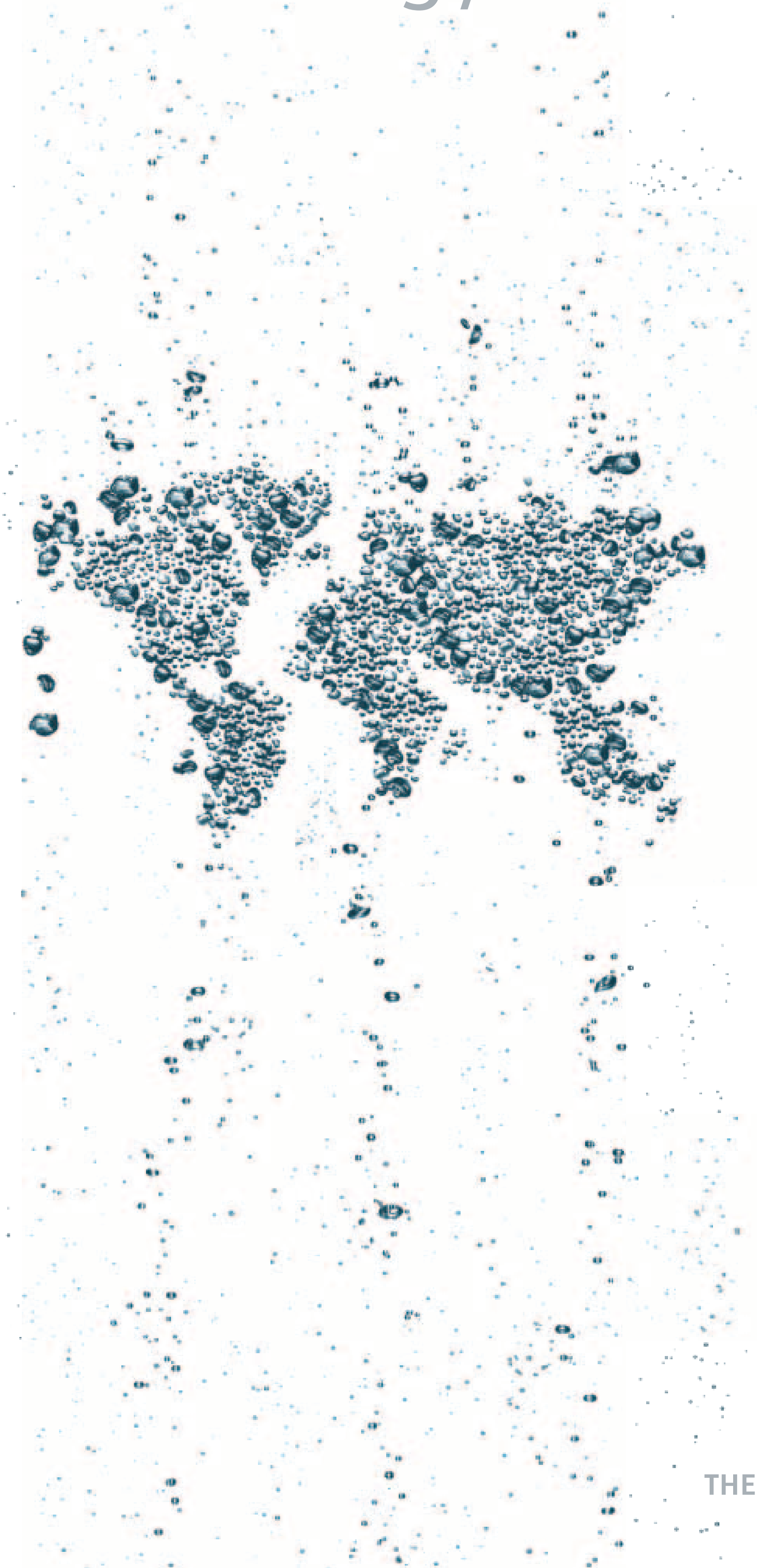
The Linde Annual 2011.

Clean Technology Solutions.



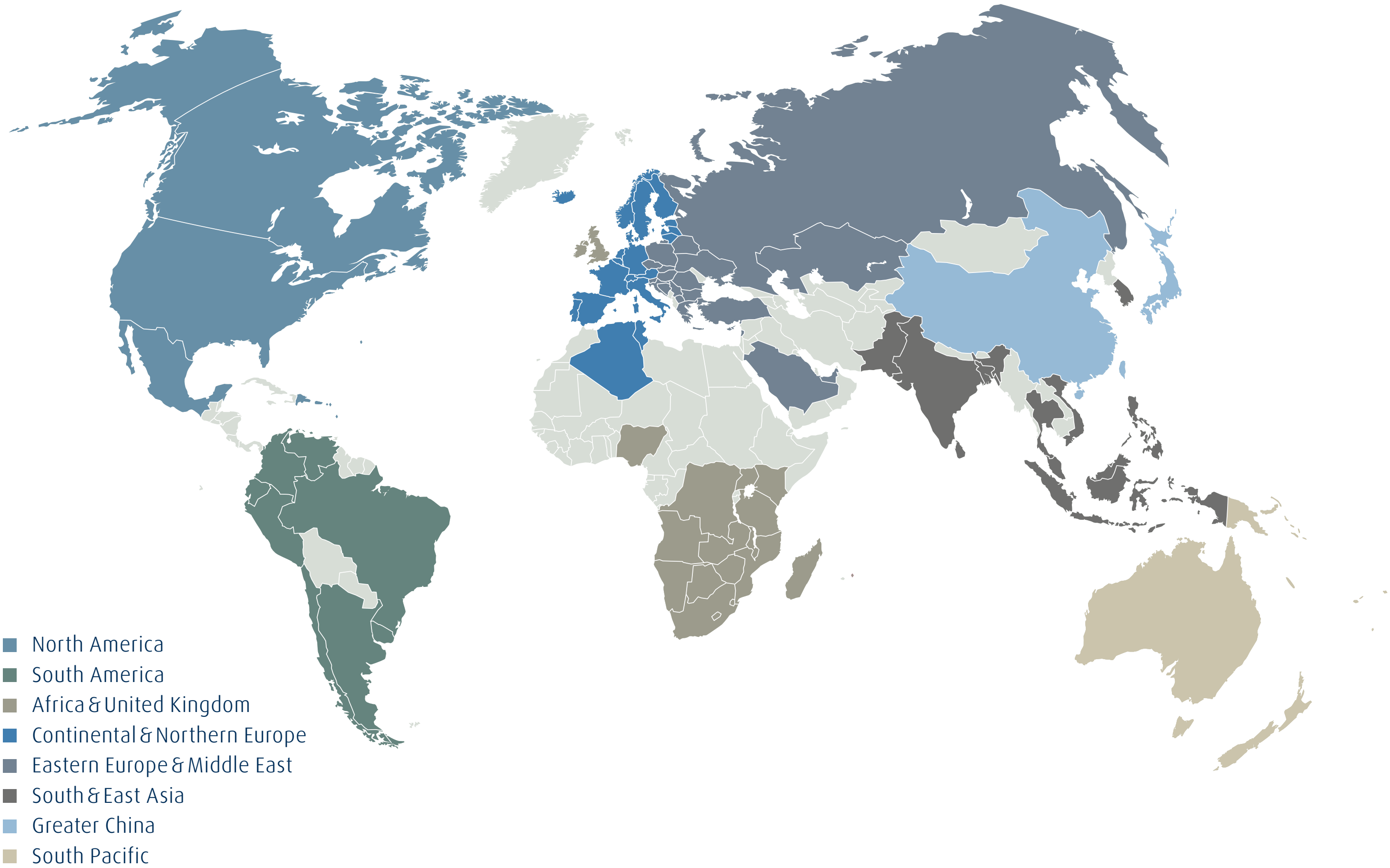
Leading.

THE LINDE GROUP

The Linde World

The Gases Division has three operating segments – EMEA (Europe, the Middle East and Africa), Asia/Pacific and the Americas. These are divided into eight Regional Business Units (RBUs). The Gases Division also includes the two Global Business Units (GBUs) Healthcare (medical gases) and Tonnage (on-site), as well as the two Business Areas (BAs) Merchant & Packaged Gases (liquefied and cylinder gases) and Electronics (electronic gases).

Active the world over, the Engineering Division specialises in olefin, natural gas, air separation, hydrogen and synthesis gas plants.



Customer segmentation within the Gases Division

Broad, well-balanced customer base ensures stability.

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

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

Corporate profile

The Linde Group

The Linde Group is a world-leading gases and engineering company with approximately 50,500 employees working in more than 100 countries worldwide. In the 2011 financial year, it achieved sales of EUR 13.787 bn. The strategy of The Linde Group is geared towards long-term, profitable growth and focuses on the expansion of its international business with forward-looking products and services. Linde acts responsibly towards its shareholders, business partners, employees, society and the environment – in every one of its business areas, regions and locations across the globe. The company is committed to technologies and products that unite the goals of customer value and sustainable development.

Organisation

The Group comprises three divisions: Gases and Engineering (the two core divisions) and Gist (logistics services). The largest division, Gases, has three operating segments – EMEA (Europe, the Middle East and Africa), Asia/Pacific and the Americas. These are divided into eight Regional Business Units (RBUs). The Gases Division also includes the two Global Business Units (GBUs) Healthcare (medical gases, supporting services and consultation) and Tonnage (on-site supply of gases to major customers), as well as the two Business Areas (BAs) Merchant & Packaged Gases (liquefied and cylinder gases) and Electronics (electronic gases).

Gases Division

The Linde Group is a world leader in the international gases market. The company offers a wide range of compressed and liquefied gases as well as chemicals, and is the partner of choice across a huge variety of industries. Linde gases are used, for example, in the energy sector, steel production, chemical processing, environmental protection and welding, as well as in food processing, glass production and electronics. The company is also investing in the expansion of its fast-growing Healthcare business (medical gases), and is a leading global player in the development of environmentally friendly hydrogen technologies.

Engineering Division

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

Linde financial highlights

in € million		January to December 2011	2010	Change
Share				
Closing price	€	114.95	113.55	1.2 %
Year high	€	125.80	115.30	9.1 %
Year low	€	96.16	76.70	25.4 %
Market capitalisation (at year-end closing price)		19,663	19,337	1.7 %
Adjusted earnings per share [1]	€	7.71	6.89	11.9 %
Earnings per share – undiluted	€	6.88	5.94	15.8 %
Number of shares outstanding (in 000s)		171,061	170,297	0.4 %
Sales		13,787	12,868	7.1 %
Operating profit [2]		3,210	2,925	9.7 %
Operating margin		23.3 %	22.7 %	+60 bp[3]
EBIT before amortisation of fair value adjustments		2,152	1,933	11.3 %
Earnings after taxes on income		1,244	1,064	16.9 %
Number of employees		50,417	48,430	4.1 %
Gases Division				
Sales		11,061	10,228	8.1 %
Operating profit		3,041	2,766	9.9 %
Operating margin		27.5 %	27.0 %	+50 bp[3]
Engineering Division				
Sales		2,531	2,461	2.8 %
Operating profit		304	271	12.2 %
Operating margin		12.0 %	11.0 %	+100 bp[3]

[1] Adjusted for the effects of the purchase price allocation.
[2] EBITDA including share of income from associates and joint ventures.
[3] Basis points.

Our company values

Passion to excel.

Innovating for customers.

Empowering people.

Thriving through diversity.

Our vision

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

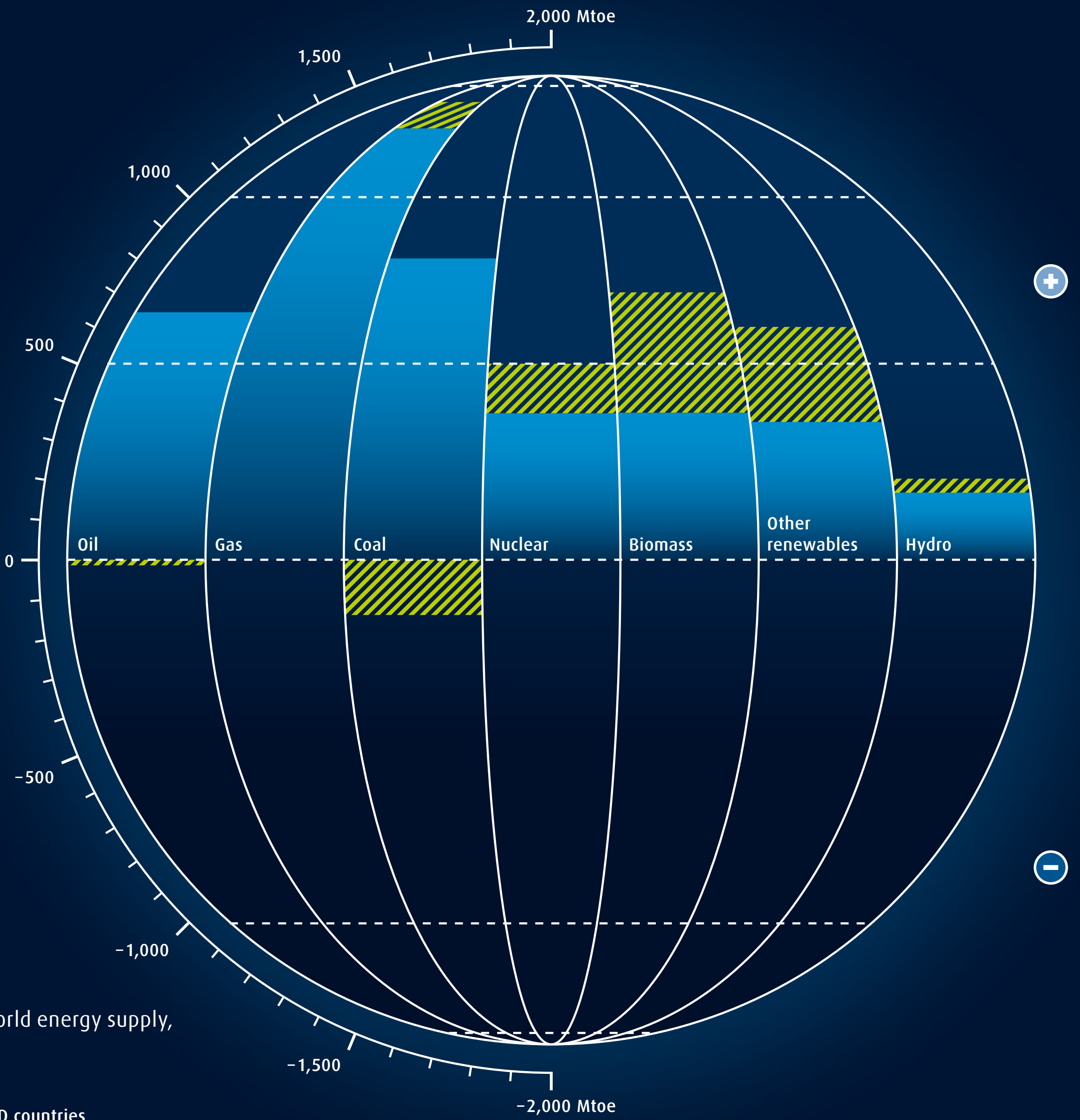
Front cover fold-out:
C3: The Linde World/Customer segmentation within the Gases Division, C4: Corporate profile/Linde financial highlights

Clean Technology Solutions.

Modern society depends on an affordable, reliable, environmentally sound supply of energy. And securing that supply is one of the biggest challenges we currently face. Global demand for energy continues to rise, exposing our climate and environment to growing risks. The journey to a cleaner energy economy involves the systematic advancement of renewable sources of energy and the deployment of new, sustainable technologies. Linde covers the full competence chain required to efficiently recover, develop and use the earth's valuable resources. The company also has a broad portfolio of clean technologies, putting it in an excellent position worldwide to capitalise on the fast-growing energy and environmental markets and make a valuable contribution to a sustainable energy sourcing and supply architecture.

Global energy supply is set to rise sharply in the years up to 2035.

→ Non-OECD countries[1] will account for sharpest rise in energy production.
→ Natural gas is set to grow in importance as a source of power.
→ Only OECD countries[2] will reduce their production of energy based on coal and oil.



Projected world energy supply, 2009–2035

Non-OECD countries

OECD countries

OECD: The Organisation for Economic Co-operation and Development unites 34 countries around the world in their commitment to democracy and market economies. The OECD promotes policies that support sustainable economic growth, improve the economic and social well-being of people around the world, foster the development of non-OECD countries and thus contribute to an increase in global trade.

Source: World Energy Outlook 2011, New Policies Scenario, International Energy Agency.

Mtoe = Million tonnes of oil equivalent

[1] Non-OECD countries: Mostly emerging or less developed economies with comparatively low per-capita income.

[2] OECD countries: Mostly developed, industrialised countries with high per-capita income.

The energy of the future.

Dr Fatih Birol is Chief Economist of the International Energy Agency (IEA). In this article for the Linde Annual, he looks at the global energy economy of the future, exploring ways of balancing the conflicting goals of energy security, climate protection, energy access and economic competitiveness.

Dr Fatih Birol oversees the annual *World Energy Outlook,* which is the flagship publication of the IEA and is recognised as the most authoritative source for energy analysis and projections. He is also the founder and chair of the IEA Energy Business Council, which brings together leaders of some of the world's largest energy companies and policymakers to seek solutions to global energy challenges.

Dr Birol has been named by *Forbes Magazine* among the most powerful people in terms of influence on the world's energy scene. Throughout his career, he has been awarded by many governments and institutions for his outstanding contribution to the profession.

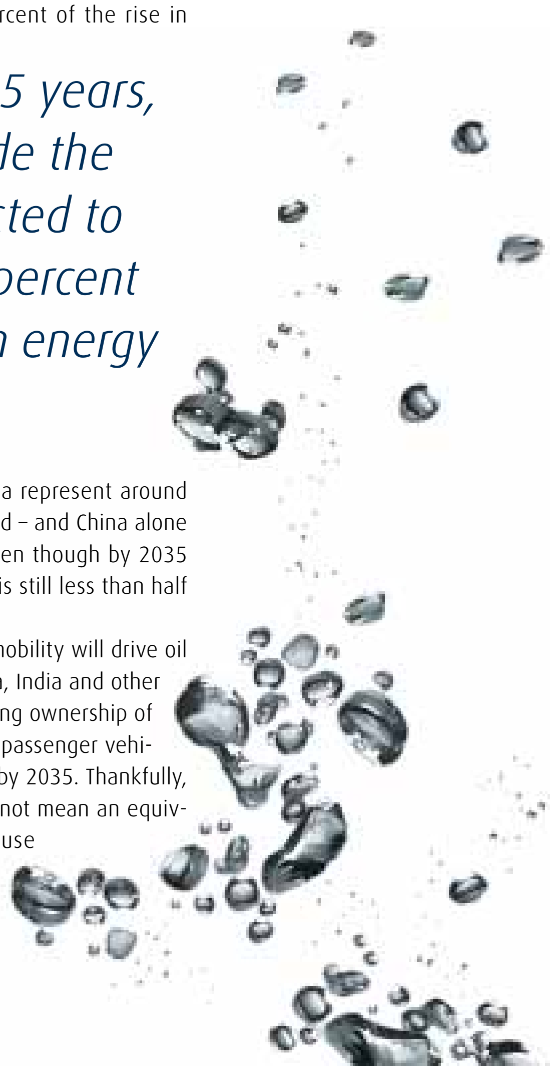
Growing populations and economies are set to keep demand for energy on an upward path over the coming decades. This trend presents the energy industry with a number of daunting challenges. It needs to meet rising demand in ways that are reliable, affordable and do not compromise the environment that we leave for future generations. The industry's ability to rise to these challenges is complicated by the interplay of a number of different factors, most of which are hard to predict accurately. But today, more so than ever, the industry is facing a period of unprecedented uncertainty – over the economic outlook, over future policy directions – and this has the potential to hamper investment decisions.

IEA's analysis of energy and climate trends, outlined in detail in our flagship publication the *World Energy Outlook*, provides a quantitative look at the risks and opportunities facing the global energy economy up to 2035. One of the key conclusions is that there is no single 'energy of the future': how we produce and use energy in the decades to come depends crucially on actions taken by governments around the world, the policy frameworks they put in place, and how the energy industry and energy consumers respond. But looking at the energy and environmental policies that are in place today – and taking a cautious view on the prospects for implementation of new policies that have been announced by governments – we can point to some of the key considerations and questions that will drive the global energy economy.

The dynamics of energy markets will increasingly be determined by decisions taken in Beijing and New Delhi. The year 2009 saw a historic re-ordering of global energy, as China overtook the United States to become the world's largest energy consumer. Over the next two and a half decades, countries outside the OECD are expected to account for 90 percent of global population growth, 70 percent of the increase in economic output and 90 percent of the rise in energy demand. China and India represent around half the growth in global demand – and China alone represents almost one-third, even though by 2035 China's per capita consumption is still less than half the level of the United States.

Over the next 25 years, countries outside the OECD are expected to account for 90 percent of the growth in energy demand.

Ever-increasing demand for mobility will drive oil markets. Rising incomes in China, India and other non-OECD countries means soaring ownership of vehicles – we expect the global passenger vehicle fleet to double to 1.7 billion by 2035. Thankfully, doubling the vehicle fleet does not mean an equivalent rise in oil demand because the increase is moderated by improved fuel economy and, in the medium to long term, a



Beyond crude oil.

State-of-the-art technologies have the potential to enhance recovery of fossil fuels and reduce dependency on oil-producing countries.

1

growth in alternative fuel vehicles such as natural gas vehicles, flex-fuel cars using either conventional oil liquids or biofuels, electric cars and hydrogen fuel cell vehicles.

Looking at the supply side, technology is unlocking new hydrocarbon resources but the global oil supply outlook still depends on events in the Middle East and North Africa. The world still relies on this region for the bulk of its additional supply – the expected growth in output from this region by 2035 is set to cover 90 percent of the rise in global oil demand. However, the supply picture is vulnerable to any cut-backs in investment in this region that might be caused by increased perceptions of risk or shifting policy priorities after the recent 'Arab Spring'. New sources of oil are emerging from the deep offshore or the 'light tight oil' that is now being developed in the United States because of advanced drilling techniques. These technologies also bring new risks – in particular environmental risks – that the industry has to address.

There are good reasons on both the demand and supply sides to foresee a bright future, even a golden age, for natural gas.

The United States is the largest oil-importing country in the world and, some years ago, it was widely expected that the United States would also become a major importer of natural gas. But the boom in unconventional gas production (mainly shale gas) turned this expectation on its head. Now, a combination of increased transport efficiency and increased domestic oil supply promise a drastic reduction in the United States' oil imports as well. By 2015, oil imports to the European Union surpass those to the US, and around 2020, China becomes the largest single oil-importing country. The European Union is already the largest importer of natural gas in the world and gas imports to China and other fast-growing Asian economies are also rising rapidly. These changing patterns of global trade prompt shifting concerns about the cost of imports and about oil and gas security, and a further sea-change in the geopolitics of energy.

There are good reasons both on the demand and supply sides to foresee a bright future, even a golden age, for natural gas. We expect that demand for natural

gas will catch up with that for coal by 2035, with most of the additional demand coming from countries outside the OECD, notably China, India and countries across the Middle East. For these countries, gas is a particularly attractive fuel in the move to satisfy rapidly rising energy demand in fast-growing cities. On the supply side, unconventional gas now accounts for half of the estimated resource base and it is more widely dispersed than conventional resources, a fact that has positive implications for gas security. Unconventional production is expected to rise to account for one-fifth of total output by 2035, although the pace of unconventional development varies considerably by region – with the United States, China and Australia taking the lead.

The age of fossil fuels is far from over, but their dominance is set to decline.

Natural gas is the cleanest of the fossil fuels and so can play an important role in the transition to a low-carbon energy future. However, increased use of gas in itself (without carbon capture and storage; see glossary) does not provide the answer to the challenge of climate change.

Coal was the big winner of the energy race over the last decade, but the future of the 'forgotten fuel' is less certain.

Coal accounted for nearly half of the increase in global energy use over the last decade, with the bulk of this increase meeting demand for electricity in emerging economies, and coal has been instrumental in expanding access to modern energy services. The international coal market is very sensitive to developments in China, which accounts for almost half of global production and demand, and increasingly also to India, which is expected to overtake the United States as the world's second-largest coal consumer and to become the largest coal importer in the 2020s. Policy and technology choices will be key in these markets and elsewhere. One of the key questions will be how to mitigate the environmental impacts of coal use through the uptake of more efficient power plants and the development of technology for carbon capture and storage.

These projections for oil, natural gas and coal in the global energy economy indicate that the age of fossil fuels is far from over, but their dominance is set to decline. An expansion of nuclear power post-Fukushima is still on the cards as there has been no change of policy in the key countries driving the expansion of the nuclear industry such as China, India, Russia and Korea. What is more, renewables are set to come of age, underpinned by continued government subsidies. The share of renewable energy (excluding large hydropower) in global electricity generation is set to increase from around 3 percent today to 15 percent in 2035, with the European Union and China taking the lead in pushing the introduction of green technologies. Wind generation increases by more than eight times by 2035 compared with 2010. The subsidy cost per unit of renewable energy declines as costs are reduced and in some cases renewable technologies are becoming competitive without support, as for example onshore wind in the European Union around 2020 and in China around 2030. But in most cases, renewable energy requires continued subsidies: the global cost of subsidies is expected to rise from USD 66 bn in 2010 to USD 250 bn by 2035 as supply grows from renewable sources. This delivers

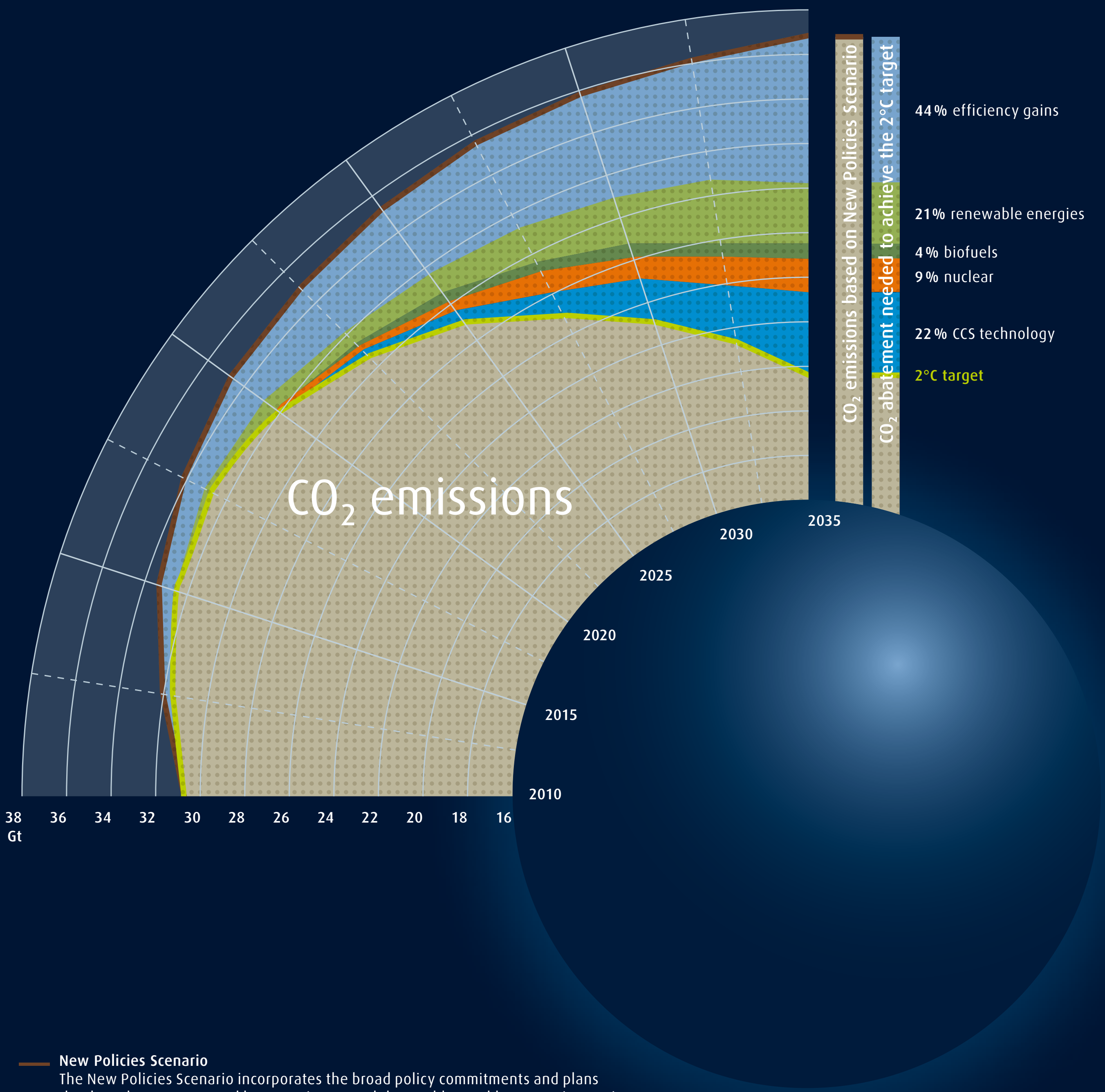
The emerging favourite.

Natural gas is a particularly attractive option for countries looking to meet rapidly rising energy demand in fast-growing cities. Unconventional gas resources are expected to account for a growing share of the resource base, partly due to the fact that they are more widely dispersed than conventional resources.

The future of coal.

Looking at the future of coal, one of the key questions is how to mitigate its environmental impacts through the uptake of more efficient power plants and the development of technology for carbon capture and storage.

Additional CO_2 savings needed to limit global warming to 2°C.



1

New Policies Scenario
The New Policies Scenario incorporates the broad policy commitments and plans that have been announced by countries around the world to tackle energy insecurity, climate change and local pollution, and other pressing energy-related challenges, even where the specific measures to implement these commitments have yet to be announced.

450 Scenario
The 450 Scenario depicts an energy pathway that is consistent with a 50 percent chance of meeting the goal of limiting the increase in average global temperature to 2°C compared with pre-industrial levels.

The graphic shows that CO_2 emissions will have to be drastically reduced in order to limit global warming to 2°C. This can only be achieved by deploying innovative technologies such as carbon capture and storage. A look at the Current Policies Scenario, however, shows that we are still a long way off target.

Source: World Energy Outlook 2011.

Gt = gigatonne

lasting benefits, such as a more diverse electricity mix and a reduction in emissions of greenhouse gases. The experts assume that the contribution of hydropower to global power generation will remain at around 15 percent in 2035, with China, India and Brazil accounting for almost half of the new capacity.

We should also not forget that the energy of the future is, for some, a future without energy. Today, 1.3 billion people do not have access to electricity and 2.7 billion still rely on the traditional use of biomass for cooking. Providing modern energy services would not cost the earth and would make a huge contribution to human development and welfare. However, without a significant increase in investment, the global picture is set to change little from today – and in sub-Saharan Africa it is set to worsen. National governments, international institutions and the private sector all have vital roles to play.

Overall, there is much to be done to put the world on the path towards a more reliable and sustainable energy future – and there are few signs that the necessary change in direction in global energy trends is underway. According to our analysis, the world is in real danger of missing the chance to reach its long-term target of limiting the global average temperature increase to 2 degrees Celsius. If stringent additional action is not forthcoming by 2017, then the world's capital stock – its power plants, buildings, factories and so on – will generate all the CO_2 emissions permitted under a 2-degree scenario up to 2035, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon, which would be extremely costly.

The most important contribution to reaching global climate change objectives comes from the energy that we do not consume. A much greater focus on energy efficiency is vital – a real transformation in the way that we produce and use energy. Green technologies, nuclear power and technologies such as carbon capture and storage all have important roles to play as well. If there is a substantial global shift away from nuclear power[1], or if carbon capture and storage technology is not widely deployed already in the 2020s, this would make it harder and more expensive to combat climate change and put an extraordinary burden on other low-carbon technologies to deliver lower emissions.

We need to fundamentally change the way we generate and use energy.

In this context, policymakers and industry leaders must redouble their efforts to overcome the energy challenges that they share. At the heart of policymaking will be the difficult task of balancing the conflicting goals of energy security, climate protection, energy access and economic competitiveness, while providing the energy industry with the long-term and stable framework that it needs to confidently move ahead with the huge investments that can transform our energy future.

Innovative energy for mobility.

In the medium to long term, vehicles powered by hydrogen fuel cells, batteries, natural gas and biofuels are promising alternatives to the world's rising mobility needs.

The rise of renewables.

The share of renewables in the total energy mix is expected to rise from 3 percent to 15 percent by 2035. Despite the subsidies this will require, the IEA sees this as a positive global trend overall as it will result in a more ecologically sound energy balance and lower greenhouse gas emissions.

[1] Our latest *World Energy Outlook* includes a 'Low Nuclear Case' in which nuclear capacity additions are one half of those anticipated in our central scenario. This creates some opportunities for renewable energy sources, but also boosts demand for fossil fuels substantially, raising additional concerns about energy security and increasing CO_2 emissions.

2

↳ The majority of the world's energy needs are met with resources that we recover from below the earth's surface. And this will continue to be the case for the foreseeable future.

→ Chapter 2

Extracting fossil fuels.

The efficient, environmentally sound way.

Separating air to obtain natural gas.

The two industrial-scale air separation plants operated by the Linde/ADNOC joint venture Elixier produce 670,000 cubic meters of nitrogen per hour. From this site in Mirfa, Abu Dhabi (United Arab Emirates), the nitrogen is transported inland via a 50-kilometre pipeline to the Habshan gas field, one of the largest in the region. The nitrogen is pumped into the natural gas field to increase recovery efficiency. This is a strategic project, as ADNOC has access to around 90 percent of Abu Dhabi's crude oil and natural gas reserves – estimated to be the fourth largest in the world.

2

2

More people – more demand for raw materials.

The world's population is growing rapidly, with the earth now home to over seven billion people. This increase is fuelling demand for energy, particularly in emerging economies. And that rise in demand will continue to be met predominantly through fossil fuels.

Innovative fossil fuel technologies.

Coal, oil and natural gas will remain a crucial part of the world's energy landscape for the foreseeable future. Innovative technologies are key to ensuring that these fossil fuels are recovered efficiently and consumed with minimal environmental impact. Linde has the skills and portfolio to meet the needs of this dynamic, billion-euro growth market.

2

Renewable energies take centre stage in public discussions about future energy supplies. Yet these debates often overlook the fact that, in the medium term, renewables such as water, wind and solar power will only be able to cover a fraction of the world's rising energy demands. Industrialised countries and – even more so – booming emerging markets will remain reliant on fossil coal, natural gas and crude oil for decades to come. These resources must be developed efficiently with minimal ecological impact in order to meet rising environmental and climate protection standards and ensure sufficient reserves for future generations.

Linde is a trusted partner to major energy companies and its sophisticated technologies and processes help customers achieve these goals.

+60 %

crude oil thanks to nitrogen.

Nitrogen from Linde's air separation plant in Cantarell (Mexico) enabled engineers to increase yield from the local oil field by 60 percent in the first year alone.

Efficient crude oil and natural gas extraction

Industrial gases such as nitrogen play a crucial role in enhanced oil and gas recovery (EOR and EGR). Pumping nitrogen underground, for example, makes it easier to extract valuable fossil resources.

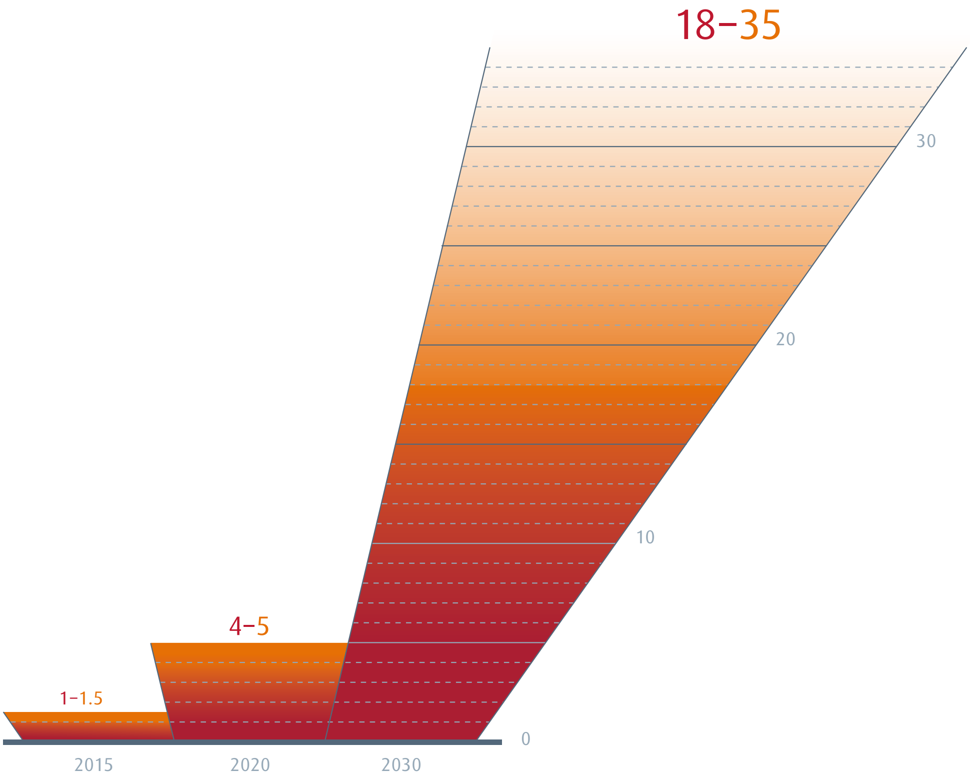
↳ Elixier II in action: The air separation plants at Mirfa, Abu Dhabi, were designed and built by Linde's Engineering Division.

Enhanced oil and gas recovery requires large quantities of nitrogen. To meet this need, Linde has designed and built some of the world's biggest air separation plants in recent years.

In the summer of 2011, two major facilities went on stream in the coastal town of Mirfa (Abu Dhabi, United Arab Emirates). Linde was commissioned to build these air separation plants by Elixier, a joint venture between the Abu Dhabi National Oil Corporation (ADNOC) and Linde, with a 51 and 49 percent stake respectively. A total of around USD 800 m was invested in this industrial-scale project.

Dynamic growth.

Global demand for enhanced oil and gas recovery technologies (EUR billion).



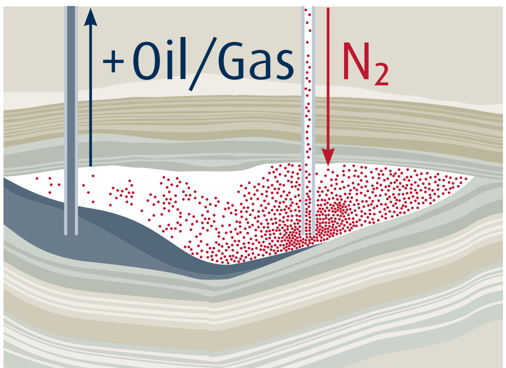
Source: Linde estimates.

The two plants produce around 670,000 normal cubic metres of nitrogen per hour from the surrounding air. The gas is piped 50 kilometres inland to the Habshan field, where it is injected into the gas reservoirs to ensure consistent yields – above all of condensate – and raise production levels. Prior to using nitrogen, the company injected natural gas into the Habshan gas field to keep pressure steady during condensate extraction. Now, this valuable raw material can be used to generate energy in the rapidly expanding region.

Mirfa is a strategic project for the international energy market as a whole. ADNOC has access to around 90 percent of Abu Dhabi's crude oil and natural gas reserves, and these are estimated to be the fourth largest in the world.

The new air separation plants in Mirfa are based on a proven design concept: they are almost identical to the five major air separation plants that Linde has built in Cantarell, Mexico, since 2000. Within twelve months of the plants going on stream, the nitrogen they produced increased crude oil yields by around 60 percent at the Cantarell field in the Gulf of Mexico.

Experts predict above-average growth rates for the global EOR and EGR market; increasing from EUR 1 to 1.5 bn by 2015 and expanding to as much as EUR 35 bn by 2030.



Enhanced oil and gas recovery.

Enhanced oil and gas recovery involves injecting gases, for example nitrogen, into an oil well at high pressure. The gases increase dwindling pressure in the oil or gas reserves, significantly raising yields.

↳ Gas storage tanks at Europe's largest natural gas liquefaction plant, on the island of Melkøya off the Norwegian coast near Hammerfest.

Natural gas liquefaction.

In the liquefaction unit, raw gas is first fed through a system of pipes known as a slug catcher to separate the gas from condensate, water and glycol. Carbon dioxide, mercury and any remaining water are then filtered out of the gas stream before the actual liquefaction process starts. The gas is liquefied in a multi-step cooling process tailored to local conditions on site. For the Melkøya plant, Linde developed a special, energy-efficient liquefaction process known as Mixed Fluid Cascade (MFC®; see glossary).

2

Growing market for natural gas liquefaction

Natural gas is becoming an increasingly important fossil fuel. The world's gas reserves will last significantly longer than dwindling oil deposits. Natural gas is also much kinder to the climate.

Companies are therefore looking to develop gas fields in regions and reservoirs that were previously regarded as impossible or difficult to access. The Snøvhit natural gas field in the Barents Sea, on the southern edge of the Arctic Ocean, is one such example. The gas is extracted from the field by Norwegian energy group Statoil and transported 140 kilometres by pipeline to the island of Melkøya, near Hammerfest. It is then liquefied in a special terminal before being transported in custom-built tankers to customers in southern Europe and the US.

Statoil appointed Linde as the main contractor for this project, responsible for the engineering, procurement and assembly of the natural gas liquefaction plant. With a liquefied natural gas (LNG; see glossary) production capacity of four million tonnes per year, it is the largest facility in Europe. The contract was worth over EUR 900 m for Linde.

LNG is also a growth market. Experts currently estimate that the global LNG engineering market will be worth between EUR 3 and 4 bn by 2015, and expect this to rise to as much as EUR 23 bn by 2030. These figures also include Floating Production, Storage and Offloading (FPSO) LNG units (see page 19).

Storing CO_2 under the Barents Sea

For the Snøvhit project, Linde engineers were responsible for building the purification and liquefaction stages. They were also tasked with capturing and compressing most of the CO_2 separated from the natural gas stream. The idea was to feed the CO_2 back into the gas field instead of releasing it into the atmosphere. Around half of the CO_2 (approximately 700,000 tonnes per year) is now piped 2.6 kilometres below the ocean floor and stored there. This milestone carbon capture and storage facility will serve as a reference project for future natural gas liquefaction plants. The Melkøya facility has earned its title as the most energy-efficient plant of its kind in the world.

–700,000 t

CO_2 emissions using new natural gas liquefaction technology from Linde.

At the Melkøya natural gas liquefaction plant, an environmentally friendly procedure known as carbon capture and storage is used to recover 700,000 tonnes of CO_2 each year and feed it back into the gas field. This process prevents the greenhouse gas from escaping into the atmosphere.

Recovering unconventional reserves

Innovative drilling technologies combined with new transport and storage options are opening up natural shale gas reserves that were previously difficult to access. Worldwide, these unconventional reserves contain enough gas for at least the next 200 years.

Shale gas has already triggered a boom in the US energy sector. Thanks to these new reserves, the United States has now overtaken Russia as the world's largest natural gas supplier. This energy carrier now accounts for around 14 percent of the US natural gas market, and the International Energy Agency (IEA) expects this figure to rise to 45 percent by 2035. IEA

Extreme technology.

Building Europe's largest natural gas liquefaction plant in the icy climes of northern Norway brought its own people and technology challenges. The facility is now a reference project for future plants in the growing global LNG market.

experts also estimate that around 920 trillion cubic metres of natural gas is stored in unconventional reserves across the globe.

Europe is also home to unconventional natural gas reserves offering sizeable market potential. These shale gas reserves are locked in almost impermeable stone and coal seams, the most significant of which are located in Poland, France, Norway and the Ukraine. Reserves have also been found in the UK, the Netherlands and Germany.

Backed by its expertise in extracting, liquefying and storing natural gas, Linde is ideally placed to capitalise on this global growth market.

Separating nitrogen from natural gas

Linde has developed a nitrogen rejection unit (NRU) for LNG plants, which also has the potential to open up reserves previously regarded as uneconomical. It does this by removing almost all the nitrogen from natural gas streams, enabling it to meet the requisite quality standards (less than 1 percent nitrogen content) with a high energy density.

At the end of 2011, Linde successfully started production at a natural gas liquefaction plant equipped with an NRU. The Group built the facility for its customer Woodside, Australia's largest crude oil and natural gas company. The plant processes natural gas from the Pluto and Xena fields off the coast of western Australia. The natural gas in these reserves comprises over 6 percent nitrogen. Rectification columns (see glossary) in the NRU remove the nitrogen from the natural gas, leaving it with a nitrogen content of less than 1 percent.

The new plant puts Linde in a strong position to win future contacts in this growth market. Experts believe that more and more developers will be turning to reserves with a high nitrogen content in the coming years in order to meet rising global demand for natural gas.

Looking to the future with floating LNG factories

Natural gas extraction is not limited to extreme climates such as the Barents Sea. In future, extraction will also move further away from coastal waters into the open sea. Yet many reservoirs are either too far away from land for pipelines to be laid or are not large enough to be considered economically viable. Linde and its project partner SBM Offshore (the Netherlands) are working on a solution to these challenges. The two companies are developing floating LNG factories, which can help make smaller, isolated reserves more economically viable.

In June 2011, Linde and SBM signed a cooperation agreement with the Thai petroleum group PTT (Petroleum Authority of Thailand) to develop a floating LNG facility in the Timor Sea, north of Australia. The facility will liquefy natural gas from three fields. Once the scope of the reserves has been confirmed, the project will move into the concrete planning phase. The final investment decision is expected at the end of 2012. Commercial extraction and liquefaction could then start in 2016.

Natural gas is a key stepping stone on the road to sustainable, environmentally sound energy supplies. And floating LNG factories are one of the building blocks that will help energy companies make the most of this crucial resource.

↳ (top) Linde's natural gas liquefaction plant is located off the Norwegian coast on the island of Melkøya, near the city of Hammerfest.

↳ (bottom) At full capacity, around six billion cubic metres of liquefied natural gas will be shipped from here each year.

→ Chapter 3

Using natural gas intelligently.

Cost-effective, climate-friendly solutions.

3

World's largest air separation plant contract.

The world's largest gas-to-liquids facility went on stream in 2011 in the State of Qatar. Each day, the plant converts 140,000 barrels of natural gas into liquid hydrocarbons. Eight large air separation plants built by Linde supply the facility with the oxygen it needs – around 860,000 cubic metres per hour.

Liquefied natural gas – around the world in tankers.

Linde has opened its first LNG terminal, thus rounding off its LNG engineering portfolio. Since May 2011, Linde has been supplying the entire Baltic Sea region with liquefied natural gas from its Nynäshamn terminal in southern Sweden. The gas is liquefied at Linde's Stavanger LNG facility and shipped to the terminal in storage tanks. Here it is stored for onward transport in a tank capable of holding up to 20,000 cubic metres of LNG – in other words, around twelve million cubic metres of gas.

LNG worldwide

Across the globe by tanker.
(Source: Linde Technology, 01.2011)

3

No need for pipelines.

Liquefying natural gas reduces its volume by a factor of 600, making liquefied natural gas (LNG) an increasingly interesting commodity. Transporting gas by pipeline is only economically viable up to a distance of around 3,000 kilometres. LNG, however, can be transported across the globe by ship at a temperature of minus 162 degrees Celsius. According to a study carried out by the California Energy Commission, there are natural gas liquefaction and export marine terminals in 15 countries. In contrast, there are 60 import terminals spread across 18 different countries. The Commission also reports that, in addition to these existing terminals, 65 liquefaction marine terminals and approximately 180 regasification terminal projects have either been proposed or are currently being constructed around the globe.

LNG hubs

Reference plants: selected Linde LNG projects across the globe.

The benefits of small and mid-sized LNG plants.

Linde covers the full competence chain for small and mid-sized LNG plants. This market segment is expanding, as more compact and micro designs offer numerous benefits such as short planning and construction timelines. They can also be used to turn small, isolated reserves into economically viable sources of fuel, and, thanks to their dimensions, can be built close to industrial parks and cities, thus shortening the distance to customers. Yet regardless of size, their CO_2 balance makes them a real bonus for the environment.

Bridging tomorrow's energy supplies.

Natural gas is becoming an increasingly important energy carrier and industrial raw material the world over. Thanks to mature liquefaction, storage and transport technologies, it can now be delivered anywhere around the globe – even to locations not connected to a pipeline grid. Building on its own technologies, Linde masters every step of the natural gas value chain, from liquefaction through transport to safe delivery at the final point of use.

Impressive dimensions.

With a storage capacity of up to 20,000 cubic metres, the Nynäshamn terminal is the largest of its kind in Europe.

Demand for natural gas is rising steadily worldwide, driven primarily by the fact that it is significantly kinder to the environment than crude oil or coal, and releases around 30 percent less carbon dioxide when burnt.

This upward trend is also mobilising the liquefaction market as it fuels demand for plants to liquefy natural gas.

Sweden's first LNG terminal at Nynäshamn

As a leading gases and engineering company, Linde is ideally placed to capitalise on this trend. Global market reach coupled with a wide portfolio of proprietary, energy-saving liquefaction technologies means the company covers every step in the natural gas processing chain.

In May 2011, Linde closed the last gap in the liquefied natural gas (LNG) value chain when it started production at Sweden's first LNG terminal in Nynäshamn, to the south of Stockholm. The Group uses the facility to supply a number of customers, including the neighbouring crude oil refinery Nynas. In order to process crude, the Nynas refinery needs hydrogen gas, which it previously produced from naphtha. Now, however, it has switched to natural gas as feedstock, reducing carbon dioxide emissions by up to 58,000 tonnes per year. Energy company Stockholm Gas is also using LNG from the terminal to improve its climate balance and expects to cut its annual CO_2 footprint by around 50,000 tonnes.

–30%

CO_2 emissions when fossil fuels are replaced with natural gas.

Natural gas is an environmentally sound alternative to other fossil fuels such as diesel, petrol or oil.

Stavanger liquefaction plant set to expand

The natural gas for the terminal in Sweden is sourced from the Stavanger LNG plant in Norway. Linde built this plant for the company Skangass AS and put it on stream at the end of 2010. It produces 300,000 tonnes of LNG each year. Around one sixth of this is transported by tanker to Nynäshamn, where it is distributed by Linde throughout the Baltic Sea region.

At the heart of the Nynäshamn terminal is a double-walled concrete tank with a diameter and height of almost 35 metres and a storage capacity of up to 20,000 cubic metres of LNG. This corresponds to around twelve million cubic metres of gas, as LNG regasifies to six hundred times its liquid volume. As Sweden does not have a pipeline network to transport the gas, the LNG is pumped into storage tanks on trucks at a temperature of minus 162 degrees Celsius and either transported directly to customers or to a pipeline link where it can be fed into an existing gas

Putting an end to boil-off losses.

More and more LNG tankers are being equipped with reliquefaction units, a technology that enables evaporated gas to be reliquefied in transit. In tankers not equipped with these units, up to 3 percent of the LNG payload can boil off during a twenty-day journey.

grid. At these points, the LNG is carefully heated in Linde regasification plants, from where it is distributed to end customers.

To meet the steady rise in demand for LNG, Skangass AS and Linde intend to double production capacity at the Stavanger liquefaction plant and the Nynäshamn terminal.

Mid-sized plants growing in popularity

Even following the planned increase in capacity, these two facilities will still be classified as mid-sized plants. Demand for facilities of this size is rising, as they offer numerous benefits over larger, world-scale projects. They can be built close to industrial parks and cities, thus shortening the distance to customers. They can also be planned and built in shorter timeframes, turning small, isolated reserves that would otherwise be regarded as impractical into economically viable sources of gas.

Linde occupies a strong position in this market, as it covers all links in the technology and competence chain required to engineer and equip mid-sized LNG plants. The company's patented cooling process, for example, consumes significantly less energy than conventional methods.

+10 %

demand for liquefied natural gas each year.

LNG is easier to transport than conventional natural gas, making it an increasingly popular option.

Powering ships with LNG

Strict environmental regulations in Scandinavia also make LNG produced at the Nynäshamn terminal an increasingly popular, climate-friendly fuel. Taxis at Stockholm airport, for example, must have hybrid, electric or gas drivetrains. In Norway, legislation stipulates that car ferries must run on natural gas. By 2013, 40 ships will be powered by LNG, and most of these will be equipped with Linde technologies.

In general, the international shipping business is moving away from harmful heavy oil in favour of natural gas in order to significantly reduce CO_2, sulphur and

At home on land and sea.

Liquefied natural gas is a particularly promising fuel for marine traffic. Increasingly strict environmental regulations are prompting a growing number of shipping companies to consider switching to more environmentally sound LNG-powered engines.

nitrogen oxide emissions. In 2015, sulphur thresholds for marine traffic in the North and Baltic Seas will be lowered from today's 1.5 percent to 0.1 percent. And this 0.1 percent sulphur threshold already applies to ships at berth in European ports today.

Major cruise ship operators and well-known shipyards such as Meyer Werft (Germany) are also assessing the environmental benefits of LNG-powered engines for new ships.

If natural gas is to capture the shipping market, however, it must be backed by a global network of port-side LNG terminals. And Linde's terminal in Nynäshamn is an important reference project for just such a network.

LNG for haulage in Australia

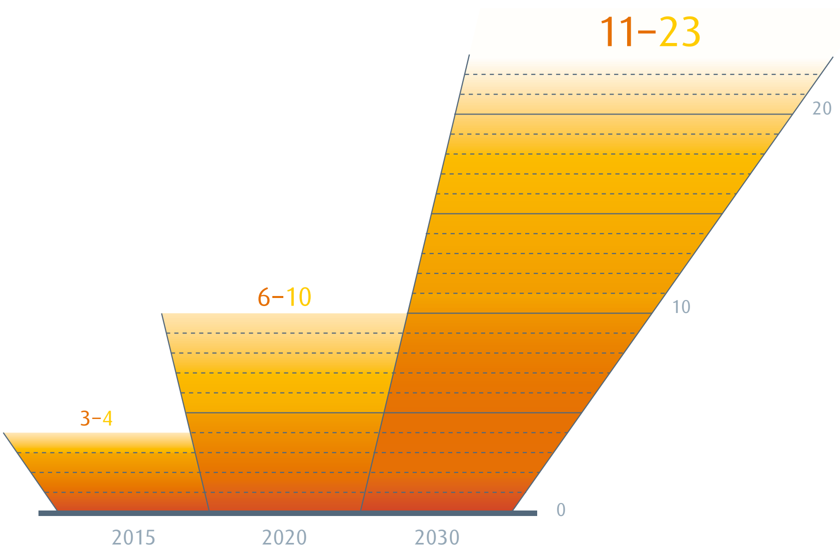
In Australia, Linde is exploring the benefits of LNG for long-haul road transport. A network of LNG fuelling stations is springing up along the country's east coast and on the island of Tasmania, enabling drivers of heavy goods vehicles (HGVs) to capitalise on this comparatively climate-friendly and predictably priced fuel.

To advance this network, Linde has already built three smaller-scale facilities known as micro-LNG plants. The Group is also modernising its Dandenong plant near Melbourne. The facility has been in operation for over thirty years and will now see its production capacity increase to 100 tonnes of LNG per day.

3

Promising market.

Global demand for LNG plants (EUR billion).



Source: Linde estimates.

Linde's micro-LNG plant in Chinchilla (Queensland) uses coal seam gas as feedstock. The gas contains CO_2, sulphur and moisture, all of which have to be removed before it can be cooled and liquefied in special heat exchangers.

The plant which Linde put on stream in Westbury (Tasmania) in January 2011 is part of a supply network for regional haulage companies in the timber industry. The companies will have recouped the cost of converting vehicles from diesel to natural gas within just three years, as natural gas costs less than diesel and LNG engines last longer.

Oxygen for GTL production

The huge potential of natural gas as a source of energy is particularly evident at the Pearl gas-to-liquids (GTL; see glossary) plant operated by Qatar-Shell GTL Ltd. in Ras Laffan Industrial City, Qatar. This is the largest integrated complex of its kind in the world. At full capacity, it produces around 140,000 barrels of liquid hydrocarbons per day from natural gas. These include naphtha, GTL fuels, paraffin, kerosene and lubricants. The plant also produces around 120,000 barrels of condensate, liquid petroleum gas and ethane per day.

The ethane is processed into ethylene, which is used at the site to make plastics.

Linde has built eight large air separation units for the Pearl complex on behalf of Qatar-Shell GTL in recent years. At full capacity, these units will be producing around 860,000 cubic metres of oxygen per hour from mid-2012 . The oxygen will be used across the widest range of production processes at the complex. Linde was awarded the contract in 2006 – the largest ever to have been tendered for air separation plants.

Work on this unique natural gas and chemical complex started in February 2007. At the height of construction activity, up to 52,000 people from around 50 countries were working on the Pearl GTL site. Most of the work was completed by the end of 2010 and the first natural gas from the offshore field started flowing into the plant on 23 March 2011. The first four air separation giants went on stream in May 2011.

The natural gas for the complex is extracted from the North Field (60 kilometres off the coast of Qatar) by two drilling platforms. The field contains around 15 percent of all known gas reserves, making it one of the largest gas deposits in the world.

High output.

The GTL plant in Qatar produces around 140,000 barrels of liquid hydrocarbons per day, including naphtha, GTL fuels, paraffin, kerosene and lubricants.

New source of energy for Southeast Asia

LNG is becoming an increasingly important source of energy, especially in the fast-growing region of Southeast Asia. The rapid pace of industrialisation, rising oil prices and the need to extract resources from remote regions and islands are accelerating the adoption of LNG as a source of electricity, in particular. Here also, reserves that had previously been seen as economically unviable are now moving into focus thanks to sophisticated extraction technologies, liquefaction processes and the possibility of transport by sea. Tax incentives from governments looking to promote domestic energy resources and reduce dependency on foreign imports are providing additional impetus.

The need for energy is rising sharply across the mining industry in eastern Indonesia, for example. In future, the raw materials extracted here will have to be processed within the country before being exported. The spotlight is increasingly shifting to local, stranded gas fields (see glossary) and liquefaction to meet these rising energy requirements.

Linde and Pertagas (PT Pertamina Gas) are currently assessing the economic viability of a mid-sized LNG plant on the island of Pulau Dua to capture gas from the Salawati field. The plant would produce 300 tonnes of LNG per day and be equipped with a 7,500 cubic-metre storage tank and a docking area for ships. The LNG would be taken to the island of Halmahera, where it would be used to generate electricity for the nickel processing industry.

860,000 m^3

oxygen produced each hour at eight air separation plants in Qatar.

This enables Linde to meet the oxygen needs of the world's largest gas-to-liquids plant in Qatar.

Similar to Indonesia, Malaysia, Vietnam and Singapore are looking to open up previously inaccessible natural gas reserves with the help of small and mid-sized LNG plants.

As a producer and supplier of LNG, Linde is actively helping to develop the market in Southeast Asia. The company's energy-efficient technologies play an important role in enabling these countries to capitalise on their natural resources without harming the environment.

International team.

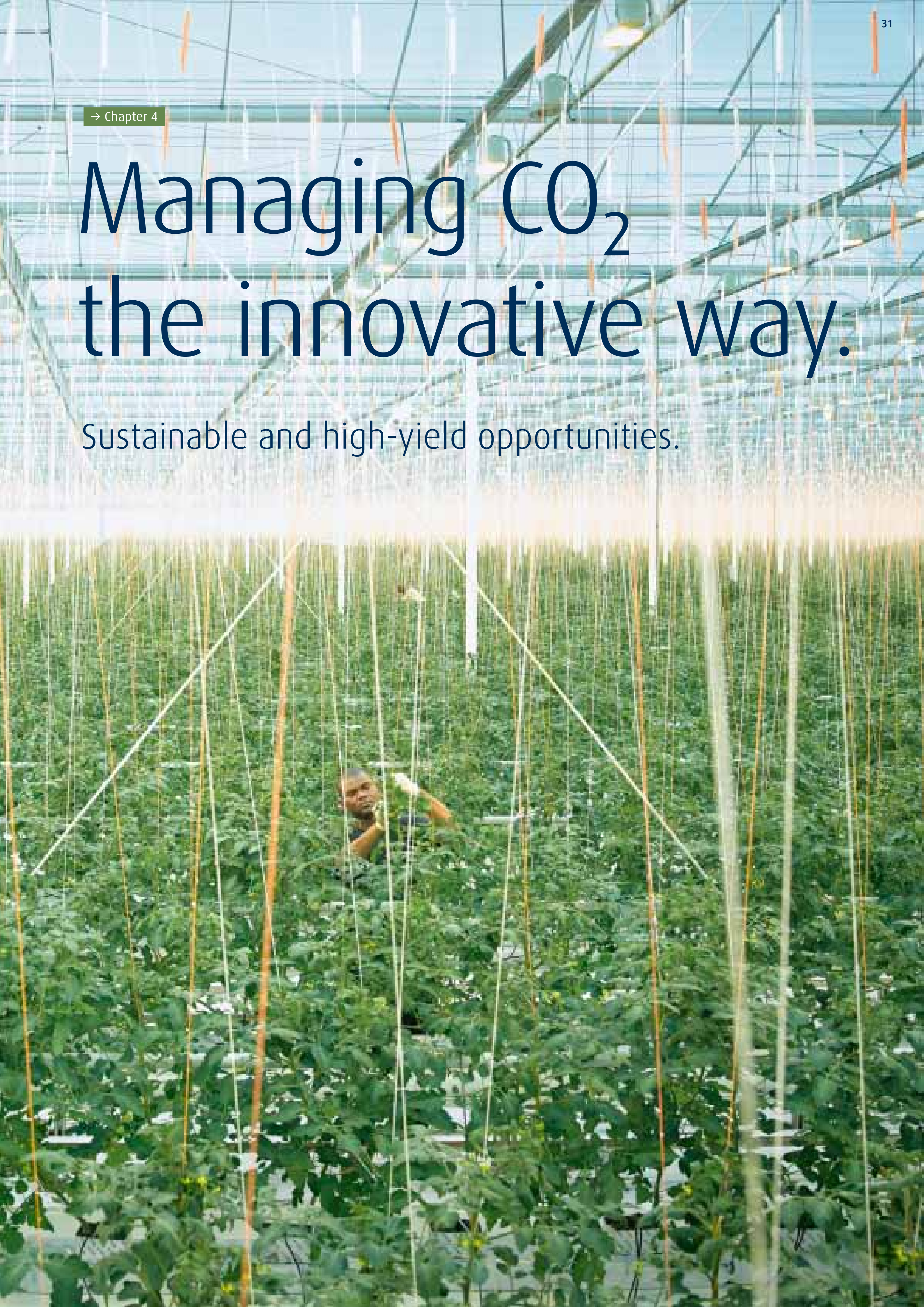
At the height of construction activity, 52,000 people from 50 countries were working on the Qatar site.

↳ CO_2 speeds up plant growth in Dutch greenhouses.

→ Chapter 4

Managing CO_2 the innovative way.

Sustainable and high-yield opportunities.



4

↳ Tomatoes (shown here in cross section) need an optimum supply of carbon dioxide.

Recovering CO_2 emissions to promote plant growth

Each summer, 350,000 tonnes of carbon dioxide from a Shell oil refinery near Rotterdam are fed into hundreds of Dutch greenhouses. The annual greenhouse gas savings from this intelligent recycling solution correspond to the CO_2 emissions of a large Western European city. A smaller volume of recovered CO_2 is also supplied to the food industry, where it is used to keep products fresh. As the greenhouses do not require CO_2 during the winter, Linde – through the OCAP joint venture – is currently working on ways of storing the winter stream in depleted natural gas fields south-east of Rotterdam. These stores have the capacity to accommodate emissions for the next thirty years.

↳ Stronger, bigger, greener – cucumbers, tomatoes and lettuce grow faster, yield larger crops and are more resilient thanks to CO_2.

4

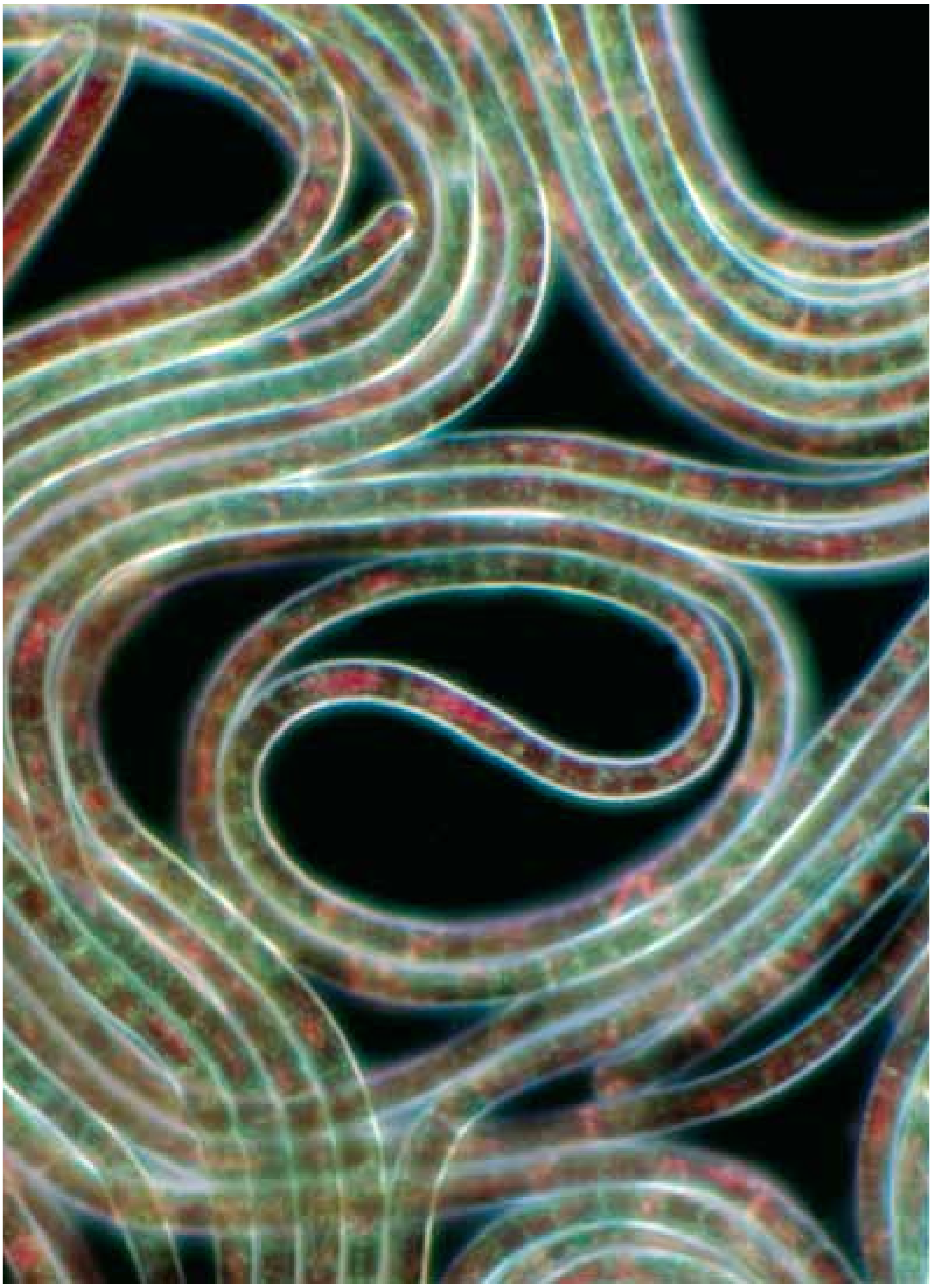
↳ Algae are cultivated in open ponds, where they are fed with light and CO_2.

CO_2 in – fuel out.

Fed on a diet of sunlight and CO_2, algae produce oxygen and green crude. Algae farmers therefore need large amounts of CO_2.

↳ Linde partner: An algae farm owned by US company Sapphire in San Diego (California).

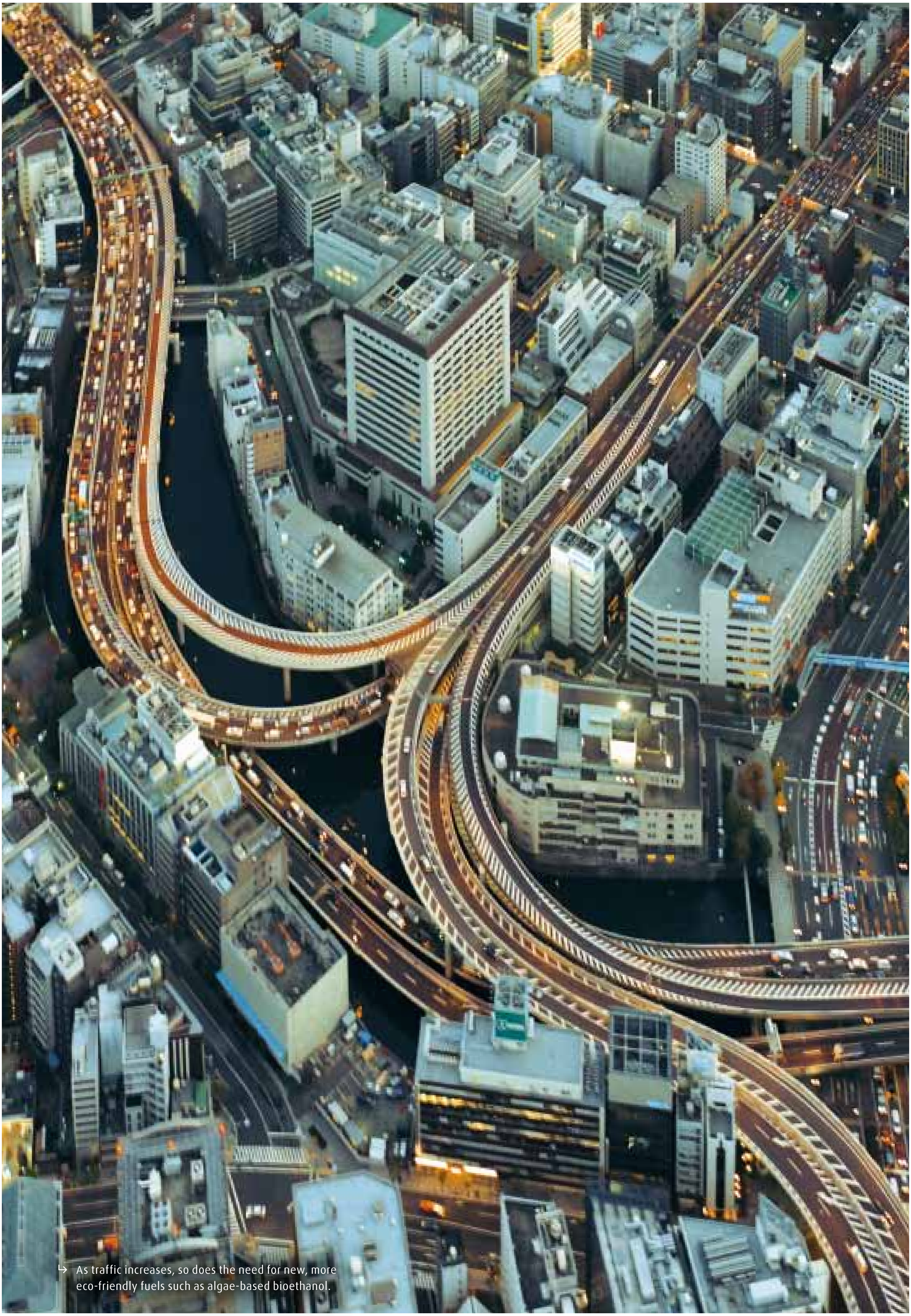
4



↳ Microscopic image of a blue-green algae (cyanobacterium).

Unexpected, promising new talent

Blue-green algae produce approximately 350 litres of ethanol from one tonne of CO_2 – an ideal climate-neutral fuel for the cars of tomorrow. Linde and US algae expert Algenol have formed a research collaboration to unlock the potential stored in these mini-factories from the sea. Linde's gas experts are responsible for capturing, scrubbing and transporting the CO_2. The experts at Algenol are making the cyanobacteria more efficient. The new hybrid algae recycle CO_2 and convert it to energy. They also replace fossil fuels, which means they have a negative CO_2 balance.



↳ As traffic increases, so does the need for new, more eco-friendly fuels such as algae-based bioethanol.

Reduce, reuse, restore.

Carbon dioxide (CO_2) is a natural part of our atmosphere. It plays a vital role in food production and many other industrial processes. Yet CO_2 is also responsible for climate change. Which is why we need to reduce global emissions of this greenhouse gas and learn to reuse it intelligently. Linde has the technologies to achieve these goals along the entire CO_2 value chain.

↳ Coal power with reduced CO_2 emissions – oxyfuel pilot project in Schwarze Pumpe, Germany.

According to the International Energy Agency (IEA), global energy demand is set to double by 2050 – fuelled by dynamic industrialisation in emerging economies such as China, India and Brazil. To meet this demand, fossil fuels will have to remain part of the energy mix for decades to come. This calls for innovative technologies that allow fossil resources to be harnessed with as little impact on the climate as possible.

CO_2 management processes developed by Linde engineers and technicians are already making a vital impact here by enabling energy to be efficiently generated and consumed.

Separating CO_2 in power plants

Pre-combustion capture removes CO_2 from fuels before combustion. It takes place in a combined cycle power plant, also referred to as combined cycle gas turbine (CCGT), and involves a process called integrated gasification combined cycle (IGCC; see glossary). During this process, pure oxygen is used to turn pulverised coal into a synthesis gas, primarily comprising carbon monoxide and hydrogen. In a second step, steam is used to convert the majority of the carbon monoxide into carbon dioxide and additional hydrogen. The carbon dioxide can be easily removed by scrubbing, allowing it to be desulphurised and compressed or liquefied. In this state, the CO_2 can then be reused or stored.

+20 to 40

EUR billion demand for CCS technologies between now and 2030.

The market for carbon capture and clean coal is extremely promising. Experts predict that the global market will grow to between EUR 20 and 40 billion 2030.

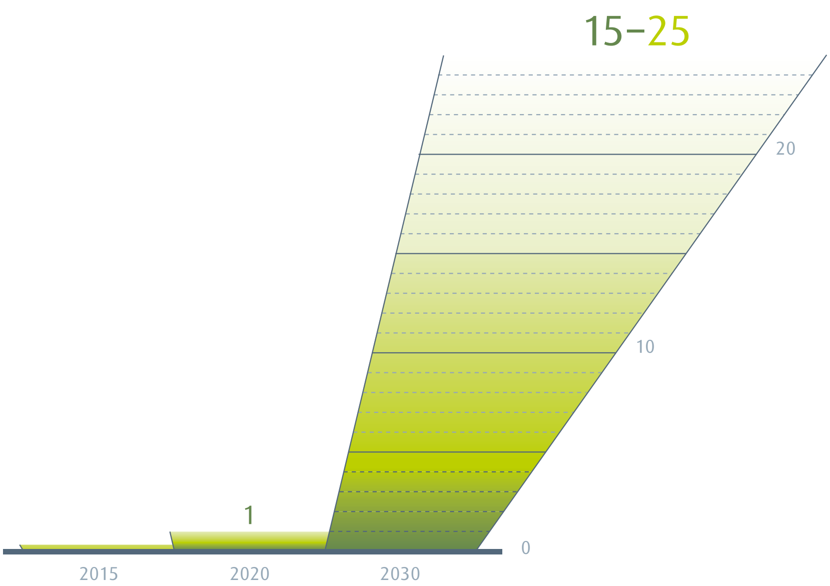
During oxyfuel combustion, CO_2 is separated from the flue gases that are emitted when coal is burnt. These emissions primarily comprise carbon dioxide and steam. By simply cooling the flue gases, the relatively pure CO_2 can be easily separated and captured from the steam, allowing it to be compressed and transported to a storage site. The oxygen used during combustion is produced in an upstream air separation plant. The majority of the nitrogen-free flue gas is fed back into the furnace where it is used to regulate the flame. The oxyfuel process generates high temperatures – a further benefit that increases power plant efficiency.

Linde has joined forces with Vattenfall Europe Technology Research GmbH to further develop the oxyfuel process. This extensive technology partnership focuses on testing the combustion procedure for lignite and anthracite and developing the technology for use in large-scale power plants. Vattenfall has been operating a 30 megawatt pilot facility since September 2008 at its lignite power plant site in Schwarze Pumpe, in the German state of Brandenburg. Linde delivered a wide range of components for this project and designed the overall process architecture. Some of the carbon dioxide from the Schwarze Pumpe plant has already been successfully compressed as part of the CO_2MAN research project in Ketzin (Brandenburg).

In 2011, Linde was awarded a further contract for carbon capture and storage, this time in Italy. The company will be supplying energy group ENEL SpA with CO_2 scrubbing, liquefaction and storage technology for its coal-fired power plant Federico II, near the city of Brindisi. The plant will serve as a pilot CCS project for a larger facility in the Porto Tolle coal-fired power plant. It is being funded by the European Union.

Promising market.

Global demand for CO_2 networks (EUR billion).



Source: Linde estimates.

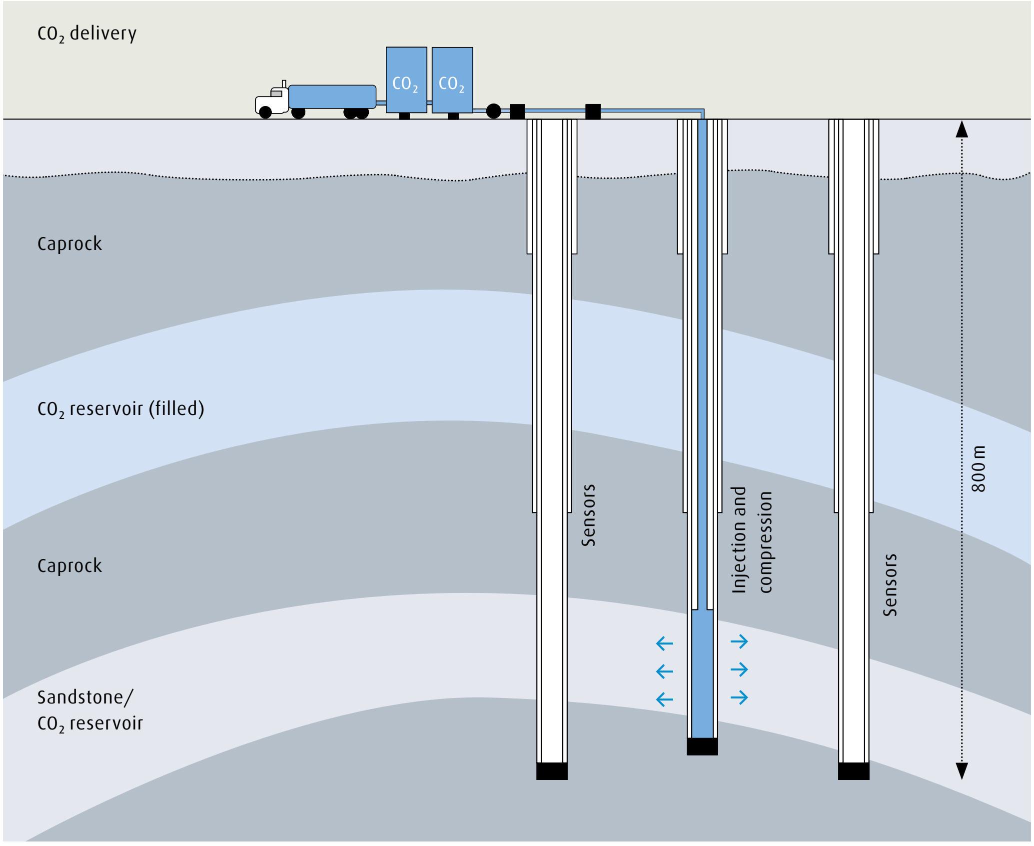
Vattenfall tests oxyfuel process with support from Linde.

Oxyfuel technology is an innovative example of CO_2 recovery during energy production. It involves injecting pure oxygen instead of air into the coal combustion furnace. The resulting CO_2 can be captured and sequestered.

CO_2MAN research project

Since June 2008, the CO_2MAN project has been pumping 1.5 tonnes of CO_2 per hour into plutonic rock through arm-width pipes at a pilot site for CO_2 storage in Ketzin. The CO_2 is injected into a saline aquifer featuring porous sandstone reservoirs filled with highly concentrated salt water. If the gas is injected at high enough pressure, some of it dissolves into the water. The rest of the CO_2 forces the water out through the pores in the rock. Measurements made here will give the first detailed picture of how CO_2 dissipates underground. The most important question of all is whether the final storage site is leak-proof. The prevailing view among geologists is that the layer of plaster and clay that caps the several square-kilometre sandstone formation should be completely impenetrable, even if it had to cope with ten times the planned volume of 60,000 tonnes of CO_2.

The majority of the CO_2 for Ketzin is sourced from the Leuna chemical park, 175 kilometres away, where it occurs as a by-product of ammonia synthesis. Linde purifies and treats the CO_2 in a multi-step process, and liquefies it at temperatures of between minus 35 and minus 25 degrees Celsius. The Group then transports the liquid CO_2 by truck to Ketzin, where it is temporarily stored (as a liquid) in tanks. The CO_2 is gasified before being pumped 700 metres below ground at a pressure of between 70 and 100 bar.



Europe’s largest off-shore CO_2 injection project

Linde is involved in another landmark project off the Norwegian coast near Hammerfest, at the liquefaction site for natural gas extracted from below the Barents Sea. Linde is now liquefying the CO_2 separated from the natural gas stream and feeding it back to where it was originally sourced, the Snøvhit natural gas field (see page 18). This method is used to store around half the CO_2 generated at the site (approximately 700,000 tonnes a year) 2.6 kilometres under the ocean floor. Once underground, the CO_2 bonds with the rock and is safely encapsulated, over 100 kilometres from the next human settlement.

↳ Pilot CO_2 scrubbing plant operated by RWE, BASF and Linde in Niederaussem, Germany. The partners expect the process to be commercially viable for lignite power stations in Germany by 2020.

Post-combustion CO_2 capture

Post-combustion CO_2 capture uses scrubbing agents to separate carbon dioxide from the flue gases of conventional coal-fired power plants following desulphurisation. This is the only process that can be retrofitted to existing power plants, and is therefore particularly important for climate-friendly energy supplies in the near future.

The most important component in post-combustion scrubbing is the absorber. This is where the hot, desulphurised flue gas comes into counter-flow contact with a scrubbing agent. This aqueous solution comprises amines, a group of organic substances that absorb the CO_2 in the gas stream. Once the flue gas has passed through the agent, it only contains low levels of CO_2. Before leaving the absorber, it is sprayed with water to remove any remaining traces of the scrubber. The flue gas is then released into the atmosphere via chimney stacks or cooling towers. The scrubbed CO_2 is heated in a desorber and removed

–90 %

CO_2 in power plant flue gases.

The post-combustion process separates carbon dioxide after desulphurisation. Once this has been done, the majority of the flue gas can be stored underground. Post-combustion capture is currently the only CO_2 scrubbing process that can be retrofitted to existing power plants.

↳ (left) Greenhouses require a lot of CO_2. Linde ensures a steady supply.

↳ (right) Exemplary CO_2 infrastructure: Carbon dioxide from a refinery near Rotterdam is transported to Dutch greenhouses via a dense network of pipes. The CO_2 is used to increase plant yields.

from the liquid. The scrubbing agent is then cooled and pumped back to the absorber for another scrubbing cycle.

Energy provider RWE Power has been testing this technology since summer 2009 in a pilot facility at its lignite-fired power plant in Niederaussem, in the German state of North Rhine-Westphalia. The process can remove over 90 percent of CO_2 from a power plant's flue gases, enabling it to be stored underground.

Linde has accumulated decades of experience in CO_2 scrubbing through its collaboration with various companies from the chemical industry. Since 2007, the company has been partnering closely with RWE and the chemical group BASF to realise the pilot CO_2 scrubbing plant in Niederaussem. Linde constructed the scrubbing unit for the RWE power plant, while BASF provided new solvents for long-term tests to determine the most efficient method of capturing carbon dioxide. All three partners aim to make carbon capture commercially viable for lignite power plants in Germany by 2020. These plants are a major source of energy in Germany.

The CCS and clean coal market has huge potential. Experts predict that the global market will be worth between EUR 20 and 40 bn by 2030.

Part of this growth will be fuelled by North America, where demand for clean coal solutions is rising steadily. Linde is also advancing carbon capture technologies for coal-fired power plants in the US. The US Department of Energy (DoE) is providing USD 15 million in funding for a pilot plant in Wilsonville, Alabama. From 2014 onwards, the facility will be used to test innovative CO_2 scrubbing processes aimed at identifying the most energy-efficient and cost-effective carbon capture methods. Linde plans to separate at least 90 percent of the carbon dioxide from the plant's flue gases without increasing energy costs by more than 30 percent.

Speeding up plant growth with CO_2

A project in the Netherlands is showing just how useful recycled CO_2 can be. Under the umbrella of the Organic CO_2 for Assimilation by Plants (OCAP) joint venture, Linde and the construction company VolkerWessels are working together to supply over 550 greenhouses with CO_2. The CO_2 is sourced from a Shell refinery near Rotterdam and pumped to customers via an 85-kilometre pipeline linked to a 300-kilometre distribution network. Over 350,000 tonnes of CO_2 are recycled in this way each year.

The gas promotes photosynthesis, enabling greenhouse operators to shorten growth times for tomatoes, cucumbers, lettuces and other types of vegetable. Before this initiative, operators used to generate the extra CO_2 themselves by burning natural gas in their own furnaces.

–190,000 t

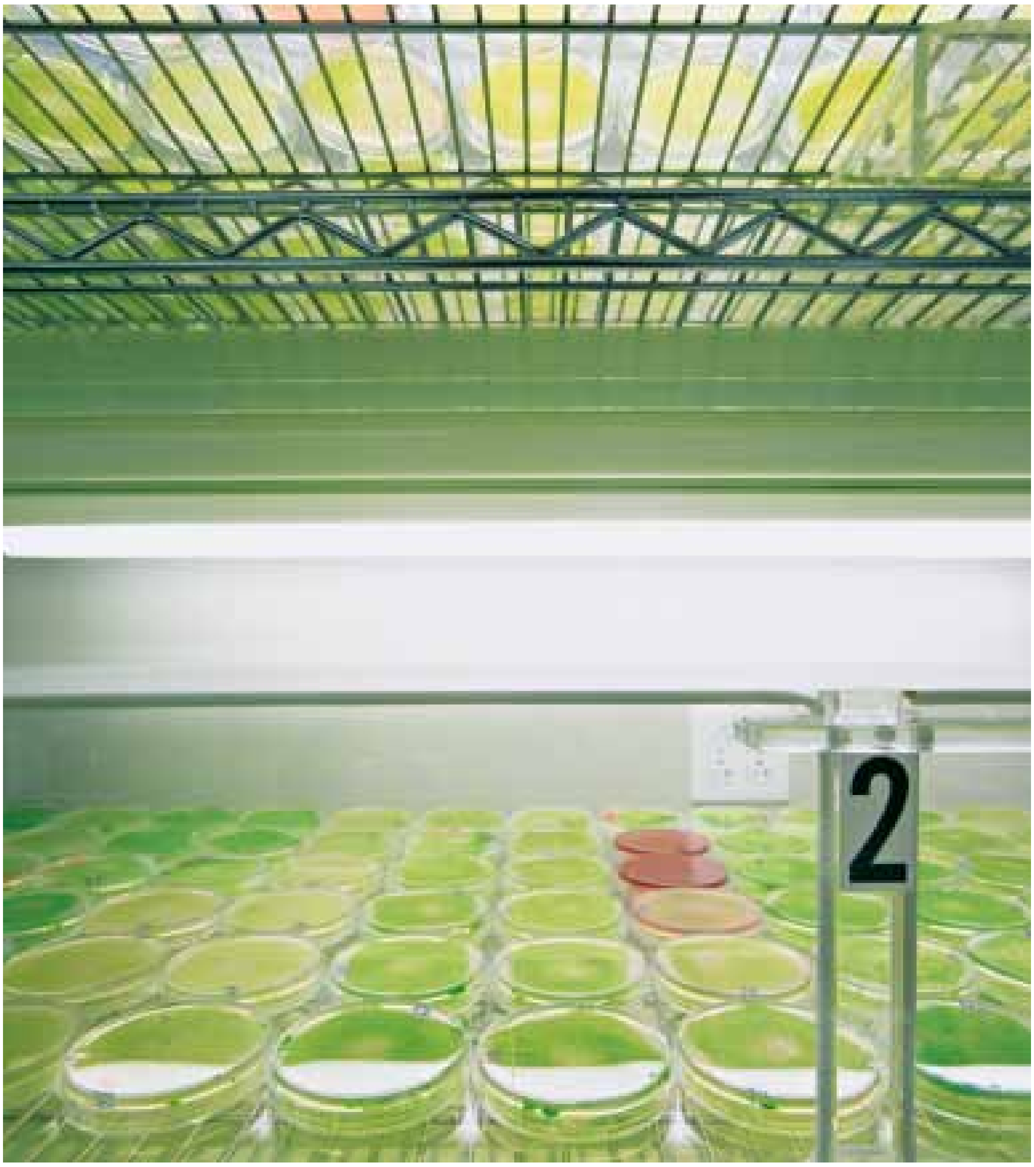
CO_2 each year thanks to Linde's OCAP joint venture in the Netherlands.

Carbon dioxide emitted from a Shell oil refinery near Rotterdam is used for speeding up vegetable and plant growth in Dutch greenhouses. The amount of CO_2 recycled in this project corresponds roughly to the annual emissions of a European city with 150,000 inhabitants.

Using CO_2 from the refinery eliminates the need to combust around 105 million cubic metres of natural gas and avoids 190,000 tonnes of CO_2 emissions each year – a footprint that corresponds roughly to the annual emissions of a European city with 150,000 inhabitants.

Greenhouse operators, however, only need the CO_2 from the refinery in summer. In winter, they can use the carbon dioxide generated from the heating systems they use to heat their greenhouses. The OCAP partners are therefore looking to pump excess car-

↳ Sophisticated development process: Over a long series of tests, scientists have cultivated hybrid algae with a metabolism that specifically increases bio-oil production.



4

The Algenol process.

Algenol cultivates the algae in special photobioreactors that allow sunlight to shine through, providing the bacteria with an energy source. The large oblong bags are filled roughly up to the quarter mark with the algae/saltwater mixture. The heat of the sun causes a mix of ethanol and water to vaporise and collect in the space above the mixture. The gas can be collected at night when it cools, condenses and runs off along special grooves on the plastic surface. The liquid contains approximately 1 percent alcohol. The algae experts aim to produce up to nine litres of ethanol per square metre each year. Algae cultivation does not threaten land needed for food production, as facilities can even be built in desert regions.

bon dioxide into depleted natural gas fields. These stores have the annual capacity to accommodate around 280,000 tonnes over a period of almost 30 years. Storage capacity is even expected to rise to over 400,000 tonnes in a few years, when a further reserve becomes available. OCAP aims to transport the CO_2 to the empty natural gas fields via new pipelines and use compressors to condense it for storage. The first CO_2 stream is set to enter the storage sites in 2013. In the long term, the pipeline network could also be expanded to support offshore carbon storage.

CO_2 management for algae cultivation

In the US, Linde is involved in another particularly promising CO_2 recycling project. The gas is being used in a number of pilot plants to support the metabolism of algae that produce environmentally sound fuels (green crude) and base chemicals. These saltwater microscopic cyanobacteria, also known as blue-green algae, need just sunlight and carbon dioxide to metabolise. The sunlight triggers photosynthesis, causing the algae to inhale CO_2 and drink the saltwater in which they live. During this process, they

9 litres

of ethanol per square metre of algae – Algenol and Linde's shared vision.

Genetically modified blue-green algae produce green crude when supplied with CO_2 from flue gases. Today, scientists can obtain 5.6 litres of bioethanol from an area of one square metre. Linde and Algenol aim to raise this to nine litres per square metre.

release oxygen and, under the right conditions, produce bioethanol.

The blue-green algae are a particularly interesting option for fuel as they can process significantly more CO_2 than other plants. Maize plants, for example, can be used to produce 0.37 litres of ethanol per square

↳ Sapphire Energy: The bio-oil or green crude produced in test labs can be used to make fuels such as kerosene, diesel and petrol.

metre. In contrast, the same area of blue-green algae can currently be used to produce 5.6 litres. And scientists aim to increase this to nine litres per square metre in the future.

Linde is working with US company Algenol Biofuels to provide the most cost- and energy-efficient CO_2 management system for the algae farms of tomorrow. The aim of the collaboration is to scrub flue gases from coal-fired power stations and refineries to just the right point, so that the microorganisms do not die. Every additional step – whether purification, compression or liquefaction – consumes energy and increases the carbon footprint of the entire process. The ultimate aim is to achieve a negative CO_2 balance, ensuring that the process remains ecologically and economically viable.

Scientists at Algenol Biofuels have developed a particularly efficient type of algae. Unlike conventional species, this variety also produces ethanol when exposed to plenty of sunlight, and secretes this into the seawater culture. There is a major benefit to this direct process, as the ethanol can be obtained straight from the green solution without having to harvest the algae. This kind of algae can produce approximately 350 litres of ethanol from one tonne of CO_2.

–70 %

CO_2 emissions with green crude.

Generating biofuel from algae cuts CO_2 emissions by 70 percent compared with fuels obtained from conventional crude oil.

Widespread commercial adoption of algae as a climate-friendly source of energy hinges on economic viability. In order to test this on a large scale, Linde entered a cooperation agreement with US company Sapphire Energy, one of the world's leading manufacturers of algae-based renewable green crude. In May 2011, the two partners agreed to co-develop a carbon dioxide management system for commercial-scale algae-to-biofuel plants. Linde will also supply all of the CO_2 needed for Sapphire's commercial demonstration facility in Columbus, New Mexico.

Sapphire Energy has developed its own technologies for the entire algae-to-biofuel value chain, from the biological process and cultivation through harvest and extraction to refining. The resulting green crude can be used to produce fuels such as kerosene, diesel and petrol – all of which can be used without difficulty in existing infrastructures and engines. Viewed along the entire process chain, green crude generated from algae reduces CO_2 emissions by 70 percent compared with fuels manufactured from regular petroleum.

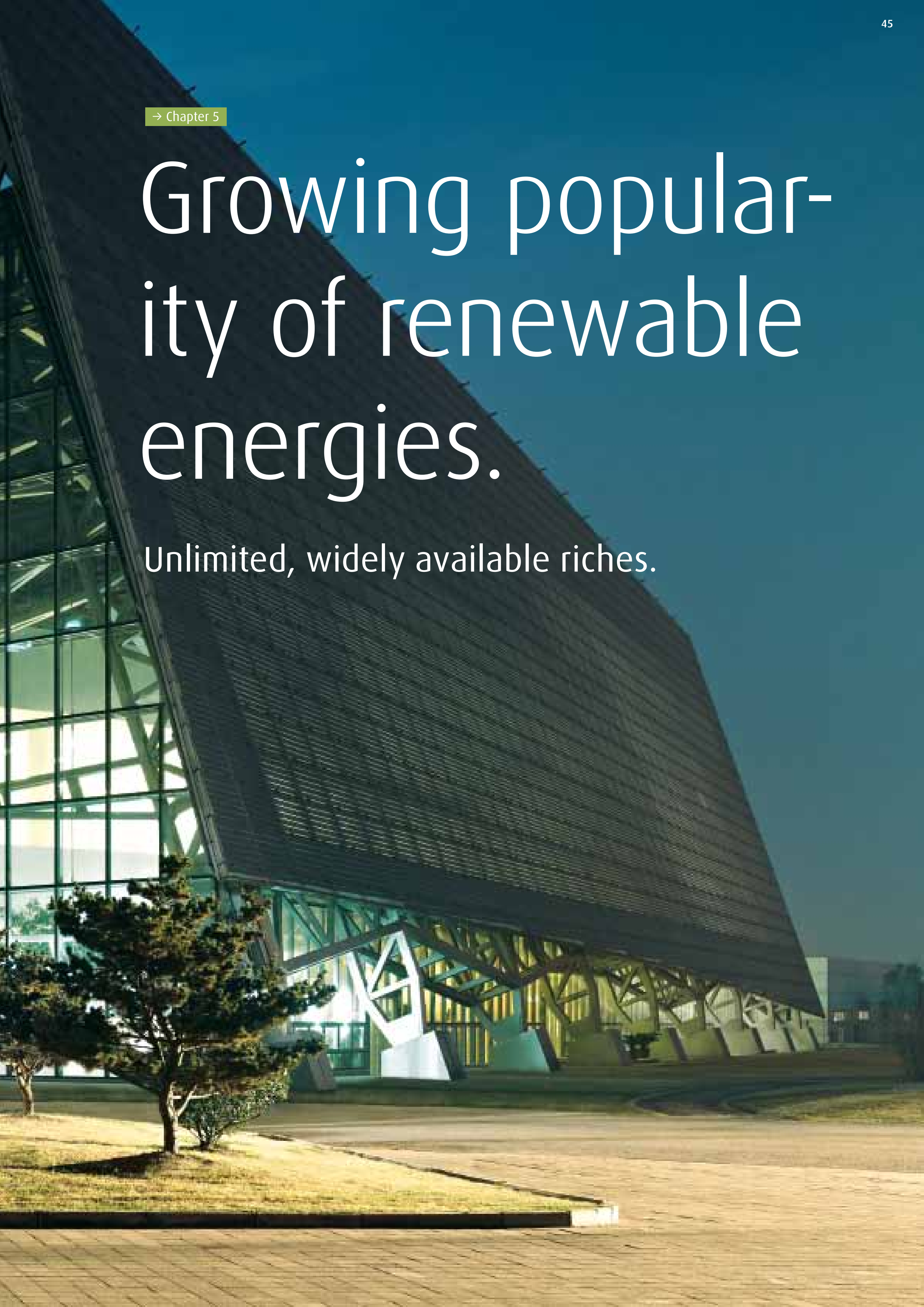
The global market for the installation of CO_2 management networks is expected to rise to between EUR 15 and 25 bn by 2030.

Looking to a greener future

Using CO_2 to produce regenerative fuels has the potential to significantly reduce greenhouse gases. A single commercial algae-to-fuel production facility based on Sapphire's model requires an estimated 10,000 tonnes of CO_2 per day. This corresponds to around 30 percent of the current merchant market for CO_2 in the US.

5

↳ Full of energy: Solar modules cover the facade of Suntech's headquarters in Wuxi. Linde supplies the Chinese solar cell manufacturer with speciality gases.



→ Chapter 5

Growing popularity of renewable energies.

Unlimited, widely available riches.

5

Solar

Steady source of power from space.

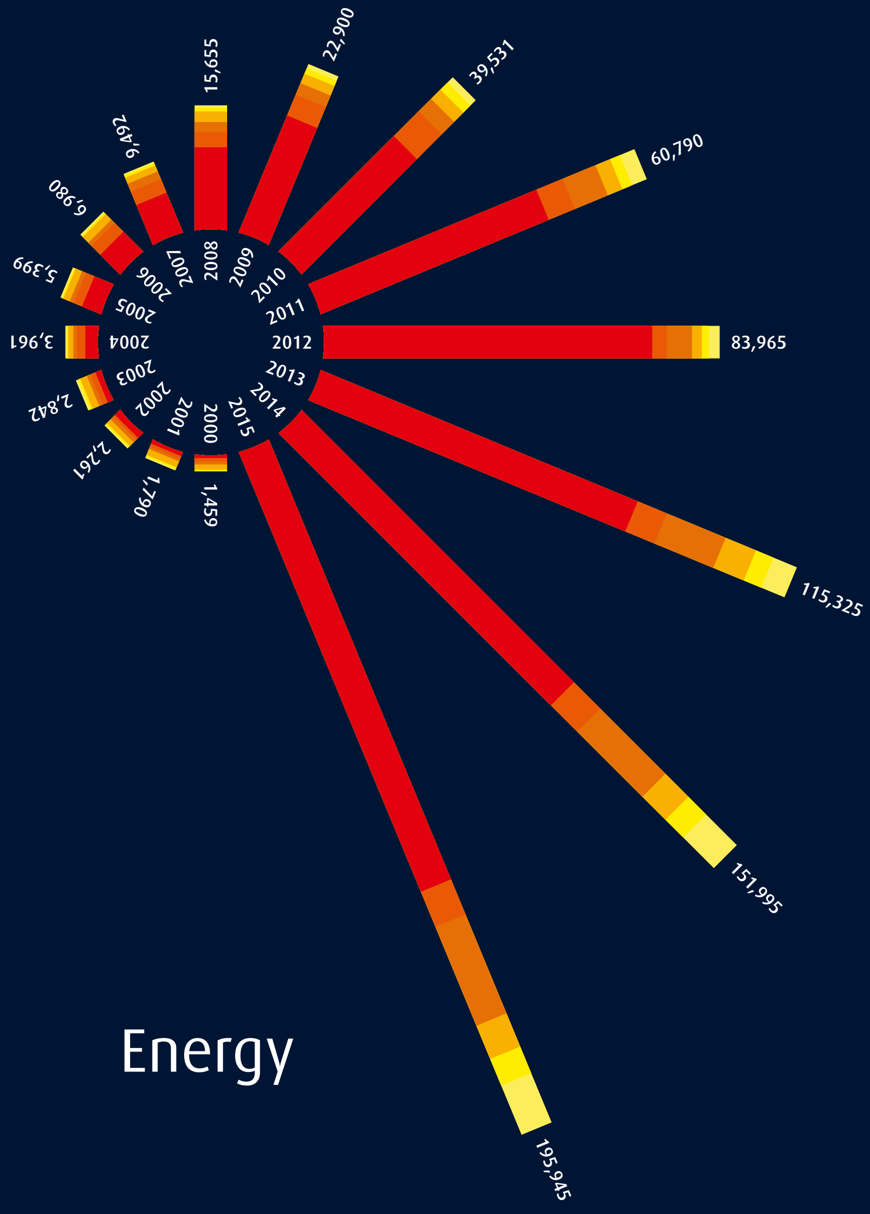
Unlike fossil fuels, solar energy is unlimited in supply. Solar power does not release greenhouse gas emissions or damaging soot particles when used. Linde has been working with a network of solar cell manufacturers to develop a procedure that will make tomorrow's solar technology even more efficient and economically viable. Manufacturers can now significantly cut the amount of emissions released during energy-intensive solar cell production by using the environmentally neutral gas fluorine.

Global demand for solar energy up to 2015 (gigawatts).

- EU
- Japan
- North America
- Rest of the world
- APEC
- China

APEC = Asia-Pacific Economic Cooperation

Source: EPIA, Global Market Outlook for Photovoltaics until 2015.



Energy

The growing global solar market.

Photovoltaic technology is becoming an increasingly competitive and indispensable source of energy across the European Union. On the global stage, solar energy is also gaining in importance. Innovations are making production processes more efficient and advancing this industry. In particular, shrinking manufacturing costs are making this natural power source an increasingly attractive option for investors and national energy providers.

Waste

Harnessing the potential of waste.

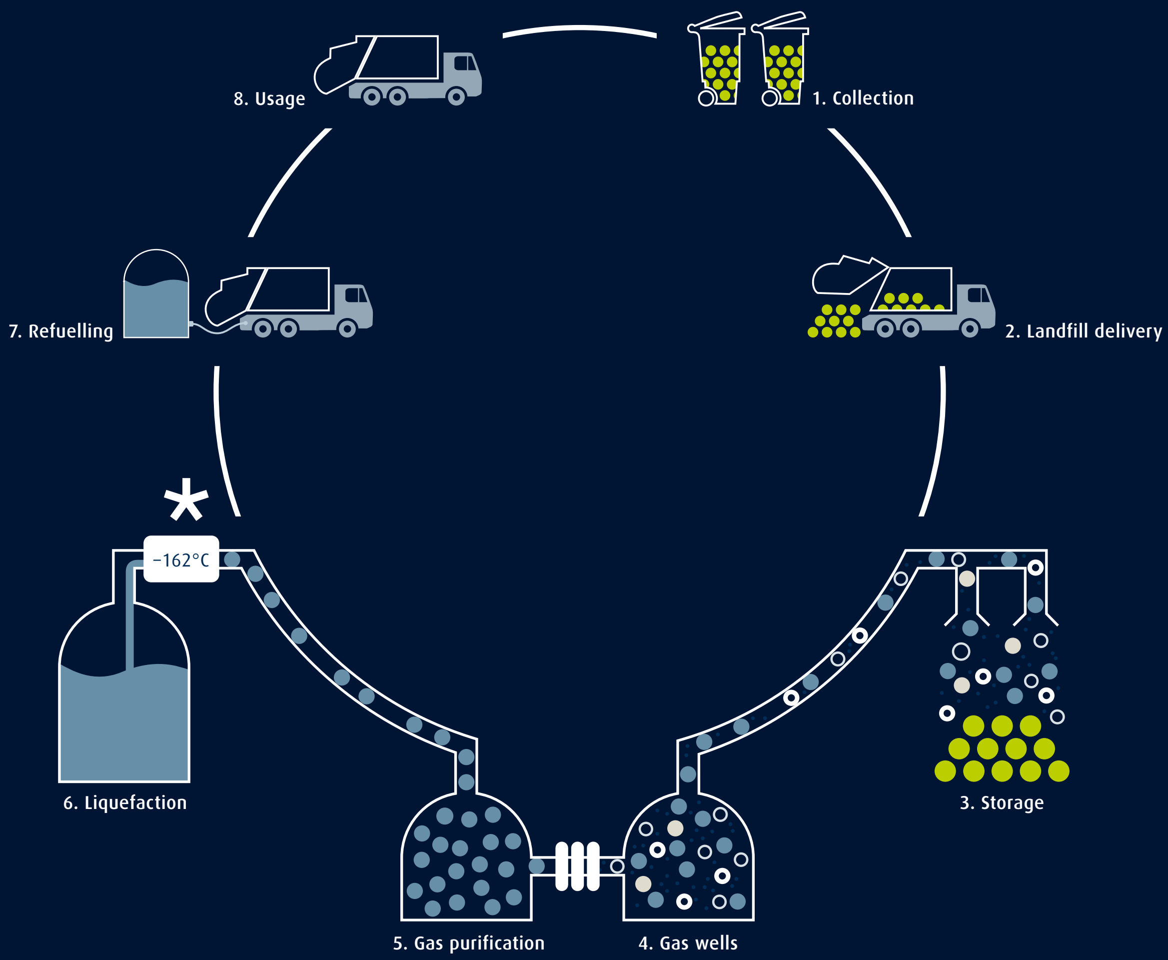
Not all waste is bad waste. Organic waste, for example, can be an extremely useful raw material. The warm, damp, anaerobic conditions in compost containers provide the perfect environment for landfill gases. Bacteria convert the waste into methane, CO_2 and other substances. Methane is the most energy-rich of these by-products – one cubic metre has an energy content of almost ten kilowatt hours. New Linde technologies enable methane to be turned into an environmentally friendly biofuel.

Waste management cycle.

Gas

Waste

Source: Waste Management and Linde.

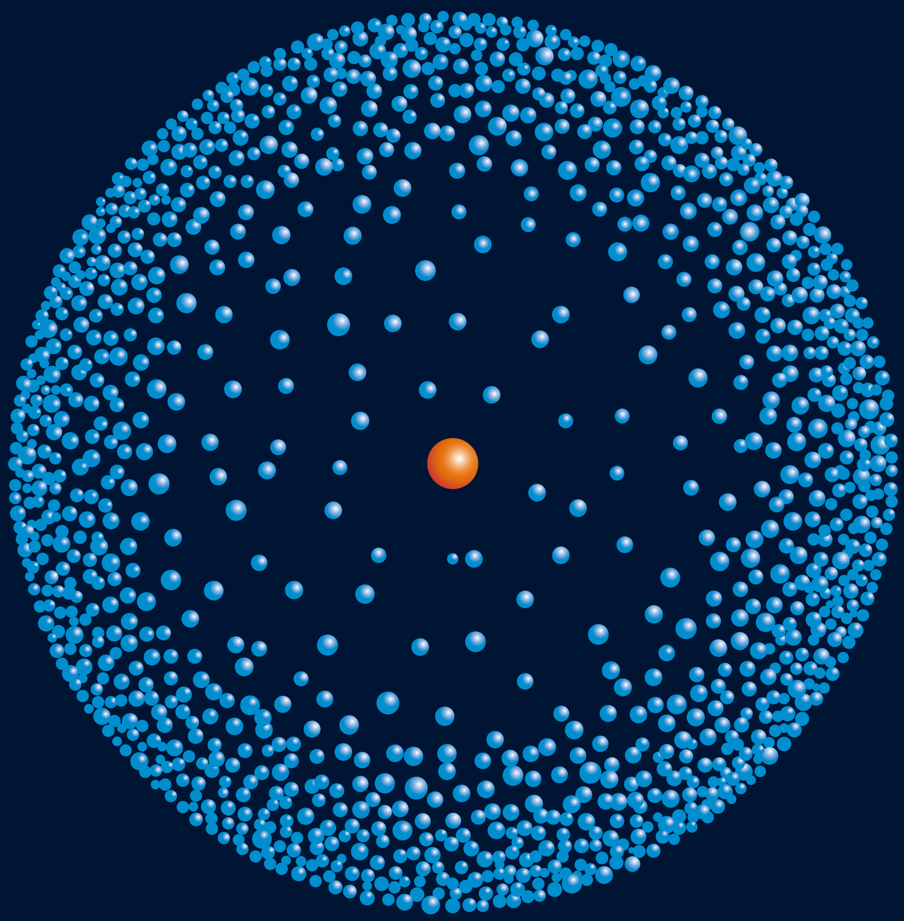


Management

Green cycle.

Landfill methane is compressed, purified and cooled at Linde's facility near San Francisco. It is then liquefied at a temperature of minus 162 degrees Celsius and transported to local fuelling stations. The biogas generated in this way is significantly cleaner and even burns more quietly than diesel. It releases 90 percent less particulate matter and considerably less nitrogen oxides and sulphur dioxide into the atmosphere. And as the fuel is generated and processed locally, it eliminates the need for long delivery routes.

5

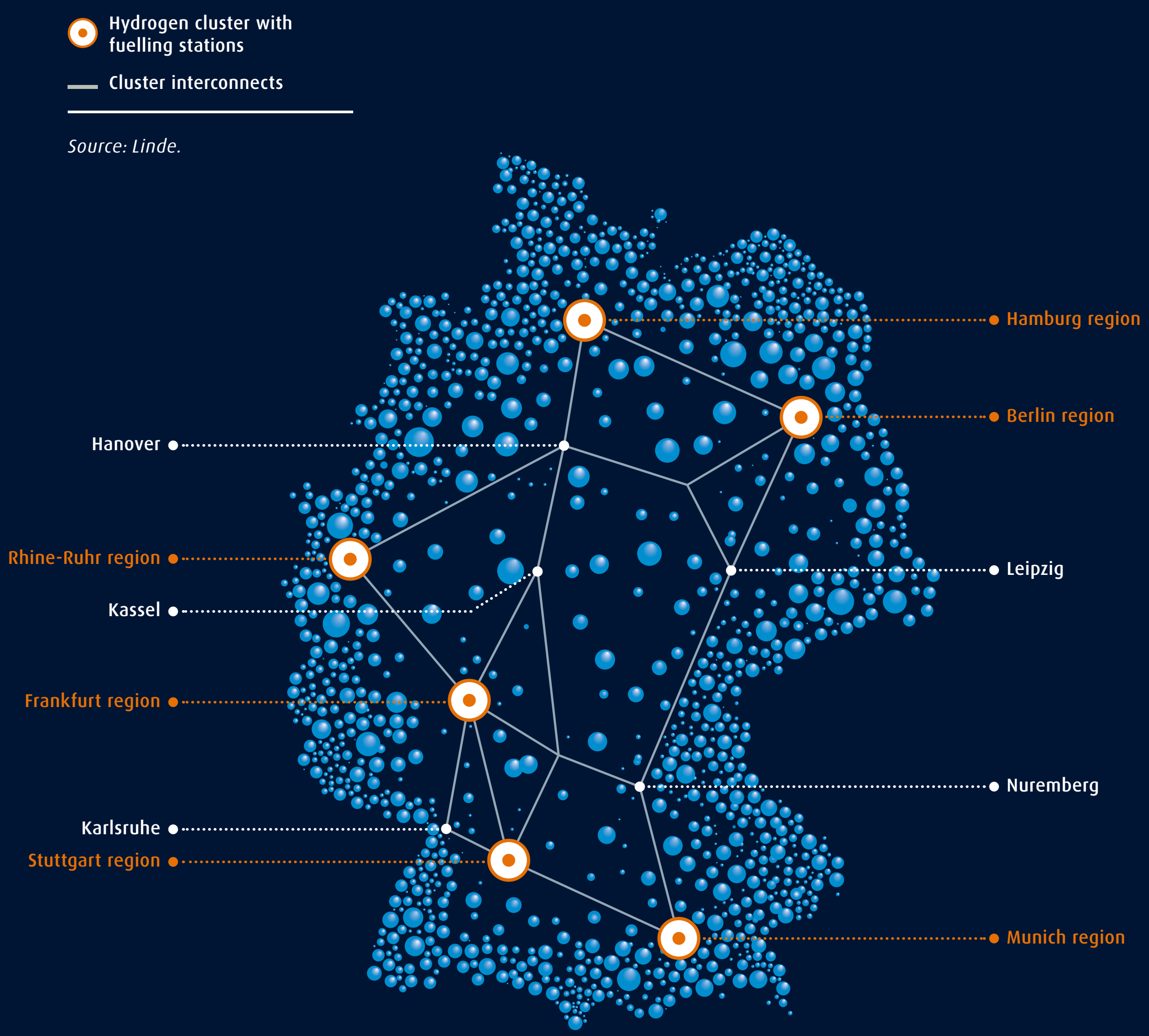


Hydrogen

Energy carrier of the future.

Hydrogen is the most abundant chemical element in the universe. It is present in water and forms part of most organic compounds, so is practically unlimited in availability. It is represented by the chemical symbol H_2 and delivers more energy than an equivalent weight of any other fuel. Hydrogen is an environmentally friendly option, especially if it is obtained using regenerative energies such as wind or biomass. It shows huge potential as a fuel for the transport sector.

Expanding the
H_2 infrastructure.



Source: Linde.

Mobility

H_2 infrastructure.

Together with Daimler, Linde will be setting up a further 20 hydrogen refuelling stations in Germany over the next three years, ensuring that the steadily growing number of fuel-cell vehicles can be supplied with H_2 generated solely from renewable resources. The initiative will more than triple the number of public hydrogen refuelling stations in Germany. The new facilities are planned for the existing hydrogen hubs of Stuttgart, Berlin and Hamburg, as well as along new, end-to-end north-south and east-west corridors. These corridors will then make it possible to travel anywhere in Germany with a fuel-cell vehicle.

A greener future starts today.

In the face of growing global energy requirements and continued climate change, the quest to obtain energy from renewable sources is gaining momentum. Linde's technology portfolio covers all the main sustainable sourcing opportunities for power and fuel – from solar energy through biogas and biodiesel to green hydrogen.

Energy generated from renewable resources such as wind, water, sunlight, land heat and biogas (see glossary) is set to play an increasingly important role in the global energy mix of the future. The contribution of each carrier to the overall mix will vary from one region to another. Climatic conditions like solar intensity and wind strength are crucial here, as are other factors such as the availability of cultivable land for energy crops or water resources for hydropower plants.

Technical leaps in the development of solar power

Solar energy is rapidly growing in popularity, thanks largely to huge advances in the enabling technologies coupled with efficiency gains in production processes. In 1974, the manufacturing cost of solar cells was more than 100 USD per Watt; expert estimates for 2012 place this figure at 50 cents.

Thin-film technology (see glossary) has played a significant role in this development, enabling mass production of large-scale solar modules and requiring just 1 percent of the silicon (see glossary) used to manufacture conventional, polycrystalline solar cells. Some manufacturers expect that improved technologies will reduce production costs by a further 50 percent over the coming years.

Linde is collaborating within a network that brings leading manufacturers of solar cells and production facilities together with notable research institutes to increase solar cell and module efficiency even further. The shared aim of these partners is to make solar power more cost-effective and solar cell manufacturing more eco-friendly.

↳ Gases for China: Linde's Suzhou plant produces electronic gases for customers to use in solar module production.

>100 USD

savings due to more efficient solar cell production.

Experts predict that the manufacturing cost of solar cells will be just 50 cents per Watt in 2012 compared with more than USD 100 in 1974. This is all down to technical advances and efficiency gains.

The global market for gases required in solar cell production is also set to expand further in years to come. Experts anticipate that it will be worth around EUR 1 bn by 2015, with forecasts leaping to EUR 3 bn by 2030.

Hydrogen for GCL-Poly Energy in China

Linde opened two new production plants for high-purity hydrogen in mid-2011. Located in China, these will supply GCL-Poly Energy – one of the world's leading polysilicon manufacturers and China's largest – with hydrogen for its production processes. Group subsidiary GCL Solar has had a manufacturing output of around 21,000 tonnes of polysilicon per year since the end of 2010. It has also started setting up solar

↳ (left top) Linde has strengthened its collaboration with Suntech, China's largest polysilicon manufacturer.

↳ (left bottom) Valuable commodity – gas cylinders at Suntech.

PEPPER research project.

Since September 2010, Linde has been participating in the international research project PEPPER, alongside leading companies and research institutes from the solar sector. This project aims to increase the efficiency of thin-film silicon modules within the next three years, while simultaneously cutting costs. It also sets out to evaluate and reduce the environmental impact of the entire manufacturing process for solar modules. PEPPER has a budget of EUR 16.7 m, over half of which stems from European Commission funding.

cell production facilities, which have now reached a capacity of one gigawatt.

The new hydrogen plants at Xuzhou Industrial Park mark another phase of the successful ongoing collaboration between Linde and GCL-Poly Energy. Prior to that, Linde was already supplying GCL with hydrogen via pipeline. This latest project brings Linde's investment commitment to GCL's gas supply infrastructure in Suzhou to around EUR 30 m.

Environmentally neutral gases for solar module production

In Germany, too, Linde has continued to build business relations in the solar industry over the last year. In September 2011, the Group signed a long-term supply contract with Schüco TF, Germany's largest manufacturer of solar modules, to deliver fluorine (F_2) to Schüco's new thin-film mass production site in Grossröhrsdorf, eastern Germany. As part of this agreement, Linde will construct the largest electronics on-site F_2 production plant in Europe to date.

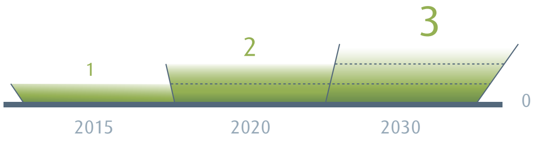
As an environmentally neutral gas, the fluorine will be used to clean process chambers, replacing the nitrogen trifluoride (NF_3) previously used – a greenhouse gas with a global warming potential over 17,000 times greater than that of carbon dioxide. Commissioning the new plant and switching to F_2 will enable Schüco to reduce its emissions by more than 100,000 tonnes of CO_2 equivalent per year.

Linde and Schüco have been working together to advance gas technologies in the solar industry since 2008. In March 2009, Linde began supplying Schüco's plant in Osterweddingen (Germany) with fluorine produced in an on-site generator.

Altogether, Linde has installed over thirty on-site fluorine generators for customers worldwide.

Steady growth.

Global demand for gases required for solar production (EUR billion).



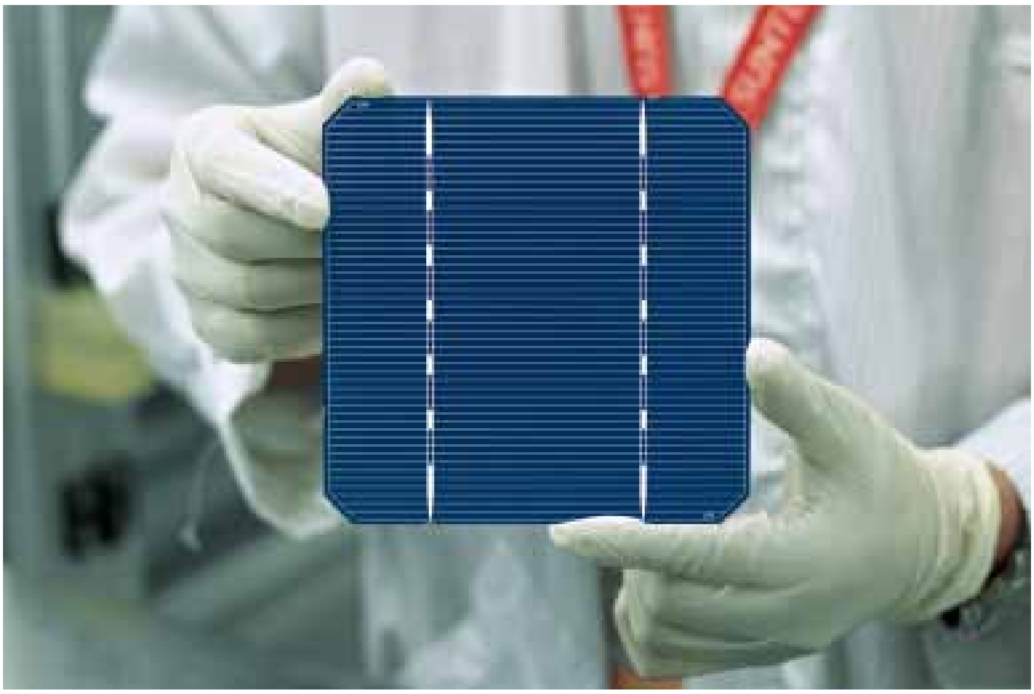
Source: Linde estimates.

5

–100,000 t

CO_2 thanks to fluorine.

Linde customer Schüco, Germany's largest solar module manufacturer, is able to reduce emissions at its new plant by more than 100,000 tonnes of CO_2 equivalent every year by using the environmentally neutral gas fluorine.



↳ Crystalline silicon solar cell.

↳ Successful partnership: Linde processes landfill gas into liquid biogas for US company Waste Management at the Altamont landfill site near Livermore, east of San Francisco.

Turning waste into biofuel

In California, the US state with the most stringent environmental legislation, Linde has formed a joint venture with leading waste disposal company Waste Management Inc. Together, they have developed a system to turn landfill gas into valuable fuel for refuse collection trucks. The gas originates from composting waste at the Altamont landfill site near Livermore and is converted into liquid biogas at the world's largest facility of its kind. This went on stream in November 2009 and has since been generating 50,000 litres of liquid biogas per day, used to fuel the refuse trucks. As part of this partnership with Waste Management, Linde engineered the gas liquefaction facility and provided the storage tanks and vehicle refuelling technology. The venture is proving a great success – July 2011 saw Waste Management add the thousandth truck to its biogas fleet. Converting the vehicles to this climate-friendly fuel prevents combustion of around 31 million litres of petrol or diesel per year, reducing CO_2 emissions by approximately 45,000 tonnes. Waste Management now intends to expand its biogas stream from landfill gas and is planning to construct a second liquefaction plant in California.

– 45,000 t

CO_2 thanks to biogas.

By converting its vehicles to climate-friendly biogas, Waste Management saves around 31 million litres of petrol and diesel per year, reducing CO_2 emissions by approximately 45,000 tonnes.

Energy from landfill.

5

In the absence of oxygen, the warm, damp conditions in compost containers provide an ideal environment for bacteria to break down organic matter and release landfill gases such as methane and carbon dioxide. The energy released by this decomposition process primarily takes the form of combustible methane. A cubic metre of pure methane has an energy content of almost ten kilowatt hours. To put this energy to good use, the landfill gas is first collected in gas wells. The entire depository is equipped with vertical collection pipes for this purpose, in which blowers create a slight negative pressure that sucks in the gas. At the Livermore plant in California, around 200 cubic metres of landfill gas are obtained per tonne of waste in this way. The next step is to compress the gas at the liquefaction facility, removing sulphur, carbon dioxide, nitrogen, alcohols and other impurities. Finally, the purified methane is cooled to minus 162 degrees Celsius in a heat exchanger and thus liquefied. The electricity required for this process is also obtained from landfill gas.

In contrast with fossil-based natural gas, gas from the waste disposal site is climate-neutral when used to power engines, only releasing as much carbon dioxide as the organic matter previously absorbed. Biogas engines also emit 90 percent less particulate matter, nitrogen oxides and sulphur dioxide than conventional drivetrains.

↳ Once the waste has been collected, it is composted and turned into biogas by Linde. Waste Management uses the environmentally friendly fuel to power its garbage collection trucks.

Green hydrogen from glycerine

In the medium term, hydrogen and fuel cells (see glossary) take pride of place on the agenda for sustainable, climate-friendly fuels and drivetrain technologies. Leading automotive manufacturers have announced series production of hydrogen-powered fuel-cell vehicles for 2014/2015. Meanwhile, the necessary infrastructure is advancing too, with hydrogen stations complete with sophisticated fuelling technology springing up at key transport hubs (see page 51).

At present, the lion's share of the hydrogen used in the mobility sector still has to be generated from fossil fuels such as natural gas. But the future is already unfolding. At the Leuna industrial park in Germany, Linde opened a pilot plant in autumn 2011 to convert raw glycerine into hydrogen. In regular mode, the plant has an output of 50 normal cubic metres of sustainable hydrogen per hour.

Raw glycerine occurs as a by-product of biodiesel manufacture from plant oils such as rapeseed, for instance. It contains a high level of hydrogen and does not conflict with food production. It is also easy to transport, non-toxic and available all year round.

For the first time, Linde's landmark facility in Leuna provides proof of concept for the cost-effective, energy-efficient conversion of glycerine into hydrogen. The plant uses the pyroreforming process developed by Linde. Production begins with an initial distillation step to purify the raw glycerine, which contains around 17 percent water and salts. Pyroreforming proper can then begin. This involves cracking the desalinated glycerine molecules under high pressure and at temperatures of several hundred degrees Celsius. Like natural gas, the pyrolysis gas consists primarily of methane. Following pyrolysis (see glossary), the gas is fed into a steam reformer, where it is heated further to generate a hydrogen-rich synthesis gas. This synthesis gas, which still contains large amounts of carbon monoxide, is fed into the existing purification stage of the conventional hydrogen production process at the Leuna site and concentrated to the necessary purity. Alternatively, Linde can directly liquefy the hydrogen obtained from glycerine.

Linde called in TÜV SÜD to analyse the carbon footprint of the entire production process – from delivery of the glycerine to Leuna right through to the electricity consumed to light the demo plant. The outcome speaks for itself: deployed on a major industrial scale, this H_2 process chain has the potential to reduce CO_2 emissions during production by up to 80 percent in comparison with H_2 captured from conventional natural gas steam reforming (see glossary).

En route to a hydrogen-based society

Under the umbrella of the Clean Energy Partnership (CEP; see glossary), climate-friendly hydrogen from Leuna is already used to power fuel-cell vehicles, for instance in Berlin. Shell opened its first hydrogen refuelling station here in summer 2011. Engineered by Linde, this facility can refuel around 250 vehicles per day.

The potential of hydrogen extends beyond eco-friendly transport. Major customers such as crude oil refineries and chemical companies, whose production processes require large amounts of hydrogen, could also contribute to a cleaner environment by increasing their share of sustainably generated hydrogen in the future.

In a society increasingly committed to energy from renewable sources, the importance of hydrogen as a means of energy storage is also set to grow. It is an ideal medium to store surplus electricity from wind turbines, for instance (see page 67).

–80 %

CO_2 emissions thanks to sustainably produced hydrogen.

Linde's pilot plant at the Leuna chemical hub has been converting glycerine to hydrogen since autumn 2011. Biogenic raw materials hold the key to sustainable, economically viable hydrogen production.

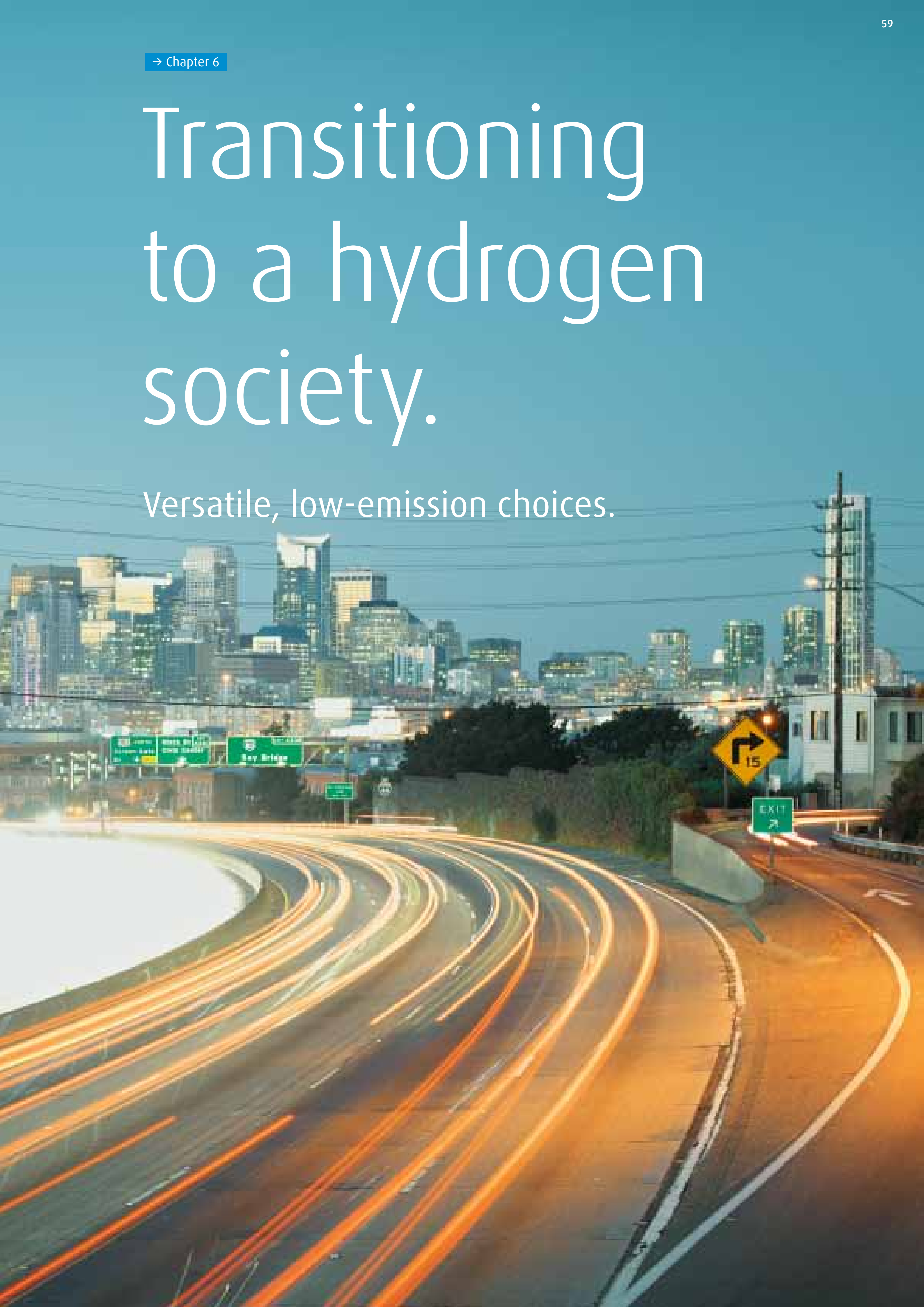
↳ Pilot plant in Leuna: Linde uses an innovative procedure to convert raw glycerine into hydrogen.

6

→ Chapter 6

Transitioning to a hydrogen society.

Versatile, low-emission choices.



6

↳ Fuel-cell vehicles are already part of the public transport infrastructure in California. Linde has built two H_2 fuelling stations for bus operator AC Transit in Oakland and Emeryville.

Always mobile, increasingly ecological.

The future of mobility is green – and hydrogen has a key role to play here. In conjunction with fuel cells, it has the potential to make both private and public transport more environmentally sound.

↳ Hydrogen station in Berlin: Drivers can also fill up on green fuel in Munich, Hamburg or Stuttgart.

A denser network for increased flexibility.

Germany continues to expand its network of hydrogen fuelling stations. Together with Daimler, Linde will be setting up twenty new H_2 fuelling stations in Germany over the coming months. This initiative underscores the companies' commitment to zero-emissions mobility.

Clean mobility, powered by hydrogen.

Hydrogen has the potential to play a key role in tomorrow's energy mix. The lightest element in the universe, hydrogen can be used as a fuel for zero-emissions mobility and as a storage medium for electricity from renewable sources. Linde has the technological expertise to master the entire hydrogen value chain and is active on numerous fronts to drive widespread adoption of this environmentally friendly energy carrier.

6

The foundation has been laid for the first series-produced electric cars powered by hydrogen (H_2) fuel cells. Extensive road tests with different vehicles, innovative fuelling technologies and a variety of hydrogen production processes have established the everyday viability of this environmentally sound energy carrier for zero-emissions mobility. At the same time, industry continues to expand the reach of the existing H_2 refuelling infrastructure.

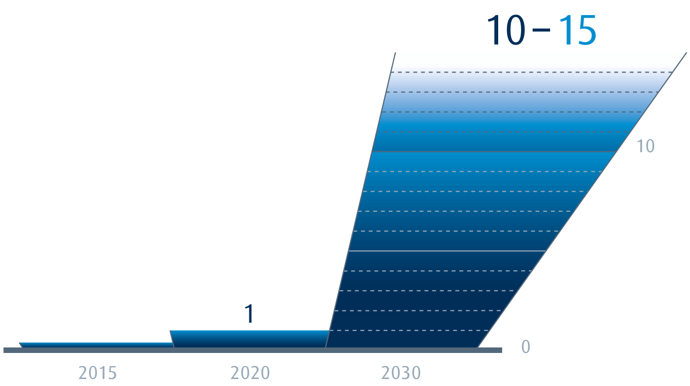
Increasing H_2 mobility

Linde is involved in many initiatives worldwide to drive widespread adoption of hydrogen technologies. Germany is leading the way here. Linde, for example, is a founding member of the Clean Energy Partnership (CEP) and H_2 Mobility, two industrial initiatives sponsored by the German National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP). Both organisations are committed to promoting the commercialisation of hydrogen as a fuel and to building the first nationwide hydrogen infrastructure in Germany. Partner companies represent the energy, transport and automotive sectors; all are committed to supporting the automotive industry in its goal to launch the first series-produced hydrogen-powered fuel-cell cars in 2014/2015. CEP activities in 2011 culminated in the opening of new H_2 refuelling stations equipped with Linde technology in Berlin and Hamburg.

In the UK, Linde played a key role in the country's first public H_2 filling station, which opened in September 2011. The company constructed and now runs the facility at car manufacturer Honda's production site in Swindon.

Sustainable growth.

Global demand for hydrogen fuel (EUR billion).



Source: Linde estimates.

Hydrogen technology is becoming a particularly important factor in climate protection thanks to ground-breaking developments in sustainable H_2 production. From glycerine and blue-green algae through biological waste products to electrolysis powered by regenerative electricity, Linde is testing and utilising a wide range of methods to reduce or even eliminate emissions during hydrogen production.

Cryogenic hydrogen from Leuna.

Compressing or cryogenically liquefying hydrogen reduces its volume for efficient storage. At its chemical hub in Leuna, Linde operates Germany's only industrial-scale hydrogen liquefaction facility. The plant has an hourly production capacity of around 33,000 litres of cryogenic liquid hydrogen (LH_2). This is much denser than gaseous hydrogen and therefore significantly easier to store, transport and manage.

↳ Hydrogen fuelling station in Berlin's Sachsendamm: Linde supplies the station with green hydrogen.

20 new H_2 fuelling stations in Germany

In June 2011, Linde and car manufacturer Daimler agreed to build 20 new H_2 fuelling stations in Germany over the next three years. This investment in the double-digit million euro range will form a bridge between the existing H_2 Mobility and Clean Energy Partnership infrastructure projects. It will also more than triple the number of public hydrogen refuelling stations in Germany. The new stations will be built in the hydrogen hubs of Stuttgart, Berlin and Hamburg and along new end-to-end north-south and east-west corridors. The aim is to make use of existing, easily accessible locations belonging to various petroleum companies. These corridors will then make it possible to travel anywhere in Germany with a fuel-cell vehicle. The 20 new H_2 stations will be supplied with sustainable hydrogen from Linde's Leuna plant.

+20

new H_2 fuelling stations will soon make it possible to travel anywhere in Germany with a fuel-cell car.

Linde and Daimler are investing in the double-digit million euro range to build twenty new H_2 stations in Germany.

Around the world with hydrogen

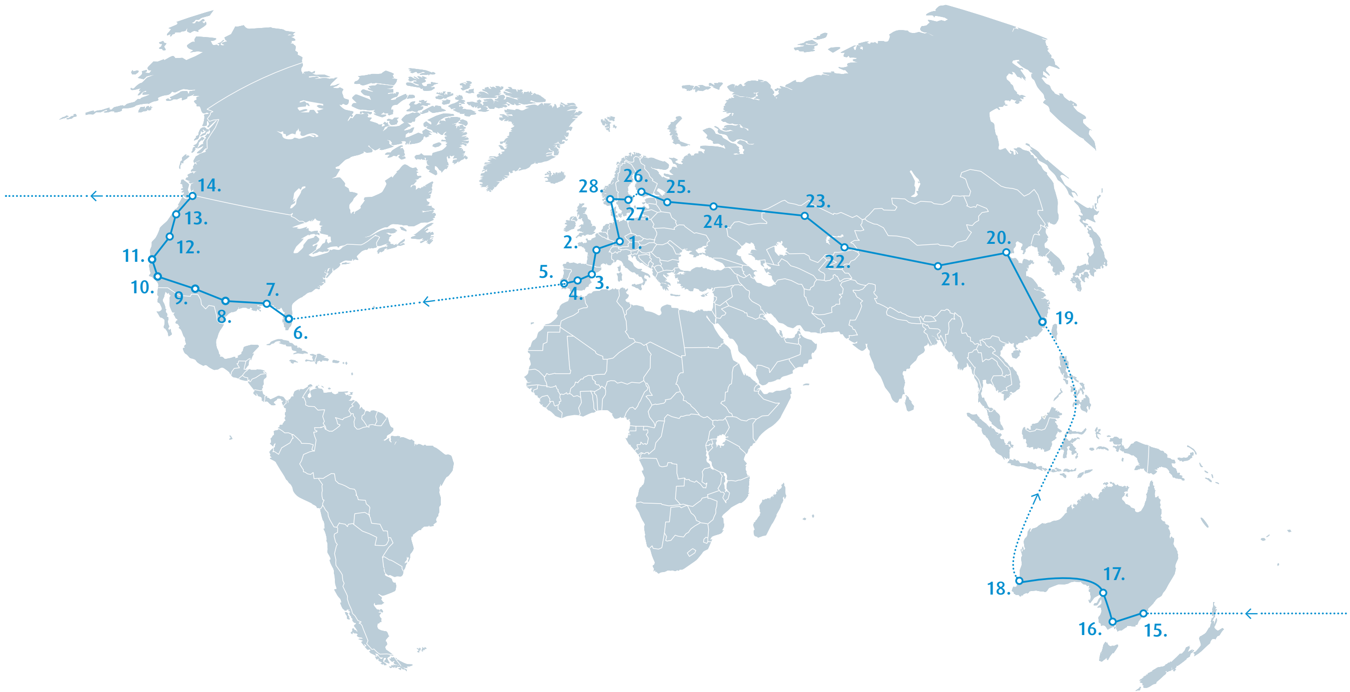
Linde and Daimler took part in an unusual project last year to prove that hydrogen is already up to the rigours of life on the road. In January 2011, three B-class F-CELL hydrogen-powered fuel-cell cars set off to tour the globe in 125 days. The trip covered a distance of 30,000 kilometres, taking the cars through 14 countries and numerous climates on asphalt roads and dirt tracks. This unique journey proved the perfect platform for Daimler to demonstrate the cars' technical maturity.

During this world tour, the vehicles were supplied with hydrogen from a new 700-bar mobile refuelling unit developed by Linde and Daimler. This mobile station is equipped with an ionic compressor (see glossary) and all the technology required for compressing hydrogen and refuelling the cars. The Linde-developed ionic compressor is ideal for H_2 refuelling, as it uses ionic liquid instead of a conventional solid compression piston. During compression, these organic salts act like a solid medium.

Proven H_2 production processes

Steam reforming natural gas is currently the most economically viable method of producing hydrogen. Catalytically splitting steam and natural gas in a steam reformer at temperatures of around 800 degrees Celsius produces hydrogen, carbon monoxide and carbon dioxide. In a subsequent step known as the CO shift reaction, the carbon monoxide reacts with steam, creating CO_2 and more hydrogen. Over 75 per cent of the direct hydrogen market is produced in this way.

Linde's long-term goal is to significantly increase the share of hydrogen produced using renewable energies such as wind, water and biomass. Electrolysis, for example, can be used to produce a zero-emission hydrogen energy cycle, provided the energy it uses comes from regenerative sources. During electrolysis, water is split into its constituent parts – namely oxygen and hydrogen. A membrane between the anode and cathode prevents the two gases from mixing and reverting back to water. If this process is carried out under pressure, it also makes subsequent compression easier and reduces energy and space requirements. Linde has a wealth of experience working with hydrogen electrolysers – as well as the expertise to incorporate them into existing hydrogen technology chains.



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Hydrogen pit stops on the world tour.

1. Stuttgart
2. Paris
3. Barcelona
4. Madrid
5. Lisbon
6. Miami
7. New Orleans
8. San Antonio
9. Phoenix
10. Los Angeles
11. Sacramento
12. Salem
13. Seattle
14. Vancouver
15. Sydney
16. Melbourne
17. Adelaide
18. Perth
19. Shanghai
20. Beijing
21. Xi'an
22. Almaty
23. Astana
24. Moscow
25. St. Petersburg
26. Helsinki
27. Stockholm
28. Oslo

↳ Right around the globe: The Mercedes-Benz F-CELL World Drive took three fuel-cell cars on a journey of around 30,000 kilometres each. The tour clearly demonstrated that hydrogen and fuel-cell technology is more than a match for the day-to-day rigours of the open road.

California's green buses

Hydrogen-powered fuel cells are not only making inroads into private transport, they are also gradually making their mark in public services. And not only in Germany. Linde has built two hydrogen fuelling stations for bus operator AC Transit in the Californian cities of Emeryville and Oakland. California is a pioneering region for hydrogen mobility and the stations now supply hydrogen to a dozen fuel-cell buses. Some of the hydrogen is produced without any CO_2 emissions, using regenerative energy sources. The roofs of the fuelling stations are fitted with solar panels that supply more than 700 kW of power to an electrolyser, which produces 60 kilograms of H_2 every day. This suffices for two of the buses. The remaining ten are fuelled from a tank that can hold up to 34,000 litres of liquefied hydrogen. This hydrogen is generated from methane, which cuts the buses' CO_2 footprint by 40 percent compared with diesel or petrol-powered vehicles.

The market for H_2 fuel is set to grow further. Market experts predict that around one million hydrogen vehicles will be on Europe's roads by the year 2020. Studies show that by 2050, over a quarter of the world's passenger cars could be powered by hydrogen-sourced electricity. Industry experts also predict that the global market will be worth EUR 10 to 15 bn by 2030.

Using H_2 to remove sulphur from fuels

Moving beyond the possibilities of hydrogen in tomorrow's energy mix, the lightest element in the universe has been a key enabler of numerous industrial processes for many years now – a fact that is often overlooked. Almost half of the hydrogen produced worldwide is used in the chemical industry for ammonia and methanol synthesis. Hydrogen is also used in crude oil refineries to remove sulphur from conventional fuels. Large amounts of hydrogen are also required in the metal, glass, electronics and food industries.

–40 %

CO_2 emissions in public transport services.

Buses powered by methane-derived hydrogen almost halve the carbon dioxide emissions of diesel or petrol-driven vehicles.

Global demand is estimated at over 600 billion cubic metres per year. To produce this massive volume of hydrogen, fossil fuels such as natural gas are

↳ The future has already begun: Bus operator AC Transit carries more than 200,000 passengers across the San Francisco Bay Area every day in its environmentally friendly hydrogen-powered buses.

steam-reformed in hydrogen plants. This accounts for around 70 percent of the current volume. Having already built over 200 hydrogen production plants worldwide, Linde holds a leading position in this market and continues to benefit from buoyant demand.

One of the company's latest developments is the HYDROPRIME® line of plants. These standardised, compact facilities are aimed at customers who require small to medium amounts of hydrogen. HYDROPRIME® plants are shipped to customers by truck, almost entirely pre-assembled. They are extremely reliable and both cost-effective and energy-efficient to operate. These remote-controlled, fully automatic units can be adapted to individual customer needs.

Using hydrogen to store energy

Hydrogen is an environmentally sound energy carrier. It is also an ideal medium for storing energy from regenerative sources such as wind and solar power, which, by their very nature, are subject to fluctuations. The wind doesn't always blow and when it does, it is never at a consistent speed. Similarly, the sun only shines during the day, and in more temperate climates it is only strong enough in summer months.

On-demand access to energy from regenerative sources such as these thus hinges on effective storage solutions. Hydrogen has a key role to play here, as energy from wind and solar plants can be used to power electrolysis of water. The resulting hydrogen can then be compressed or liquefied and stored for as long as necessary. When the energy is needed, the hydrogen can be burnt to create zero-emissions electricity or heat, or converted directly into electricity with the help of fuel cells. The first hybrid power plants capable of harnessing wind power and hydrogen to create and store energy are currently being tested.

The hydrogen age has already dawned.

Fuel cell vs. battery

Fuel cells and batteries are two promising and mutually complementary electric drivetrain technologies. With comparatively long charging times and shorter ranges, battery-powered cars are particularly suited to shorter distances in urban areas. In contrast, hydrogen-powered fuel-cell vehicles can be refuelled within three minutes using Linde's ionic compressor and can cover distances of over 500 kilometres on a single tank.

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Our Annual Report, which includes The Linde Annual and the Financial Report of The Linde Group, is available in English and German. You can download either version from our website at www.linde.com. You will also find an interactive version of the Annual Report online.

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Review of the year

JANUARY

↳ Linde becomes the preferred engineering partner of the South African company Sasol Technology (Pty) Ltd. The agreement is for an initial term of 10 years and relates to a major portion of Sasol's coal gasification technology: downstream aspects such as raw gas cooling, by-product processing and overall integration of the gas island.

↳ Linde is selected as Daimler's exclusive hydrogen partner for the Mercedes-Benz F-CELL World Drive. This endurance trip sends three B-class F-CELL hydrogen-powered fuel-cell cars right around the world. Linde is the sole supplier of mobile hydrogen for the zero-emissions vehicles for the entire tour. The trip takes each of the cars around 30,000 kilometres across four continents and 14 countries in 125 days.

FEBRUARY

↳ In Tasmania, Linde officially brings on stream Australia's first micro-LNG plant. The joint venture project involves investment of AUD 150 m and includes the supply of six filling stations for the transport company LNG Refuellers Pty Ltd in the region.

↳ At its Cebu site in the Philippines, Linde invests EUR 3.8 m in the construction of a plant to produce carbon dioxide. The new plant, which produces 24 tonnes of carbon dioxide per day, supplies the shipbuilder Tsuneishi Heavy Industries.

MARCH

↳ In Pasir Gudang in Malaysia, Linde officially opens a new air separation plant. The EUR 47 m project is Linde's biggest single investment in Malaysia and demonstrates that here too the Group is gearing its business towards long-term growth. The plant had started production in the second half of 2010.

↳ Linde introduces its new segment structure in the Gases Division. The Group also sets out reallocated regional responsibilities. Linde's Gases Division now reports on the basis of the following three reportable segments: EMEA (Europe, Middle East, Africa), Asia/Pacific and the Americas. Linde also establishes a specific regional responsibility on the Executive Board for the Asia/Pacific segment to capitalise on the huge potential offered by growth markets in Asia.

APRIL

↳ Linde announces that it is further advancing the use of hydrogen as an environmentally sound fuel in North America. At Coca-Cola's production site at Coca-Cola Bottling Co. Consolidated in Charlotte, North Carolina, Linde will set up a zero-emissions hydrogen fuelling system to supply 40 forklift trucks.

MAY

↳ Linde is to build and operate a large hydrogen and synthesis gas plant in Chongqing Chemical Park in western China. Linde implements the project in a joint enterprise with Chongqing Chemical & Pharmaceutical Holding Company (CCPHC). The new on-site plant will in future supply carbon monoxide, hydrogen and synthesis gas to the BASF and CCPHC production plants based there. The investment in the project is around EUR 200 m. The new plant, which is being supplied by Linde's Engineering Division, is expected to come on stream in the third quarter of 2014. This project strengthens Linde's presence in western China and reinforces its position as the leading gases and engineering company in China.

↳ In Sweden, Linde officially opens the country's first terminal for liquefied natural gas (LNG). Linde is the owner and operator of the terminal and sells the LNG to customers in industry, transport and shipping. With this new terminal, Linde has gained entry into a promising growth market.

JUNE

↳ Linde announces that it is working together with car manufacturer Daimler to press ahead with the development of an infrastructure for fuel-cell vehicles. Over the next three years, the two companies plan to build an additional 20 hydrogen filling stations in Germany, thereby ensuring a supply of hydrogen produced exclusively from renewable sources for the steadily increasing number of fuel-cell vehicles on the roads. As a result of the Linde/Daimler initiative, which involves investment in euro running into the double-digit millions, the number of public hydrogen filling stations in Germany is set to more than triple.

Back cover fold-out:
C5/C7: Review of the year, C6: Glossary

Review of the year

JULY

↳ Linde paves the way for entry into the promising market segment of floating LNG plants. Together with its project partner SBM Offshore, Netherlands, the Group signs a cooperation agreement with the Thai oil group PTT (Petroleum Authority of Thailand) to develop a floating natural gas liquefaction plant in the Timor Sea off the northern coast of Australia. The project will involve the conversion of natural gas from three gas fields into LNG. If the gas reserves meet expectations, the project will move into the front-end engineering and design phases. The final investment decision should be made at the end of 2012. Commercial production would be expected to commence at the end of 2016.

↳ Linde enters into an agreement with the Chinese Yantai Wanhua Group to build two air separation plants. The plants will have a total production capacity of 110,000 standard cubic metres of oxygen and nitrogen per hour, and will also supply third-party customers. They are expected to come on stream at the beginning of 2014.

AUGUST

↳ Linde is involved in the major pipeline project, Nord Stream, which has assured the supply of natural gas from Russia to 26 million European households since the end of 2011. For a whole week, without interruption, Linde supplied 14,000 standard cubic metres of nitrogen per hour, injecting it into the pipeline. This was for the inertisation of the pipeline: i.e. rinsing the pipes with nitrogen to remove reactive gases.

↳ With the support of the US Department of Energy (DoE), Linde is continuing to develop carbon capture and storage (CCS) technology in coal-fired power stations in the United States. The DoE is providing USD 15 m of funding to build a pilot plant in Wilsonville, Alabama, to test innovative CO_2 scrubbing processes as of 2014. These processes aim to separate the CO_2 in the most energy-efficient and cost-effective way. In the plant, Linde will seek to remove at least 90 percent of the carbon dioxide from the power station flue gases. Energy costs will rise by only 30 percent as a result.

SEPTEMBER

↳ Working together with a number of partners, Linde launches the first public hydrogen filling station in the UK. Both 350 bar and 700 bar technology can be used at the filling station, which is situated in Swindon on the M4 motorway between London and Swansea.

↳ Linde signs a contract to build Europe's largest on-site fluorine production plant for Schüco TF, Germany's leading manufacturer of thin-film silicon solar modules. By using environmentally friendly fluorine, Schüco is able to reduce emissions from its production plants by 103,000 tonnes of CO_2 equivalent per annum.

OCTOBER

↳ In South Korea, Linde starts production at the new air separation plant on the Giheung site. The plant produces 3,000 tonnes of nitrogen per day for customers in the electronics and semiconductor industries. At EUR 130 m, this air separation plant is Linde's biggest investment to date in South Korea.

↳ Linde launches a new model range in the growing market segment of small hydrogen plants. With its HYDROPRIME® product, Linde is expanding its portfolio to include a standardised range, so that it can offer the market the whole spectrum of sizes for hydrogen and synthesis gas plants.

NOVEMBER

↳ Linde builds up its business relationships with the Chinese steel industry and commits to providing all the gas supplies for Hebei Puyang Iron and Steel in Wu'an in northern China. Under this on-site agreement, Linde will acquire and operate the seven existing air separation plants and an existing pipeline network, equipping them with the latest technology. At the same time, Linde's Engineering Division will construct a new air separation plant on the site, which will have a production capacity of 30,000 standard cubic metres of oxygen per hour. The investment in the project is around EUR 120 m.

DECEMBER

↳ Linde invests EUR 42 m in the Jilin Chemical Park in north-east China to build a new hydrogen plant. The new plant is expected to come on stream at the end of 2013 and will supply high-purity hydrogen to several companies at this integrated chemical complex. Production plants situated here include those of Evonik Industries and Jishen, a joint venture between PetroChina Jilin Beifang Chemical Group and Jilin Shenhua Group.

Glossary

→ Biogas
Biogas is generated when plant matter decays in biogas facilities. Its main components are methane and carbon dioxide. Methane – also the primary component of natural gas – is recovered to produce energy.

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

→ Clean Energy Partnership (CEP)
CEP is Europe's largest proof-of-concept project demonstrating the viability of hydrogen for everyday mobility. It is a flagship project for road transport within the German National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP). The German Ministry of Transport has been sponsoring CEP since 2008. The partnership brings technology, oil and energy companies together with car manufacturers and two public transport service providers. Linde is one of the founding members of CEP.

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

→ Fuel cell
A system in which hydrogen and oxygen react to form water without a flame (cold combustion), generating a significant amount of electrical energy. So fuel cells transform chemical energy into electrical power.

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

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

→ Ionic compressor
Ionic compressors represent a huge leap in the evolution of compression technology. Here conventional metal pistons are replaced by a specially designed, nearly incompressible ionic liquid. These organic salts remain liquid within a specified temperature range. The innovative design enables compression at a near-isothermal temperature. Which means that drivers can refuel much faster. A bus can be refuelled in just six minutes using Linde's MF-50 ionic refuelling system, for example. And the MF-90 refuelling system for cars takes only three minutes to fill the tank – providing enough fuel to last 400–600 kilometres.

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

→ Mixed Fluid Cascade (MFC®) liquefaction process
Three custom-mixed refrigerant cycles provide the cooling and liquefaction duty with this process. Specially developed for industrial-scale natural gas plants, MFC® maximises energy efficiency.

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

→ Rectification column
This is where rectification – also known as counter-flow distillation – takes place in a natural gas plant. This is a multi-step process that separates a mixture into its component fractions.

→ Silicon
Silicon is a hard, brittle non-metal with a dark grey sheen and a diamond-like lattice structure. Crystalline and amorphous silicon can be differentiated by the size of the crystals. Silicon is a typical semiconductor element. Its ability to conduct electricity increases with temperature. Adding metal atoms (impurities) also increases silicon's conductivity.

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

→ Stranded gas
This refers to a natural gas reserve that has been discovered but remains unusable for physical or economic reasons. Stranded reserves are generally either too small or too remote to justify the considerable expense involved in building a pipeline infrastructure.

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

→ Thin-film technology
To manufacture solar modules, extremely thin (0.001 millimetres) layers of photoactive semiconductors are applied to a substrate material. These thin films significantly reduce manufacturing costs by cutting the bill of materials for silicon – an otherwise expensive commodity.

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