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Carbon Capture and Storage

Building a Bridge to Sustainable Energy

E.ON

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Technological innovations will be essential to feed the world's energy appetite, which is growing and will continue to grow. To satisfy this appetite, we'll need to produce more energy. But we'll also need to dramatically reduce the amount of energy we derive from oil, coal, and natural gas so we can halve carbon-dioxide emissions by 2050. There's broad consensus among climate researchers that halving emissions is the only way to halt the rise in global temperatures.

The way out of this bind is to change. All of us. The utility industry must produce energy more cleanly. And consumers must use energy more wisely. At E.ON, we're committed to being a pacesetter for energy change.

One important way we're changing is by systematically making our energy mix cleaner and at the same time ensuring that we can meet rising demand and keep energy affordable. The energy mix we're now developing will enable us to halve our carbon emissions per kilowatt-hour of electricity by 2030.

It's a massive undertaking. Integral to this undertaking is innovate.on, our group-wide research initiative: making coal a low-carbon option, developing the next generation of nuclear power plant, rapidly expanding renewables, and helping our customers use energy more efficiently.

One aspect of this initiative is our effort to develop carbon capture and storage (CCS) technology. CCS could reduce the carbon emissions of fossil-fuelled power generation to nearly zero. We think CCS has great promise as a bridging technology on the way to a truly sustainable energy system. That's why E.ON is working hard to make CCS commercially viable as quickly as possible, while also investing heavily in other, new generation technologies.

Unfortunately, there's no silver bullet to stop climate change. No single technology is enough. We need to explore all available options so that we can achieve a balance between climate protection, supply security, and affordability. At E.ON, we believe that CCS is an important option and one that's worth pursuing. We invite you to read on and learn how CCS can help us all make the transition to a truly sustainable energy future.

Carbon capture and storage (CCS) could dramatically reduce the carbon emissions of power generation, acting as a bridging technology for the transition from fossil fuels to renewables.

Why CCS?

By far most of the electricity, around 80 percent worldwide, comes from fossil fuels like coal and natural gas. Fossil-fuelled power stations release large quantities of carbon dioxide (CO_2)—one of the greenhouse gases—into the earth's atmosphere. Consequently, power generation is one of the biggest contributors to climate change.

The transition from high-carbon to low-carbon energy is under way around the world. But to effectively slow climate change, the transition must be rapid. This presents enormous challenges to governments and power companies alike.

Developing and deploying new technologies on this scale is a vast undertaking. And throughout the transition, electricity networks must remain reliable and electricity prices affordable—unless we want to risk supply shortages and economic dislocation.

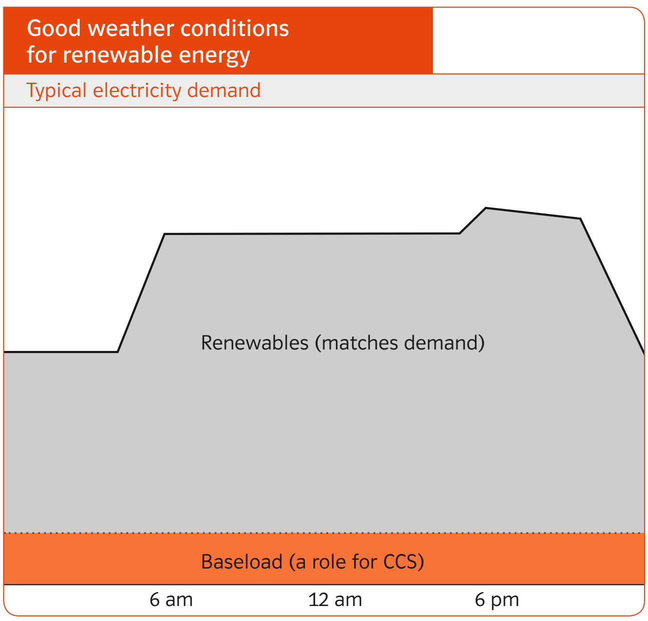
CCS technology could play several roles in the energy industry's transformation to a low-carbon, sustainable future.

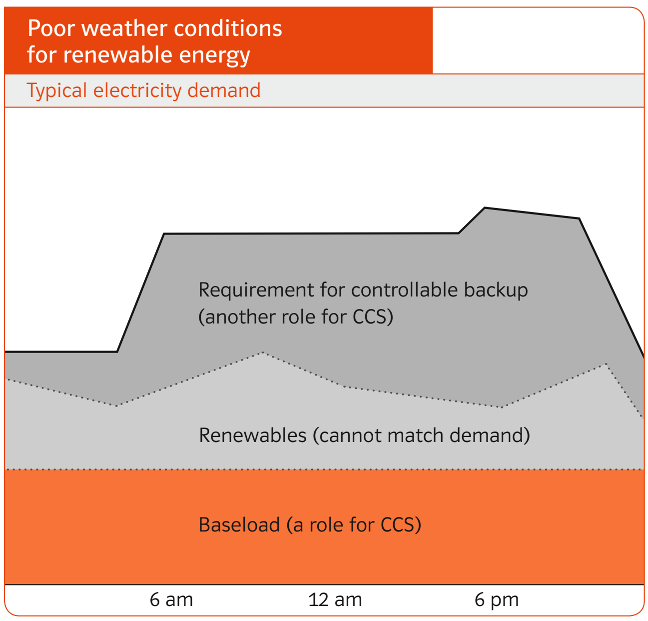
CCS is an important additional option for significantly cutting CO_2 emissions

We believe it's prudent to pursue all CO_2-abatement technologies. That's why E.ON is developing a diverse range of low-CO_2 options that complements energy-efficiency measures with renewable technologies, nuclear power, and CCS. This broad approach will ensure that we have all the tools we need for a sustainable energy business.

Renewables & CCS

Even when most of our energy comes from renewable sources, there may still be a need for fossil-fuel power as baseload and back-up—which will need CCS to stop CO_2 being emitted.





CCS is a useful bridging technology

Increasing the share of low-carbon energy technologies on the scale required to tackle climate change is a huge undertaking that will take decades. Developing CCS—particularly for retrofitting onto existing power stations—would enable the energy industry to cut CO_2 emissions dramatically enough and soon enough to help mitigate climate change, while keeping the lights on as we make the transition to true sustainability.

CCS allows electricity production to match demand

Currently, nuclear power and most renewable technologies can't effectively match their output to consumer demand. Nuclear tends to run only at full output, while the output of many renewable technologies tends to vary with weather conditions. Fossil-fuelled power stations can vary their output on demand. CCS will enable some of these power stations to continue to provide this flexibility without significantly increasing overall CO_2 emissions.

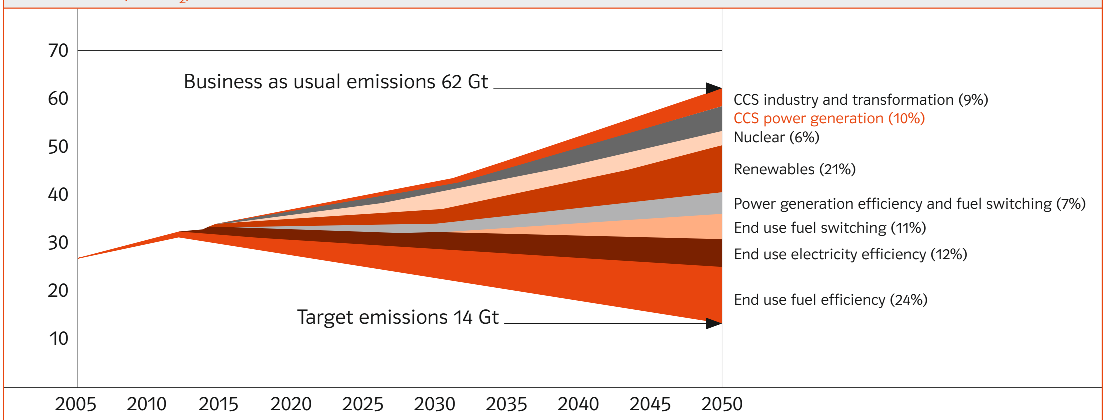
CCS helps maintain supply security

The key to maintaining a reliable and affordable energy supply is diversity. It's like the old adage not to put all your eggs in one basket: a problem with any single fuel source or electricity generation technology is not necessarily a problem for your whole energy supply if you have other fuel sources and other generation technologies to fall back on.

For this reason, many believe it's important to keep coal in our energy mix.

Coal offers real advantages. It's cheap and relatively abundant compared with other fossil fuels and is mined in many countries around the world. It's also easy to store at a power station, for use when needed.

Energy technologies and their expected contributions to tackling climate change



Source: IEA 2008.

The technology to capture CO_2 from a mixture of gases already exists. The chemical industry has been using it for decades. The challenge for the energy industry is to develop CO_2 capture techniques that work efficiently for large-scale power generation where the amount of CO_2 to be captured is significantly greater.

Capture

A number of techniques are currently being developed that could make CO_2 capture commercially viable on a scale big enough for power stations. These techniques can be grouped into three main categories.

Oxyfuel

Today's power stations burn coal in air. Their exhaust stream consists of a mixture of gases (predominantly water vapour, nitrogen, and CO_2). An oxyfuel power station would burn coal in almost pure oxygen. Its exhaust stream would consist of almost pure CO_2 and water. Any remaining impurities are then removed and the CO_2 is ready for transport and storage.

One drawback is that separating oxygen from air is energy-intensive. Another is that burning coal in pure oxygen results in very high temperatures—too high for standard boilers. The solution to this problem is to pipe some of the exhaust gas back into the boiler, which moderates the combustion temperature. But this means you have to modify the boiler to exhaust gas and operate with a mixture of oxygen and exhaust gas instead of air.

Pre-combustion

As the name suggests, the pre-combustion technique involves removing the CO_2 from the fuel before the fuel is burned. In the case of coal, you do this by transforming coal into a mixture of CO_2 (which you capture and store) and hydrogen (which you use as fuel to generate electricity). An advantage of the pre-combustion technique is that hydrogen is a very clean fuel. The only by-product of hydrogen combustion is water.

But pre-combustion capture has similar drawbacks to the oxyfuel process: parts of the process are energy-intensive, and you have to design an entirely new—and quite complex—power plant.

Post-combustion

Power stations already have access to equipment that removes nitrous oxides, sulfur dioxide, and other pollutants from their exhaust gas. The post-combustion capture technique adds another step to the process: the capture of CO_2.

This is accomplished by running the exhaust gas through a special washing solution that absorbs CO_2. The CO_2 is then separated from the solution, which is recirculated into the scrubbing process, creating a continuous cycle.

This is the method already used to separate gases in the chemical industry. In other words, it's a proven technology. And it has another big advantage: it can be retrofitted onto existing power stations or any other industrial process that emits lots of CO_2.

Making it happen

All three capture techniques show great promise. That's why governments and energy companies the world over are investing millions to perfect them as quickly as possible.

But right now, each technique involves a process—producing pure oxygen, separating CO_2 from gas mixtures, or heating the washing solution—that uses too much energy. Refining these processes to significantly reduce their energy consumption is the main aim of CCS development programmes.

It's important to remember, though, that all forms of pollution control make power stations less efficient. So even if CCS becomes commercially viable, power stations that have CCS will always be less efficient than those that don't.

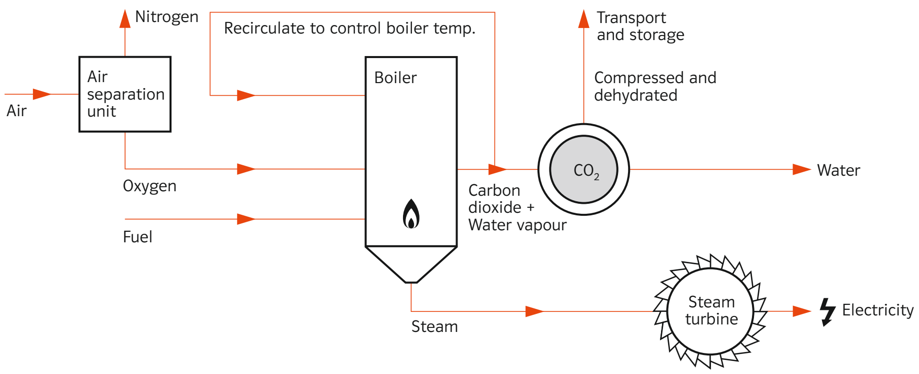
For more detailed information about carbon-capture technologies, visit eon.com/ccs.

E.ON's view

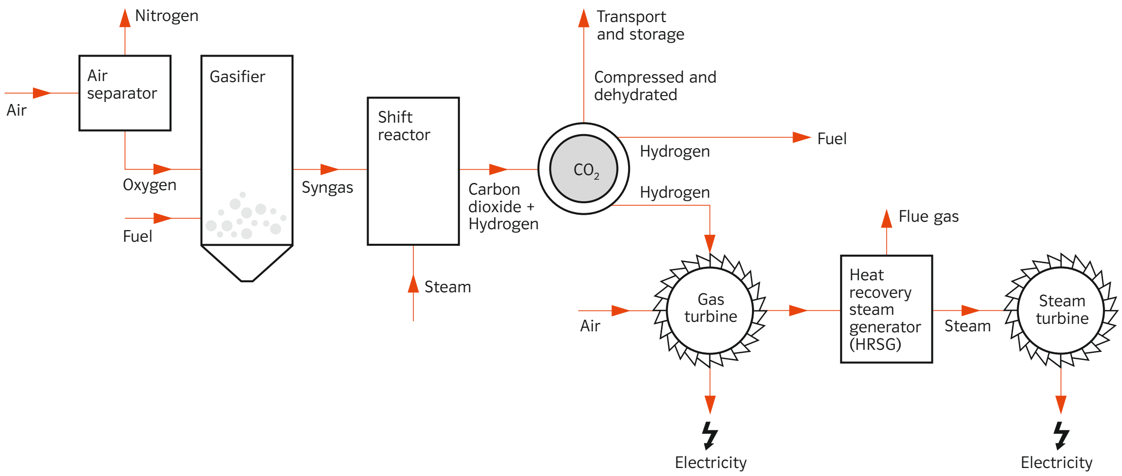
We're developing all three capture techniques. But we think that post-combustion capture has the most promise. It will be more cost-effective and has a decisive advantage: it can be retrofitted onto existing power stations.

Three main capture processes

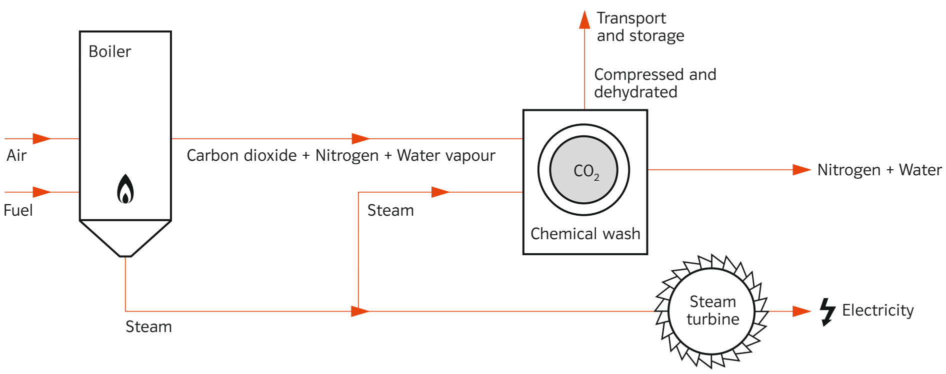
Oxyfuel



Pre-combustion

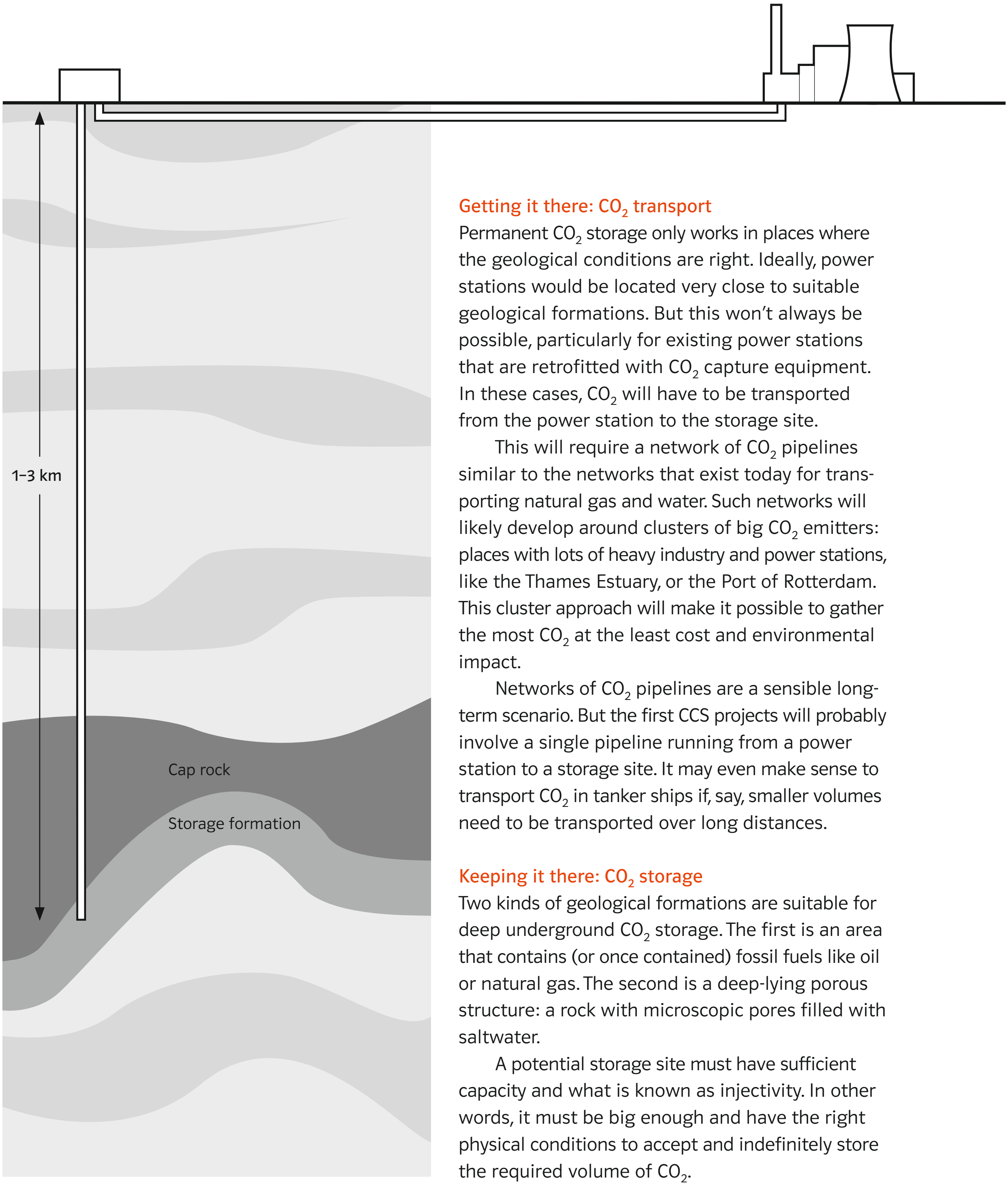


Post-combustion



Once captured from power stations, CO_2 must be moved to a storage facility. Permanent underground CO_2 storage is only possible in particular kinds of geological formations with specific features. So a network of pipelines will be needed to connect power stations to storage facilities.

Transport and Storage



Getting it there: CO_2 transport

Permanent CO_2 storage only works in places where the geological conditions are right. Ideally, power stations would be located very close to suitable geological formations. But this won't always be possible, particularly for existing power stations that are retrofitted with CO_2 capture equipment. In these cases, CO_2 will have to be transported from the power station to the storage site.

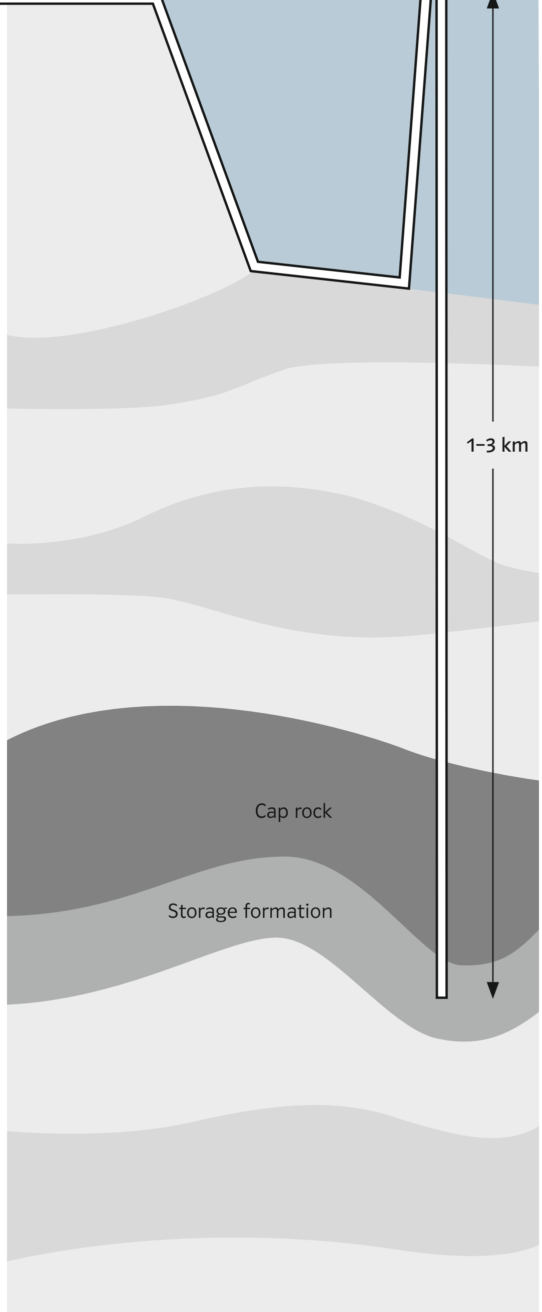
This will require a network of CO_2 pipelines similar to the networks that exist today for transporting natural gas and water. Such networks will likely develop around clusters of big CO_2 emitters: places with lots of heavy industry and power stations, like the Thames Estuary, or the Port of Rotterdam. This cluster approach will make it possible to gather the most CO_2 at the least cost and environmental impact.

Networks of CO_2 pipelines are a sensible long-term scenario. But the first CCS projects will probably involve a single pipeline running from a power station to a storage site. It may even make sense to transport CO_2 in tanker ships if, say, smaller volumes need to be transported over long distances.

Keeping it there: CO_2 storage

Two kinds of geological formations are suitable for deep underground CO_2 storage. The first is an area that contains (or once contained) fossil fuels like oil or natural gas. The second is a deep-lying porous structure: a rock with microscopic pores filled with saltwater.

A potential storage site must have sufficient capacity and what is known as injectivity. In other words, it must be big enough and have the right physical conditions to accept and indefinitely store the required volume of CO_2.

Such sites exist deep underground both on land and offshore. Identifying them is a meticulous task similar to exploring for oil or natural gas. Here, industry's decades-long experience in underground natural-gas storage is particularly useful. This geological expertise can be transferred to the task of finding and developing safe and secure CO_2 storage sites.

It may be possible to combine permanent CO_2 storage with oil and gas production. This process, known as enhanced recovery, involves injecting CO_2 into a nearly depleted oil or gas field in order to flush out the final reserves. It has been used in the oil industry for many years.

Monitoring it along the way: regulation for the new CO_2 infrastructure

Like any other industrial operation, CO_2 transport and storage will be regulated by governments and monitored by independent agencies to ensure safety and environmental compliance. Much of the regime used for natural-gas transport can be transferred to CO_2 transport.

As with transport, storage monitoring can also draw on industry's considerable experience. Monitoring technology already exists that can provide assurance that a storage site remains safe and secure, and many CO_2 storage facilities are already in operation around the world.

Though already good, monitoring technology is getting even better, and significant advances are expected by the time CCS would become commercially viable. Research in the area of monitoring technology is currently under way to improve existing approaches and to find new methods that provide even more information.

At E.ON, our business is power and gas. We have outstanding engineering expertise in all areas of the energy industry. We make and deliver power where it's needed, safely and efficiently.

Engineering

Engineering design: a 3-D computer-generated image of a CCS demonstration plant on a full-scale coal-fired power station.

1 Boiler House

Coal is ground to a fine powder and mixed with warm air before being burned in the boilers. Inside the boiler house, water is fed through miles of pipes and heated to steam at very high temperature and pressure.

2 Turbine Hall

The energy in the steam is transferred to the turbines, which are connected to generators producing electricity. Once as much energy as possible has been taken out of the steam, it is condensed to water and recirculated to the boiler house.

3 Transformer

The electrical power generated by the power station is transformed to a very high voltage (e.g., 400,000 volts) ready for transport along the transmission system.

4 NO_X Reduction

Exhaust gases from the burning of coal in air contain nitrogen oxides (NO_X) which contribute to acid rain. A process known as selective catalytic reduction reduces NO_X by over 70 percent.

5 Electrostatic Precipitators

The exhaust gases also contain dust and particulates. Electrostatic precipitators use an electric charge to attract and remove 99.8 percent of dust particles. The collected dust is recycled for use in the construction industry.

6 Flue Gas Desulfurization (FGD)

Sulfur present in the coal during burning is transformed to acidic sulfur dioxide (SO_2). The desulfurization process removes over 90 percent of this by using the SO_2 present in the exhaust gas to transform limestone into gypsum, which is used in the construction industry.

7 Absorber

The remaining exhaust gas is now ready to have its CO_2 removed. In the absorber column, it meets a counterflowing washing solution which absorbs around 90 percent of the CO_2. What is left (now mostly nitrogen) passes on to the chimney.

8 Stripper

The washing solution is now heated, which drives out the absorbed CO_2, which is then cooled and dried for transport. This process uses heat from the power station, reducing the station's efficiency. The washing solution is recirculated to the absorber and used again.

9 Compressor

The CO_2 is compressed for pipeline transport.

10 Pipeline

The CO_2 is transported via pipeline to a permanent, secure storage site deep underground.

CO_2 is all around us. It makes up a tiny proportion (about 0.04 percent) of the air we inhale and a bigger proportion (about 4 percent) of the air we exhale. CO_2 doesn't burn or explode. It puts bubbles in fizzy drinks, is used in fire extinguishers, and its solid form (dry ice) has many uses. CO_2 can be safely handled and used. It can also be safely and securely transported and stored.

Safety and Security

Pipeline transport is safe: for CO_2, too

People understand pipelines. We know that when we light a burner on a gas stove or switch on the heating, pipelines stretching hundreds—perhaps thousands—of kilometers run from our kitchen or heating to the regions where natural gas is produced. We tend not to worry about gas pipes in the walls of our homes and under the side-walks of our neighbourhood. We're confident that the technologies and practices involved are proven, safe, and properly monitored and regulated.

CO_2 transport will be very similar, except that CO_2 isn't flammable and the pipelines would form a transmission network located far from most people's homes. It may surprise you to learn that thousands of kilometers of CO_2 pipelines are already in operation around the world, many of them in the United States. The safety procedures for CO_2 transport are well known and tested.

Creating the infrastructure necessary for large-scale CO_2 transport from power stations will be a huge engineering undertaking. But CO_2 transport itself doesn't pose an unknown safety challenge.

Nature stores CO_2: we can, too

Underground gas storage seems harder for people to understand. How can a gas be pumped underground and stay there without leaking?

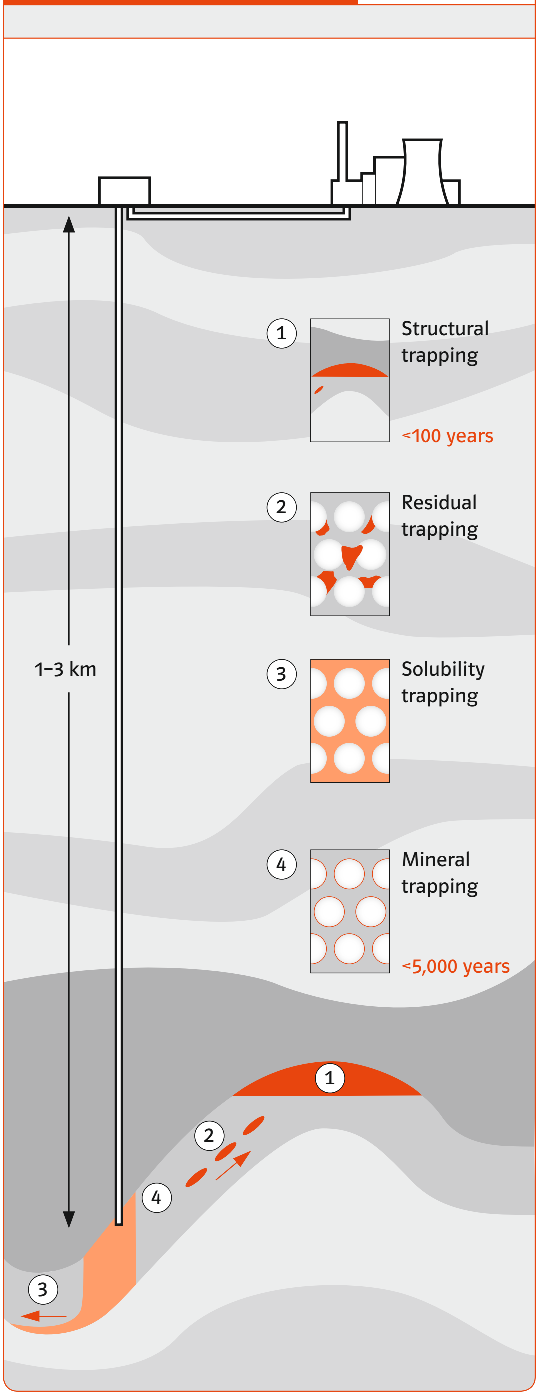
Here, it's helpful to remember that, prior to extraction, natural gas is in permanent storage. It has been trapped underground naturally—without leaking—for millions of years. It would remain there for millions more if people didn't drill for it. CO_2 also occurs naturally in leakproof geological formations.

There are four complementary ways that CO_2 can be trapped in geological formations:

1. In structural or stratigraphic trapping, CO_2 resides in the tiny spaces (known as pore spaces) of the reservoir rock. When this porous rock lies beneath a layer of different rock that's impermeable (known as cap rock), the CO_2 is trapped. This is how natural gas is trapped underground for millions of years. Under the right conditions, this type of storage is effectively permanent.
2. In residual trapping, a microscopic physical process causes some of the CO_2 to adhere to the surface of the pore spaces, effectively preventing it from moving and creating what's known as an immobile phase.
3. In solubility or dissolution trapping, some of the CO_2 dissolves into the saltwater contained in the pore spaces, preventing escape; this makes the CO_2-laden saltwater tend to sink further underground because it's heavier than the saltwater alone.
4. Finally, in mineral trapping, some of the CO_2 reacts chemically with its surroundings to form a new substance that becomes part of the rock.

All these processes only occur under certain conditions, and some, such as mineral trapping, can take a very long time. However, all trapping mechanisms are complementary and act to increasingly immobilize the CO_2 over time.

CO_2 trapping processes



Though CCS technologies aren't new, they're unfamiliar to most people. It's understandable that people have questions. And even that people may be sceptical. Here are our answers to some of the most common questions about CCS.

Questions & Answers

Is it safe to store CO_2 underground?

Yes. In fact, underground CO_2 storage occurs naturally. Companies and research consortia around the world are already using what they've learned from nature to operate safe and secure CO_2 storage sites. Further research is under way to refine these techniques and ensure that they're absolutely safe for indefinite storage.

It's important to remember that it's in no one's interest to pursue unsafe practices. At E.ON, we're working closely with regulators to make sure that there's an efficient and effective system in place wherever we operate to ensure the safety and security of all CCS operations.

"Safety and Security" (pages 12 and 13 of this brochure) provides an overview of the processes involved in storing CO_2.

Isn't CCS just a way for companies like E.ON to keep on doing what they've always done: burn fossil fuels?

No. We know that climate change is real and that we must dramatically lower our CO_2 emissions as quickly as possible by changing the way we produce and supply energy. CCS is one of several ways—along with renewables, nuclear power, and energy efficiency—that we're moving towards a low-carbon future.

If everything goes right, renewables could, one day, meet all our energy needs. But we need to get from here to there. We believe that CCS could play a key transitional role in significantly lowering CO_2 emissions while renewable energy increases its share of energy production.

For information about the role CCS we think could play, check out "Why CCS?" on pages 4 and 5 of this brochure.

Will CCS be ready in time to make a difference?

All aspects of CCS technology are already in use across the world. The task we're working on now is to scale up these technologies and make them more efficient so that they can be used on the much larger scale necessary to capture CO_2 from power plants.

This will take time. But the first demonstrations of CCS technologies in Europe will be ready by 2015, and we expect these technologies to be commercially viable by 2020. It's expected that fossil fuels will still be making up a significant proportion of global electricity generation at that time, so CCS will be able to make a substantial difference.

"Capture" (pages 10 and 11 of this brochure) describes the capture technologies we're currently developing.

Isn't CCS too costly to ever be commercially viable?

From watches and mobile phones to the pollution control equipment already fitted to power stations, all technologies are costly in their initial phase (just look at how mobile phone technology has advanced and the costs of owning one reduced over the last few years). This is also true of CCS. Today's CCS technologies are expensive to build and run. But that's because they've not yet been developed to an industrial scale, the process that's under way now.

Will CCS be a cheaper option to reduce CO_2 emissions than other options like renewables or nuclear power?

That's difficult to foresee. We believe that the best way to ensure that the most effective and efficient solutions are deployed is to ensure that all options are developed and available.

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