Cleaning up coal

Can we turn the dirty black stuff into the zero-emission fuel of the future? **Fred Pearce** checks out progress so far

COAL is our cheapest and most abundant source of fossil-fuel energy. We probably have enough to keep the world powered for hundreds of years. Trouble is, the carbon emissions from burning it all would make the planet uninhabitable long before then. Is there a way to get the energy without the emissions?

There certainly is, say coal technologists. Capture the carbon dioxide produced when coal burns and bury it underground, back where the coal came from. Most of the technology to do this is proven, and there are enough places underground to store the CO_2 and keep it secure for thousands of years. That at least is the pitch for carbon capture and storage (CCS). If it lives up to the claims, the vast coal reserves in the US, China, India and elsewhere could fuel the post-industrial era just as European coal fuelled the industrial revolution two centuries ago. Forget renewables, coal can be a zero-carbon energy source too. So what are we waiting for?

CCS has no shortage of fans. Last October, the British government's senior minister for business, John Hutton, predicted that by 2030 wide use of CCS "could see up to a third of British electricity generated in this way". In Germany, only CCS can make sense of an energy policy that combines a large number of new coal-fired power stations with plans for a 40 per cent cut in CO_2 emissions by 2020.

Unfortunately, few in the energy industry believe these deadlines are remotely achievable. A study by the Massachusetts Institute of Technology called *The Future of Coal*, published last year, suggests that the first commercial CCS plants won't be on stream until 2030 at the earliest. Thomas Kuhn of the Edison Electric Institute, which represents most US power generators, half of whose fuel is coal, takes a similar line. In September, he told a House Select Committee that commercial deployment of CCS for emissions from large coal-burning power stations will require 25 years of R&D and cost about $20 billion.

The energy company Shell, though enthusiastic about the technology, doesn't foresee CCS being in widespread use until 2050. Yet some governments appear oblivious to this. When Germany recently approved its new coal power stations, it stipulated that the plants must be compatible with any future carbon capture technology. The UK is likely to take the same approach if ministers, as expected, approve a new coal-fired station at Kingsnorth in Kent. However, these installations are likely to have reached the end of their useful lives before the technology arrives.

From this you might suspect that policy-makers are seizing on CCS as a painless way out of the difficult political choices posed by climate change. Yet it is no such thing. The belief that CCS will save them from acting against coal could prove as false as the belief half a century ago that nuclear power would be so cheap it wouldn't be worth metering. This time, though, the consequences of being deluded will be far more damaging.

Beneath the seabed

The idea of CCS goes back to 1979, when Cesare Marchetti of the International Institute for Applied Systems Analysis, an east-west think-tank based in Austria, proposed a CO_2 burial system as a way of countering climate-changing carbon emissions. Yet it took until 1996 for the first such project to be launched, when Statoil, Norway's state oil company, began stripping CO_2 out of natural gas from the Sleipner West gas field in the North Sea and pumping it back down into a sandstone aquifer beneath the seabed. The project is still burying a million tonnes of CO_2 every year. Similar schemes now operate at Weyburn in Saskatchewan, Canada, and at In Salah in Algeria. Both pump CO_2 into existing oil wells to help flush more oil out.

Though welcome, these projects cannot handle the volume of CO_2 from a large coal-fired power station, nor dent the total emissions of CO_2 from human activity – about 24 billion tonnes per year. To cut that by just 4 per cent would require 1000 Sleipners.

Apart from these schemes, all we have is a flurry of R&D projects, many of which have yet to make it off the drawing board. This lack of urgency was underlined earlier this year by the fate of a proposed CCS plant at Mattoon ▶

in Illinois. In December 2007, a US government and industry consortium called FutureGen had announced that Mattoon would be the site for a new power station that would test carbon capture technologies. The plan was to begin burying CO_2 in rock beneath the power station by 2013. "Our strong coal tradition will be revitalised as we become the home of the cleanest fossil-fuel-fired power plant in the world," said Illinois governor Rod Blagojevich. Six weeks later, the project was scrapped, after the government baulked at its $1.3 billion share of the bill.

Back in Europe, the EU says it hopes to have a dozen demonstration plants working by 2015. In November 2007, for instance, the UK government announced a competition to build a 300-megawatt power station that would store CO_2 in exhausted oilfields beneath the North Sea. Unfortunately, support for such schemes remains half-hearted at best. In a statement on energy policy in January, the EU once again declared its enthusiasm for CCS, but warned there was "no possibility of significant funding from the EU budget".

One of the brighter spots today is Australia, a country heavily dependent on coal, which has state-backed plans for a power plant at Fairview in Queensland that will burn methane from unmineable coal seams and bury the resulting CO_2. Another is China, where a high-tech coal power station being built outside Tianjin will include a carbon capture plant.

If all goes to plan, these projects could become the basis for a huge global industry. Around a third of human-made CO_2 emissions come from large, fixed sources that could be captured. The world has 5000 power stations and 3000 industrial plants that emit more than 100,000 tonnes of CO_2 a year (see Map).

Capturing the CO_2 at such plants can be done before, during or after the fuel reaches the combustion chamber. The pre-combustion option is the most complex: the coal is initially converted into a mixture of gases from which hydrogen is extracted to be fed to a gas-turbine power generator, while the CO_2 goes for burial. This is the technology that will be used in Tianjin, and would have been adopted at Mattoon. It is widely regarded as the next big thing in coal power generation, regardless of its potential for CCS.

CO_2 can also be extracted directly from the combustion chamber if the coal is burned in pure oxygen rather than air. But oxygen is expensive and the technology is still at an early stage. The simplest and most developed method is to wait till the coal has been burned and pass the flue gases through a scrubber containing organic chemicals called amines, which react with the CO_2. The CO_2 can then be collected and buried, while the amines are recycled. The British government wants to use this technology in its pilot project, partly because it is the only one that can be retrofitted to existing power stations.

Burial sites

Whichever of these strategies is adopted, the scale of any worthwhile CCS project will have to be huge. Coal produces around three times its own weight of CO_2. This will all have to be pressurised, liquefied and moved to a site where it can be interred at depths of a kilometre or more, where the pressure will ensure that it stays liquid.

Where will these sites be? On the face of it, the best candidates would be the voids left in worked-out oilfields, such as those beneath the North Sea. The rocks held oil or gas for millions of years, so they should be able to hold CO_2 too, the thinking goes. Recent studies show that natural CO_2 has been held within the North Sea's Miller oilfield for the past 120 million years. Oil and gas fields could hold up to a trillion tonnes of CO_2 – or 50 years' worth of emissions at the rate at which it is likely to be produced in 2030. Another possible dump is unmineable coal seams, where CO_2 would be adsorbed in a layer on the surface of the coal.

Then there are deep, porous rocks such as sandstone formations that are capped by an impermeable layer of shale or other rock that would trap the CO_2. These are widespread beneath both the continents and the oceans (see Map). According to some estimates they could provide storage space for as much as 10 trillion tonnes of CO_2, or 500 years' worth.

How secure would these burial grounds be? Opponents of CCS schemes recall the disaster in 1986, when a million tonnes of CO_2 belched from the bottom of Lake Nyos in Cameroon. Being denser than air, the gas formed a blanket that asphyxiated some 1700 people. Though the event was entirely natural, it has left a potent image of what could go wrong. As Bert Metz, co-author of a 2005 report on CCS by the Intergovernmental Panel on Climate Change, says: "Public acceptance is a possible show-stopper if things are not done properly."

Geologists don't dismiss the possibility of a catastrophic release, after an earthquake perhaps. But they see slow seepage as at least as important a concern. To prevent climate change, CO_2 has to be stored safely for millennia. Even a leakage rate of 0.01 per cent a year – a suggested industry standard – would see almost two-thirds of the gas gone within 10,000 years. The legal question of who has long-term responsibility for stored carbon is also unresolved, and it could prove as convoluted a debate as that over nuclear waste. No surprise then, that next to designing a capture plant, assessing the leakage threat is the major research focus for CCS.

In 2006, engineers from Australia completed a trial project to store CO_2 in deep coal seams in Silesia in southern Poland. This year, in a project sponsored by the Australian government, 100,000 tonnes of CO_2 will be injected into a saline aquifer off the coast of Victoria and closely monitored. The EU is sponsoring a similar project in Germany.

The furthest-advanced project is a test site at which engineers have injected 1600 tonnes of CO_2 into a sandstone formation known as the Upper Frio on the Gulf coast of Texas. The rock, which once contained oil, is now flooded with salt water. An early report on the Frio project, published in the journal *Geology* by Yousif Kharaka of the US Geological Survey, points to a possible danger of storing CO_2 in formations like these. The CO_2 has acidified the brine, allowing it to dissolve metal-oxide minerals in the rock, and this, Kharaka says, might eventually create tunnels in the cap rock through which CO_2 might escape.

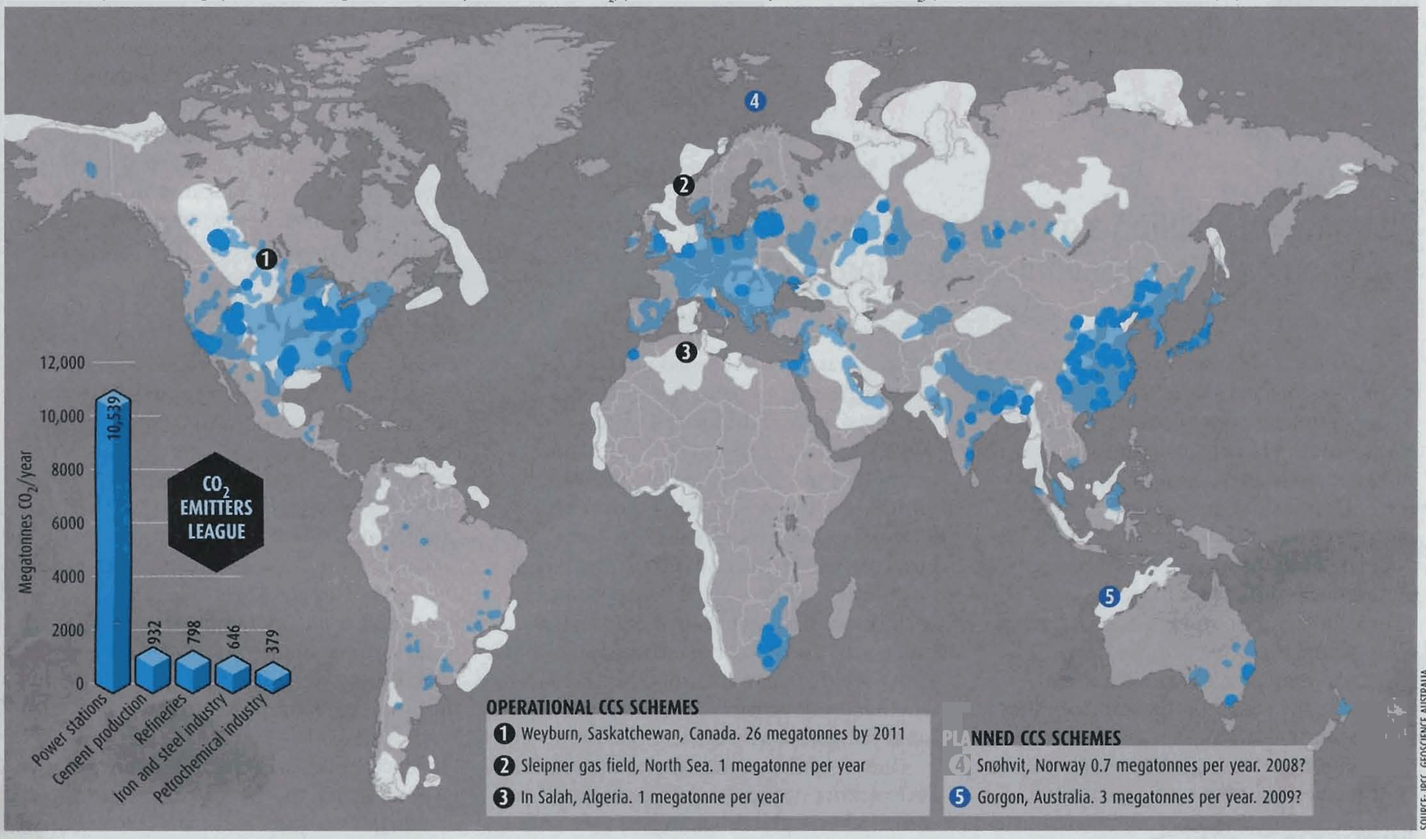
Not everyone involved shares these fears. Nick Riley of the British Geological Survey, who collaborated on the Frio project, believes that the danger of a leak occurring this way is slight. He accepts that there was some acidification, and that a small amount of CO_2 did escape into the overlying layer of rock, but insists that it poses no problem. Susan Hovorka of the University of Texas, Austin, the project's principal investigator, agrees. "The CO_2 has smeared... until it cannot move much further." In fact, far from being a problem, the

"Carbon capture and storage itself consumes a huge amount of energy"

BURYING THE PROBLEM

Around 40 per cent of global CO_2 emissions come from industrial plants or power stations that burn coal. Many of these "stationary emitters" are not close to suitable underground burial sites, and so will require a network of pipelines to transport liquefied CO_2 from source to sink

○ Sedimentary rocks with high potential for storage ● Stationary emitters 0.9-9 $MtCO_2$/year ● Stationary emitters 10-50 $MtCO_2$/year ● Industrial-scale carbon burial project



chemical reactions might gradually convert the CO_2 into carbonate rock that would keep the carbon locked underground indefinitely.

So far, tests have been small-scale, short-term and largely at sites that geologists judge will perform best. In the real world, Hovorka points out, geologists will be under pressure to find burial sites close to power plants, where the rock formations may be less than perfect. "We know how to recognise an excellent site," she says. "But we need confidence about when to screen out sites that are too risky." She also admits there is no method yet for deciding how much CO_2 a particular rock formation can absorb before leaking, and how to spot if things are going wrong. A study in the journal *Advances in Water Research* warns that algorithms modelling the seepage of gas through rock are untested, so the results could prove inaccurate.

Even moving the gas from power station to burial ground won't be simple, as the volumes involved will be vast. A study by the International Energy Agency suggests that the EU would need 150,000 kilometres of pipeline to trunk its CO_2 emissions to the North Sea. Operations will have to be continuous, and a vast new industry will be required.

The necessary capital investment will be huge, as will the cost of operating any CCS system. The US government reckons CCS will increase the cost of coal-fired power generation by 75 per cent. For this to be commercially viable, it has been calculated that a price tag of more than €30 per tonne will need to be imposed on CO_2 emissions, either via a carbon tax or through a continuation of the emissions trading system introduced under the Kyoto protocol.

So exactly what would this hugely costly undertaking achieve? One EU document on CCS says beguilingly: "The possibility exists for a CO_2-free energy system based on fossil fuels." Yet even the best CCS systems will not capture all the CO_2, and existing methods typically capture only about 85 per cent. In reality the figures are even more unfavourable, as the CCS process itself consumes anything from 10 to 40 per cent of the energy produced by a fossil-fuel power station.

Another factor to be taken into account is the energy used by diggers, trucks and trains to extract coal and transport it to the power station. In all, this may take up to a quarter of the energy the coal produces at the power plant, and none of these emissions disappears when CCS kit is bolted on.

Add all this together, and what do we get? The most detailed published assessment, by Peter Viebahn of the German Aerospace Center in Stuttgart, estimates that at best CCS will reduce greenhouse gas emissions from coal-fired power stations by little more than two-thirds. That compares with life-cycle emissions for most renewable energy technologies that are 1 to 4 per cent of those from burning coal.

We are unlikely to give up burning coal any time soon, and CCS could eventually have an important part to play by allowing coal to be used without doing unacceptable damage to the global climate. But that isn't going to happen tomorrow. And as to the dream of coal becoming a zero-emissions source of power – forget it. ●

www.newscientist.com/channel/earth/energy-fuels