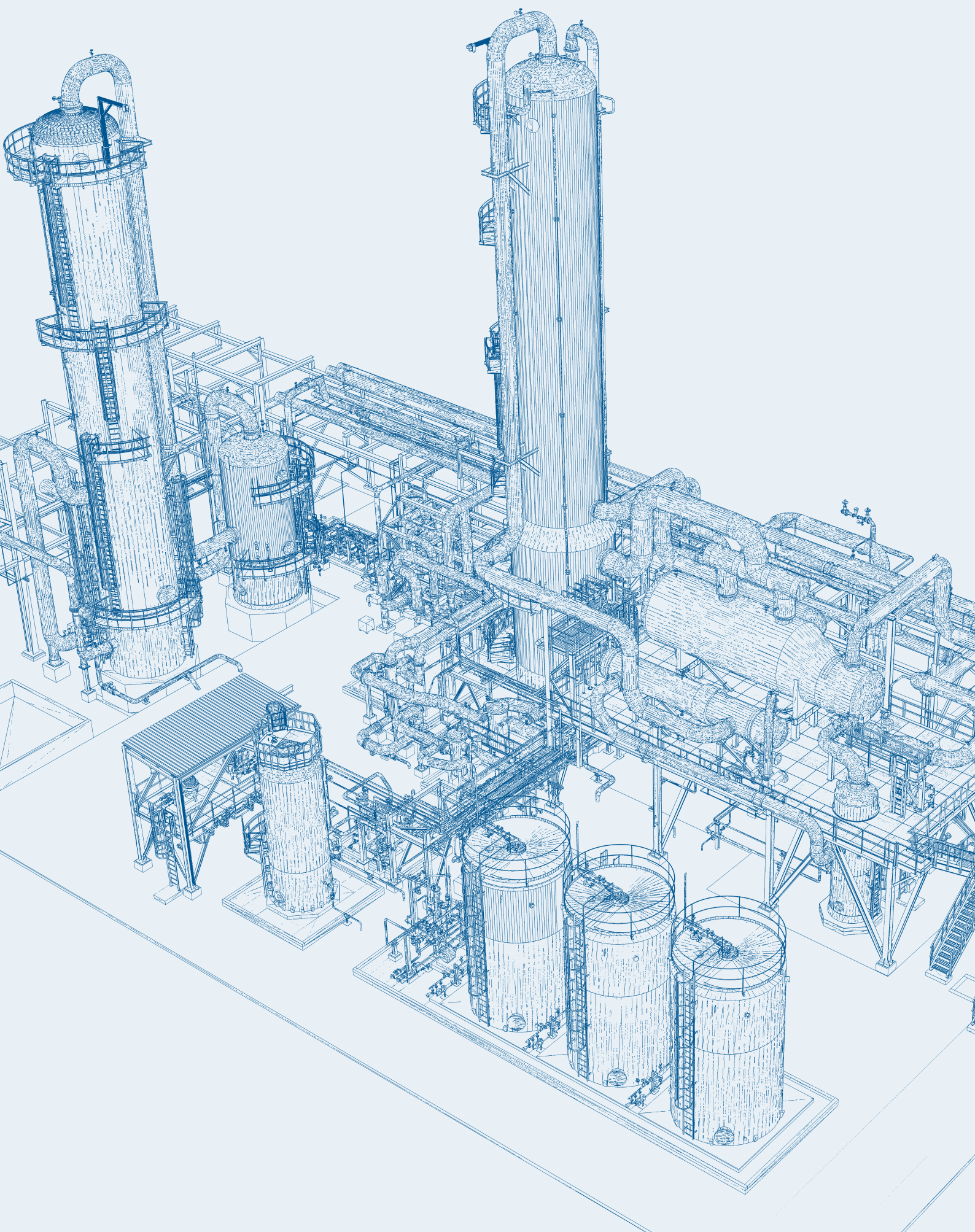


# Carbon capture, storage and utilisation

Linde & BASF team up to innovate carbon capture







# Growing pressure to mitigate climate change.

## Tackling congestion to CO<sub>2</sub> emissions

Global warming and climate change concerns are intensifying global efforts to reduce the concentration of greenhouse gases such as carbon dioxide (CO<sub>2</sub>) in our atmosphere. Increasingly, attention is focusing on the need to remove CO<sub>2</sub> from the flue gases released by combustion processes in countless industries including power, chemicals and steel. Carbon capture is a key strategy in meeting today's CO<sub>2</sub> emission reduction targets. Post-combustion capture (PCC) typically uses a solvent in a specially engineered plant to chemically absorb the CO<sub>2</sub> from the flue gases after the combustion process.

The captured gas can be used commercially – for example as food-grade CO<sub>2</sub>, to enhance oil recovery (EOR) or as a feedstock for the production of commodities like methanol or urea. Alternatively, it can be stored underground as a carbon abatement measure.

## Teaming up to drive innovation in carbon capture

To meet the growing need for carbon capture, RWE Power, BASF and Linde partnered and joined forces to develop and advance PCC technologies. This alliance bundles Linde's strengths and proven track record in the design and delivery of turnkey industrial plants with BASF's leading role in high-performance gas treatment technologies for carbon capture.

Under its OASE® brand\*, BASF developed a range of high-performance gas treatment technologies. The BASF OASE® process is used successfully in more than 400 plants worldwide to scrub natural, synthesis and other industrial gases. With OASE® blue, BASF developed a technical solution specifically for PCC. The OASE® blue package includes an aqueous amine-based solvent which is highly stable.

BASF and Linde decided to demonstrate this technology at two pilot plants based at RWE Power, Niederaussem (Germany) and NCCC, Wilsonville (US). The operational experiences gained at these pilot plants has confirmed the technical readiness of this technology for industrial scale. It is ideally suited to a range of industries including coal-fired power plants, gas turbine applications and waste incineration.

## Benefits of Linde/BASF alliance at a glance

- Synergised offer covering process design, engineering, construction and operation
- Complete, one-stop solution for entire capture plant including CO<sub>2</sub> compression, drying, liquefaction and storage
- Operational insights gained from numerous large-scale gas treatment references
- Integration of energy/heat process flows
- Proven and tested licensed processes with operational guarantees
- Unique emissions control technology with minimum environmental impact
- Optimised total cost of ownership

*"Understanding our customers' needs, offering a value-creating solution and executing are key capabilities at Linde Engineering."*

Jürgen Nowicki  
Managing Director, Member of  
the Board of Directors Linde Engineering Division

\* OASE® is a registered trademark of BASF in several countries.



## Successful reference projects.



Post-combustion capture plant, Niederaussem, GER.



Post-combustion capture plant, Wilsonville, USA.

### Post-combustion capture plant, Niederaussem, Germany

#### Customer

RWE Power AG, one of Germany's leading energy companies.

#### Timeline

In 2009, Linde successfully completed installation of a PCC pilot plant connected to the world's most modern 1,000 MW lignite-fired power plant run by RWE in Niederaussem, Germany. RWE operated the plant from 2009 till 2017 as part of a common project between RWE, BASF and Linde.

#### Deliverables

The PCC plant was engineered and built by Linde based on BASF's OASE® blue technology.

#### Design capacity

1550 Nm<sup>3</sup>/h flue gas equal to 7.2 t/d CO<sub>2</sub> captured.

#### Outcome

Over approximately 55,000 operating hours, the pilot plant achieved above-average availability rates of more than 97%. The plant continues to deliver valuable insights through tests on novel technologies including new solvents.

### Post-combustion capture plant, Wilsonville, USA

#### Customer

National Carbon Capture Center (NCCC). The NCCC is a U.S. Department of Energy (DOE) research facility managed and operated by Southern Company in Wilsonville, Alabama.

#### Timeline

Between January 2015 and July 2016, Linde and BASF successfully operated a custom-built joint PCC pilot plant to improve the capture of carbon dioxide from flue gas in Wilsonville.

#### Deliverables

The project combined BASF's OASE® blue technology with the novel CO<sub>2</sub>-capture process and engineering innovations developed and built by Linde.

#### Design capacity

6500 Nm<sup>3</sup>/h flue gas equal to 30 t/d CO<sub>2</sub> captured.

#### Outcome

The pilot project was a success, demonstrating over more than 3,200 operating hours that this technology package is ready for larger-scale testing and commercialisation. The plant captured more than 90 percent of CO<sub>2</sub> from the flue gas at a purity level of more than 99.9 percent. The plant also demonstrated cost savings relative to other amine-based technologies.

## Commercial readiness of Linde/BASF PCC package.

These reference projects enabled Linde and BASF to complete the various milestones necessary to scale up to commercial readiness. These include:

- Process evaluation for different flue gas sources like flue gases from lignite, hard coal and gas-fired power plants
- Long-term testing of solvent stability (more than 55,000 hours' operational experience in the pilot and demonstration plant)
- Testing of optional reclaiming technology
- Validation of different measures to mitigate emissions
- Testing of new and different types of equipment

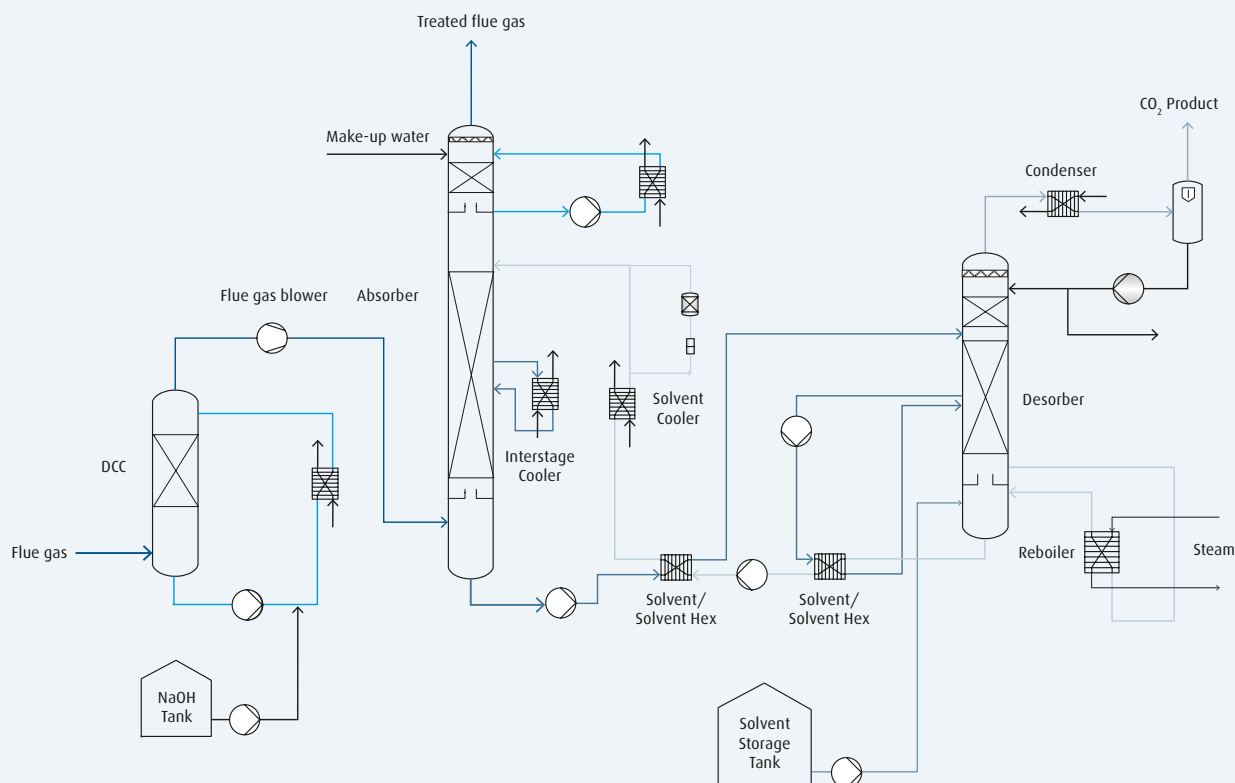
- Material selection for each individual item of equipment, based on intensive materials testing
- Process behaviour assessments during operational changes
- Design tool validation
- Risk assessments
- Scale-up procedures based on large gas scrubbing units previously built
- Development of large-scale concepts (> 1,000 t/d)

PCC plants combining Linde's engineering skills and BASF's OASE® blue solvent technology are now commercially available for a wide range of applications.

Specific  
energy demand for  
regeneration:

2.5 GJ/t CO<sub>2</sub>

## Flow chart of typical carbon capture plant



## Carbon capture plants in detail.

For many years now, the chemical industry has been using CO<sub>2</sub> scrubbing to recover CO<sub>2</sub> generated as by-product of production processes. Linde's Engineering Division is successful worldwide thanks to its core competence in complex, high tech plants. Drawing on its bundled know-how in chemical plant engineering and over fifty years experience in gas wash, this division is actively progressing CO<sub>2</sub> scrubbing.

There are several steps involved in post-combustion carbon capture. These are outlined in the following. Building on its long-standing experience in the design and construction of chemical wash processes, Linde Engineering has the expertise to fine-tune and customise each of these steps to optimise overall system performance – maximising the capture rate and energy efficiency of the process flow.

### Gas pre-treating

Hot flue gas is fed to the PCC plant, where it first enters the pH-controlled Direct Contact Cooler (DCC). In addition to cooling the flue gas, the DCC also removes sulfur dioxide to prevent the downstream amine loop from forming particulates. If necessary, an additional module for removing fine particles/aerosols can be included in the DCC to mitigate amine losses at the top of the absorber column. After the DCC, the flue gas flow is pressurised by the flue gas blower to overcome the pressure drop of the entire absorber column.

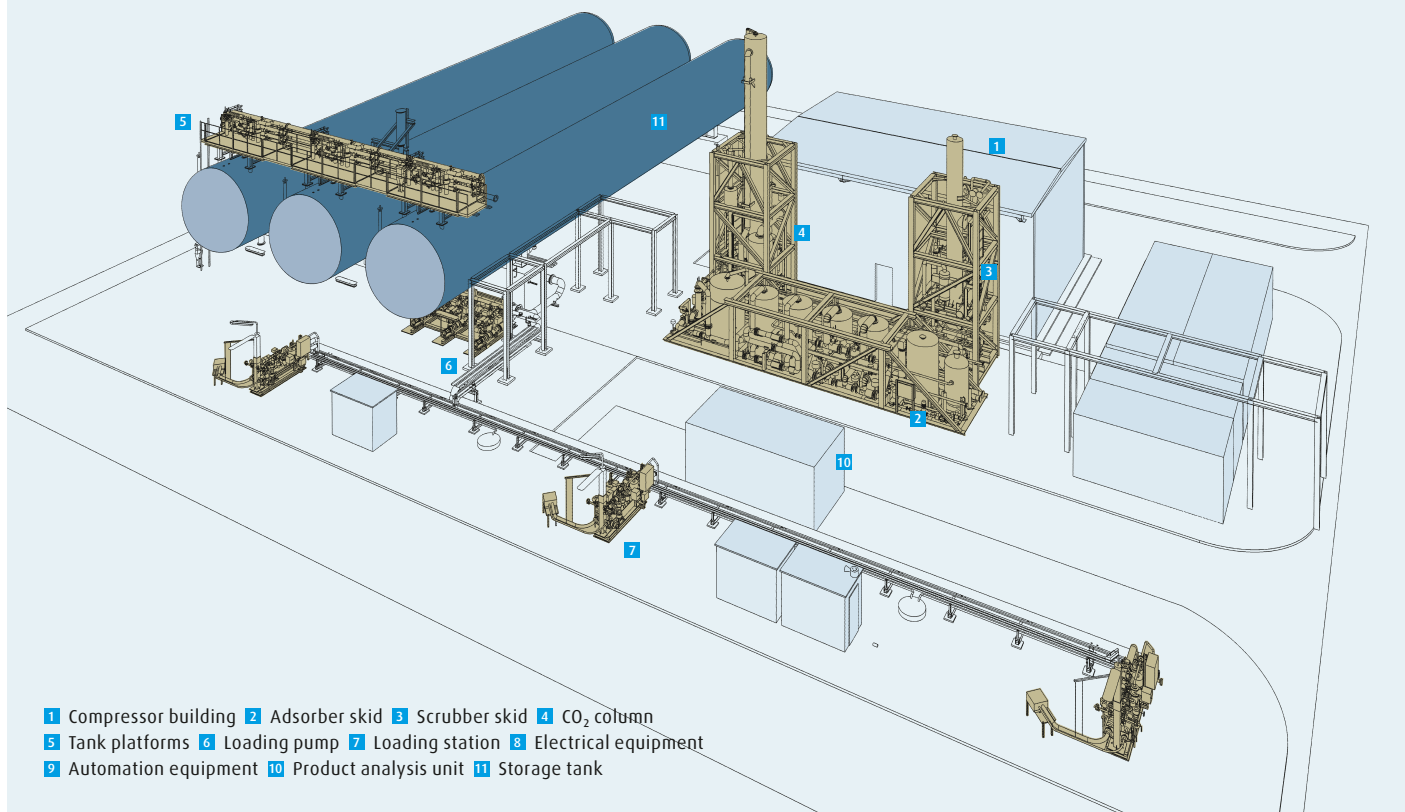
### CO<sub>2</sub> absorption

After leaving the blower, the flue gas is fed to the bottom of the absorber column where CO<sub>2</sub> is removed by the OASE® blue technology in a counter-current flow. High-performance packing is installed in order to ensure efficient mass transfer and to minimise the column diameter and pressure drop. Due to the absorption enthalpy, the temperature in this section increases and this has the effect of lowering the process efficiency overall. A gravity-driven interstage cooler is installed between the absorption beds in order to increase the general performance of the plant. The upper section of the absorber column features the advanced emission control system.

### Regeneration

The hot, rich solution enters the upper section of the desorber column and flows downwards counter-current to the vapour, which is generated in the reboiler. CO<sub>2</sub> is stripped off the amine solution at this stage. After leaving the desorber column, the CO<sub>2</sub> stream saturated with water is cooled in the overhead condenser. Condensate and CO<sub>2</sub>-rich gas are separated in the reflux drum and the condensate is fed back to the desorber column. Steam is used to provide the regeneration heat in the reboiler. The hot steam condensate is sent back to battery limit.

### Typical layout of a CO<sub>2</sub> purification and liquefaction plant



CO<sub>2</sub> purity from  
carbon capture unit:  
**> 99.9 Vol%**

## Downstream technology.

The captured CO<sub>2</sub> can be further purified and liquefied for use in chemical or other industry processes. Alternatively, it can be purified to food-grade level and used in the production of food and beverages.

Linde also specialises in CO<sub>2</sub> purification, liquefaction, storage and distribution technologies. The company offers a range of prefabricated, standardised solutions to accelerate deployment and maximise cost efficiencies. Supporting the full capacity spectrum, the company also designs and delivers customised plants.



Linde engineers at work.

## Our services for you.

At Linde Engineering, we do a lot more than deliver complete, customer-specific, turnkey solutions for carbon capture, storage and utilisation. At every stage of the project – from your very first query – our service-focused engineers are there to support you. You can rely on our team to deliver the project development services you need to evaluate the business case and decide on the investment.

### Our services include:

- Feasibility studies
- Market analyses
- Profitability analyses
- Technical design
- Front-end engineering
- Procurement of licences
- Permit management
- Complex logistics handling
- Financing solutions

In addition, you can rely on us for process gases (e.g. air and synthesis gases) in the supply mode that best suits your needs, whether that be bulk deliveries or pipeline supplies from an independent, over-the-fence facility.

*“Our people, operational excellence and patented technologies empower us to deliver value to our customers.”*

Dr Christian Bruch  
Member of the Executive Board

# Your partner for the production and processing of gases

## Delivering reliable process plants for maximum capital efficiency

Linde has been optimizing gas processing technologies for 140 years, successfully delivering more than 4,000 plant engineering projects around the globe. Favoring trusted, lasting business relationships, the company collaborates closely with customers to enhance plant lifecycle productivity and innovate process flows. The company's proven gas processing expertise plays an indispensable role in the success of customers across multiple industries – from natural gas and oil refining through petrochemicals and fertilizers to electronics and metal processing.

## Operational excellence along the entire plant lifecycle

We work closely with our customers to gain an in-depth understanding of individual needs. Building on the unique synergies of Linde as an integrated plant operator and engineering company, Linde offers innovative process technologies and services to exceed our customers' reliability and profitability expectations. This commitment to innovation extends along the entire plant lifecycle. The LINDE PLANTSERV® service team supports customers every step of the way – from maintenance and repairs to full revamps. Leveraging the latest digital technologies to offer on-site and remote operational and support services, we consistently take asset performance to the next level.

## Making the impossible possible

From the desert to the Arctic, from small- to world-scale, from standardized to customized designs, Linde's engineering specialists develop solutions that operate under all conditions. The company covers every step in the design, project management and construction of gas processing plants and components. Customers can always rely on Linde to deliver the plants, components and services that fit their needs best – anywhere in the world.

Discover how we can contribute to your success at [www.linde-engineering.com](http://www.linde-engineering.com)

Get in touch with our sales team:

Phone +49 351 250-3203, inquiry: [www.linde-engineering.com/contact](http://www.linde-engineering.com/contact)

## Core competencies at a glance

### Plant engineering

- Air separation plants
- LNG and natural gas processing plants
- Petrochemical plants
- Hydrogen and synthesis gas plants
- Adsorption plants
- Cryogenic plants
- Carbon capture and utilization plants
- Furnaces, fired heaters, incinerators

### Component manufacturing

- Coldboxes and modules
- Coil-wound heat exchangers
- Plate-fin heat exchangers
- Cryogenic columns
- Cryogenic storage tanks
- Liquefied helium tanks and containers
- Air-heated vaporizers
- Water bath vaporizers
- Spiral-welded aluminum pipes

### Services

- Revamps and plant modifications
- Plant relocations
- Spare parts
- Operational support, troubleshooting and immediate repairs
- Long-term service contracts
- Expert reviews for plants, operations and spare part inventory
- Operator training

