THE LINDE GROUP

CCS technology for a more sustainable future:

Reducing, separating, storing and recycling CO_2

Despite the many efforts to advance clean sources of energy, fossil fuels such as coal are set to remain our main source of energy for decades to come. Engineers the world over are thus working to reduce harmful CO_2 emissions from coal-fired power plants. One of the key technologies in this context is Carbon Capture and Storage (CCS). The Linde Group is actively helping to develop three processes that capture carbon dioxide emitted by coal-fired power stations. The company is also working with partners to investigate the possibilities of storing CO_2 under the ground and seabed.

Carbon is an essential part of life on earth – no organic life forms could exist without it. It plays a crucial role in the energy cycle of animals and plants. However, climate change is throwing an increasingly critical spotlight on the Carbon Age, forcing us to bring it to a close. At the same time, however, global demand for energy is rising. Which presents us with a dilemma as the electricity generated by burning fossil fuels is one of the main sources of CO_2 responsible for global warming. And time is pressing. Advancing industrialisation among densely populated countries such as China and India is set to send energy consumption sky-rocketing. In its World Energy Outlook 2008 report, the International Energy Agency (IEA) predicts that global demand for primary energy will rise by 45 percent by the year 2030. The report also predicts that fossil fuels will account for around 80 percent of the total primary energy mix at that time. Coal will continue to meet more than one third of total energy requirements in this future scenario.

So it is clear that we will not be switching over to a new energy mix at the touch of a button. In the EU alone, we rely on coal for around 30 percent of our power supplies. By 2030, the German Energy Agency 'dena' predicts a minimum deficit in Germany of 12,000 megawatts in generating capacity. Which would make new power plants running on fossil fuels inevitable. Around twelve new industrial-scale plants would be needed to close this energy gap. Broadening this perspective to a European scale, experts anticipate that a 170,000-megawatt deficit will have to be bridged with new power plants. In short, the power industry will be increasing – and not decreasing – CO_2 emissions over the coming decades.

Linde is convinced that Carbon Capture and Storage (CCS) technologies have huge potential to release the energy payload of fossil fuels in a more environmentally sound manner in future. The Linde Group has teamed up with energy providers to tackle this challenge. For example, Linde engineers are refining existing processes in coal-fired plants to minimise the carbon balance of fossil fuel combustion. Concrete measures range from innovative ways to reduce combustion-induced CO_2 emissions through processes aimed at capturing CO_2 from the flue gas to storage methods for harmful gases. To advance progress in this area, Linde is involved in numerous CCS pilot and demo projects.

Energy providers the world over need CCS technologies to manage emissions as we transition to a low-carbon economy. Widespread commercialisation hinges on sponsored research projects that test and demonstrate CCS capabilities to speed industrial-scale deployment. According to expert analyses, we can assume that successful commercialisation of CCS as of 2020 will reduce annual European CO_2 emissions by 400 million tonnes or so by 2030.

There are three basic ways to reduce CO_2 levels in flue gas emitted by combustion processes fired by fossil fuels such as coal and natural gas:

— **Pre-combustion** or **IGCC** (Integrated Gasification Combined Cycle): This process combines upstream gasification of coal with pre-combustion separation of the CO_2.

— **Oxyfuel combustion:** Here the fuel is combusted with pure oxygen to create mainly steam and CO_2. The CO_2 can then be easily separated from the flue gas.

— **Post-combustion** or **CO_2 scrubbing:** The CO_2 is separated from the flue gas following combustion by binding it to a scrubbing agent. This technology can be easily retrofitted to existing plants.

According IZ Klima (German information platform dedicated to raising awareness and acceptance of CCS technologies), the various CO_2 separation processes result in an efficiency loss in the region of eight to twelve percentage points. However, they enable between 80 and 90 percent of the CO_2 generated by the power plant to be captured, dramatically improving the carbon balance of fossil-fuel power plants.

All three strategies – pre-combustion, oxyfuel combustion and post-combustion – are growing in popularity among power plant engineers in the drive to mitigate CO_2 emissions. And engineers at The Linde Group are also working to actively advance all three methods. The company is collaborating, for example, with power plant operator RWE and chemical company BASF on the development of a process for retrofitting coal-fired power stations with CO_2 scrubbing technology. And since mid-2008, the energy group Vattenfall has been running a CCS pilot plant using oxyfuel technology from Linde at the Schwarze Pumpe industrial park in Brandenburg (Germany).

Looking further afield, the Chinese government also aims to significantly reduce harmful CO_2 emissions from Chinese coal-fired power plants. And Linde is supporting this mission, for example through its new research and development centre in Shanghai. The company's collaboration with Tsinghua University is a case in point. A far-reaching R&D project will be focusing on CO_2 separation and absorption, and will involve Linde setting up a pilot plant at its site in Shanghai to put new CO_2 technologies to the test.

The various methods aimed at CO_2 separation can only really make a significant contribution to climate protection if the technologies and possibilities for CO_2 storage are further researched. Storage still raises various questions and uncertainties. The CO_2 emitted by a plant can rarely be stored directly on site. Which calls for a transport infrastructure. According to experts, transport accounts for around 10 percent of total cost in the CCS process chain.

The research spotlight is currently on sequestration. This involves storing CO_2 below the ground or seabed. The gas can be stored in crude oil or natural gas reservoirs, saline aquifers or coal seams. Linde engineers are working on refining today's sequestration technologies.

CO_2 recycling can also have a positive impact on carbon accounting. Linde has already successfully brought a recycling concept to market. Under the umbrella of the OCAP (Organic CO_2 for Assimilation by Plants) project, Linde supplies CO_2 recycled from a Dutch refinery to over 500 greenhouses. Each year, OCAP delivers over 350,000 tonnes of CO_2 by pipeline.

CO_2 emitted by power stations or chemical processes can also be captured, treated and supplied to industrial applications – many of which rely on CO_2. Numerous car manufacturers, for example, utilise CO_2 that has been purified, liquefied and stored using special technologies from Linde. They need it, for instance, to clean paint and impurities from metal and plastic surfaces. Similarly, the food and beverages industry requires high volumes of CO_2. Without it, there would be no carbonated drinks. Under its BIOGON® brand, Linde supplies over 160,000 tones of liquid CO_2 in food-grade quality every year to German drinks manufacturers alone. The company has developed a sophisticated supply system to serve this target market.