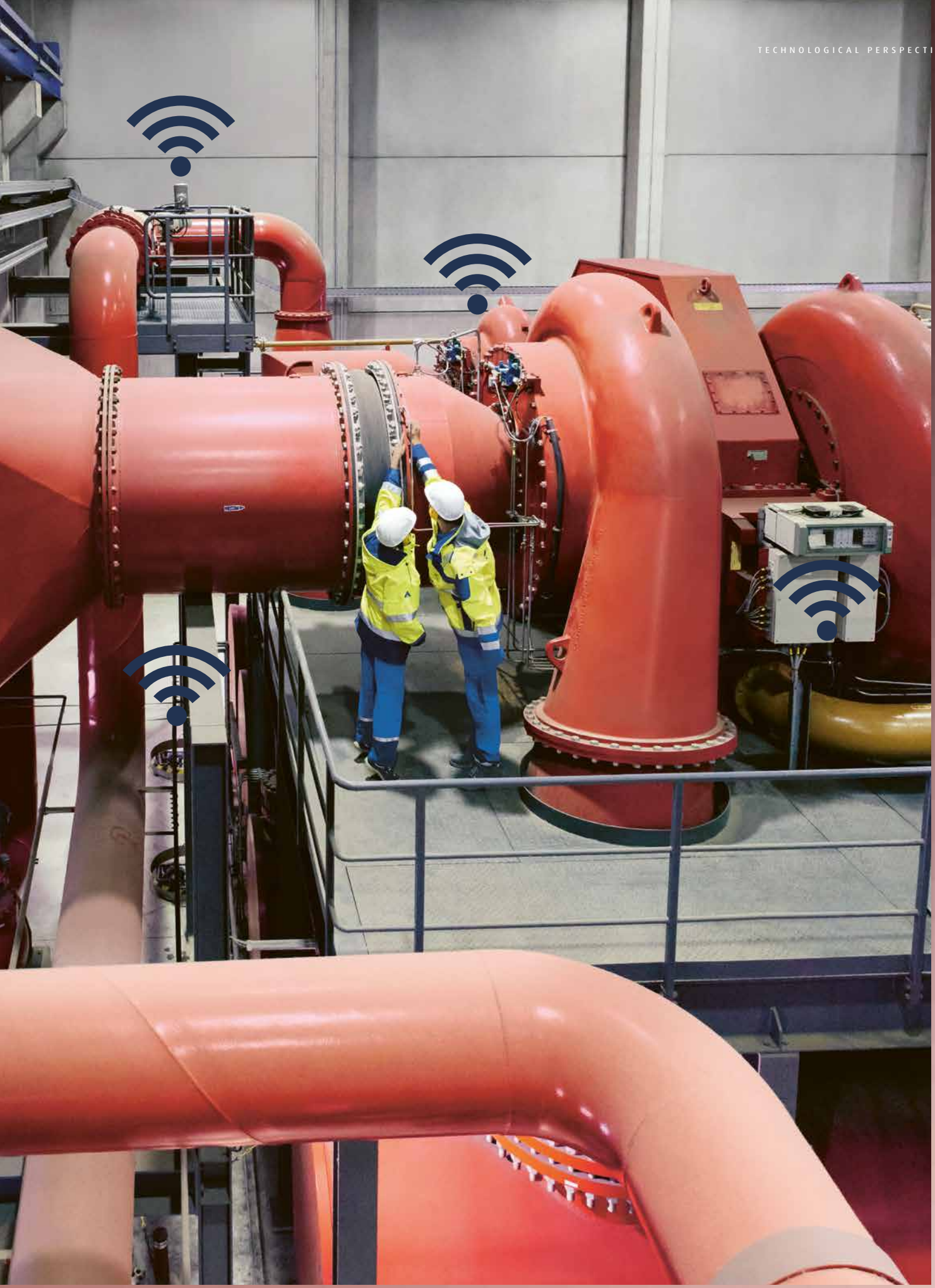
It is a mighty torrent – every hour of every day. In any given minute, Linde records 650,000 data points. At seven remote operating centres, the data streaming from hundreds of production facilities gives insights into pressure, flow, temperature, vibrations, product quality, energy consumption and more. Since 2007, the company has gathered 20 terabytes of data from plants it operates around the globe. These bits and bytes document the history and health of each plant over its entire service life, also flagging weaknesses and outages.

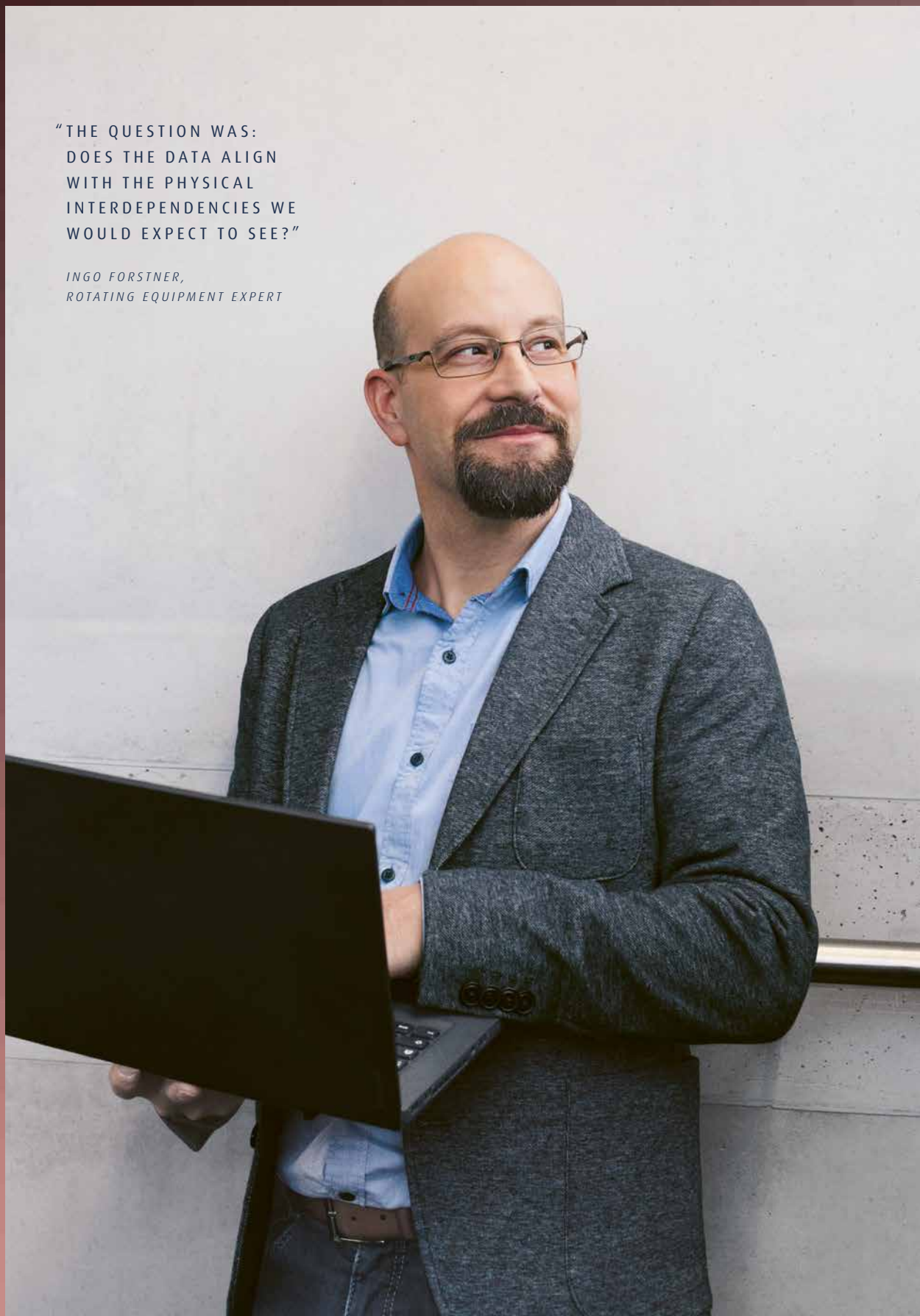
And the surge of data shows no signs of easing, with five new gigabytes arriving every day. This might sound overwhelming to some, but for rotating equipment expert Ingo Forstner, it is a gold mine. Together with his colleagues, Forstner is responsible for determining the condition of the compressors that pump air into the separation process. Every four to six years, these giant air separation units need to be partially dismantled in order to maintain them and replace worn components.

ESCALATING COSTS DUE TO UNPLANNED DOWNTIME

Depending on the equipment in question, this can take up to four weeks. During that time, the gas supply is interrupted, so steelworks, for instance, don't have the oxygen and argon they need for their furnaces or food manufacturers don't have the nitrogen they need to freeze their products. Scheduled downtime can result in revenue losses many times higher than the maintenance costs.

500,000 sensors collect information that the algorithm then evaluates. These insights form the basis for predictive maintenance.





"THE QUESTION WAS: DOES THE DATA ALIGN WITH THE PHYSICAL INTERDEPENDENCIES WE WOULD EXPECT TO SEE?"

INGO FORSTNER,
ROTATING EQUIPMENT EXPERT

Worse still are unplanned outages, when a facility suddenly has to be shut down to protect people and machinery. Given the high stakes, the on-site maintenance team is often expected to get the job done in even less than four weeks.

Efficiency is essential, especially as it can take several months for an ordered part to be delivered and then installed. So the better the team's insights into the inner health of a plant, the more efficiently they can plan and work. Linde's maintenance experts decided to team up with both the Digital Base Camp – Linde's internal accelerator for digital projects – and an external service provider to develop an algorithm that could raise an alarm whenever an item of equipment shows signs of sub-optimum performance. For the algorithm, the experts analysed the data stream from 30 machines across 7 facilities over an entire year.

"The question was: Does the data align with the physical interdependencies we would expect to see?" outlines Forstner. The engineers know that a bearing temperature increase will result in a measurable upturn in vibrations, for instance, while a change in pressure has an impact on both vibrations and temperature. The algorithm first had to learn about these interdependencies over an extended period of time.

UP TO SPEED IN SIX MONTHS

This might at first sound simple but in fact entailed six months of detailed work, since almost no two plants are the same and the operating conditions vary from one location to another. A great deal depends on differences in climate and on customer requirements. Thanks to the massive data stream and large number of facilities in operation worldwide, the engineers can now see which parameters indicate an imminent system failure and which represent the optimum condition.

THE ALGORITHM TRIGGERS AN ALARM WHENEVER AN ITEM OF EQUIPMENT SHOWS SIGNS OF SUB-OPTIMUM PERFORMANCE.

"We used mathematical models to analyse the historical data and predict what might be a healthy value for the relevant sensors on a future date," describes Markus Frondorf, Founder and CEO of anacision – the data science company supporting Linde with this project. During the pilot phase, which ran until the end of 2017, the team of engineers and data analysts compared the desirable healthy value from their calculations with the corresponding measurement from the historical data set. "What we want is an early warning system to alert us to all impending failures. So our model searches through the historical trove of data to predict possible outages."

PREDICTIVE POWER OF ALGORITHMS

Almost a year after the project was kicked off, the algorithm is now ready for operational deployment. Checks against the historical data reveal that it would have flagged up many failures weeks in advance if it had been running at the time. Forstner is confident: "We have developed predictive analytical capabilities with this algorithm."

The remaining question is how effectively Linde will be able to use this new algorithm. Not that the company lacks experience in maintaining its own facilities, but the efficiency gains of decisions based on the algorithm will only emerge in 2018, when it transitions from the lab to a live environment in Asia.

Thomas Heinzerling, Head of Regional Operations, is confident that the algorithm will help to turn unplanned downtime into scheduled maintenance windows – and, above all, pave the way for more dynamic, demand-driven maintenance schedules. "Sometimes we look inside a compressor after six years and find nothing wrong." In these cases, the software could indicate that maintenance should be pushed out. The opposite also holds true: maintenance could be pulled forward if the parameters signal a downward curve.

In the long term, Heinzerling anticipates that the predictions and analyses delivered by algorithms will become increasingly detailed – to the point where the installation team will know what to expect even before they look inside the system. Ultimately, Linde might also be able to pinpoint equipment offering scope for structural optimisation and these insights could be channelled into operational or even engineering enhancements.

650,000
DATA POINTS
ARE RECORDED EVERY MINUTE BY LINDE

20 TB
OF DATA
HAVE BEEN RECORDED SINCE 2007

500 KM
STACK OF PAPER
WOULD HAVE BEEN NEEDED TO RECORD THIS VOLUME OF DATA

ALL EYES ON THE FUTURE

Virtual reality: Thanks to interactive, immersive 3D technology from Linde, operators can familiarise themselves – from anywhere in the world – with a new plant before it even goes on stream. This new training format opens up interesting new opportunities for the established plant engineering business.

Around 8,000 kilometres to the east of Moscow in the Siberian wilderness, Linde is constructing one of the world's largest natural gas processing plants (GPP). Amur GPP spans 800 hectares, equivalent to around 1,120 football pitches. When it is fully up and running, it will employ some 200 operators tasked with managing the plant and controlling all of its processes. The challenge lies in preparing the team up front for the huge range of tasks they will need to master. Say, for example, that a specific valve needs to be opened by hand for the controlled release of excess pressure. In order to reach the component deep inside the plant, a technician has to climb steps, walk along passageways, turn to the right or left several times, duck under pipes, locate the valve and open it – which is like turning a heavy steering wheel.

VIRTUAL REALITY ENABLES OPERATORS TO TRAIN IN FUTURE PLANTS – BEFORE THEY HAVE EVEN BEEN CONSTRUCTED.

The training scenario may look real to the technician but it is, in fact, only an illusion as Amur GPP does not yet exist – it is currently being built. The mechanic is not walking along the concrete floor of the plant, but is moving around a training room located thousands of kilometres and several time zones away. A virtual reality (VR) headset has transported the trainee to their future place of work.

TURNING GAS PLANTS INTO EXPLORABLE 3D WORLDS

Engineers use computer-aided design (CAD) tools to build gas processing plants on their screen. Linde then works with VR specialists to turn this raw design data into explorable 3D worlds. Long before the plant is completed,

"WE CAN USE VIRTUAL REALITY TO TRAIN OPERATORS IN PLANTS THAT HAVE NOT YET EVEN BEEN COMPLETED. SO WORKERS KNOW 'WHAT, WHERE AND HOW' ON THEIR VERY FIRST DAY ON THE JOB."

NANNA THIELE, PROGRAMME MANAGER DIGITALISATION

operators equipped with VR headsets can then familiarise themselves with the plant's inner workings and process flows, and thus prepare for unusual or irregular situations. "They are able to practise in a virtual version of their future working world," enthuses Nanna Thiele, Programme Manager Digitalisation. Her burning goal is to fast-track this virtual reality tool – piloted in Linde's Digital Accelerator – into a scalable, fully featured digital service capable of offering customers time, efficiency and financial gains.

TRADITIONAL CLASSROOM TRAINING IS PASSÉ

DIGITAL TRAINING IS MORE EFFICIENT THANKS TO SIMPLIFIED LOGISTICS.

Up to now, operator training has taken place in physical classrooms; something Benjamin Krebs, System and Startup Engineer, describes as "your typical instructor-led classroom setting". As the person responsible for operator training, he has held a large number of these events over the years. Nevertheless, he was quick to recognise the potential of VR technology. Previously, operators could only start to put theory into practice once the plant had been constructed. "Now, thanks to VR, we pull the training process forward," explains Thiele. This means that the operating crew has already been trained by the time Linde hands the plant over to the customer, and the customer can fast-track the live date.

VR has the potential to fundamentally change the way training is delivered. Operators can use the VR training platform to familiarise themselves with the plant and rehearse various scenarios they may encounter on the job. What is more, they can do this from anywhere in the world. "This means a big reduction in air miles as the trainer doesn't need to travel to the classroom and operators don't have to travel to the plant before they are needed," adds Thiele. She is working on a digital licensing

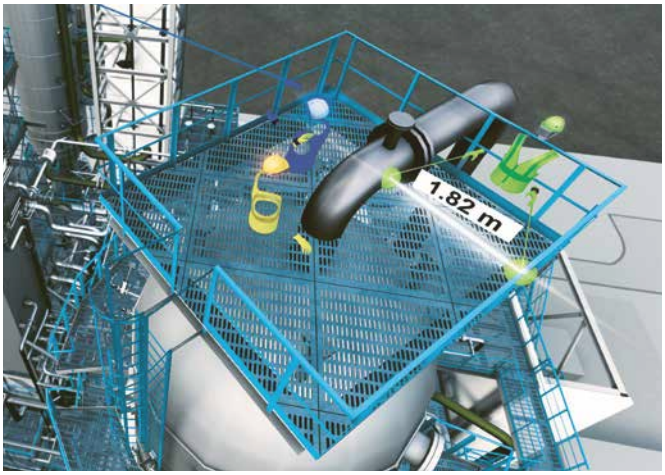
Linde's "plant in a box" contains everything an operator needs to train on a future plant: laptop, controller, VR headset and sensors.

model for the service similar to that of the software industry, where users can simply buy rights of use online. All of the required hardware – laptop, VR headset and controller – can be packed in a specially adapted hardshell case and shipped to any corner of the world. "We call it our plant in a box," says Thiele.

Looking beyond the logistical benefits, studies indicate that VR technology makes the learning process 15 times more effective than classroom-based training, with learning curves accelerating by 33 percent. The power of immersion is what gives VR its edge – the feeling of actually exploring the plant and engaging with the surroundings combine to outperform conventional learning methods. The VR experience blends visualisation, spatial orientation and interaction with objects. It helps the participants find their bearings more quickly, for example, so they are less likely to go wrong later. The on-site team is thus ready to spring into action much earlier and will be able to work in a more efficient, targeted way. "It's a bit like learning to ride a bike," maintains Thiele. "Through practice and repetition, a skill becomes hard-wired. It's not something you easily forget."

GAMING SPIRIT

Krebs is in charge of developing the VR training scenarios. He has borrowed from the world of computer gaming to add an all-important reward component, so bonus points are awarded to players who fix problems faster than their colleagues. "The gaming-inspired incentive element has really worked," according to Krebs. "Everyone wants to speed up and improve their performance," adds Thiele. "This provides great motivation." The next stage of development could see several operators rehearsing a training scenario and tackling challenges together. Another plus is that all tasks and activities are measurable. "We can analyse with precision what an operator does on the VR platform, what steps they execute and whether they are improving," says Krebs.



The software is designed in such a way that several operators – or their avatars to be more precise – can participate simultaneously in training.

ENGINEERS LAY DIGITAL FOUNDATION

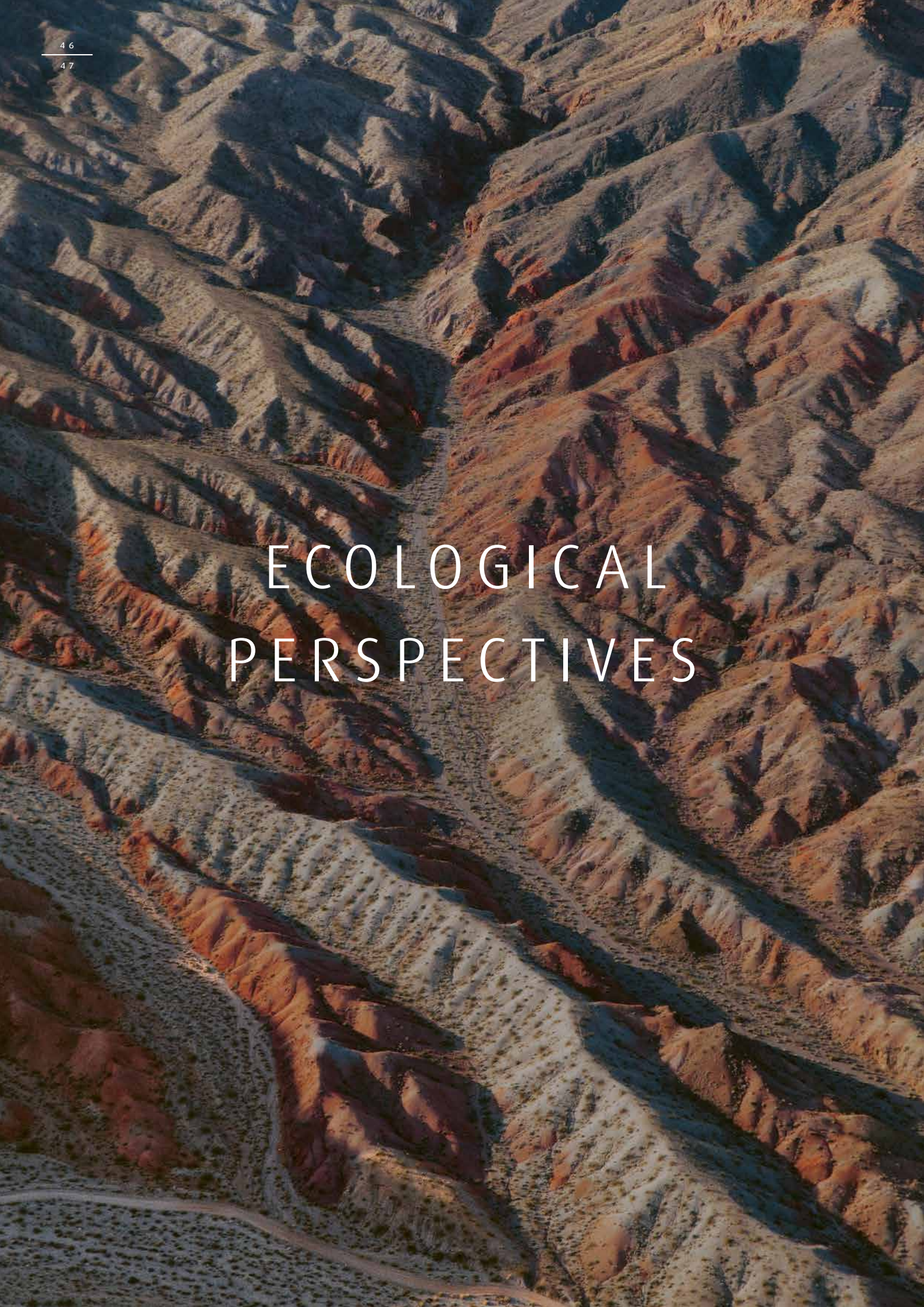
Humans are still needed to create a realistic VR environment based on plant data. VR software is not currently able to automatically render objects like pipes with the proper surface (texture), so VR designers have to intervene to make sure that everything looks true to life. Thiele and her team are working to fix this by asking the CAD engineers to add digital tags to the plant design data from the outset. These virtual tags will contain metadata specifying details like colour and function. "In the future, we will be able to create VR environments at the click of a button," she affirms.

A pilot project has inspired a scalable, full-featured service thanks to the team led by Thiele and Krebs. It shows that Linde does not regard digitalisation as an end in itself, but rather as a catalyst to drive selective modifications to existing processes. Virtual reality is part of the smart revolution and is set to have a lasting impact. Linde's VR application bolsters the natural gas plant business, reinforces Linde's role as a trusted partner and strengthens customer ties. In a nutshell, virtual reality technology opens up interesting new opportunities for plant projects, customer collaboration and the next generation of services.

33 %

FASTER LEARNING CURVE

WITH VR COMPARED WITH VIDEO TRAINING.



ECOLOGICAL PERSPECTIVES

The world's carbon cycle is out of balance. The CO_2 emissions released by humans can no longer be offset by nature. Linde's carbon capture and utilisation (CCU) technology can help to mitigate the pace of climate change. What's more, it turns what would otherwise be a waste product into a valuable raw material.

TURNING GREENHOUSE GAS INTO A VALUABLE COMMODITY

The challenge lay in reducing carbon emissions by 500,000 tonnes and – even better – turning what would have been a waste gas stream into a valuable industrial resource. Not a problem for Linde, having successfully engineered the world's largest carbon dioxide (CO_2) purification and liquefaction plant in Saudi Arabia to do just that.

Typically, CO_2 is vented to the atmosphere as a waste product. Now though, the petrochemical industry is starting to explore the industrial-scale potential of this gas as a production resource. As a result, companies are taking a keener interest in carbon capture and utilisation (CCU) technologies, previously only deployed in isolated cases. This is not a resource that is set to run out any time soon – over 30 billion tonnes of CO_2 are emitted worldwide each year, mostly originating from industrial facilities. Linde's new CCU flagship project now demonstrates how environmental responsibility can be balanced with financial gain.

WORLD'S LARGEST CCU PLANT ON STREAM

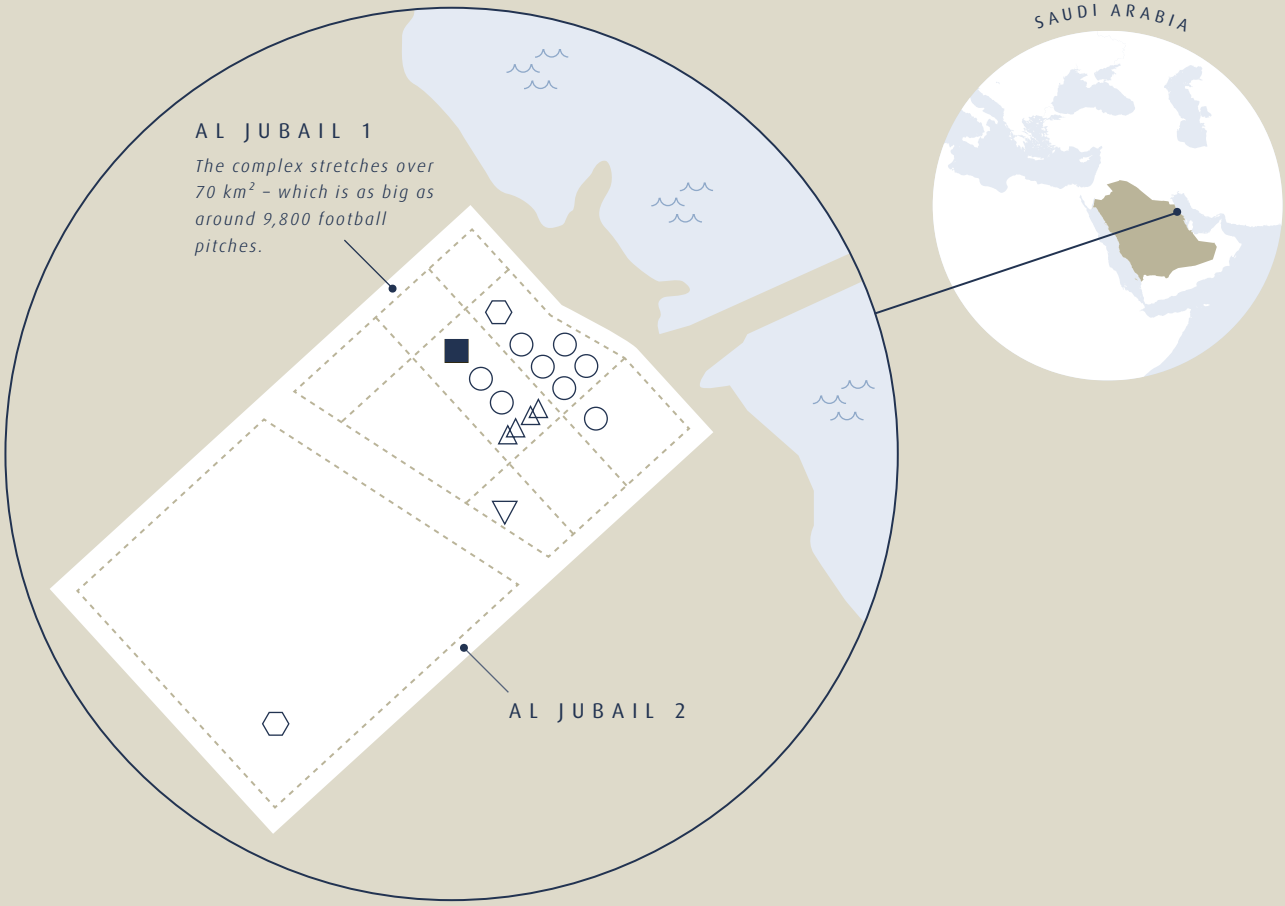
The United Jubail Petrochemical Company (UNITED), an affiliate of Saudi Arabian petrochemical giant SABIC, has taken a defining step in the move to harness the potential of CCU more effectively. It entrusted Linde with the task of overseeing construction of the world's largest CO_2 purification and liquefaction plant. Located at the Al Jubail industrial complex in Saudi Arabia, the plant has been fully operational since February 2017 and now has the capacity to produce around 1,440 tonnes of carbon dioxide per day. The CO_2 to be purified comes from two nearby ethylene oxide plants, where it occurs as a by-product of ethylene oxidation. Muhammad Muhammadieh, Managing Director of Linde Engineering Saudi Arabia, gives an impressive rundown: "We've fundamentally redesigned the entire recovery and utilisation process to reduce carbon emissions by 500,000 tonnes every year. In other words, that's half a million tonnes of greenhouse gas that never makes it into the atmosphere."

Al Jubail, one of the world's largest petrochemical complexes, unlocks promising carbon capture and utilisation opportunities.

Linde Engineering also built a polyethylene plant at the Al Jubail complex.

SUCCESS STORY IN THE DESERT

Since 1991, Linde Engineering has been successfully adding various plant components to the Al Jubail industrial complex, giving the company added confidence that it was up to the challenge of engineering the world's largest carbon capture and utilisation (CCU) plant. Implemented in close collaboration with the customer, the plant opens up new business opportunities – not just in the Arabian Gulf, but worldwide.



■ CO_2 PLANT

- *Carbon capture and utilisation (CCU) plant*

○ PETROCHEMICAL PLANTS

- *Hydrocarbon (C10) and amine scrubbing, capture and utilisation plant*
- *Linear alpha olefin (LAO) plant*
- *Acrylic acid plant*
- *Ethane propane cracker*
- *Polyethylene plant*
- *Ethylene glycol plant revamp*

⬡ HYDROGEN PLANTS

- *Synthesis gas plant for hydrogen and carbon monoxide (HyCO) as well as ammonia (NH_3)*
- *Single mixed refrigerant (SMR) unit*

△ AIR SEPARATION UNITS (ASU)

▽ COMPONENT SUPPLY

Having the carbon source and point of use on the same site is a key success factor for the Al Jubail complex in the Arabian Gulf.

A project that surely sets a new gold standard – not just in the Arabian Peninsula, but worldwide.

DECARBONISATION BECOMES A BUSINESS OPPORTUNITY

This new sustainability mind-set is captured in Saudi Arabia's Vision 2030 – a transformation roadmap actively embraced by the Kingdom. For decades, the country has been one of the world's biggest crude oil producers and a favoured location for major petrochemical groups – and it is now taking significant steps to prepare itself for the post-fossil fuel era.

SAUDI ARABIA IS ON THE QUEST FOR ALTERNATIVES TO CRUDE OIL AS IT TRANSITIONS FROM CRUDE SUPPLIER TO SPECIALTY CHEMICALS LEADER.

The chemical industry, too, is making radical changes to reduce its dependency on crude oil. Khalid Al-Falih, Saudi Minister of Energy and Industry, has even made a public appeal to the nation's companies: "We must step up to this challenge." That means identifying alternative feedstocks, for instance to manufacture plastics without crude oil, and extending the value chain beyond basic building blocks for the chemical industry. The aim is to become a technology leader for specialty chemicals, providing innovative products for customer-specific applications.

Linde's know-how is playing a valuable role on this transformation journey. SABIC, the parent group of UNITED, asked Linde to develop concepts for the commercially viable use of CO_2. Based on the carbon sources available at UNITED's industrial complex, project teams from Munich and Dresden investigated a wide range of approaches for separating and processing CO_2. "SABIC project managers were very clear about the need to balance ecology with economy – this was never going to be a case of 'either or'. So we knew from the outset that this project – if successfully implemented – would be a milestone development for the entire region. A flagship project for the entire world, in fact," reports Muhammad Muhammadieh with a certain degree of pride.

Presented with all the concepts, SABIC ultimately decided to capture the carbon from an ethylene plant. Various development gates had first to be passed, however. In the initial phase, the Linde experts from Munich and Dresden worked on the process with SABIC through to completion of the feasibility study. But then, following the tender, the contract for planning, constructing and commissioning the CCU plant was also awarded to Linde.

PIONEERING A NEW PLANT GENERATION

At first glance, the finished plant blends in perfectly with the gigantic industrial complex, with its huge steel containers, maze of shiny pipes and countless levers and valves. Yet its inner workings could inspire a whole new generation of CO_2 facilities. On arrival from the neighbouring ethylene oxide plant, the carbon dioxide is initially condensed by two compressors before being purified in the scrubbers, the catalytic oxidiser (catox) unit and the activated carbon filters. From the rectification columns, it is then transported via six kilometres of pipeline to nearby facilities, which use it to produce methanol and urea.

Olaf Christoph, Project Manager Business Development & Sales at Linde Engineering, spent several months on site with an assembly team to support plant completion and start-up. With twelve years' experience in Linde environmental technologies behind him, the energy and process engineer was more than ready to see CCU technology implemented in a project of this scale. "Having the source and point of use on the same site is a key success factor here, since short pipeline distances boost cost-effectiveness. Given this need for proximity, major industrial complexes such as Al Jubail provide an ideal implementation environment."

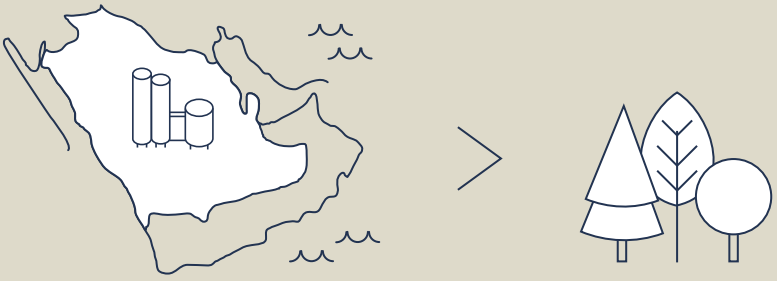
"SABIC PROJECT MANAGERS WERE VERY CLEAR ABOUT THE NEED TO BALANCE ECOLOGY WITH ECONOMY – THIS WAS NEVER GOING TO BE A CASE OF 'EITHER OR'."

MUHAMMAD MUHAMMADIEH,
MANAGING DIRECTOR OF LINDE ENGINEERING SAUDI ARABIA

Evolving technologies that balance ecology with financial gain spur Linde experts on.

CLIMATE MITIGATION POWER OF 40 MILLION BEECH TREES

A quick comparison with nature illustrates the Al Jubail plant's contribution to climate mitigation. An average-sized beech tree, around 23 metres high, binds 12.5 kg of CO_2 every year. So it would take 80 of these trees to sequester one tonne of CO_2 per year.



0.5

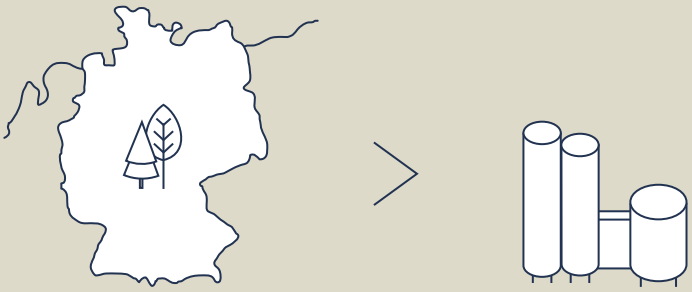
MILLION TONNES OF CO_2

ARE NEUTRALISED BY THE CCU PLANT IN AL JUBAIL EVERY YEAR.

40

MILLION TREES

WOULD NEED TO BE PLANTED TO ACHIEVE A COMPARABLE IMPACT WITHIN A SINGLE YEAR.



52

MILLION TONNES OF CO_2

ARE ABSORBED BY GERMANY'S FORESTS EVERY YEAR ACCORDING TO THE GOVERNMENT'S CARBON INVENTORY FOR 2012.

104

CCU FACILITIES

LIKE THE ONE IN AL JUBAIL WOULD BE NEEDED TO NEUTRALISE A SIMILAR VOLUME OF CO_2.

35,000 MIO

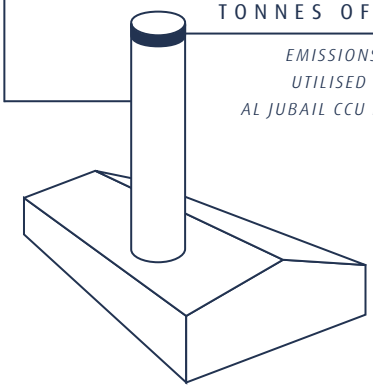
TONNES OF CO_2

WERE EMITTED WORLDWIDE IN 2016.

0.5 MIO

TONNES OF CO_2

EMISSIONS WERE UTILISED BY THE AL JUBAIL CCU PLANT.



The CCU plant at Al Jubail is turning carbon dioxide into a valuable commercial-scale commodity for the Saudi chemical industry, enabling the users – nearby facilities manufacturing methanol and urea – to substantially increase their production capacity. Methanol is primarily used as a synthesis platform molecule by the chemical industry and is distributed worldwide. However, now that larger amounts are available, it can also be processed directly on site to produce a specific type of polymer known as POM (polyoxymethylene). With its high molecular weight, this thermoplastic is one of the structural materials of choice in industries such as automotive and electrical engineering.

This new production step enables SABIC to extend its value chain as a chemical group. Looking beyond plastics, there are other, more familiar applications for CO_2 as a raw material; global applications that are not tied to the source of the gas. The Al Jubail plant also generates 200 tonnes of liquid, food-grade CO_2 every day, which is stored temporarily and then delivered by truck to surrounding food and beverage producers.

Although CCU technology has matured, it has not yet reached the point of large-scale commercialisation across every continent. However, industrial-scale applications are providing fresh momentum and positioning CCU as a financial driver, with major petrochemical facilities offering a broad platform of opportunity. Originally built at the end of the 1970s, the giant Al Jubail industrial complex (Jubail 1) began its second wave of expansion in 2011 (Jubail 2). So far, 26 individual facilities now occupy an area as large as 9,800 football pitches, their output varying from plastics to fertilizer.

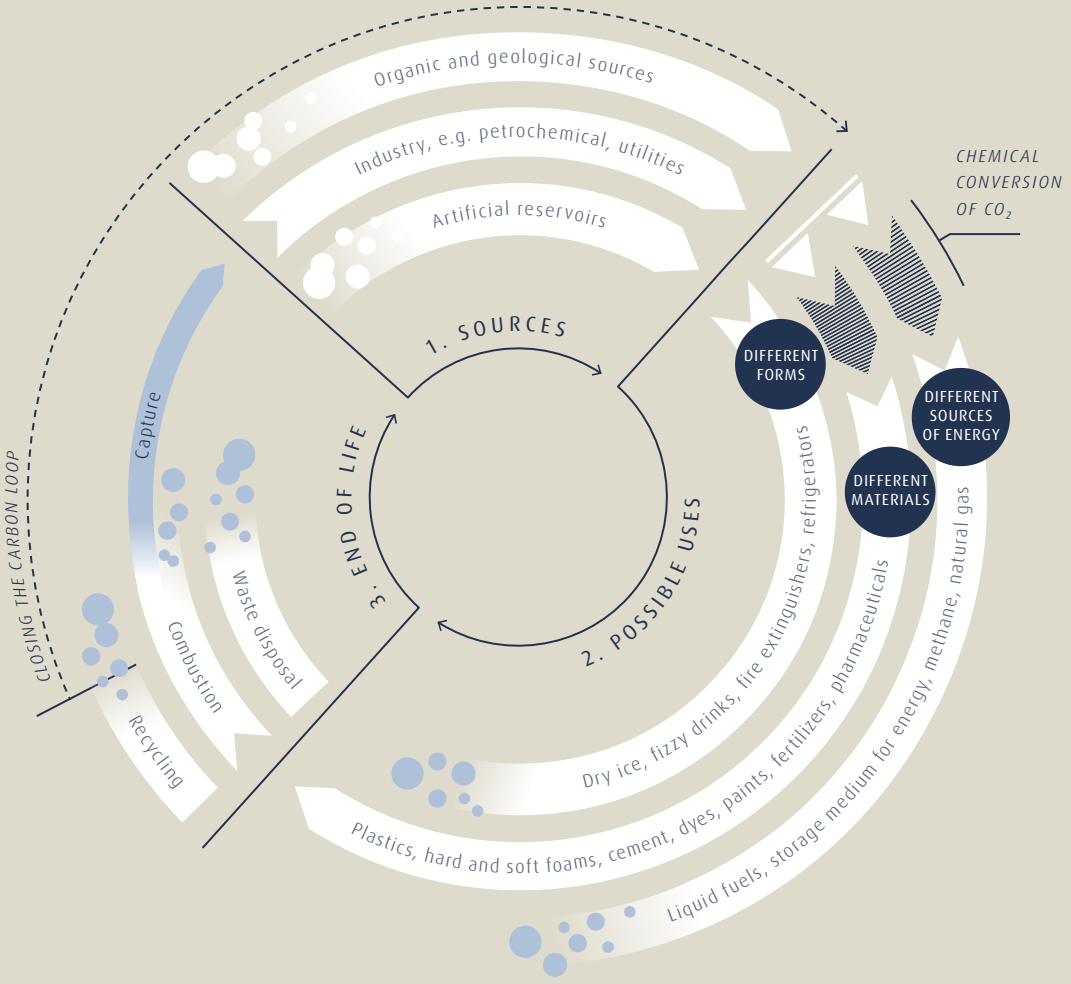
Since 2016, three million tonnes of various fine chemicals and high-performance plastics are produced here annually. These, in turn, serve as base materials for a wide range of products across the most varied of industries – from automotive through construction to electronics. Given this diversity, experts see many more opportunities to separate and utilise carbon dioxide by means of CCU.

INTERNATIONAL SPOTLIGHT ON LINDE TECHNOLOGY

Even before the Paris climate agreement, it was obvious that greenhouse gas emissions urgently need to be reduced. Increasing the sustainability of investments calls for global efforts and interdisciplinary collaboration between all the various experts and decision-makers. So the international community follows flagship projects such as the Al Jubail facility with great interest. After such a positive experience, SABIC, for its part, is now planning other, similar plants. Meanwhile, ARAMCO, another of Saudi's major petrochemical groups, is already holding discussions with Linde. And there are chemical complexes on a similar scale across Europe, North America and Southeast Asia too.

NEW MOMENTUM FOR THE CARBON CYCLE

Humans have thrown the earth's natural carbon cycle out of synch. Since the Industrial Revolution, we have released more CO_2 than nature can absorb through conversion mechanisms or storage systems. Technology can help to redress this imbalance – at least in part. The basic idea is to turn a waste product into a useful raw material – so binding CO_2 to create higher-value products in this instance. Advances in chemical processing now make this possible.



SAFETY

As a fire extinguisher, CO_2 is as effective as water – and the only agent to leave no residue.

WELDING

Both colourless and odourless, CO_2 makes a useful shielding gas to prevent steel from burning when welded.

FOOD AND BEVERAGES

CO_2 plays a role in preserving foods, carbonating drinks and recycling water.

PLASTICS

Replacing crude oil as a raw material, CO_2 can be used to produce polyurethane – a plastic used, for instance, by the automotive industry (lightweight components) and the manufacturing industry (mattresses and ski boots).

PHARMACEUTICALS

CO_2 is used in aspirin production, for example.

FERTILIZERS

Nitrogen fertilizers are manufactured from ammonia and CO_2.

COOLING

CO_2 serves as a coolant in the most diverse technical processes.

Globalisation has fuelled a dramatic rise in global trade, much of which is carried around the world by some 90,000 or so shipping vessels. Most of these run on heavy fuel oil with a high sulfur content, which poses a health hazard for people. But the shipping industry is under growing pressure. From 2020 onwards, the sulfur content in heavy fuel oil will be subject to a new upper limit. This is creating demand for the kind of clean solutions that Linde's visionary energy team have developed.

SOCIAL PERSPECTIVES

CLEAN FUEL FOR CLEAN SEAS

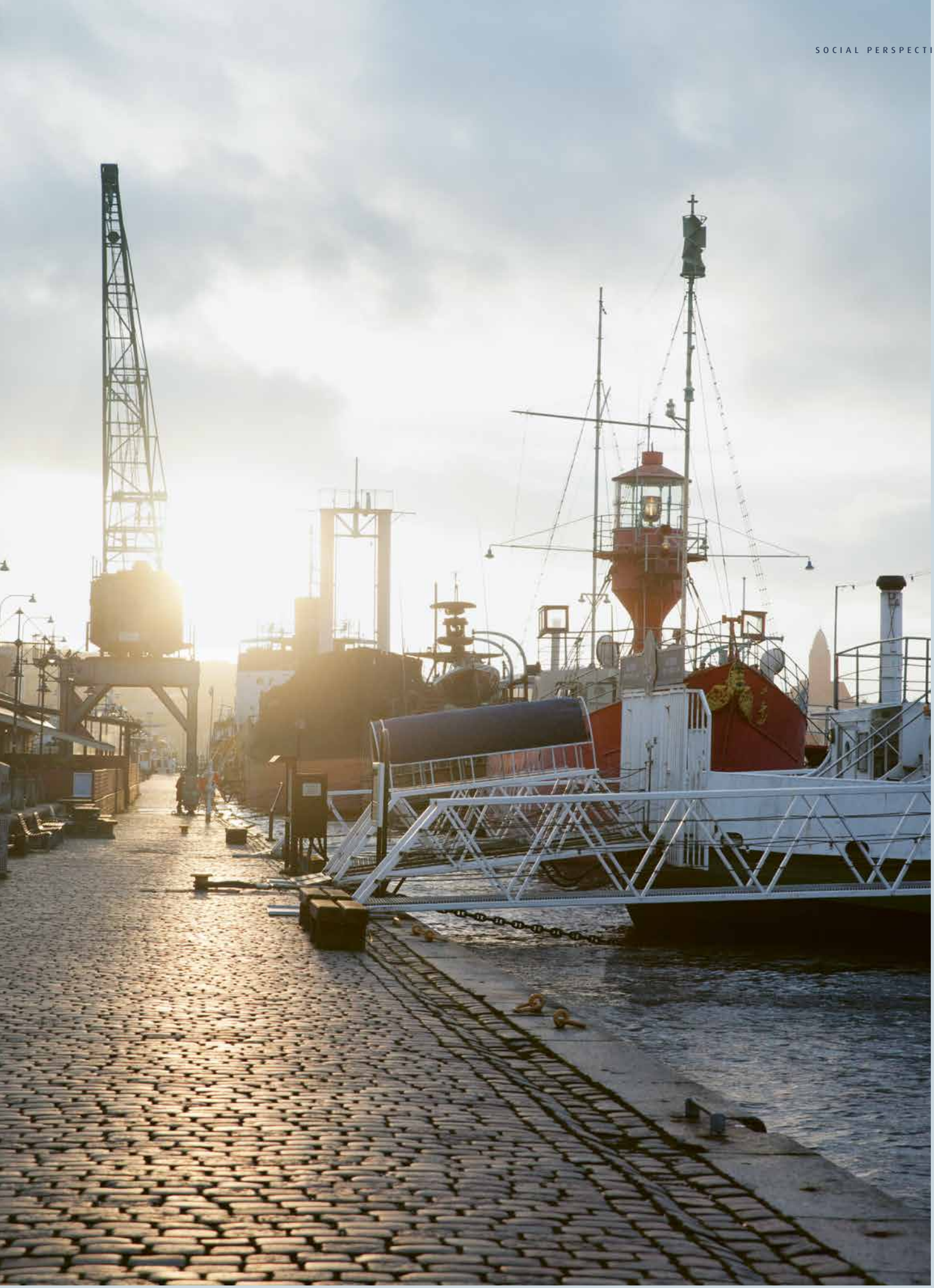
For decades, emissions from maritime shipping have far exceeded those of road transport. Now that is about to change. From 2020 onwards, the sulfur content of marine fuel will be subject to a much lower threshold. Operators are already looking for cleaner alternatives. Liquefied natural gas and hydrogen are set to play a key role in this new seascape.

The New Älvsborg Fortress at the entrance to Gothenburg port cannot lay claim to any great historical achievements. It failed to repel attacks by the Danes some 350 years ago and today its canons point silently out to sea, serving merely as a decorative backdrop for tourist selfies. Ocean giants gliding past the island on their way through the Skagerrak strait to the North Sea or into Gothenburg port barely notice it. They should though, because behind the historic façade lies technology potentially more threatening to shipping than the canons ever were. Johan Mellqvist calls it the "sniffer" – a sensor located on the roof of the fortress that "smells" the 10,000 ships that sail into Gothenburg harbour every year.

LIFEBLOOD OF THE GLOBAL ECONOMY

Almost two standard containers are handled in Gothenburg every minute, adding up to an annual total of 800,000. This makes Gothenburg Scandinavia's largest port, even if it does lag far behind the world's busiest port of Shanghai, which handles 37 million containers. The shipment of standard containers is the lifeblood of the global economy. Ocean-going vessels carry 90 percent of the world's trade, driven by supply and demand, and – incidentally – heavy fuel oil, a viscous residue from the petroleum industry that is typically high in contaminants. Its low price has made it the fuel of choice for ships' engines – a choice with far-reaching consequences, however.

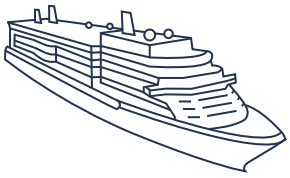
The port of Gothenburg offers a mix of conventional and alternative fuels, thus pioneering the move to reduce maritime emissions.



"THE 'SNIFFER' MAINLY DETECTS TWO SUBSTANCES: SULFUR DIOXIDE AND CARBON DIOXIDE. IT CAN CHECK AROUND ONE THIRD OF THE SHIPS THAT SAIL INTO OR PAST THE PORT OF GOTHENBURG."

JOHAN MELLQVIST,
CHALMERS UNIVERSITY OF TECHNOLOGY, GOTHENBURG

Professor Johann Mellqvist developed the sniffer (above). The Swedish transport authorities use this device to work out what ships are emitting how much sulfur oxide.



43

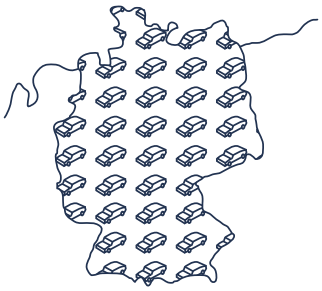
CRUISE LINERS

EMIT AS MUCH SULFUR DIOXIDE AS

ALL

THE CARS

REGISTERED IN GERMANY (56 MILLION).



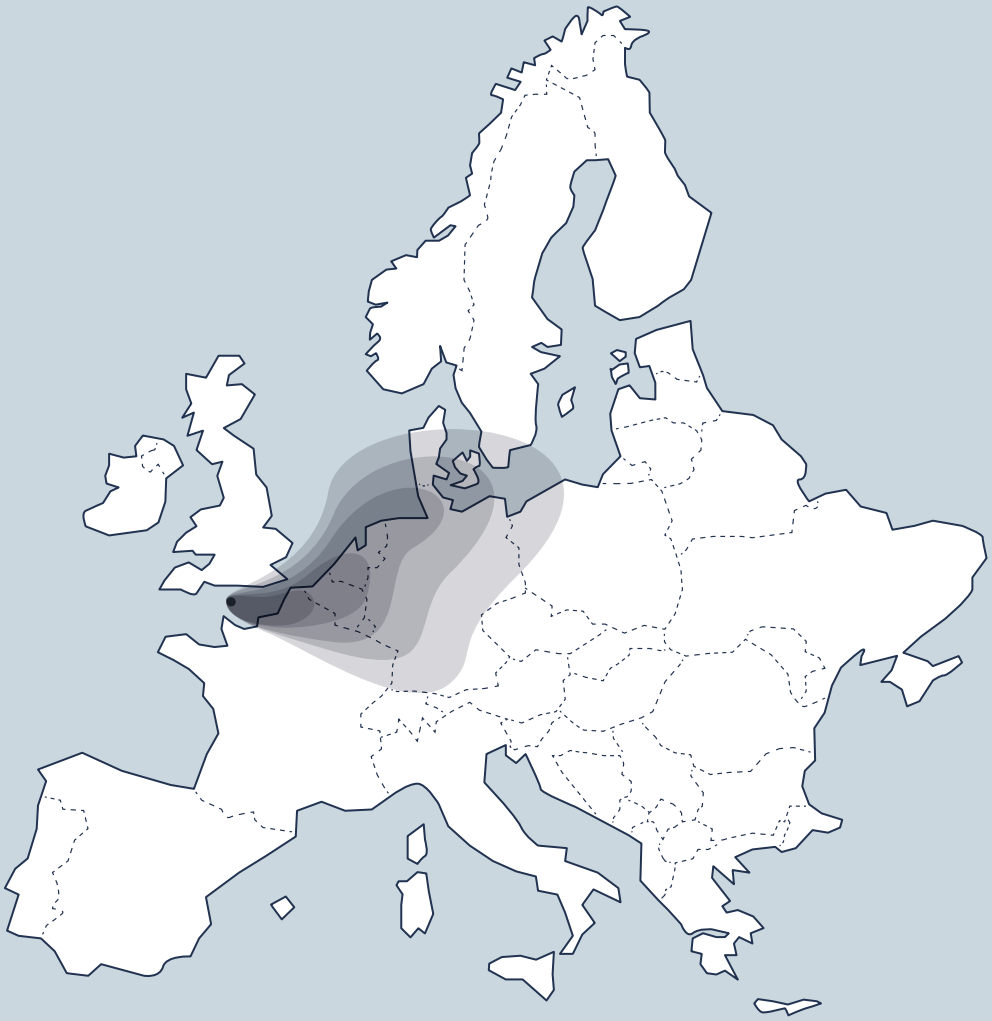
In 2012, shipping accounted for approximately 940 million tonnes of climate-damaging CO_2 emissions. That exceeded Germany's entire 2012 footprint, which amounted to 926 million tonnes of CO_2 that year. Today, the 90,000 or so ships navigating the high seas around the globe pump around 11 million tonnes of sulfur oxide into the atmosphere every year. Put another way, even the 300 or so liners cruising the world's seas emit almost seven times more sulfur dioxide than all German cars put together.

And that's not all. There is also the issue of soot particles – easily visible through the black plumes of gas drifting above the ship's funnels. Globally, this particulate matter is responsible for around 60,000 premature deaths due to heart and lung disease every year. A study by the University of Delaware found that most of these deaths occur in coastal regions of Europe as well as in South and East Asia. Despite this, the shipping industry has been excluded in the past from treaties like the Paris climate agreement.

Johan Mellqvist's technology is now helping to "sniff" out the culprits. This sensor measures the exhaust gases emitted by passing ships.

The problem is that the pollutants are not confined to the coast. Gaseous sulfur dioxide (SO_2) and nitrogen oxide (NOx) emissions from ships are converted into sulfate (SO_4) and nitrate (NO_3) aerosols, particularly in the summer months. In this form, they can be transported several hundred kilometres inland, according to findings by the German Climate Computing Centre. Exhaust gases emitted in the English Channel or to the west of France, for example, are – depending on weather conditions – likely to be blown over a wide expanse of the continent stretching from Brittany to Germany and as far east as Poland.

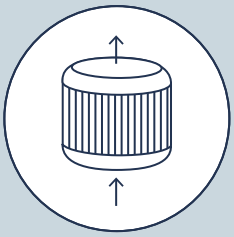
POISONOUS CLOUD BLOWING IN FROM THE ENGLISH CHANNEL



Although ships emit air pollutants on the open sea, these harmful gas streams directly affect large sections of the population in Central Europe. Exhaust gases are carried thousands of kilometres inland across Europe. A typical westerly wind would sweep gases emitted, for instance, in the English Channel or to the west of France in a wide easterly arc stretching as far as the Baltic region. The English Channel is one of the world's busiest shipping routes.

The year 2020 is set to mark a watershed. From then on, the sulfur content of marine fuel will be limited to 0.5 percent instead of the current 3.5 percent. This decision was adopted by the International Maritime Organization (IMO), a specialised agency of the UN. Despite the downsides, cargo ships are, by virtue of their sheer size, still the most energy-efficient way to transport goods around the world. In order to comply with the new requirements, ship operators will be able to use marine diesel, which is low in sulfur but expensive. They also have the option of installing a scrubber to remove sulfur oxide from the exhaust gases, or they can try alternative fuels.

SCRUBBER



Scrubbers are used to desulfurise emissions from ships by removing sulfur oxide from the exhaust gas. Sea or fresh water can be used in these scrubbers. They can be retrofitted to existing ships, allowing them to continue to run on heavy fuel oil.

"The decision by the IMO puts an end to the serious pollution issues caused by heavy fuel oil," says the Managing Director of Linde subsidiary Nauticor, Mahinde Abeynaike. "Liquefied natural gas is a strong competitive alternative under the IMO ruling," he continues. "It is cheaper than traditional heavy fuel oils, its price will drop further due to over-capacity, and it complies with upcoming regulations."

THE END OF AN ERA

In the medium term, alternative fuels like liquefied natural gas (LNG) are also a better solution for the environment since LNG not only reduces emissions of sulfur oxide, but also of the greenhouse gases produced by the shipping sector. In theory, ship operators could also choose a fourth option, which would be to simply ignore the new ruling given the uncertainty around enforcement of the sulfur cap. The IMO is not responsible. Instead, responsibility lies with the flag state (the place where the ship is registered), the port state (where the ship is anchored) and the bunker state (where it is fuelled). How this split will actually work in practice remains to be seen – we will have to wait until 2020.

Since 2006, Gothenburg has been designated an Emission Control Area, with an even lower sulfur cap. Vessels here must use fuel with a sulfur content of less than 0.1 percent since 2015. Approximately 95 percent of ships respect this limit according to Mellqvist. It is a different story outside of the ECAs, however. On the high seas, different laws apply and policing them becomes rather more difficult. The sniffer sensor's range is limited to 500 nautical miles (926 km), and even at close range, the instrument can only measure the emission clouds that are blown in the right direction by the wind. This means that the Älvsborg sniffer can only monitor around a third of the passing traffic.

Shifting market dynamics present LNG suppliers like Nauticor with an element of business uncertainty, as Abeynaike well knows. For him, the biggest question is how the price of low-sulfur fuel will develop relative to that of LNG. But he is optimistic. After all, Nauticor is currently constructing the world's largest natural gas bunker ship in South Korea – a move that is resonating with customers. At the end of 2017, Nauticor closed a deal with Destination Gotland, one of Scandinavia's largest LNG-powered ferry lines.

AS LONG AS A QUESTION MARK HANGS OVER THE ISSUE OF EXECUTIVE AUTHORITY, MARKET FORCES WILL DETERMINE WHICH SOLUTION WILL PREVAIL.

250
MILLION
TONNES
OF FUEL ARE CONSUMED BY THE SHIPPING INDUSTRY EVERY YEAR

The global fleet of in-service and on-order LNG-powered ships stands at just over 200 – which is an extremely small share of the total count, which amounts to around 90,000. The limited number of ships currently running on LNG are mainly passenger liners and ferries. The conversion of cargo ships to alternative fuels would have a much bigger impact, however, since they account for 90 percent and therefore the lion's share of the 250 million or so tonnes of fuel consumed by the shipping industry every year. "In ten years' time, LNG could account for as much as 20 percent of total fuel consumption," reckons Abeynaike. And that would be a massive jump from the current level, which is not even close to one percent.

But it is not all plain sailing. German shipping company Wessels believes that "widespread adoption of LNG in the maritime value chain faces a classic chicken or egg dilemma. No demand, no viable LNG infrastructure – and vice-versa." One of the first container ships to fit a flexible dual-fuel engine (oil and natural gas) is the Wes Amelie operated by Wessels. After a two-year conversion project partly funded by the German Federal Ministry of Transport, Nauticor used tankers to fuel the Wes Amelie with LNG for the first time in August 2017 in Bremerhaven.

LNG

Liquefied natural gas (LNG) is considered one of the cleanest of all maritime fuels. Increasingly strict legislation means that LNG is set to play an increasingly important role in the coming years – although this will be largely restricted to new builds as converting existing ships to LNG would be extremely costly.

NEW FLAGSHIP IN THE BALTIC

Nauticor's bunker ship in South Korea will be ready to set sail in 2018, when it will head straight for the Baltic Sea. With a tank capacity of around 7,500 cubic metres, it will send a strong signal as Nauticor's flagship. "We believe that this ship gives The Linde Group a first-mover advantage," maintains Abeynaike. "This state-of-the-art bunker will give huge momentum to the supply of LNG to ships docked in the Baltic Sea." Linde's bunkering strategy could also be suited to other global shipping hotspots.

In China, President Xi Jinping has called for an "energy revolution", signalling a move towards clean sources of energy. In 2015, the country introduced its own Emission Control Areas for densely populated stretches of coastline, and from 2019, a maximum sulfur concentration of 0.5 percent will be imposed on certain regions. It would appear that these changes are a sign of things to come.

Linde is having an LNG bunker ship built in South Korea. On completion, it will be deployed for fuelling in the Baltic Sea.


MAX 46 TON

90 percent of the world's trade is carried by ocean-going vessels. The busiest shipping routes run along the coastlines of Asia, Europe and North America. Consequently, the emissions levels in these regions are extremely high.

LOW-SULFUR FUEL IS THE LEAST COMPLEX SOLUTION FOR SHIPPING COMPANIES. IT REMAINS TO BE SEEN, HOWEVER, WHETHER REFINERIES HAVE SUFFICIENT HYDROGEN CAPACITY TO DESULFURISE THE REQUIRED FUEL VOLUMES.

The situation as it stands is uncertain, however, and until the introduction of the new sulfur cap in two years' time, many shipping companies could resort to short-term solutions. The biggest question is how the oil industry will react to the new regulation. Rising demand for cleaner fuels could result in price increases even before 1 January 2020, which could ultimately also affect the retail price of the goods being shipped. Uncertainty also surrounds the ability of refineries to produce sufficient volumes of low-sulfur fuel. A study commissioned by the IMO concluded that the oil industry is able to meet demand – even if it rises above today's average levels.

The consulting firms EnsysEnergy and Navigistics take a different view, however. They have presented a supplementary study maintaining that the oil industry's current capacities are too limited to meet rising demand for low-sulfur fuel.

TURNING WASTE INTO A VALUABLE COMMODITY

At the moment, refineries are offloading their heavy fuel oil to the shipping industry at a profit, but they will not be able to do this for much longer. Heavy fuel oil currently accounts for as much as 84 percent of shipping fuel, but the International Energy Agency (IEA) predicts that, moving forward, this fuel will either have to be desulfurised or be replaced by LNG, biofuel or other synthetic fuels.

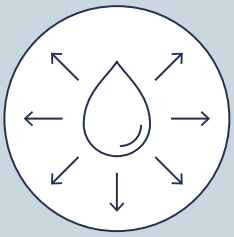
The share of heavy fuel oil in the fuel mix will decline to 30 percent by 2020, according to the International Transport Forum, an OECD think tank. Higher-grade fuels would then make up 70 percent of fuel consumption. This would shift demand by two million barrels per day – towards more complex and thus more expensive products. The refineries would most likely pass on the extra expense of the additional desulfurisation production step, which involves adding huge amounts of hydrogen to the distilled crude oil in a hydrotreater.

In the early stages, shipping companies will have little interest in switching to more expensive fuels. Nonetheless, demand for desulfurised marine diesel is on the rise, especially in Scandinavia. The Finnish oil refining company Neste expanded its range of low-sulfur marine fuel in 2017 and is now supplying ports in Sweden.

Since 2014, Neste has been relying on a Linde plant to produce the hydrogen required to desulfurise the fuel it refines at its Porvoo complex. Instead of going to waste, the elemental sulfur thus produced is sold separately to various industries, where it is used to manufacture fertilizers, for instance.

The Finnish example suggests that regulatory ceilings, greater transparency – thanks to solutions like Mellqvist's sniffer – and improved public awareness can change the habits of the shipping industry. It shows how a regional

DESULFURISED FUEL



Operators do not need to invest in new technologies or redesign their ships to convert to desulfurised fuel. It combusts so cleanly that it complies with all current sulfur thresholds. The only downside is that it is quite expensive compared with conventional fuel.

supplier successfully recognised that it makes sense to add desulfurised marine diesel to its portfolio. And if a small-scale business case like this can succeed, the global potential is even more impressive.

If shipping companies do indeed replace heavy fuel oil with low-sulfur fuels to the extent forecast by the OECD and the IEA, the demand for hydrogen would increase by 41 billion cubic metres per annum according to Tim Buttkus, who is responsible for oil and gas in Linde's strategy department. This corresponds to the extra volume of hydrogen that would be required to convert 60 to 70 percent of the heavy fuel oil currently used to low-sulfur products like LSFO. In total, more than 100 additional hydrogen plants would be needed to meet global demand for the type of clean marine diesel that is already being sold at the port of Gothenburg.

AN APPEALING OFFER

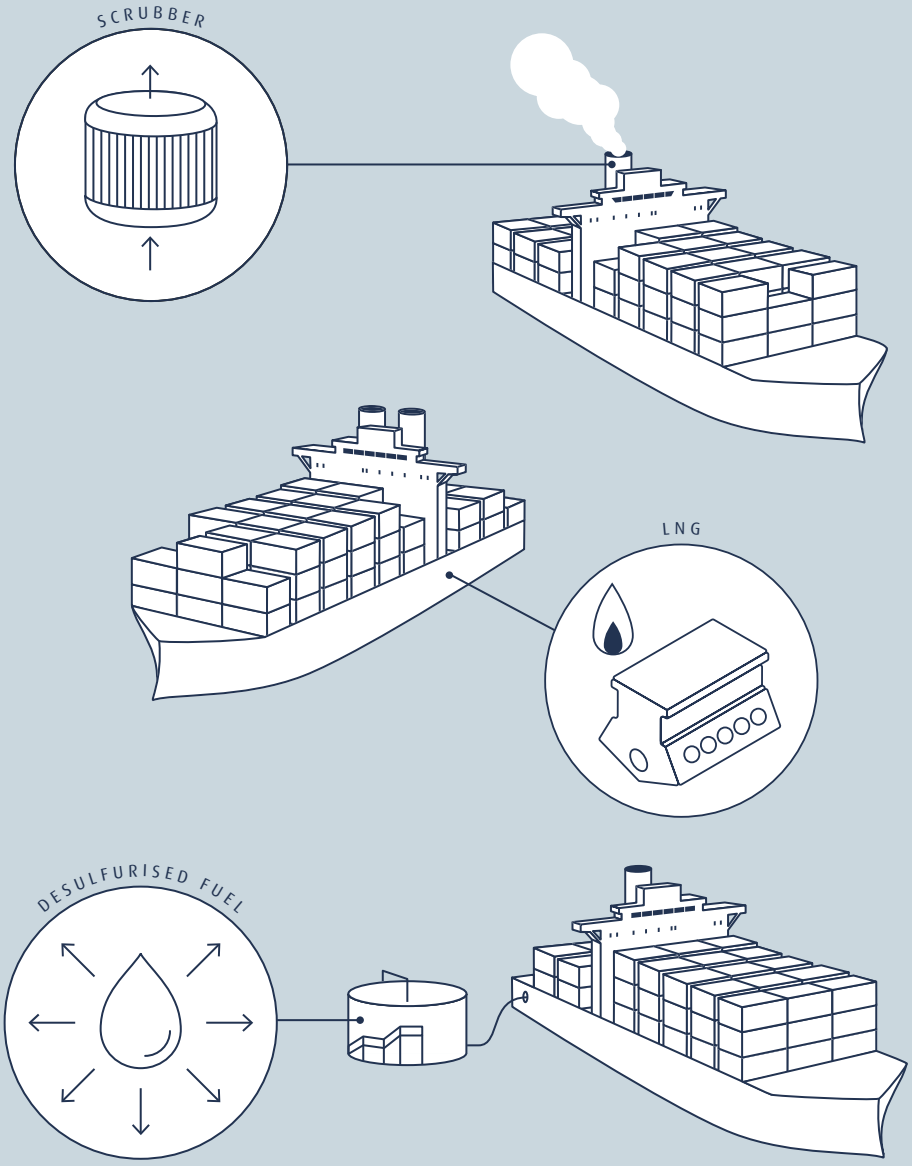
Edvard Molitor is responsible for environmental protection at the city's port authority. He sees low-sulfur fuel as an environmentally friendly and typically Swedish service within the port's offering. "We are a small country that depends on good connections with the rest of the world." Gothenburg port's offering should be of interest to every ship's captain.

Back in 2010, the Gothenburg port authority introduced a financial incentive system in favour of low-sulfur fuels. Since 2015, a 10 percent discount is deducted from the port charges if operators reduce the emissions, waste water and waste produced by their ship. Electricity and hot water are also available at the quayside so that the vessels moored there no longer need to switch on their generators, which for the most part also run on heavy fuel oil. The success of the Gothenburg port's initiative has spread to many other ports, where authorities now also offer discounts on charges and electricity. Molitor is keen to share his success story and experiences with others. Since April 2017, he has also been chair of the Sustainable Development Committee of the European Sea Ports Organisation. And in the vicinity of the port, he has helped to reduce sulfur dioxide emissions by 70 percent in the space of a year. It seems that Gothenburg has already set sail for the future.

GOOD ENVIRONMENTAL PRACTICE PAYS: OPERATORS OF ENVIRONMENTALLY FRIENDLY SHIPS SAILING INTO THE PORT OF GOTHENBURG QUALIFY FOR A 10 PERCENT DISCOUNT ON PORT TARIFFS.

The Neste refinery in Finland is using a hydrogen plant built by Linde to produce low-sulfur marine diesel. More than 100 of these hydrogen plants will be needed if shipping companies are to comply with the new thresholds.

REDUCING SULFUR EMISSIONS FROM SHIPS: THREE OPTIONS



At present, there are three ways to balance business interests with environmental protection regulations. The first entails building a scrubber into the ship so that it can continue to run on heavy fuel oil as before. However, it is expensive to retrofit and operate scrubbers. Secondly, operators can convert to LNG – but the conversion process is often complex and expensive, due in part to the large tank that needs to be built in. The upside is that LNG doesn't just lower sulfur emissions, it also significantly reduces nitrogen oxide, particulate and CO_2 levels.

LNG is also cheaper than desulfurised fuel, making it a very attractive, future-proof option especially for new builds. The third option entails switching to fuel that has been desulfurised with the help of hydrogen gas. This is the easiest route forward for shipping companies, although desulfurised fuel is more expensive than the heavy fuel oil used to date. Operators do not need to make any structural or design changes to their ships to run on desulfurised fuel, making this an easy way for existing ships to comply with the new regulations.

The history of hydrogen

1910
WATER GAS SEPARATION

At the suggestion of Adolph Frank and Nikodem Caro, Linde designs and builds a water gas separation plant. The method developed for producing hydrogen is known as the Linde-Frank-Caro process.

1920s
ETHYLENE RECOVERY

Linde develops a method to separate coke oven gases into the components hydrogen, nitrogen, methane and ethylene using extremely low temperatures. This process know-how laid the foundation for recovering ethylene from natural gas and oil.

1950s
STEAM REFORMING

Steam-reforming natural gas emerges as an economical way to produce hydrogen.

1970s
HYDROGEN MOBILITY

Rising environmental awareness again shines the spotlight in both political and business circles on hydrogen as a primary source of energy, with the potential in particular to meet mobility needs. Linde develops various concepts for the production, storage, transport and fuelling of hydrogen.

1999
PUBLIC FUELLING STATION

Together with its partners BMW and Aral, Linde opens the world's first public fuelling station for liquid and gaseous hydrogen at Munich Airport.

2015
SUSTAINABLE SOURCING

Linde collaborates with the Mainz utility company to build Energiepark Mainz. Here, surplus power from wind turbines is used to produce hydrogen, thus successfully turning wind energy into "green" hydrogen.

Working in cooperation with the chemists Adolph Frank and Nikodem Caro, Carl von Linde developed a method for producing hydrogen in the early 20th century. As with his research into refrigeration and air liquefaction, Linde's first priority was to understand and analyse the challenge. Several years elapsed before the initial idea and the suggestions put forward by Professor Frank from the Technical University of Berlin and his student Caro, Director of Bayerische Stickstoffwerke, culminated in a trial plant. Linde worked alongside his son Richard to refine the process in a specially erected corrugated iron hut on the Höllriegelskreuth grounds. Carl and Richard Linde managed to obtain hydrogen with a purity of 98 percent, thus laying the groundwork for what has since developed into a flourishing hydrogen business.

IMPRINT

PUBLISHED BY

Linde AG
Klosterhofstrasse 1
80331 Munich
Germany

CONTACT

Linde AG
Klosterhofstraße 1
80331 Munich
Germany

Phone: +49.89.35757-01
Fax: +49.89.35757-1075

www.linde.com

CORPORATE COMMUNICATIONS

Phone: +49.89.35757-1321
Fax: +49.89.35757-1398

media@linde.com

INVESTOR RELATIONS

Phone: +49.89.35757-1321
Fax: +49.89.35757-1398

investorrelations@linde.com

CONTACT DETAILS FOR NOTIFICATION OF VOTING RIGHTS

Fax: +49.89.35757-1007

ANNUAL FINANCIAL REPORT

The Linde Annual and the Financial Report of The Linde Group are available in both German and English. The Financial Report can also be downloaded from our website at www.linde.com. On request, we can also provide you with supplementary information about Linde.

CONCEPT, DESIGN, PRODUCTION

hw.design, Munich
Germany

TEXT

Plan.Net Pulse
Linde AG

PHOTOGRAPHY

Sigrid Reinichs
[5, 6, 9, 10/11, 27, 37, 41, 43, 63, 64]
Robert Fischer
[4, 12, 15, 16/17, 31, 32, 34, 38]
Josh Robenstone
[18, 21, 22/23]
Tasneem Alsultan [55]
Nathan Roser [46]
Linde AG
[44, 45, 47, 48, 50/51, 53, 56, 69, 74]
Samuel Zeller [60]
Fancy Crave [61]
Johan Mellqvist [65]
pipehorse/Adobe Stock [66]
Prasit photo/Getty Images [70/71]

PRINT

G. Peschke Druckerei GmbH
85599 Parsdorf/Munich
Germany

Curious Matter, Goya White [cover]

Metapaper Smooth White [content]

ClimatePartner°
climate neutral
Print | ID 53152-1802-1006

FSC www.fsc.org
MIX
Paper from responsible sources
FSC® C002390

Published by

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