Beyond fracking

The next energy revolution could be fired by coal – literally. Can we afford the risks, asks **Fred Pearce**

IF YOU thought shale gas was a nightmare, you ain't seen nothing yet. A subterranean world of previously ignored reserves is about to be opened up. These are the vast coal deposits that have proved unreachable by conventional mining, along with gas deposits around them. To the horror of anyone concerned about climate change, modern miners want to set fire to these deep coal seams and capture the gases this creates for industry and power generation. Some say this will provide energy security for generations to come. Others warn that it is a whole new way to fry the planet.

A primitive version of the technology behind this Dantean inferno of underground coal gasification (UCG) has already been running for 50 years in the former Soviet republic of Uzbekistan. Some 300 metres beneath the plains east of Tashkent, Stalin's engineers and their successors have been burning a seam of brown coal that can't be mined conventionally. There are two well heads on the surface: one pumps air down to fan the flames while the other retrieves a million cubic metres of combustion gases a day. Scrubbed of coal dust, cooled and compressed on site, the gases are then sent down a pipeline that snakes across the countryside to a sprawling power station on the outskirts of the industrial town of Angren, where they are burned to generate electricity.

A deadbeat town in a forgotten rust-belt backwater of the former Soviet Union is an unlikely test bed for a cutting-edge technology. But if it can be scaled up successfully, the Australian engineers who bought the operation seven years ago think it could transform the world's energy markets, open up trillions of tonnes of unmineable coal and provide a new carbon-based energy source that could last a thousand years.

With trials of UCG under way globally from China to Queensland, and South Africa to Canada, the stakes are high. Not least for the atmosphere. Without a way to capture all the carbon and store it out of harm's way, it could raise the world's temperature by 10 degrees or more. Is this burning desire for fossil fuel pushing us towards disaster?

"The real prize is to create yet more methane, by setting fire to huge amounts of buried coal"

Until recently, only reserves with rich concentrations of coal, oil and natural gas were exploited – but not any more. With those reserves approaching exhaustion, the hunt is on to tap huge volumes of "unconventional" energy sources, particularly natural gas, or methane. With these we could keep the lights on, power vehicles, deliver feedstock for the chemicals industry, and quite possibly heat the planet, for centuries to come.

In the past decade, the focus has been on shale gas: methane tightly trapped in tiny pores and fractures in shale, a sedimentary rock made up of mud and clay mixed with minerals such as quartz. Capturing that gas required two crucial new technologies. Horizontal drilling launched from conventional vertical wells can penetrate for up to 3 kilometres along shale beds. And hydraulic fracturing, or fracking, blasts high-pressure water into the shale to fracture the rock and release the gas. As well as opening up the shale, these technologies open the door to a wide range of alternative sources of methane. They can release methane trapped within coal seams, for example, notably in the coalfields of Wyoming and Montana. Methane is often produced as seams develop, as the

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coal becomes compacted and heated deep underground. The gas has always been the bane of coal mining, but if collected and pumped to the surface, it becomes an asset.

According to the International Energy Agency's latest estimates, some 400 trillion cubic metres of economically recoverable methane lies trapped in coal and shale beds around the world. It roughly doubles estimates of how much gas miners may be able to get their hands on. But that is just the start. There might be even more gas down

> **"The idea is to exploit coal once thought too deep, too costly or too dangerous to mine"**

there in different rock strata, much of which has migrated from coal seams over millions of years. And why limit the plan to existing gas? The real prize, the miners say, is to create yet more methane by setting fire to the huge amount of unmineable coal lurking underground.

Setting fire to coal and capturing the gaseous emissions has long been routine above ground. Till half a century ago, many of us got our gas for heating and cooking from gas works that ignited and "gasified" coal. The combustion converts the carbon in the coal to carbon dioxide while providing heat for subsequent reactions in which the CO_2 reacts with steam to produce hydrogen, carbon monoxide and methane.

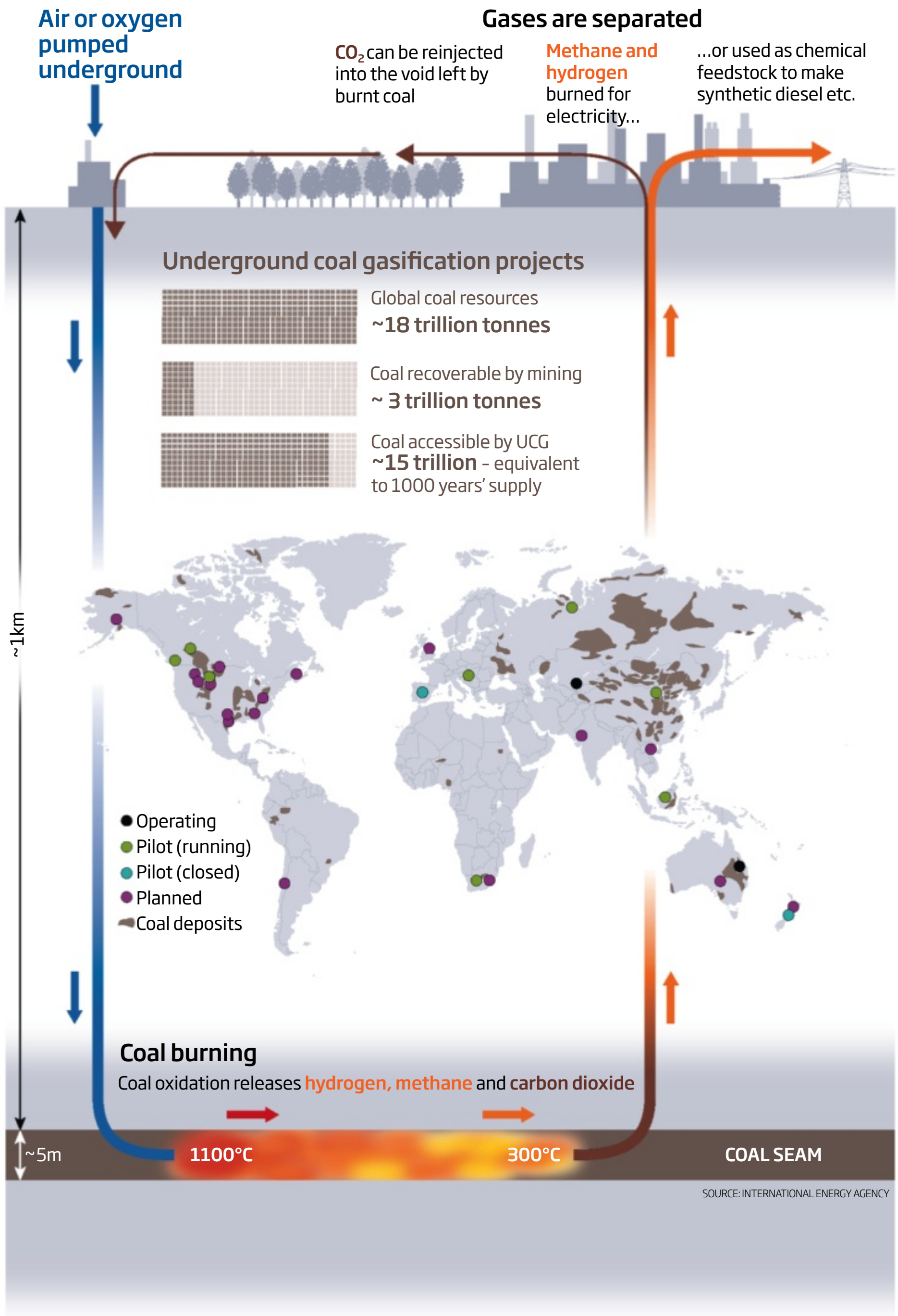
In most countries, gas works have been superseded by natural gas from oil fields. But now the idea is to turn coal seams into underground gas works. That, say proponents of the idea, exploits coal once thought too deep, too costly or too dangerous to exploit. It also saves time and money in mining, and land isn't spoiled by mines and waste dumps – not to mention the costs and environmental hazards of conventional gas works. Any nasty by-products can be left below ground (see diagram, right).

The idea of UCG originated with the German engineer William Siemens in the 1860s. It was first tried out a century ago by British Nobel prizewinning chemist William Ramsay, at the end of tunnels in conventional mines in the Durham coalfield in northern England. The experiments successfully produced useful gas, but only the Soviet Union followed it up.

Then in the 1990s, Australian engineers led by Len Walker, and Cliff Mallett from CSIRO,

Fire in the hole

Underground coal gasification (UCG) is a process of extracting energy from coal that cannot easily be mined in the traditional way. The coal seam is set on fire, and the gases produced are pumped to the surface



SOURCE: INTERNATIONAL ENERGY AGENCY

the Australian government research agency, developed their own systems that borrowed techniques in horizontal drilling from the US oil industry. Walker set up Linc Energy and began trials at Chinchilla, in Western Downs, Queensland. Within two years the plant had shown UCG was feasible.

By 2002, both Linc and Mallett's Carbon Energy appeared on the brink of commercial operation. In 2006, Walker also set up Cougar Energy. And in 2007, Linc bought into Soviet operational experience by acquiring a controlling stake in the Uzbek operation. But then things turned sour.

Following groundwater contamination with benzene during UCG trials in the US, the Queensland state regulators wanted to be sure that underground fires wouldn't create similar problems that surface later. In 2011 the Queensland authorities shut down Cougar's operations at Kingaroy after benzene and toluene seeped into a nearby water borehole. And last July, a state-sponsored scientific review vetoed commercial operations by Linc and Carbon Energy until the companies could demonstrate safe decommissioning, by extinguishing the fires, shutting off reactions and preventing groundwater contamination. Both companies reacted angrily. They say decommissioning is no big deal, but demonstrating you can do it for a commercial-size operation is difficult when you don't actually have such an operation. In response, Linc announced that it is shutting its Chinchilla project after more than a decade of production, and moving to China and the US. Meanwhile Carbon Energy is busy in China, Argentina and Chile, and Walker's Cougar Energy has shifted its attention to Indonesia.

All systems go

Despite those setbacks, Julie Lauder, CEO of the UK-based UCG Association, says the success of the Chinchilla trials was a "eureka moment" for the nascent industry and there have never been more UCG trials set to go round the world (see map, left). At Cook Inlet in Alaska, and Swan Hills in Alberta, Canada, there are plans to go commercial as early as 2015. Excited by the success of shale gas in the US, UCG enthusiasts think their time may have come. And nowhere more so than in the UK, where they know a thing or two about coal. While there is plenty of coal untouched beneath the rolling hills of England, some of the best coal is out of reach, under the North Sea. These seams are now the prime targets for half a dozen British start-ups, including the biggest and most ambitious, Five Quarter Energy.

Contaminated water was detected near a pilot coal gasification plant in Queensland, Australia, in 2011

LUKE MARSDEN/NEWSPIX/REX

Late last year, I sat with the company's three founders in a hotel suite in the heart of Newcastle upon Tyne in north-east England. We were less than a hundred metres from the banks of the River Tyne, where since the 13th century they have cut coal to fuel domestic grates and industrial boilers. Coal mining in the region has virtually ground to a halt in the past 30 years, but there is still plenty down there, says Harry Bradbury, a British-born geologist, formerly of Yale University. "More than 70 per cent of UK coal has never been mined; it is still underground. We want to burn it where it sits to revive new industry." He founded Five Quarter, named after a famous local coal seam, with Dermot Roddy, a chemical engineer till recently at Newcastle University, and Glasgow University engineer Paul Younger.

The company has a licence to prospect for UCG sites in seams beneath more than 400 square kilometres of the North Sea, from Sunderland to the Scottish border. It could be bringing gas to the surface before the end of this year. "We estimate the area contains 10 billion tonnes of coal," says Bradbury. "We can turn a third of that into gas."

As we talk, Younger drags out a chart, complete with detailed borehole data on the coal seams collected by mining geologists decades ago. The data and maps came close to being shredded when coal mining shut down a generation ago. "We call them the North Sea scrolls," he jokes.

The team are still working out the detailed chemical engineering. "The black arts lie in controlling the combustion," says Roddy. "We want to produce the valuable hydrogen, methane and carbon monoxide, while minimising gases we can't use, such as carbon dioxide." Pumping down oxygen rather than air raises the temperature of combustion and produces more methane and less CO_2. The perfect combustion temperature, says Roddy, is 1500 °C, "but 900 °C is good enough". The Uzbek plant, by contrast, pumps down air rather than ›

CHEMICAL TOOLKIT

Unlike shale gas, which is entirely methane, the gas created by burning coal underground comes as a cocktail, with a range of potential uses. It is a mixture of methane (natural gas), carbon dioxide (CO_2), carbon monoxide (CO) and hydrogen. The CO_2 can be separated out and disposed of safely so that it does not add to global warming. The rest has value and there are four main ways to use it:

GAS TO ELECTRICITY **Power stations can burn methane to produce electricity for the grid**

GAS TO CHEMICALS **Hydrogen, methane and CO all have value as feedstock for the chemicals industry**

GAS TO LIQUID **Methane can be liquefied (LNG) for storage or transport, or the CO and hydrogen converted through the Fischer-Tropsch process to synthetic diesel fuel for vehicles**

GAS TO TECH **Hydrogen can provide an alternative transport fuel** oxygen, burns at cooler temperatures and delivers ten times as much CO_2 as methane.

But the Five Quarter team have even bigger plans. They say the other strata beneath the North Sea are full of methane too, and they want to tap that in a strategy they call "deep gas winning". For instance, there is a shale seam below the coal that is their prime target. Fracking could release the gas in that. And nearby layers may all contain methane from the coal. "We believe we can harvest these at the same time," says Bradbury. He reckons that underground subsidence created by the burning coal seam will help liberate this gas.

"The chemicals industry is short of cheap feedstock so North Sea coal gas could be a lifesaver"

This is a break with the orthodox narrative of UCG entrepreneurs. Most insist, in public at least, that strata surrounding the coal seams are impermeable, and that any pollutants released by burning will stay within the seam. Not so, says Bradbury. "The rocks above, in particular, will be disturbed. They will be fractured. Even if they were impermeable before, they won't be afterwards. It is inevitable. We estimate the disturbance will extend up to 60 times higher than the width of the seam."

If this is true, could toxic by-products migrate into aquifers used for drinking water, as happened during Cougar's Queensland trial? As with the exploitation of shale gases, the potential contamination of underground water is a major technical and public relations challenge. But Bradbury says the dangers are greatly reduced when the coal seams you are tapping are beneath the sea. Water under the seabed is not used for public supplies, and is unlikely to be in future because most of it is saline. For him the appeal of deep gas winning is the ability to harvest more gas from a bigger area – both from coal combustion, and the stuff that has migrated out of the coal or is trapped in shale seams.

SIEMENS AG, MUNICH/BERLIN

Not just a fuel

Such gas is undoubtedly valuable. Most obviously, the methane can be delivered to domestic consumers or burned in power stations to generate electricity. But there are other options. In Australia they have been turning it into liquid fuel for vehicles. "Unlike with shale gas, we are not just bringing methane to the surface," said Bradbury. "We are bringing up a cocktail of gases." Five Quarter is eyeing another potential market for these gases (see "Chemical Toolkit", page 39).

North-east England's large chemicals industry is short of cheap feedstock. So North Sea coal gas could be a lifesaver. Roddy, who once ran a local chemical plant, pictures turning hydrogen, carbon monoxide and CO_2 into acetic acid and acetates; and hydrogen and CO_2 into methanol. The region already has a pipeline network for supplying hydrogen. Similarly, in Scotland, the giant Grangemouth chemicals complex is importing gas from North America while coal seams sit unused just a few hundred metres offshore under the Firth of Forth. Bradbury argues that a UCG revolution in the UK could dramatically

ROBERT NICKELSBERG/TIME LIFE PICTURES/GETTY

Could a coal gas revolution make dirty coal-fired power stations a thing of the past?

reduce the price of some feedstocks for a chemicals industry that has threatened to decamp to the US, where costs are lower. "If we don't solve the problem, then the chemicals industry will go."

Other UCG enthusiasts around the world are also keen to start – they say their technology is ready and the gases they can generate are in demand as both fuel and chemical feedstock. The trick will be to convince the regulators, investors and the industry partners who will all have to come on board to turn UCG into big business.

Late last year, the British government dipped its toe in the water when it set up an Office for Unconventional Gas and Oil and stumped up £15 million to help fund Five Quarter's plans for a plant to clean and distribute its gas. And Bradbury claims he has a big name industrial collaborator to announce soon. Meanwhile, the business press is full of stories about the presence of Algy Cluff among the UK holders of UCG offshore licences, a charismatic figure who made his name and money in North Sea oil exploitation in the 1970s.

Bradbury would be the first to admit that coal still has an image problem. Nevertheless, it is the world's most abundant fossil fuel and the great majority of it can only be accessed by burning the coal where it lies. UCG could quadruple recoverable coal reserves in the US.

An assessment by the World Energy Council puts the proportion of global coal that is readily recoverable at 15 to 20 per cent of the total, which Gordon Couch of the International Energy Agency's Clean Coal Centre puts at 18 trillion tonnes. Potentially, UCG could unleash the energy from the other 80 to 85 per cent – enough to supply the world, at current requirements, for 1000 years.

"Underground coal gasification could unleash enough energy to supply the world for 1000 years"

Industrialists may salivate at the idea of burning all that coal, but for the climate the prospect is truly terrifying. The Intergovernmental Panel on Climate Change recently reckoned that the world needs to limit total emissions of carbon, from now on, to less than half a trillion tonnes just to keep global warming below 2 °C. Most climate analysts agree even burning a large fraction of conventional fossil fuel reserves would produce unacceptable warming, let alone what could be released by UCG.

Burning dilemma

What to do? Either we have to leave the fuel in the ground, or develop a global industry for capturing CO_2 at the source and storing it out of harm's way. In the case of UCG that would mean capturing the CO_2 produced both when the coal is burned underground and when the resulting methane is burned in power stations. Climate scientists such as Myles Allen at the University of Oxford argue that carbon capture and storage (CCS) is the only practical way forward. And this is where UCG has something to offer. Burning coal in situ leaves huge voids that are ideal places for burying captured CO_2. And the infrastructure created to bring coal gas to the surface, purify it and deliver it to power stations would be ideal for carrying the CO_2 away again.

So far efforts to kick-start CCS technology have failed. A plan to burn UK coal seams beneath Hatfield in South Yorkshire, to supply gas to a power station and strip out CO_2 for burial beneath the North Sea, was scrapped by the government in late 2012, despite backing from the European Union. Ministers said it did not offer value for money.

But Bradbury remains enthusiastic. "Half the cost of CCS will be transport and storage," he says. "Why not pay for it through profits made from extracting the gas from the coal seams?" Nice idea. But suppose things don't work out as expected. What if there are no profits? Even fracking, which is now seen as a deliverer of golden eggs, took three decades to become profitable. What if CCS technology proves as slow to develop as UCG has already been? A 2007 study by the Massachusetts Institute of technology concluded that commercial CCS development was unlikely before 2030, and since then little progress has been made. And what if the regulators backslide on their insistence that UCG cannot go forward without CCS? To its critics, UCG still sounds like playing Russian roulette with the climate – and the onus is on those who want to develop yet more fossil fuels to prove them wrong. ■

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