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Can carbon capture and storage deliver on its promise?

By **Prachi Patel**
Feature Editor **Partow Pakdel Henriksen**

The W.A. Parish generating station 27 miles southwest of Houston is Texas' largest coal-fired power plant. It also has the reputation of being one of the dirtiest in the United States. But in January 2017, it took a big step toward becoming one of the cleanest. The plant's new Petra Nova facility began piping carbon dioxide from the plant's exhaust to an oil field, where the gas is being used to force out more oil, and in the process being permanently stored underground.

Petra Nova is designed to trap 90% of the carbon emissions from a 240 MW generating-capacity coal unit, sequestering 1.4 million tons of the gas annually. It is the largest carbon-capture retrofit at a coal plant. And while using CO_2 for oil recovery isn't the best solution to climate change, proponents are calling the facility a beacon for large-scale carbon capture and storage (CCS) since it came in on time and within budget.

CCS, despite its association with coal, covers technologies to capture CO_2 from a range of power and industrial processes, such as steelmaking and oil refining, and to transport it for storage in underground geological formations. High cost has been the technology's Achilles heel. Simply put, it costs more for utilities and industry to trap and store emissions than to dump them into the atmosphere. But cost calculations typically don't consider the true cost of fossil fuels, which benefit from hidden subsidies and burden society with long-term health costs due to pollution and carbon emissions.

Expense, newness, and perceived risk of CSS have bred uncertainty, resulting in diminished interest from the private sector and major setbacks. The global financial crisis compounded the issue, prompting the cancellation of large projects, such as FutureGen in the United States and Vattenfall in Germany. The latest to be shelved was the UK's USD$1.25 billion CCS Commercialization Programme in 2015.

But the International Energy Agency (IEA) calls CCS a "sleeping giant" that needs to be awakened. As global fossil fuel use continues to grow, carbon capture could be critical for keeping average global temperatures from rising above the 2°C target set by the Paris accord. Switching completely to renewables will simply take too long. "To decarbonize our system, we'll need a mix of renewables, nuclear, and fossil fuels with CCS," said Howard Herzog, senior research engineer at the MIT Energy Initiative. "Diverse systems are the most robust and cost-effective. Having CCS in the arsenal will be very important."

Petra Nova is one of several projects that prove CCS works. Scientists are developing new materials and methods for capturing CO_2 to cut cost. Large-scale deployment will help gain more experience and boost confidence; cost also goes down with every new plant built. "The policy side is what really needs attention," said Ron Munson of the Global Carbon Capture and Storage Institute (GCCSI). "Government incentives or tax breaks would put carbon capture at the same level as other low-carbon technologies such as renewables."

The world puts 40 billion tons of CO_2 into the atmosphere worldwide every year. The IEA projects that CCS could trap 20 percent of carbon emissions by 2050. To achieve that, 100 projects will have to be built by 2020. But only 21 large-scale CCS projects are in operation or under construction so far, according to the GCCSI. Another 18 are at various stages of planning.

Four facilities with a capture capacity over 1 million tons should begin operation this year. The Kemper County Energy Facility in Mississippi will use trapped CO_2 for oil recovery, and the CCS project at a bioethanol refinery in Illinois will store captured CO_2 in a saline aquifer. The Gorgon project in Australia, meanwhile, could become the world's largest CCS project with a capacity to put away 4 million tons of the gas every year.

Ongoing projects show that underground storage is reliable. Norway's Sleipner project has been injecting CO_2 into sandstone below the seabed for more than 20 years; it has put away more than 16 million metric tons. In Canada, a CCS retrofit at Saskpower's Boundary Dam coal plant and Shell's Quest project to store CO_2 from its Alberta tar sands operations, both relatively new, are performing as expected.

Leakage has happened once, at a test site in Algeria where natural fractures in low-permeability rocks allowed CO_2 to move up a well bore. Concerns about such induced seismic events and accidental releases of CO_2 have diminished support for CCS in Europe.

But storage is, in general, proving reliable, said Sally Benson, professor of energy engineering at Stanford University. Computer models predict accurately where CO_2 is going, and monitoring technologies keep track of that movement. "We now understand the science of CO_2 storage extremely well both with regard to migration and behavior in reservoirs, and to factors that would contribute to efficacy of the seal," said Benson.

Over the past two decades, scientists have been applying concepts from soil science, hydrology, and oil and gas exploration

Partow Pakdel Henriksen, SINTEF, Norway
Prachi Patel, prachi@lekh.org

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to advance storage. Studies show that potential storage around the world is enormous. The GCCSI estimates that the geological storage capacity in the United States is more than 2376 gigatons, 1500 gigatons in China, and 78 gigatons in the United Kingdom. Meeting the 2°C scenario by 2050 requires storage of 94 gigatons.

The biggest hurdle for widespread CCS deployment is cost. Here, steady progress in research and development has helped, especially in capture, which accounts for 70% of the cost of a project. The conventional method is to bubble flue gas through amine-based sorbents, which react only with the CO_2. The mixture is then heated to 120°C to release CO_2 for compression and storage, and to free the solvent for reuse.

Reducing the energy used to separate amines and carbon is key, said Thor Mejdell, a senior research scientist at the research organization SINTEF in Trondheim, Norway. Mejdell and his colleagues are developing amine solutions that can release CO_2 at lower temperatures, and that are more stable under heat and oxygen so that they can be reused more often. They are also testing better-insulated reaction vessels, playing with different vessel dimensions and temperatures, and trying to integrate equipment. In the past decade, researchers have brought the energy use down from 4 gigajoules per kiloton to nearly 2.5 gigajoules, said Mejdell.

A 16-foot-diameter duct takes flue gas from a coal plant at the W.A. Parish generating station near Houston, Texas, to the Petra Nova carbon capture facility. There, carbon dioxide is removed by an amine solution in the tall absorption tower; separated from the amine as 99.9% pure carbon dioxide in the smaller regenerator tower to the right; and then compressed and delivered to an oil field. Photo: *Business Wire.*

Others are working on new sorbent materials, from metal–organic frameworks to functionalized carbon. An offshore sequestration project in Brazil uses polymer membranes to separate CO_2 from sorbents at relatively low temperatures of 50–60°C.

More radical concepts for lowering energy use and cost are also in the works. A technology called chemical-looping combustion is closest to commercial deployment, with several small pilot plants successfully demonstrated across the world. In traditional power plants, pulverized coal is burned in air to produce steam for spinning turbines. Chemical looping involves combusting the fuel—coal, biomass, or natural gas—by having it react with a metal oxide. The reduced metal is exposed to air in a reactor to oxidize it for another coal-burning cycle. The exhaust from the reducer is nearly pure CO_2, so "you don't use any energy to capture it," said Yngve Larring of SINTEF.

Two large-scale plants—a 1 MW coal-fueled unit at Germany's Darmstadt University and a 3 MW plant in Connecticut—became operational in 2011. Larring said that SINTEF is planning a 10–15 MW demonstration in Norway or Sweden if they get government funding.

Meanwhile, Durham, N.C.-based NET Power is building a first-of-its-kind CCS plant in La Porte, Texas. The USD $140 million plant will test the company's Allam Cycle Technology, which involves burning natural gas with pure oxygen instead of air, and using high-pressure CO_2 to drive turbines. The output is pipeline-ready pressurized CO_2. By integrating CO_2 into power generation rather than trapping it at the tail end, the process makes CCS more efficient and less expensive.

NET Power said the cost should be comparable to a state-of-the-art natural gas plant. With validation from the 50 MW pilot plant, slated to go online in 2017, the company plans to build the first 295 MW commercial-scale plant. NET Power could be a game changer for CCS in the United States, where cheaper natural gas is taking over coal for power.

In China and India, on the other hand, retrofitting coal plants with CCS will be critical. China has approximately 900 GW of installed coal-fired power capacity—nearly half of the world's capacity—of which more than 310 GW of is suitable for retrofits, per the IEA. The country has stated strong interest in the technology through bilateral CCS agreements with the United States and other countries, and the release of a China CCS Roadmap in 2015.

A chemical plant in southern India was recently able to capture CO_2 from their boiler at a cost of USD$30 per ton and turn it into baking soda. The plant uses a new amine that is more efficient, requires less energy, and needs smaller equipment. Crucially, the plant's engineers said it is running without subsidies, which is a first for an industrial plant capturing carbon.

Major cost reductions can only happen with large-scale project deployments. As with any new technology, the first big projects cost more. Saskpower believes that lessons learned at Boundary Dam could help them cut capital costs by 20–30% on the next unit.

Government incentives and financial support will be key for big CCS projects. Carbon taxes have driven CCS projects in Norway. In Canada, the driver has been regulations on coal plant emissions as well as financial help. Government grants have played a big role in all the projects coming online now.

Experts calculate that it costs USD$60–80 to trap a ton of CO_2 emissions for an Nth-of-a-kind plant, said Benson. These numbers sound high, but are comparable to the true cost of renewables without subsidies, even though the technology is newer. "Wind and solar are assisted by enormous subsidies in Europe, China, and the US, yet they're still not cost-competitive with fossil fuels," said Benson. "CCS got going in earnest in about 1996, so it's 20 years behind solar and wind."

Education and a change in public perception would also help. "CCS is at a crossroads," said Herzog. "It's an orphan technology in some ways. Those who like fossil fuels but don't believe in climate change don't embrace it. Those who don't like fossil fuels don't embrace it. Ideology might be getting in the way of a very good technical solution." □

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