

Carbon Capture and Storage

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Rising oil and gas prices, insecure energy supplies, and increased energy consumption in transition economies have boosted the use of coal—the most abundant fossil fuel and one that many countries have considerable reserves of. The United States, China, and some other countries are highly dependent on coal. In the United States, coal-powered plants generate more than half the electricity, and some observers expect that expanding the use of coal will help reduce U.S. reliance on foreign oil.

But coal is the most carbon-intensive fossil fuel. Thus a new technology called carbon capture and storage (CCS) has recently gained considerable attention. CCS aims to capture carbon dioxide (CO₂) from any large point source, liquefy it, and store it underground. Because of its high costs and complex infrastructure, CCS is by necessity suited primarily for centralized, large-scale power stations or big industrial facilities like cement plants and steelworks.

With today's technologies, there are three ways to capture CO₂. Post-combustion capture, which involves capturing CO₂ from flue gases in conventional power stations, is bas-

ically available today, but it has not yet been demonstrated at a commercial power station scale. In the longer term, this technology is unlikely to become widely established unless its energy consumption can be reduced significantly.

A more efficient method is pre-combustion capture of CO₂ in coal-fired power stations with integrated gasification combined cycle technology. These plants use heat to gasify coal that is then burned to generate electricity. During the gasification step, CO₂ can be removed relatively easily. Apart from its higher efficiency levels, the prime advantage of this method lies in its flexibility in terms of both fuel (coal, biomass, and substitute fuels) and product (electricity, hydrogen, synthetic gas, and liquid fuel). Pre-combustion capture of CO₂ has not yet been demonstrated on a large scale.

The so-called oxyfuel process currently offers the best prospects for CO₂ capture in terms of achievable overall process efficiency as well as costs because it is largely based on conventional power station components and technology. Combustion takes place in 95 percent pure oxygen rather than air, enabling efficient CO₂ capture due to the concentrated flue gas. This process is still near the beginning of its demonstration phase. It is expected to capture 99.5 percent of the emissions directly at the stack, while the post-combustion and pre-combustion methods would reduce CO₂ by 88–90 percent on average.¹

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Once CO₂ has been captured from industrial sources and pressurized into a quasi-liquid form, it can be pumped into geological formations such as deep saline aquifers more than 2,000 feet underground, depleted oil and gas fields, and deep and non-exploitable coal seams. It can also be deposited deep in the ocean. Furthermore, the productivity of oil and gas fields in their final stages of exploitation can be increased by injecting CO₂ into them, something the oil and gas industry has been doing for years. A mineralization process for binding CO₂ to silicates is also under discussion as a way to sequester and store the gas, along with a method for fixing CO₂ using algae to produce biomass that can be turned into animal fodder, biodiesel, or construction materials.²

Along with the overriding motivation of climate protection, questions of security of energy supply, technological aspects, and in some cases immediate economic considerations have increased interest in carbon capture and storage. Technology that can facilitate progress in international climate protection negotiations is of particular importance. Some of the strongest supporters of CCS are governments that have so far rejected the international climate protection process or adopted a wait-and-see stance, such as the United States.³

Yet several constraints make it questionable that a global rollout of CCS will consist of more than demonstration plants and some initial commercial plants. The first concern is the time frame. CO₂ capture technologies are more likely to become available in the medium than the short term. Most experts anticipate large-scale applications between 2020 and 2030. But the rush to build new coal-fired power plants will likely take place within the next 10 years—too soon to take advantage of CCS technologies.

And decisions on new power plants made today will influence the energy mix 40–50 years from now, when greenhouse gas emissions need to be substantially lower than today. For plants built before CCS is mature, only retrofitting of CCS technology, usually with the low-efficiency post-combustion method, would be an option. And retrofitting power stations would cost more and be less efficient than newly built plants fitted with CCS from day one.⁴

The number and location of safe reservoirs is a second concern. To be able to store billions of tons of CO₂ “safely and cheaply, on a global scale, both in the West and in the developing world,” one observer notes, advanced methods other than “simple” enhanced oil and gas recovery will be required. For various reasons, storage possibilities for CO₂ are restricted at both national and global levels. Gas fields are believed to have the largest potential, followed by coal seams, oil fields, and aquifers. From a purely technical perspective, there appears to be enough capacity to store global CO₂ emissions for many decades. Yet there is a great degree of uncertainty about the fundamental suitability of the various storage options. Ultimately a case-by-case analysis will be required to obtain practical and relevant results for each storage site considered. Another important question is that of liability. Undoubtedly, similar questions will arise as in discussions of nuclear energy waste disposal.⁵

High energy penalties and environmental impacts are a third constraint. Capturing CO₂ requires additional fuel consumption of 20–44 percent to generate the same amount of useful energy, which in turn leads to more CO₂ and other harmful emissions. But only the CO₂ emitted directly at the stack can be captured, in contrast to the CO₂ and other emissions of upstream and downstream



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Coal trains near Gillette, Wyoming

processes. For instance, methane emissions during coal mining or natural gas pipeline transport cannot be reduced by CCS. Yet according to the Kyoto Protocol, greenhouse gas (GHG) emissions as a whole—not just CO₂ emissions—must be reduced. Recent life-cycle assessments show that assuming a CO₂ capture rate of 88 percent, GHG emissions along the whole value chain can be reduced by only 67–78 percent, depending on the fuels or power station technologies used. Furthermore, other environmental impacts like photooxidant formation, eutrophication, or particle emissions will increase with CCS, while acidification will decrease slightly.⁶

One of the most pressing environmental

issues could be water use: it is expected that CCS will require 90 percent more fresh water. The increase of hazardous waste production due to the chemical reaction of the scrubbing agents is also important. Last but not least, CCS would only worsen many major local environmental problems tied to the extraction and transport of coal, such as habitat destruction, damage to waterways, and air pollution.⁷

The fact that alternatives to CCS have already entered the market could reduce interest in this technology. The GHG emissions associated with electricity generated from solar thermal power or wind power are just 2–3 percent of the amounts for fossil-fueled CCS plants. And the GHG emissions of electricity generated by advanced natural-gas-fired combined heat and power stations are roughly the same as those for power stations using CCS. Thus there are even fossil fuel technologies commercially available that are already as “green” as CCS power stations aim to be in 2020. Expanding use of these alternatives will of course require significant structural changes in the overall energy system.⁸

Cost is another constraint. CO₂ capture requires high investment costs in addition to the costs resulting from the energy penalty. Different sources put CO₂ capture costs at between 35 and 50 euros per ton of CO₂ in 2020, translating to a 50-percent increase in electricity generation costs (assuming no increase in fossil fuel prices). This assumes that significant learning processes will have occurred by then. Yet just when the first CCS power stations might be coming on stream, some individual renewable technologies (such as offshore wind and solar thermal power plants) could already be offering cheaper electricity. In the longer term, renewables can be expected to have considerable cost advantages due to their indepen-

dence from fuel price fluctuations.⁹

A final constraint is infrastructure requirements. Suitable storage sites will not usually be located in the immediate neighborhood of the power stations, which means that large investments in a completely new pipeline infrastructure will be necessary. In the United States, deploying a national CCS system at the scale needed would require “no less fundamental a transformation of the country’s energy infrastructure than would a huge-scale adoption of wind energy,” noted the World Resources Institute. If the storage locations are 500 kilometers or more away from the big emitters, CO₂ transport will likely not pay off. A possible solution to this problem would be to place new power stations directly at potential storage sites and to transport the electricity instead of the carbon dioxide.¹⁰

It is possible that technological developments might be able to offset some of the significant constraints on CCS. In the future, for example, the combination of CCS with biomass-fired power plants could be an interesting option due to the negative carbon balance of such a system. CO₂ is first captured from the atmosphere during biomass growth and then could again be captured from the power plant’s flue gases and sequestered afterwards. If storage works, this process could help achieve drastic CO₂ emission reductions. On the other hand, processes using biomass could meet only a part of the energy demand due to limited acreage.¹¹

In general, several national and global energy scenarios show that even ambitious greenhouse gas emission targets can be met by a three-step strategy without assuming any appreciable use of CCS within the next few decades: increased energy efficiency,

more-efficient use of primary energy by using combined heat and power plants, and ambitious development of renewable energy.¹²

Even if CCS is supposed to just be a bridging technology, significant research and development efforts are needed. Furthermore, if this technology can be demonstrated successfully, additional financing instruments will be needed to help spread the use of CCS. Including CCS-CO₂ in the carbon market, as planned by the European Union, would mean that deployment of CCS will strongly depend on the price development of CO₂ certificates. If CCS is included as an avoidance measure in the Kyoto Protocol, these projects could also be handled via flexible instruments such as the Clean Development Mechanism and Joint Implementation. Another incentive under discussion is government subsidies to make the technology competitive. Yet all these instruments raise fears that financing CCS could take funds away from renewable energy or energy efficiency measures, which would be counterproductive as these are the most robust climate protection strategies.¹³

In the end, a lot of open questions about CCS remain to be solved—technical as well as legal and socioeconomic ones. Today it cannot be foreseen if, how much, where, and when CCS will play a significant role as a strategic climate protection option. If it proves to be both commercially available and competitive, the question of suitable and safe storage places may become the tipping point for extensive use. What is clear is that there will not be a large-scale deployment of CCS in the next 10–15 years. If this time is used for ambitious development and diffusion of renewable sources, the argument for CCS as a “bridge” to renewable energy will lose its force.

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