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BURIED TROUBLE

Protesters saying "no to CO_2" are just one roadblock facing carbon sequestration — a strategy that could help prevent dangerous climate change. **Richard Van Noorden** investigates.

The idea of injecting 400,000 tonnes of carbon dioxide under a shopping mall was always going to be a tough sell. And so it proved when the Dutch minister of economic affairs, Maria van der Hoeven, came to the small town of Barendrecht in December to explain why the government supported the proposal, made by the petroleum company Shell. At a public meeting in a packed theatre, attendees hurled jeers and threats at van der Hoeven and her colleagues, who were trying to convince the residents that the injection project was safe and environmentally beneficial.

The conflict has escalated since then. Last month, the Dutch parliament voted to continue with the project, prompting Barendrecht's deputy mayor, Simon Zuurbier, to threaten legal action against Shell. "It is foolish to experiment in a residential area," he says. John Brosens, who chairs the citizens' 'No to CO_2' society, says: "We are against any underground storage of CO_2 — wherever."

Public opposition is just one of several obstacles blocking the strategy known as carbon capture and storage (CCS). The idea behind CCS is to strip CO_2 from the exhaust gases of factories and power plants, then inject it as a compressed liquid into secure geological formations, such as depleted oil and gas deposits.

Politicians and scientists have for years touted CCS as a way to help the world cut its carbon emissions. And the idea of injecting CO_2 underground is not a pipe dream: the petroleum industry has been doing it for nearly 40 years to aid the extraction of crude oil. But efforts to expand CCS to save the climate have largely stalled. Public opposition is disrupting some early pilot schemes, the process is too expensive in most cases, regulations covering its use are not yet fully in place and investors are uncertain about its viability at large scales.

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"There is lots of research and lots of talking — lots of recycling of information — but little real progress," says Heleen de Coninck, who works on climate policy at the Energy research Centre of the Netherlands in Petten.

That slow pace is especially harmful for CCS because the strategy has a limited lifetime. It is viewed as a bridge technology — one that would allow coal-rich nations such as the United States and China to burn fossil fuels guilt-free for a generation or two, until cleaner forms of energy become economically competitive.

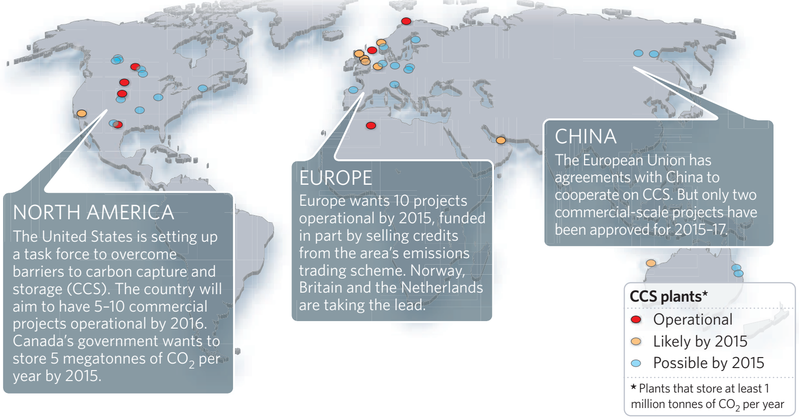
But to serve this temporary function, CCS must expand soon. The International Energy Agency (IEA) projects that the cheapest way to halve expected carbon emissions by 2050 would be to use CCS to contribute almost 20% of the necessary cuts. On that schedule, the technology must quickly grow to the scale of an oil industry: by mid-century, the volume of liquid CO_2 that must be injected underground for permanent storage each year would be three times the current amount of petroleum used every year.

In 2008, the G8 declared that 20 large-scale plants should be launched by the end of 2010. But development is way off track (see map): there are only seven large projects and most of these use the gas to loosen trapped oil — a process not designed to store CO_2.

The price isn't right

The main sticking point with CCS is its expense, which comes mostly from capturing the gas. Existing factories and power plants must install a bulky capture unit, which uses an amine-based solvent to strip CO_2 from exhaust

EXISTING AND PLANNED CARBON SEQUESTRATION PLANTS



SOURCE: SCOTTISH CENTRE FOR CARBON STORAGE/Y. BUSHBY

gases. New power plants can use a more compact strategy in which coal or other fossil fuels are transformed into CO_2 and hydrogen, and the hydrogen is then burned. A third, relatively new concept involves burning fuel in pure oxygen, creating a waste stream of water and CO_2. The chemical transformations required in all these technologies suck up energy. That means that power plants need to burn more fuel to produce the same amount of electricity, roughly doubling the cost of that energy.

From an environmental point of view, however, the technology is relatively cheap. Studies suggest that, once the technology matures, commercial carbon-capture coal plants would spend US$50–80 for every tonne of CO_2 they avoid emitting. According to estimates by Bloomberg New Energy Finance in London, the costs of electricity produced by mature CCS plants would overlap with those for other low-carbon electricity options, such as solar, wind and nuclear power (see graph).

"Of course CCS will raise energy prices, but if you look at reaching certain targets, such as keeping below 2 °C of warming, then it is a cost-effective system," says Howard Herzog, who works on carbon sequestration at the Massachusetts Institute of Technology in Cambridge.

In theory, these technologies would be more competitive if some sort of cost were associated with emitting CO_2, but few countries have taken that step. The main exception is the European Union (EU), which has a carbon emissions trading scheme that effectively sets a price on CO_2 pollution from large emitters. But at a current rate of around €13 (US$18) per tonne of CO_2, the EU price is well below the level that would provide an incentive for coal plants to capture their emissions.

Government's greenish light

Without any economic force driving companies to start capturing and storing CO_2, the CCS industry is waiting for government incentives to kick-start demonstration projects, says Tom Kerr, an IEA analyst. The agency calculates that to keep to its ambitious schedule, governments in developed nations will need to invest US$3.5 billion to $4 billion in demonstration projects each year from 2010 to 2020. Europe, Canada, the United States, Australia and China have so far publicly allocated just $7.3 billion, although they have promised a total of around $20 billion.

Private investors also complain that delays in establishing government regulations for CCS are preventing companies from making meaningful commitments. In the United States, for example, federal rules are unclear on who, if anyone, owns the pore space in the rock that will be used to store CO_2. And in Europe, national governments are only slowly incorporating existing EU laws to govern carbon storage. The absence of such laws in Germany has stymied plans by Vattenfall, a Swedish energy company, to store carbon emissions from its Schwarze Pumpe plant in Germany.

Similarly, regulators are only beginning to consider what monitoring requirements should be placed on sequestration projects to ensure that the carbon stays underground. A second major unresolved issue involves long-term liability over leakage, and how long developers will remain legally responsible for any damages after the injection is stopped. "If people want to make CCS work, we can have regulations that promote a sensible system and allow it to operate," says Herzog. "But if people want to kill it, easy — we can say we need more and more regulations, and just strangle it."

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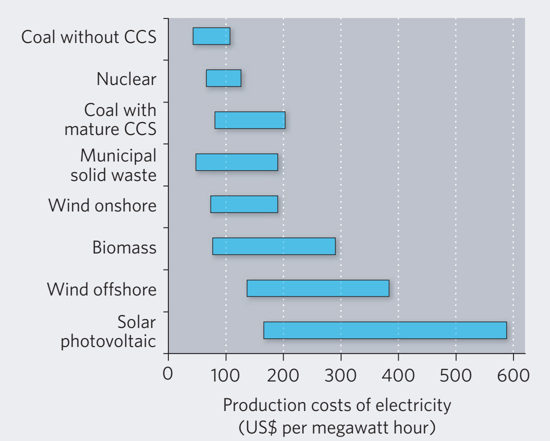
Inner space

While the regulatory uncertainty drags on, geoscientists are gaining valuable experience at several large-scale projects. At the In Salah natural-gas plant in Algeria and the Sleipner West gas field in the North Sea, for example, unwanted CO_2 present in the methane deposits is being removed and injected into aquifers covered by impermeable rock layers. "For us, carbon storage is a ho-hum activity, but to the outside world a lot of what we do is rocket science," says Iain Wright, who manages the CO_2 storage project at In Salah for BP, one of the companies that runs the plant.

But geoscientists have scant experience with CO_2 storage elsewhere. When CCS moves into settings that are less well studied, "the uncertainty levels rise", says Travis McLing, a geologist involved with the US Department of Energy's Big Sky Carbon Sequestration Partnership in Bozeman, Montana.

Experts remain unclear as to how much capacity there will be to sequester carbon when the process is scaled up to global proportions. Preliminary estimates of capacity in the United States, China and Europe suggest that the world has ample space to store CO_2, but only a tiny proportion of

COSTING THE OPTIONS



BLOOMBERG NEW ENERGY FINANCE

that is likely to be usable, says Bert van der Meer, a reservoir engineer for the non-profit research organization TNO in Delft, the Netherlands.

Engineers might find that less CO_2 can be forced into deposits than hoped because water already occupies the available rock pores. Or large projects might get bogged down if CO_2 does not spread quickly through underground deposits or if the rate at which it can be injected is slower than desired. "The ultimate test will be to try to do injections and see what push-back you get from nature," says geoscientist Stuart Haszeldine from the University of Edinburgh, UK — although he doesn't see the issue as a deal-breaker for CCS.

Jens Birkholzer, an Earth scientist at Lawrence Berkeley National Laboratory in California, calculates that an industrial-scale CO_2 sequestration plant would increase pressure within rock pores for some 100 kilometres around the injection site. He modelled the effects of 20 CO_2 storage sites across the Mount Simon sandstone formation underneath Illinois and neighbouring states; the pressure build-up eventually affected the entire 241,000-square kilometre basin. This could push brackish water into freshwater stores via existing faults, Birkholzer says. He adds, however, that previous practices, such as pumping out groundwater in Northern Illinois, drew saline waters towards withdrawal wells and dwarfed the environmental consequences of his CO_2 storage scenario.

In practice, such problems may never materialize. Unlike many investors, most geologists think that the unanswered questions simply reinforce the need to build large demonstration projects to study what happens.

Ø. HAGEN/STATOIL

At the In Salah natural-gas plant in Algeria, unwanted CO_2 is pumped underground.

Mixed reception

That try-it-and-see approach has not won over the NUMBY (not under my back yard) crowd. Aside from Barendrecht, protests have arisen at several sites for which CCS is planned or being discussed, and not just in Europe. In August last year, despite funding from the US Department of Energy, a consortium scrapped a \$92.8-million project to bury CO_2 from an ethanol plant in Greenville, Ohio. Battelle, the non-profit research organization that ran the project, said that it pulled out for "business considerations" — but local media called it a victory for protesters.

"People ask: 'why should I be the guinea pig? What's in it for me? Will this affect the value of my property? Just how dangerous is it?'," says Staffan Görtz, a spokesman for Vattenfall. Such worries have prompted many to suggest that it would be preferable, although more expensive, to store the carbon off-shore.

But geoscientists say that worries about leakage are unfounded. Seismic studies and monitoring techniques show that nothing has yet leaked from the few large-scale carbon sequestration projects already in operation. And natural deposits of CO_2 show that the gas can be trapped for millions of years (J. Lu, M. Wilkinson, R. S. Haszeldine and A. E. Fallick *Geology* **37,** 35–38; 2009).

If the CO_2 is stored correctly, the chance of a problem is near zero, says Susan Hovorka, a geochemist at the University of Texas at Austin. Right now, society is leaking almost all of the CO_2 it produces. "With CCS," she says, "we could do better than that with some degree of confidence."

Not everyone is opposed to sequestration. Sensing economic benefits, one landowner in Mississippi didn't want Hovorka's team to conduct a geological survey of his land because he was afraid they would find something that would disqualify his land as a potential injection spot.

Near L'Aquila, Italy, people live comfortably above leaky stores of natural CO_2. "There are flats built here, and CO_2 seeps into people's cellars, but they just ventilate it out again," says Tore Torp, a CO_2 storage specialist in Trondheim, Norway, with Statoil, the company that runs the Sleipner sequestration project. Although they may not know it, many more people in the United States and Europe have, for close to a century, lived above deposits of a much more dangerous gas, methane, which is injected underground every summer to store for use in the winter.

David Keith, an Earth scientist at the University of Calgary in Alberta, Canada, thinks that protests about leakage are often a tactic. "Where people have quite legitimate reasons for thinking CCS shouldn't be done, the way they get it stopped is to push on the safety issue," he says. Some environmental groups, for example, oppose CCS because they worry that industry is using it as an excuse to build more coal plants or to make extra profit from enhanced oil recovery without truly sequestering the CO_2.

But these concerns — which reflect CCS's origins in the petroleum industry — also point to a fact that many see as the technology's greatest asset: it can get polluting industries and countries talking about carbon cuts. That was one of the reasons why van der Hoeven followed up her chilly visit in Barendrecht with a trip to Saudi Arabia last month. There, she enjoyed a much warmer reception discussing plans for Saudi Arabia to collaborate on CCS with the Netherlands, Norway and the United Kingdom.

With decades of oil under the Arabian sands and more than a century of coal left in the ground worldwide, many energy researchers view CCS as a foregone conclusion. "Nobody likes it — it's a mess. But you've got to have it," says Jon Gibbins, an energy expert at the University of Edinburgh. "If the world is going to cut carbon emissions, how is it going to do it without CCS?" ■

Richard Van Noorden is assistant news editor with *Nature* in London.