FUELLING THE FIRE

The chequered history of Underground Coal Gasification and Coal Chemicals around the world

‘Fuelling the Fire: the chequered history of Underground Coal Gasification and Coal Chemicals around the world’ is a Friends of the Earth International report produced by Friends of the Earth Scotland and published in July 2016.

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Our vision is of a peaceful and sustainable world based on societies living in harmony with nature. We envision a society of interdependent people living in dignity, wholeness and fulfilment in which equity and human and peoples’ rights are realised.

This will be a society built upon peoples’ sovereignty and participation. It will be founded on social, economic, gender and environmental justice and be free from all forms of domination and exploitation, such as neoliberalism, corporate globalization, neo-colonialism and militarism.

We believe that our children’s future will be better because of what we do.

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Foreword

In the wake of the celebrated Paris Agreement we are entering the last decade with any possibility of acting to keep global temperature rise below 1.5 degrees Celsius and to avoid some of the most devastating impacts of climate change. These impacts – floods, droughts, storms and rising sea levels – will hit the world's poorest people hardest. To have any hope of keeping within our global carbon budget one thing is very clear: we cannot burn our remaining reserves of fossil fuels, let alone the vastly larger resource. We must keep them in the ground.

Against a backdrop of slow growth within the conventional coal industry, highly polluting, unconventional coal technologies threaten to further destabilise the earth's climate. If exploited these technologies could blow the global carbon budget, and in doing so spell certain catastrophe for our planet. At a time when sustainable renewable energy is proving to be cleaner, safer and better for people, it makes no sense to exploit dirty technologies like Underground Coal Gasification and Coal Chemicals that would make it vastly harder to avert runaway global warming.

While world leaders continue to take little meaningful action to halt the planetary emergency, Friends of the Earth groups together with allies and social movements are fighting dirty, polluting energy projects around the world. In the face of often devastating impacts on local environments and on the health and wellbeing of local people, it is crucial that the companies and governments responsible are stopped. We have no time to waste in transitioning to a low carbon future. Coal, the most polluting of the main fossil fuels, must be phased out urgently while the vast majority of oil and gas must stay in the ground unburned. Wealthy countries that have grown rich on the back of fossil fuels must pay their fair share to fund the energy transformation in the global south.

To invest in and open up a new frontier of fossil fuels at this critical stage in the fight against climate change is not just a crime against our planet, but a crime against humanity.

Jagoda Munić,
Chair of Friends of the Earth International

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Executive Summary

While the global coal industry is in decline, interest in newer, unconventional coal technologies including Underground Coal Gasification and Coal Chemicals processing is growing. These industries pose major risks to the environment in terms of air and water pollution as well as the huge significance for the fight against climate change from opening up previously inaccessible fossil fuel resources.

Underground Coal Gasification is a technology in commercial infancy. The process involves drilling into coal seams and combusting the coal in situ in the presence of steam, air or oxygen to create syngas (mainly hydrogen, methane, carbon dioxide and carbon monoxide) that is drawn to the surface through the production well.

The industry has been advancing primarily in Australia, South Africa, China and Europe. Though test and demonstration projects have taken place for many decades around the world, several recent trials have resulted in serious contamination of surrounding groundwater and surface subsidence. The process creates toxic waste products and polluted water that are very problematic to dispose of.

Underground Coal Gasification threatens to be a major contributor to climate change. Approximately 860 Gigatonnes (Gt) of coal is currently accessible by conventional mining[1] and around 88% of this must remain in the ground in order to have a chance of staying below 2°C of warming.[2] To keep below 1.5°C, as is the aspiration of the Paris Agreement, most likely all of this must remain unused. Underground Coal Gasification could potentially expand useable coal reserves by around 600Gt,[3] amounting to an extra 1650Gt of CO_2 if burnt.[4] The syngas resulting from UCG is extremely dirty, emitting around 8 times more carbon if used for electricity than what the UK Committee on Climate Change argue should be standard by 2030,[5] meaning that UCG is not compatible with a clean energy transition.

Coal Chemicals is the process of turning coal into liquid fuels, Synthetic Natural Gas and chemical products.[6] The industry is predominantly established in China, but there is also development in Australia, South Africa and the US. The process leaves a massive footprint in terms of coal extraction, water consumption, energy use and toxic waste creation and disposal, and large quantities of greenhouse gases are emitted. China's 2014 plans to build at least 40 Coal-to-Gas plants could potentially add a further 110Gt of CO_2 over the next 40 years.[7]

Proponents of UCG and Coal Chemicals argue that these technologies are viable in conjunction with Carbon Capture and Storage (CCS). However, CCS has failed to get off the ground commercially and technical issues remain. It remains a false solution that risks giving companies and technologies licence to keep polluting, fuelling the climate crisis.

Experience from around the world – Australia, China, South Africa and the US – shows how destructive these industries can be. Recent experience from Australia of a major contamination incident from Linc Energy's UCG trial project highlights the real risks in developing these industries. Evidence from China documents large coal conversion mega-projects impacting on arid local environments through heavy coal and water use.

These technologies cannot be expanded and must be phased out if we are to have a hope of keeping global temperature rise to anything approaching a safe level. For many people around the world safe levels have already been breached. Averting a climate catastrophe is only just within our grasp: we cannot risk pursuing these dangerous, high carbon industries that damage and delay the transition to a low carbon world.

We call for:

- No new public money into Research & Development of Underground Coal Gasification and Coal Chemicals
- An end to public subsidies for existing Underground Coal Gasification and Coal Chemicals
- A ban on new Underground Coal Gasification and Coal Chemicals development
- A rapid phase out of existing Underground Coal Gasification and Coal Chemicals industries.

Notes

1 World Energy Council, '2010 Survey of Energy Resources', 2010, p. 12, https://www.worldenergy.org/wp-content/uploads/2012/09/ser_2010_report_1.pdf (accessed 22 June 2016).

2 C. McGlade and P. Ekins, 'The geographical distribution of fossil fuels unused when limiting global warming to 2°C', Nature, vol. 517, no. 7533, 2015, pp. 187–190.

3 The World Energy Council states that 'Early studies suggest that the use of UCG could potentially increase world reserves by as much as 600 billion tonnes.' Cited in: World Energy Council, '2007 Survey of Energy Resources', 2007, p. 7, http://ny.whlib.ac.cn/pdf/Survey_of_Energy_Resources_2007.pdf (accessed 22 June 2016). However, D. Roddy and P. Younger state that 'around 4 trillion tonnes of otherwise unusable coal could be suitable for UCG' in D. Roddy and P. Younger, 'Underground coal gasification with CCS: a pathway to decarbonizing industry', Energy and Environmental Science, vol. 3, 2010, p. 403. Analysis from 2010 indicates that if 4 trillion tonnes of coal is exploited 'without the use of carbon capture or other mitigation technologies, atmospheric carbon-dioxide levels could quadruple--resulting in a global mean temperature increase of between 5 and 10 degrees Celsius.' From K. House, 'Is underground coal gasification a sensible option?', Bulletin of Atomic Scientists, 29 March 2010, http://thebulletin.org/underground-coal-gasification-sensible-option (accessed 28 April 2016). The smaller estimate of 600Gt of coal is used here because the economics of accessing 4 trillion tonnes of hard-to-reach coal is so much in question.

4 Assuming carbon content of coal is 75%, with the 44/12 equation to calculate the resulting carbon dioxide. 1650GtCO_2 would be the total maximum amount of carbon released if all 600Gt of coal was gasified and then the resulting syngas was burned for electricity. This figure would differ depending on whether the syngas was used solely for electricity or for chemical products like plastic. The 1650GtCO_2 also assumes that UCG would be used only for the 600Gt of coal resources that are currently inaccessible by conventional mining methods. It is perfectly possible, however, that UCG could be used for currently conventional coal reserves, for example easy-to-reach coal near the surface.

5 UK Committee on Climate Change has a target that the average UK electricity sector grid intensity is under 100g/kWh by 2030. See section 2.4.1.1 for UCG emissions.

6 The term 'Coal Chemicals' is not very widely used outside of China, but is used here to refer to the suite of technologies that process coal into different products through chemical reactions. Arguably, Underground Coal Gasification is a type of Coal Chemical process, as coal is turned into syngas through UCG. Indeed several UCG trial projects (for example Linc Energy's Hopeland project in Queensland) used the resulting syngas for liquefaction. The two sets of technologies are separated here to allow for a more in-depth analysis of UCG and the resulting specific local environmental impacts (i.e. groundwater contamination around the gasification cavity) that are quite different to, for example, Coal-to-Liquids where the coal is usually extracted through conventional mining before being processed.

7 C. Yang and R. Jackson, 'China's synthetic natural gas revolution', Nature Climate Change, vol. 3, October 2013, p. 852.

Abbreviations

bbl	barrels
bbl/d	barrels per day
CCS	Carbon Capture and Storage
CO	Carbon monoxide
CO_2	Carbon dioxide
CTC	Coal-to-Chemicals
CTG	Coal-to-Gas
CTL	Coal-to-Liquids
DCL	Direct Coal Liquefaction
FT	Fischer-Tropsch
GHG	greenhouse gases
Gt	gigatonne (a billion tonnes)
$GtCO_2$	gigatonne of carbon dioxide
H2	Hydrogen
ICL	Indirect Coal Liquefaction
kg	kilogram
kg/MWh	kilogram per MegaWatt hour
km	km
kt	kilotonne
LNG	Liquid Natural Gas
m	metres
m^3	cubic metres
m^3/yr	cubic metres per year
MBTU	million British Thermal Unit
mg/kg	milligram per kilogram
Mt	million tonnes or megatonne
$MtCO_2$	million tonnes or megatonne of carbon dioxide
MW	MegaWatt
MWh	MegaWatt hour
NH_3	Ammonia
NO_2	Nitrogen oxide
SNG	Synthetic Natural Gas
SO_2	Sulphur dioxide
t	tonne
tCO_2	tonne of carbon dioxide
UCG	Underground Coal Gasification
VOC	Volatile Organic Compound
WGS	Water Gas Shift
$\mu g/m^3$	microgram per cubic metre

1. Introduction: coal and climate change

The world has entered decade zero – our last chance of keeping global temperature rise to the internationally recognised limit of 1.5°C. Climate change impacts are already being felt around the world from 0.87°C of warming.[1] With more warming already locked in by our past emissions, climate impacts will continue to get worse if we carry on burning coal, oil and gas.

While the impacts of unconventional fossil fuel technologies like shale gas fracking, coalbed methane and the tar sands are well documented, Underground Coal Gasification (UCG) and Coal Chemicals have drawn less attention. Yet the potential climate change and environmental implications of these industries are staggering.

The most recent UCG developments have taken place in Australia, South Africa and Europe. All three Australian UCG trials have ended in the operators being prosecuted for environmental damage. In South Africa, a small demonstration project operated between 2007 until 2015. Several experimental trials have taken place in Eastern Europe. In Uzbekistan, a UCG project has been running since the 1960s.

UCG makes little economic sense, with the vast majority of UCG companies never making it to production, despite years of research and experimentation. In May 2016 Linc Energy – the most high-profile UCG company – filed for bankruptcy in the US and Australia. Public opposition is growing as the unacceptable environmental impacts of the industry – climate emissions, water and energy consumption, toxic waste creation – are increasingly recognised. Moratoriums are now in place in Scotland and Wales in the UK and in Queensland, Australia.

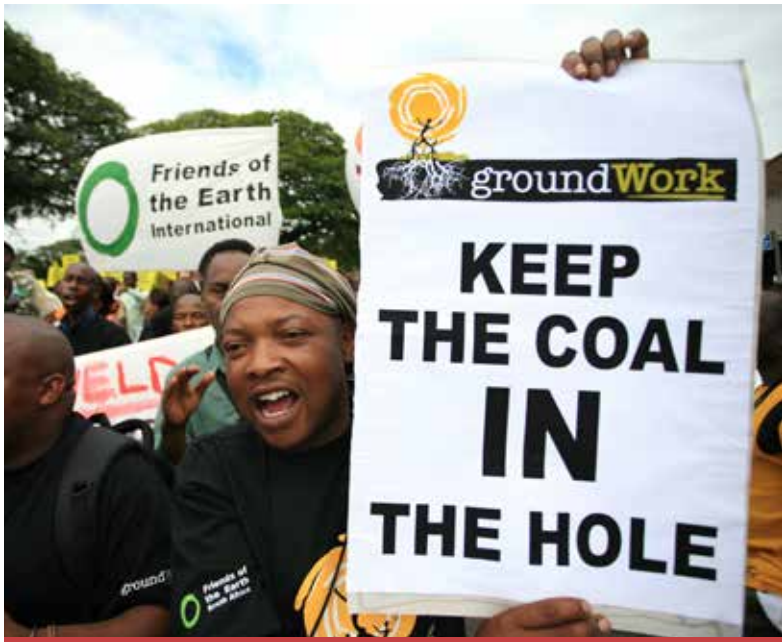
Coal Chemicals are being pursued mainly in China, but South Africa is also a key player. Large mega projects in China are polluting water, land and air, and massive coal and energy consumption threatens the local environment.

Should these unconventional technologies break through into commercial production, the climate change consequences would be enormous.

To keep below a 1.5°C temperature rise requires keeping nearly all currently accessible coal in the ground unburnt.[2] Coal reserves that could be extracted by conventional mining stand at approximately 860 Gigatonnes (Gt).[3] UCG could potentially open up access to around 600Gt more coal[4] that the world cannot afford to burn.[5] If exploited, this could release 1650Gt of CO_2 into the atmosphere,[6] more than the entire remaining global carbon budget to have a 50% chance of avoiding 2°C.

This report outlines the current status of these industries, highlights key activities by companies and countries, and details the major climate and environmental risks posed by their development. Case studies from Australia, China, South Africa, the US and UK document key developments across the world and help shine a light on the damage already done by these hugely polluting industries.

The development of Underground Coal Gasification and Coal Chemicals industries represents yet more investment in fossil fuels at a time when every economy should be transitioning to cleaner sources of energy and chemical production. With hundreds of years worth of coal still in the ground globally, it is crucial that all countries stop investing in new coal technologies and begin a full coal phase-out.



A protester at the Global Day of Action during the COP17 climate talks in South Africa in 2011

Notes

1 NASA, 'NASA, NOAA Analyses Reveal Record-Shattering Global Warm Temperatures in 2015', Goddard Institute for Space Studies, 20 January 2016, http://www.giss.nasa.gov/research/news/20160120/ (accessed 31 May 2016).

2 C. McGlade and P. Ekins, 'The geographical distribution of fossil fuels unused when limiting global warming to 2°C', Nature, vol. 517, no. 7533, 2015, pp. 187–190.

3 World Energy Council, '2010 Survey of Energy Resources', 2010, p. 12, https://www.worldenergy.org/wp-content/uploads/2012/09/ser_2010_report_1.pdf (accessed 22 June 2016).

4 'The World Energy Council states that 'Early studies suggest that the use of UCG could potentially increase world reserves by as much as 600 billion tonnes.' Cited in: World Energy Council, '2007 Survey of Energy Resources', 2007, p. 7, http://ny.whlib.ac.cn/pdf/Survey_of_Energy_Resources_2007.pdf (accessed 22 June 2016). However, D. Roddy and P. Younger state that 'around 4 trillion tonnes of otherwise unusable coal could be suitable for UCG' in D. Roddy and P. Younger, 'Underground coal gasification with CCS: a pathway to decarbonizing industry', Energy and Environmental Science, vol. 3, 2010, p. 403. Analysis from 2010 indicates that if 4 trillion tonnes of coal is exploited 'without the use of carbon capture or other mitigation technologies, atmospheric carbon-dioxide levels could quadruple--resulting in a global mean temperature increase of between 5 and 10 degrees Celsius.' From K. House, 'Is underground coal gasification a sensible option?', Bulletin of Atomic Scientists, 29 March 2010, http://thebulletin.org/underground-coal-gasification-sensible-option (accessed 28 April 2016). The smaller estimate of 600Gt of coal is used here because the economics of accessing 4 trillion tonnes of hard-to-reach coal is so much in question.

5 C. McGlade and P. Ekins, 'The geographical distribution of fossil fuels unused when limiting global warming to 2°C', Nature, vol. 517, no. 7533, 2015, pp. 187–190. McGlade and Ekins highlight that a smaller percentage of oil and gas is unburnable than coal (88%). For the purposes of this report, UCG is included in the coal percentage, as oppose to the gas percentage irrespective of what the resulting syngas is used for.

6 Assuming carbon content of coal is 75%, with the 44/12 equation to calculate the resulting carbon dioxide. 1650GtCO_2 would be the total maximum amount of carbon released if all 600Gt of coal was gasified and then the resulting syngas was burned for electricity. This figure would differ depending on whether the syngas was used solely for electricity or for chemical products like plastic. The 1650GtCO_2 also assumes that UCG would be used only for the 600Gt of coal resources that are currently inaccessible by conventional mining methods. It is perfectly possible, however, that UCG could be used for currently conventional coal reserves, for example easy-to-reach coal near the surface.

Photo credits

p. 1: Photo by Friends of the Earth International.

2. Underground Coal Gasification

Underground Coal Gasification (UCG) is a technology that gasifies coal seams in situ underground, creating syngas (or synthesis gas) – mainly a mixture of hydrogen, methane, carbon dioxide and carbon monoxide – to be used for either electricity production or industrial chemical processes.

2.1 Technology

UCG involves drilling two wells some distance apart directly into an underground coal seam. The wells are connected through the coal seam, usually through directional drilling techniques. The injection well is used to pump oxygen along with an ignition catalyst into the coal seam. The coal is ignited, and then partially combusts with the injected oxygen. Water in the coal seam or the surrounding strata flows into the cavity and is essential for the series of chemical reactions that take place to produce raw syngas, a mixture of carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), carbon monoxide (CO) and other contaminants including sulphur and trace metals. The gas mixture travels through the production well to the surface gas plant where it is treated and cleaned.[1] As the coal is gasified, the gasification cavity expands and moves along the coal seam. Eventually, this causes the cavity roof to collapse. Pyrolysis (high-temperature decomposition without oxygen) of the coal also takes place as the coal is heated.

Syngas can be used as the base feedstock for a whole variety of chemical products and processes, or combusted to produce electricity.[2]

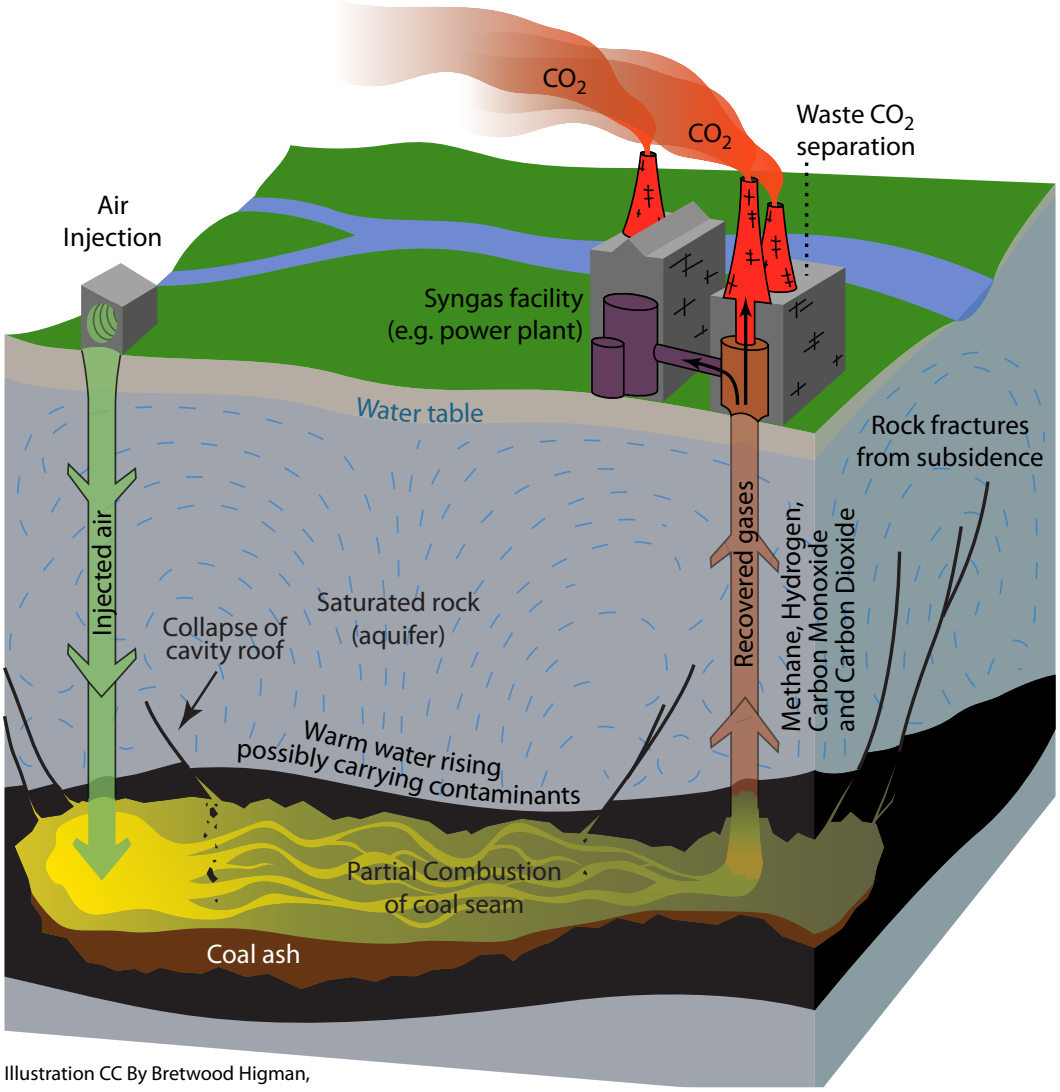


Illustration CC By Bretwood Higman,

Diagram 1: Underground Coal Gasification

2.2 Brief history[3]

The USSR researched extensively into UCG from the 1930s and by the 1960s five UCG stations were operating. Only one of these remains operating today – the Yerostigaz UCG plant in Uzbekistan that feeds syngas to the 480 MegaWatt (MW) Angren electricity station.[4]

In the US, initial tests took place in the 1940s-50s, with larger experiments conducted between 1972-1989. Several trials, including Hoe Creek, Hanna, and Rocky Mountain tests, resulted in groundwater contamination. After the 1980s' decline in oil and gas prices, large-scale UCG projects were no longer commissioned.[5]

Trials were undertaken in Europe in the 1980s, including the unsuccessful Thulin project in Belgium that failed to gasify the seam. In 1997, Spain, the UK and Belgium ran a joint UCG project at El Tremedal, Tereul, Spain where three tests were carried out. While the first two succeeded in producing syngas, the third test experienced technical problems when an aquifer above the coal seam flooded the gasification cavity. Both the ignition system and temperature measurement system failed, resulting in an accumulation of methane and a subsequent explosion.[6]

Table 1: History of UCG projects

List of UCG test projects around the world (not exhaustive)[7]				
Test site	**Country**	**Company**	**Date**	**Comment**
Angren	Uzbekistan		1965-present	Environmental impact unknown
Hanna 1	USA		1973-74	Test measured increase in metals including ammonium and boron in groundwater
Hanna 2	USA		1975-76	Very basic testing of process and monitoring equipment
Hoe Creek 1	USA		1976	Groundwater contamination including phenols, benzene, toluene and metals
Hanna 3	USA		1977	Groundwater impacts recorded related to low groundwater influx into cavity, causing low hydrogen content
Hoe Creek 2	USA		1977	Phenol concentration of up to 10mg/litre measured 10 metres from reactor
Hanna 4	USA		1977-79	Condensates from the process gases contained very high phenolic concentrations, nearly 7,000 ppm.
Hoe Creek 3	USA		1979	Groundwater contamination persisted at least 15 months after test
Pricetown	USA		1979	No environmental information available
Rawlins 1 and 2	USA		1979	Contamination by phenol and benzene recorded, above Maximum Allowable Concentration. Benzene was detected 183 metres away.
Brauy-en-Artois	France		1981	Coal failed to gasify
Thulin	Belgium		1982-84	First trial at depth below 860 metres; limited success
Centralia Tono A	USA		1984-85	No environmental information available

Centralia Tono B	USA		1984-85	No environmental information available
Haute-Deule	France		1985-86	Coal failed to gasify
Rocky Mountain 1 and 2	USA		1987-88	Groundwater contaminated with significant levels of boron, ammonia and phenols; groundwater quality was affected 120 metres away; elevated concentrations of sulphates and ammonia measured a number of years after the test.
El Tremedal	Spain		1997	3rd test resulted in methane blockage and subsequent explosion
Hopeland	Australia	Linc Energy	1999-2013	Company charged on five counts of 'wilfully and unlawfully causing serious environmental harm'; contaminants escaped the well; company now in liquidation.
Majuba	South Africa	Eskom	2007-2015	Closed in 2015; Eskom noted ZAR 1.05 billion impairment (US$70 million)
Walanchabi City	China	ENN Group Co. Ltd.	2007-?	Environmental impact unknown
Bloodwood Creek	Australia	Carbon Energy	2008-12	Company charged with releasing contaminated water into environment; fined total A$100,000
Swan Hills ISCG	Canada	Swan Hills Synfuels	2009	Depth of 1400 metres (deepest recorded)
Mikołów	Poland	EU-funded	2009-10	Groundwater contamination including arsenic, lead and mercury
Kingaroy	Australia	Cougar Energy	2010-11	Company charged with contaminating bores with benzene and toluene; fined A$75,000

2.3 Current developments

There is only one supposedly commercial UCG plant in the world. Linc Energy's Yerostigaz UCG plant in Angren, Uzbekistan, has been operating since 1965. According to Linc Energy, the plant produces 1 million m^3 of syngas a day from its coal reserves, to be used for electricity generation at the nearby 480MW Angren Power Station.[8]

Elsewhere, the last two decades have seen a surge of interest in UCG. In Australia, several companies have undertaken test trials, three of which took place in South Queensland. All three UCG projects have resulted in their operators – Cougar Energy, Carbon Energy and Linc Energy – being prosecuted over serious contamination incidents. In April 2016, the Queensland Government permanently banned UCG in response to major groundwater and soil contamination resulting from one of Linc Energy's trials.[9,10]

Eskom's Majuba UCG pilot plant in Mpumalanga, South Africa, began operations in 2007 and shut down in 2015. It initially co-fired a single burner at the nearby Majuba power station,[11] and subsequently the gas was flared.

Recent test trials have taken place in Canada and the US mainly by Australian companies. A deep test trial at a depth of 1400m has been completed in Alberta, Canada by Swan Hills Synfuels.[12]

China is heavily researching UCG with Chinese engineers obtaining many patents for the technology.[13] Pilot projects have been conducted in Inner Mongolia, including at the Gonggou mine, Wulanchabu City[14] and the Meiguiying mine.[15] India and Pakistan have

also carried out initial tests and identified sites for exploitation.

Most activity happening in Europe is taking place in Poland and Ukraine, including an EU-funded project looking at UCG and hydrogen production (called HUGE) where field-tests have been undertaken, while Bulgaria is conducting feasibility studies.[16] In the UK, two companies, Cluff Natural Resources and Five Quarter (which recently ceased trading), hold a total of 19 UCG licences, all of which are in near and offshore waters, though no trials have taken place and there is currently a moratorium on UCG in both Scotland and Wales.

2.4 Environmental risks

UCG emits greenhouse gases from the gasification process, as fugitive emissions from the site equipment and from syngas use. Although no coal mining is necessary, UCG still poses risks of groundwater and surface water contamination, ground subsidence and risks to workers' and public health. Harmful wastes are created requiring careful treatment and disposal.

Though there have been many trials around the world since the early twentieth century, there is very little evidence to suggest that the technology is viable on a long-term, commercial basis. A key challenge for operators has been controlling the gasification reaction, something 'difficult to achieve' underground, according to a UK Department of Trade and Industry review.[17]

A recent contamination incident in Australia highlights this challenge.[18] Linc Energy's Hopeland trial between 2007 and 2013 caused major contamination of surrounding soils and water from product gases, ending in the 'biggest pollution event probably in Queensland's history' according to the state Environment Minister.[19]

2.4.1 Climate change

UCG has the potential to create huge climate change emissions. Coal is a non-renewable fossil fuel; the process of turning coal into gas and then burning the resulting gas for energy generation or chemical products produces greenhouse gas emissions (GHGs) that contribute to the climate crisis.

There is international agreement that global warming must be limited to an average temperature rise of 2°C and it is also acknowledged that to avoid serious climate impacts for the most vulnerable nations temperatures must be kept lower, to below 1.5°C. This was reflected in the Paris Agreement in 2015 with governments committing 'to pursue efforts to limit the temperature increase to 1.5°C.' [20]

For a two-in-three (66%) chance of coming in under 1.5˚C, the global emissions budget [21] from 2016 is around 205Gt of carbon dioxide ($GtCO_2$).[22] For a 50% chance of staying below 1.5˚C, the carbon budget rises to $354GtCO_2$ from 2016. For a 50% chance of staying below 2°C, the remaining carbon budget from 2016 is 1,104Gt.

According to the World Energy Council, UCG could potentially open up access to around 600Gt of coal reserves,[23] though other estimations put this number far higher, at 4 trillion tonnes.[24] The carbon emissions resulting from Underground Coal Gasification of 600Gt of coal amount to 1650 Gt of CO_2:[25] more than the entire global carbon budget remaining for a 50% chance of avoiding 2˚C warming. This is of course on top of the 860Gt of coal already accessible by conventional mining,[26] at least 88% of which cannot be burned if the world is to have a chance of staying below 2°C of warming, let alone 1.5°C.[27]

2.4.1.1 Greenhouse gas emissions

If the syngas from UCG is used for electricity generation, comparisons can be made between different types of power stations in terms of GHG emissions.

Comparing only coal derived power generation, a 2014 study on life-cycle analysis of greenhouse gas emissions indicated that UCG emits less GHG emissions than all other coal-fired power electricity plants – approximately 774kg of CO_2 per MegaWatt hour of electricity ($kgCO_2/MWh$) compared to Coal-Integrated Gasification Combined Cycle ($784kgCO_2/MWh$); Supercritical Pulverized Combustion ($961kgCO_2/MWh$) and Pulverised Coal Combustion ($1,080kgCO_2/MWh$).[28]

Arguing that UCG is cleaner than conventional electricity generation from coal, the most dirty and polluting of the main fossil fuels, however, is not a reason to back UCG. The UK DTI's own comparison of CO_2 emissions (2003) suggested that a UCG-Gas Turbine Combined Cycle plant (UCG/GTCC) emitted twice as much CO_2 (around $800kgCO_2/MWh$) as a Natural Gas Combined Cycle ($400kgCO_2/MWh$).[29]

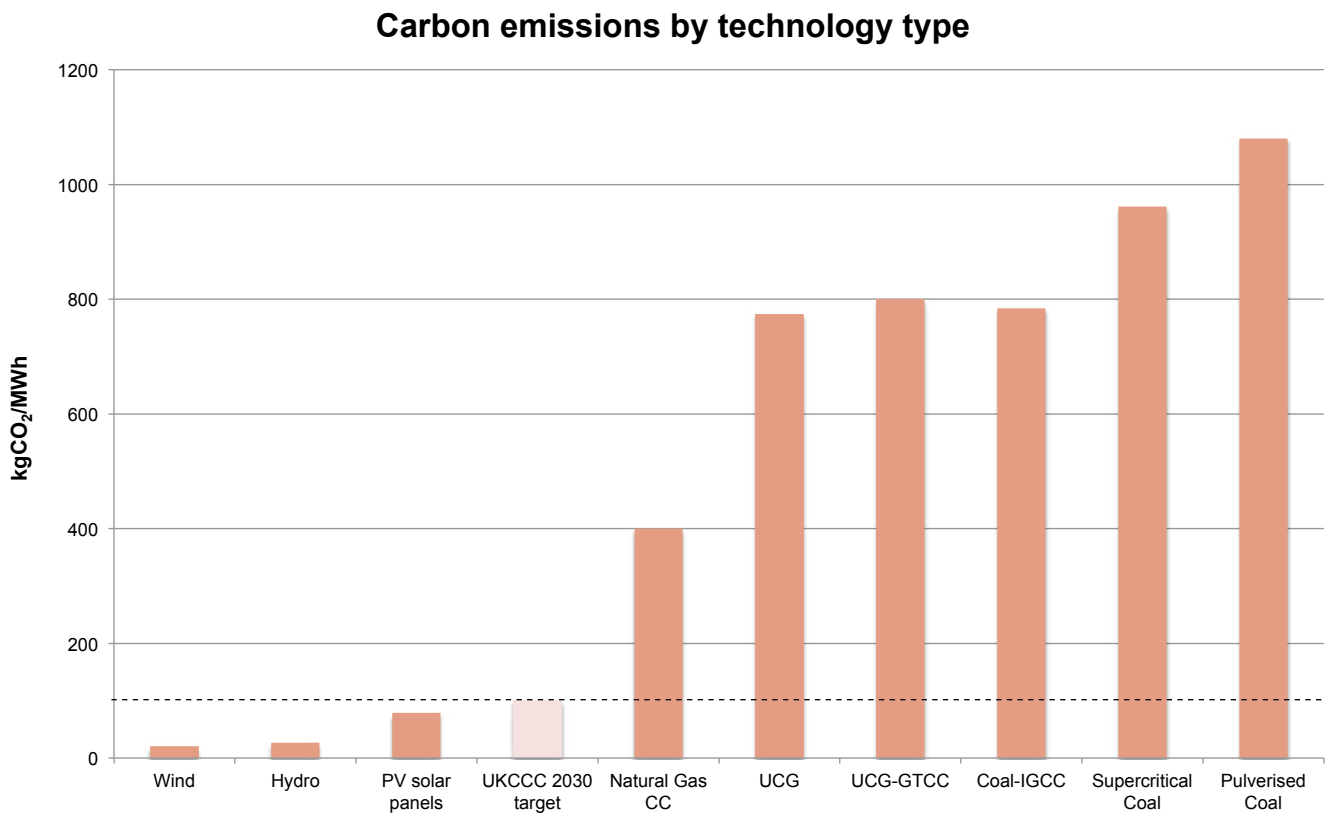


Figure 1: Carbon emissions by technology type[30]

Yet in light of the huge emissions cuts required to stay under a safe level of global warming, phasing out all fossils fuels for energy and transitioning to renewable generation in the near-term future is critical.[31] In this regard, UCG compares even less favourably with renewable sources like hydro (ranging from 3 to 27kgCO_2/MWh), wind (ranging from 14 to 21kgCO_2/MWh) and PV solar panels (around 79kgCO_2/MWh).[32] The UK Committee on Climate Change's target for electricity decarbonisation is under 100kgCO_2/MWh by 2030, around 8 times lower than UCG.

Fugitive methane emissions from UCG must also be taken into account when calculating UCG emissions and its contribution to climate change. Research has been conducted around methane leakage in coal mining,[33] natural gas,[34] shale gas fracking[35] and coal-bed methane industries,[36] as well as from the transportation of coal and gas over various distances.[37] However, UCG's infancy means there is a lack of data around fugitive methane emissions.

A cautious approach should be pursued in light of recent evidence that the US is leaking high levels of fugitive emissions of methane, previously unmeasured and unaccounted for. Methane levels in the US have increased by more than 30% over 2002-2014.[38] Commentators have made the link between shale gas fracking rigs, tanks and equipment and the methane leaks.[39] It remains to be seen whether UCG can adequately control fugitive methane emissions when large-scale development of shale gas fracking has failed to do so.

Finally, a whole life-cycle approach to carbon emissions from UCG must be considered. If the syngas from UCG is used to create Coal Chemical products such as fuels, gas and other chemicals, life-cycle emissions can further increase. The Coal Chemical section looks at this in detail.

2.4.1.2 Carbon Capture and Storage

UCG is often referred to as 'low carbon' because of its apparent compatibility with Carbon Capture and Storage (CCS) technologies. Proponents of UCG argue that CO_2 can be easily captured from the syngas using any of the three CCS methods: oxyfuel combustion which burns fuel in pure oxygen creating CO_2 and water vapour that can be separated; pre-combustion, which converts fuel into CO_2 and hydrogen to be separated; and post-

combustion, where the exhaust from the burnt fuel is chemically scrubbed of CO_2 in large silos.[40]

The International Energy Agency's latest Technology Roadmap on CCS (2013) argues that CCS technologies must be deployed at a significant rate to stop temperature rises of 2°C. It forecasts the need for around 7GtCO_2 to be stored annually by 2050.[41]

Extensive research has been done on the failure of CCS technologies to become commercially or technically viable in the last few decades. There are only 15 operating projects globally[42] which is 'far short of that required to significantly cut CO_2 emissions in the near future,'[43] particularly in keeping global temperatures below 2°C, let alone 1.5°C. Many of these projects are far from carbon neutral, with several projects using the captured CO_2 for enhanced oil recovery.[44] In the UK, the UK Government cancelled a £1bn grant competition in 2015 that aimed at developing new CCS technology,[45] causing both remaining competitors to cancel their projects. Worldwide, storage for captured carbon remains a key technical challenge.

Supporters of UCG highlight the possibility for the gasification cavity to be used for carbon sequestration, particularly if gasification has occurred at depths below 800m.[46] Researchers in 2014 analysing the potential for UCG cavities to store carbon, however, highlight challenges. First, the CO_2 may interact with substances in the gasification cavity, complicating storage.[47] There is already major uncertainty around long-term storage of CO_2. Any leakages could impact human health and the environment or the climate benefit of long-term storage.[48] Pressurised storage potentially creates seismic activity.[49]

Second, the volume of CO_2 that can be stored in the gasification cavity is much smaller than that produced during gasification – estimates have ranged from 11.6% to 20.5% storage of CO_2.[50] Third, the CO_2 can only be stored after the gasification process has stopped, creating challenges around interim CO_2 storage.[51]

CCS is a false solution to the climate crisis. In addition to the technical issues with implementation, doubts about its feasibility and serious leakage risks, it prevents serious action taking place now to reduce emissions at their source.

2.4.2 Groundwater contamination

According to a comprehensive 2004 review into the environmental implications and technological feasibility of UCG in the UK by the then Department of Trade and Industry, UCG poses risks to groundwater surrounding the gasification cavity.[52] Risks to groundwater (including nearby aquifers) depend on the depth, distance, geology, surrounding strata and other characteristics that affect the gasification process.

As the coal is gasified, product gases migrate towards the production well creating a range of hazardous environmental contaminants. These contaminants can move into surrounding groundwater during and after the termination of the UCG process,[53] as documented in the 2009 UCG field trial at the Barbara mine in Poland.[54]

Typical contaminants can include benzene, toluene, ethylbenzene, and xylenes (BTEX), phenols, coal tars, polyaromatic hydrocarbons, nitrogen oxides, ammonia, boron, cyanide, hydrogen sulphide, and heavy metals such as mercury, arsenic and selenium.[55] Different types of coal – e.g. lignite or hard coal – can produce different types of contaminants.[56]

An Eskom power plant and its surroundings, South Africa

Groundwater contamination can occur when contaminants in the form of liquids or gases flow outward from the gasification cavity into the surrounding groundwater. Theoretically, pressure and temperature inside the gasification cavity ensures that this does not happen, as groundwater should be drawn into the gasification cavity as negative pressure is maintained. However, a serious challenge with UCG is the lack of understanding around managing pressure and injection composition (air or oxygen), which enables control of the process.[57]

Contamination can also occur after gasification if pressure is not maintained. The 2009-2010 UCG trial in Poland found that solid by-products char and ash were left in the cavity after gasification had stopped. After the gasification process ceases and the coal seam cools, water invades the post-gasification cavity, causing leaching of contaminants from char and ash that contain elements such as arsenic, lead and mercury.[58] These contaminants were found in the groundwater of the Polish UCG trial.[59]

Blockages, formed when contaminants deposit or condense on to available surfaces including pipe work of the production well, can increase the risk of contamination. Blockages can form from the condensed tars from the fuel gas, causing collected water to become heavily contaminated, leading to a 'significant potential for groundwater pollution.'[60]

Previous UCG trials have resulted in groundwater contamination, for example the Hoe Creek and Hanna UCG trials in the 1970s that resulted in surrounding groundwater being polluted with 'concentrations of pyrolysis products and leachates' that exceeded pre-burn levels.[61] Phenol contamination in surrounding groundwaters was still present seven years after gasification at the Hoe Creek sites.[62] During the four Hanna trials, very high concentrations of phenols were recorded[63] and benzene persisted over many years.[64]

In Australia, Cougar Energy's demonstration plant was shut down after an independent scientific panel found benzene and toluene in nearby water boreholes,[65] as well as in the fat of nearby grazing cattle.[66]

More recently, Linc Energy's UCG test in Queensland, Australia, resulted in a major contamination incident when contaminants migrated across and beyond the reaction zone during gasification. These contaminants included 'syngas and its by-products, additional gases formed as a result of a succession of contaminating events; liquids in the form of contaminated groundwater, solids in the form of tars and oils; energy and odours; and a combination of gas-liquid mixtures.'[67] Hydrogen and hydrogen sulphide have migrated through underground pathways away from the UCG test site. An exclusion zone of 314km^2 has been put in place and farmers in the area are not allowed to dig more than two metres without notifying the Queensland Environment Department.[68] The cost of clean up is estimated at many millions of Australian dollars.[69] However, Linc Energy may never pay this as it has now gone into administration.[70]

2.4.3 Waste issues

UCG requires water as an essential component, either from within a coal seam or from a source adjoining the seam, for the gasification reaction to happen, or for post-gasification cleaning. This water will become contaminated during the gasification process.

At the 2013 UCG field trial in Poland, wastewaters from the production and cooling phase contained chlorides, cyanides and sulphates. Trace metals included arsenic, boron, chromium, zinc, aluminium, cadmium, cobalt, manganese, molybdenum, nickel, lead, selenium, titanium and iron.[71]

2.4.3.1 Waste creation

There are four phases during a UCG project that can create contaminated wastewater:[72]

1. During the initial mining phase, when water contaminated with solids from the strata is removed.

2. During the gasification process if too much groundwater infiltrates the gasification cavity and needs to be removed.

3. After gasification and pyrolysis if steam is injected to clean out contaminated substances in the cavity. This process is known as flushing or venting and will usually create the most heavily contaminated wastewater.[73]

4. After gasification when water is pumped to the surface from the gasification cavity to remove the contaminants from the ground and to maintain groundwater flow towards the cavity.

In the case of the Rocky Mountain 1 trial in 1987-88, around 16,600m^3 of water that was contaminated with

dissolved organics, heavy metals and ammonia[74] was pumped out of the gasification cavity.

As well as during the UCG process, the subsequent cleaning of the raw syngas at the surface plant creates contaminated wastewater.

Process water can be returned to the gasification cavity while gasification continues to help continue the reaction, but the water must be monitored in case contaminants build up that could compromise equipment.[75] An excess of water from the surrounding strata entering the gasification cavity can also cause operational problems, and must be pumped to the surface for treatment.[76] At the El Tremedal UCG pilot trial in the 1990s, an aquifer situated above the gasifying coal seam flooded the gasification cavity, causing a blowback of phenolic liquor that passed to the surface under pressure and coated the UCG site with toxic residue.[77]

Solid wastes are also created. Wastewater consists of produced water with particulates, dissolved gases, hydrocarbons and salts. About 3-5% of UCG wastewater settles into sludge. This sludge can be odorous and contain high concentrations of BTEX, hydrocarbons and phenols.[78]

2.4.3.2 Waste disposal

UCG waste must be carefully stored, handled, treated and disposed of to minimise health and environmental impacts.

One of the few sources of information on UCG wastewater treatment and disposal is a 2015 study looking at Linc Energy's UCG sludge. The study found that the waste contained high levels of benzene, toluene, ethylbenzene and xylene (BTEX), heavy metals and was extremely odorous. In particular the benzene concentration was at 1600mg/kg. By way of comparison, WHO guidelines state that benzene should not be above 10mg/kg in drinking water. Further, the powerful odours emanating from the sludge in the Hopeland UCG plant had, anecdotally, 'been associated with complaints in neighbouring populations, including headaches, nausea, vomiting, nosebleeds, irritation of nose, throat and eyes, rashes and sores and asthma.' [79]

The study showed BTEX, heavy metals and odour decreased when the waste is treated through oxidation, biostimulation and metal sequestration.[80] However, it also highlighted that the literature and research into treatments of UCG wastes is extremely limited.

Wastewater from syngas cleaning also requires careful disposal. Wastewaters can be odorous, leading to issues around transportation, storage and long-term monitoring if waste can only be treated to a certain standard. A fuller explanation of the syngas cleaning process and treatment can be found in the Coal Chemical section.

2.4.4 Surface water contamination

Surface water can be contaminated if:

- Contaminated groundwater from the gasification cavity or a faulty well reaches the surface
- Wastewater from UCG is discharged into local water courses
- There are spillages of contaminated fluids during the drilling, gasification, flushing and venting process on the site[81] as well as during transportation of wastewaters or contaminated products.

In 2012, Carbon Energy, a company carrying out a UCG test in Kingaroy, Queensland, were charged with 'disposing of processed water by irrigating it to land without approval' and fined A$60,000 and a further A$40,000 in legal and investigation costs.[82]

2.4.5 Subsidence

UCG increases the risks of subsidence as the gasification cavity expands, changes shape and alters temperature.

Strata characteristics, geology, coal type, groundwater, gasification capacity and other characteristics all affect the subsidence risk.[83] Gasification of a coal seam may add stress to surrounding rock causing it to collapse, which may create pathways for liquid or gas contaminants, or may enable a link between an overlying aquifer and the gasification cavity.[84] Existing natural faults in the rock as well as man-made stresses such as nearby abandoned mine workings all increase the likelihood of subsidence and the creation of contaminant pathways.

Experience of subsidence from conventional mining cannot wholly be used for modeling subsidence risks during and after UCG because the rocks are heated at

high temperatures during gasification, as opposed to just removed from the strata, which adds more stress. As well as this, bulking of the overburden rocks may happen at a slower rate because coal burning occurs from the bottom to the top of the seam, creating a slower rate of vertical displacement than conventional mining. This increases the risks of surface subsidence.[85] The behavior of coal seams and rocks at high temperatures during and after UCG is complicated, with experts highlighting the lack of certainty and need for broader knowledge and modeling around thermally-altered rocks.[86]

Generally, a larger gasification cavity creates a greater risk of subsidence[87] and a commercial-scale UCG project may potentially result in 'unignorable ground subsidence.' [88] However, there is also a lack of data that would provide concrete examples (due in part to the technology's infancy, as well as Soviet trials being conducted in isolation from the West).[89] This adds uncertainty in prediction and modeling.

It is widely acknowledged that the deeper the gasification cavity, the less risk of surface subsidence, with below 300m underground recommended.[90] However, subsidence has been measured at deeper UCG trials as well as shallow trials. For example, subsidence has been recorded in a Donetsk UCG project at 400m underground.[91]

2.5 Worker health and safety

Because there have been so few commercial scale projects of UCG around the world, comprehensive data on worker health and safety is unavailable. However, recent events in Queensland, Australia can provide some detail on the levels of risk associated with UCG.

In 2015, the municipal government of Queensland undertook an extensive investigation (not yet concluded) into whether Linc Energy had exposed workers to dangerous gases at their UCG test plant in Hopeland.[92] Anecdotal evidence from workers indicated dangerously high readings of carbon monoxide on site, leading to workers getting headaches. Other workers who were exposed to the produced water suffered nausea and chest pains.[93]

2.6 Conclusion

The development of a UCG industry will emit high levels of CO_2 further fuelling climate change, at a time when countries should be shifting to low-carbon economies and energy sources. Additionally, UCG's history of groundwater pollution, including the contamination incident in Queensland, Australia, highlight the unacceptable local environmental pollution problems, to say nothing of the problem of dealing with high levels of toxic waste.

The case studies from Australia, South Africa and the US document further experiences of pollution from UCG trials.

Countries pursuing UCG – including Australia, South Africa and Europe – must focus on the long-term environmental and health risks and ban this industry before it is responsible for even more environmental damage.

An Eskom power plant, South Africa

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p. 11: "An Eskom power plant and surroundings" by Megan Lewis, groundWork South Africa is used with kind permission.

3. Coal Chemicals

Coal Chemicals refers to the different processes of turning coal into a suite of chemical products for different uses. Most of these processes use syngas (synthesis gas – a mixture of hydrogen, methane, carbon dioxide and carbon monoxide) as their base feedstock.

Coal-to-Liquid processing turns coal into liquid products, predominantly to be used as transport fuel but also with the possibility of further refinement.

Coal-to-Gas is the process whereby Synthetic Natural Gas is created. It can be used for heating, transportation, industry and further chemical production.

Coal-to-Chemicals processes can create a range of chemical products from coal. These include methanol, ammonia, and olefins used for plastics, cosmetics, pharmaceuticals, and cleaning agents. Methanol, ammonia and olefins can be further processed to produce formaldehyde, solvents, acetyls, urea, propylene and ethylene that can be used among other things for building materials, household cleaning products, paints, cosmetics and fertilisers.[1]

Coal-derived syngas can also be used for power generation, where the syngas is burnt to produce electricity from steam turbines. This will be referred to as 'Coal Gasification for electricity' for the purpose of this report.

This chapter reviews the current status of Coal Chemicals in key countries and the environmental and climate change impacts that these industries entail.

The Coal Chemical industry is well established in several countries, meaning an exhaustive review of all activities is outside the scope of this report. However recent developments – particularly in China – are discussed in this chapter as well as in the China case study.

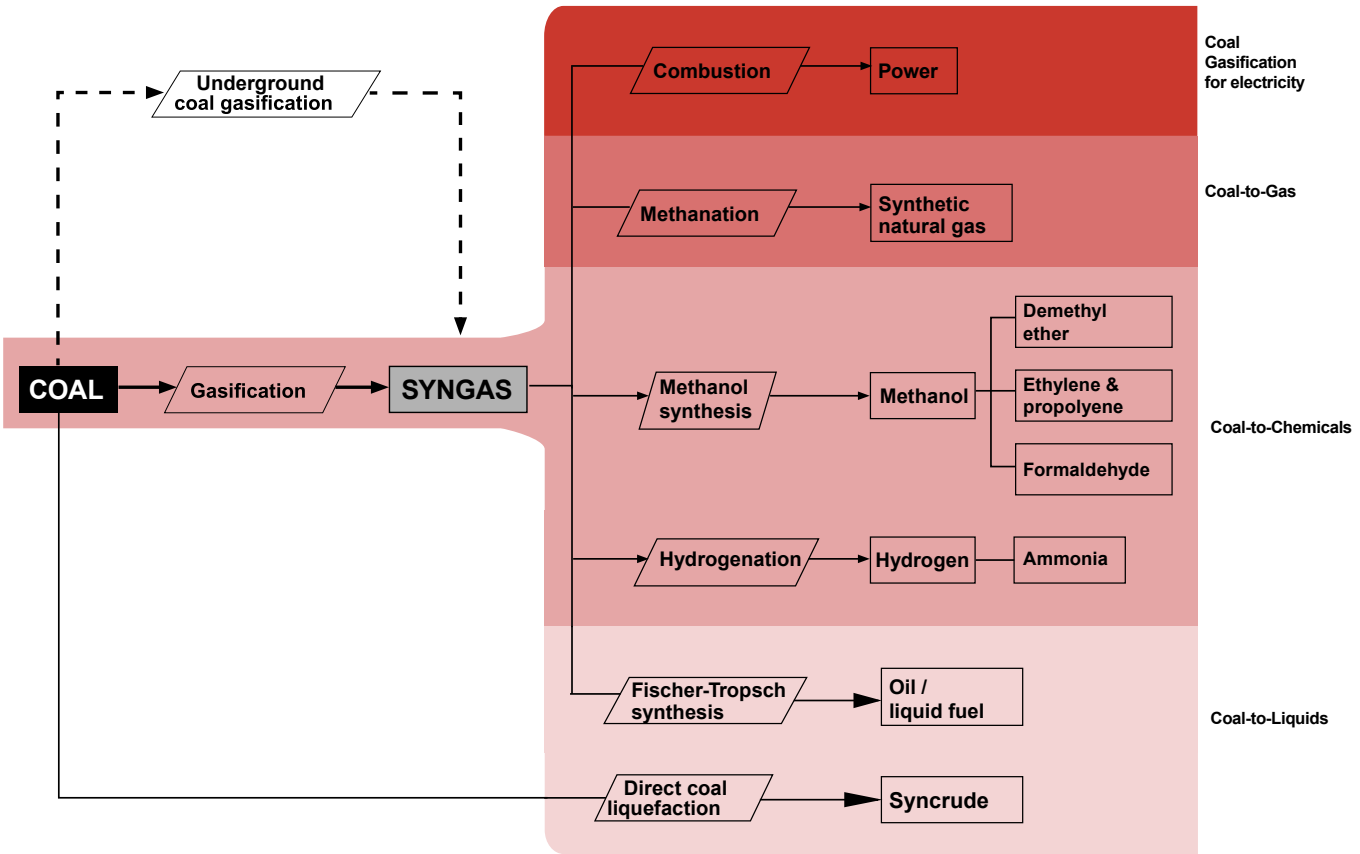

Diagram 2: Coal Chemical processes

3.1 Coal-to-Liquids

Coal-to-Liquids (CTL) technology is the process of turning coal into liquids, predominantly synthetic oils for fuel use. CTL processing is energy intensive so results in high emissions of CO_2 and creates impacts on local ecosystems through coal and water use as well as waste disposal.

3.1.1 Technology

There are two main ways to convert coal into liquid fuels. Direct Coal Liquefaction (DCL) is the process where coal is dissolved under high pressures and temperatures. The addition of hydrogen and a catalyst causes hydro-cracking, which breaks long carbon chains into shorter, liquid components. The liquid created is known as 'syncrude', and requires further refining before it can be used as a transport fuel.

Unlike DCL, Indirect Coal Liquefaction (ICL) completely breaks down the coal through gasification into syngas. The syngas is then processed with hydrogen and carbon monoxide, cleaned of impurities, and reacted over a catalyst in a process called Fischer-Tropsch synthesis.[2] ICL creates a liquid product that is regarded as cleaner and more easily useable as a fuel.[3]

3.1.2 History

Historically, development of CTL took place in Germany during the two world wars, with synthetic liquid fuel crucial to Nazi Germany's war efforts in the Second World War.[4] South Africa invested heavily in the technology during the 1950s and the industry developed further because of South Africa's increasing isolation and need for oil during the apartheid regime. CTL now plays an important role in their fuel supply. There have been smaller pilot plants in the US but these have struggled to get off the ground commercially. During the 1970s, China looked into research and development of CTL and throughout the 1980s and 1990s there were experiments in DCL and ICL. From the mid-1990s until recently, the Chinese government has supported the industry with financial incentives.[5]

3.1.3 Current developments

Many countries have an interest in CTL technology, including China, the US, India, Japan, Australia, Botswana, Germany, Indonesia and the Philippines. A large commercial ICL plant currently in operation is in South Africa, owned and operated by Sasol (see South African case study).

China is the biggest player in coal liquefaction research and development for both DCL and ICL. According to 2015 analysis by Greenpeace East Asia, around 13 CTL projects exist; 5 of these are in operation and a further 8 in the construction and planning phases. The combined capacity if all of these projects start operating will be around 18.8Mt of liquid fuel produced a year.[6] Shenhua Group is a major player with three projects in Inner Mongolia.

However, since 2008 the Central Chinese Government has been less enthusiastic and has reversed supportive policies and incentives[7] because of oil, coal, water, and land scarcity, highlighting how resource-intensive CTL technology is. Nevertheless, regional governments continue to pursue CTL technology in an effort to boost local GDP.

In Australia, the 1990s and 2000s saw many companies and projects in the pipeline, including plans for DCL and Fischer-Tropsch production. However, nearly all these projects failed to get off the ground because of huge start-up and running costs[8] as well as technical difficulties.[9] CTL was trialled at Linc Energy's UCG project in Hopeland (now closed and subject to a court case). Ackaringa Coal Chemical is planning a combined UCG-CTL-CCS facility.

In the US, plans for 13 projects were documented in a 2008 study.[10] Even with political and financial support (see US case study), only two were partially constructed and it is extremely doubtful whether they will become operational.

3.2 Coal-to-Gas

Coal-to-Gas (CTG) converts coal into Synthetic Natural Gas (SNG) to be used for heating, industry and fuel. Experience from the US highlights the lack of commercial viability in producing SNG from coal.[11] Compared to conventional natural gas (methane), more energy and processing is required to get the SNG to an adequate quality. Large demonstration CTG projects in China are causing environmental problems including excess water consumption and waste disposal issues.

3.2.1 Technology

Transforming coal into gas requires the coal to first be gasified in the presence of catalysts to create syngas. The carbon monoxide and carbon dioxide in the syngas are converted into methane in a process called methanation. To reach gas quality requirements, impurities like water and remaining carbon dioxide are removed.[12]

3.2.2 History

Development of town gas for lighting and heating initially took place in the nineteenth century. In the US, interest in SNG began in the 1960s when government and industry became concerned about shortages of natural gas due to rising demand. New research and development was undertaken into the possibility of converting coal and lignite into gas through the methanation process. The US was the key driver of the research, especially after the 1970s' oil crisis, though the UK and Germany were involved in several research projects and there was also development in Japan. A few pilots and demonstration projects were constructed in the US but only one commercial SNG plant was built. The Great Plains Synfuels Plant in North Dakota, operated by Dakota Gasification Company, opened in 1984.[13] It has been producing 4.8 million cubic metres (m^3) of SNG per day since.[14]

The Great Plains Synfuels Plant is the only large-scale commercial CTG plant outside of China, and its troubled financial history reveals the unprofitable nature of the industry. The plant opened in 1984 after it was granted US$2.05 billion in Government loan guarantees and went bankrupt within two years. Later operations relied on heavy subsidies from the US Department of Energy, as well as a 25-year agreement between the plant's operator and pipeline companies that allowed it to sell SNG above the market price of natural gas.[15] It has remained open to a large extent because of previous bankruptcy agreements and government loans as well as diversifying into other Coal Chemical products,[16] including fertilisers, solvents, phenols and carbon dioxide.[17]

3.2.3 Current developments

In 2008, there were at least 12 CTG projects in the planning stages in the US. However, the collapse of the natural gas price (from US$10/MBTU and US$12/MBTU in the summer of 2008 to below US$3/MBTU in 2012) meant that none of these projects have gone ahead.[18]

China is heavily promoting CTG for SNG to meet its rising gas demand for domestic heating, power generation, chemical industry and industrial fuel and in an effort to curb air pollution in its large cities by displacing coal-fired power generation. As of 2012, around 30 SNG projects were under construction or in the planning stages.[19] In 2013 alone, the Chinese central government approved nine large-scale SNG plants with a combined capacity of 37.1 billion m^3/yr.[20] By 2014, around 50 CTG plants with a combined capacity of 225 billion m^3/yr of SNG were being planned or constructed.[21] As of December 2015, three plants are operating with a combined SNG output of 3.11 billion m^3/yr.[22]

In South Korea, a Coal-to-Methane project operated by Posco is expected to have a capacity of 4.5 billion m^3/yr when it opens.[23] However it is behind schedule by around two years and facing financial difficulties amid low Liquid Natural Gas (LNG) prices.[24]

3.3 Coal-to-Chemicals

Syngas derived from coal can be converted into a whole range of products including methanol, ammonia and olefins. Methanol is used for plastics, cosmetics, pharmaceuticals and transport fuel. Ammonia is commonly used in cleaning agents, and olefins such as propylene and ethylene are used in plastics, fibres and building products. Methanol, ammonia and olefins can be further processed to produce formaldehyde, solvents, acetyls and urea that can be used for building materials, household cleaning products, paints, cosmetics and fertilisers.[25]

A surface coal mine in Inner Mongolia, China

3.3.1 Chemical processes

Hydrogen is required to produce methanol and ammonia from syngas. Syngas can be converted into hydrogen in a process known as the Water Gas Shift (WGS) reaction. WGS requires temperatures of 300-500°C and uses an iron-oxide based catalyst. This is usually followed by a lower-temperature reaction based on a copper-zinc oxide catalyst that produces a high conversion to hydrogen.[26]

Methanol is produced when a syngas mixture is reacted over a catalyst and combined with the WGS reaction as above. Methanol can be further processed to create olefins through a complex chemical process called steam cracking (also known as thermal pyrolysis). From olefins can be derived both ethylene and propylene.[27]

To produce ammonia, hydrogen is reacted with atmospheric nitrogen over a catalyst in a process known as hydrogenation. Ammonia can then be further processed to produce urea, used as a fertiliser.

3.3.2 History

So-called 'Clean Coal' research programmes were established in the US, Japan and the EU in the 1980s-90s. Among other things, these research programmes focused on using coal in 'cleaner ways', and became the precursor to development in the Coal Chemical industry globally. In the US, research into methanol production was carried out during the 1970s as part of the search for alternative motor fuels.[28] China has been pursuing methanol production since 1995, and the industry has grown quickly since then.[29]

3.3.3 Current developments

The vast majority of petrochemical products in the global chemical industry are derived from petroleum. However, China predominantly uses coal as the base feedstock.

China has a particular focus on methanol from coal, its production accounting for more than half the global methanol output (the other half produced outside China is predominantly made from natural gas). In 2014, China produced 37.4Mt of methanol, with around 80% of this from coal.[30] Much of Chinese methanol is used to create Dimethyl Ether (DME) for heating and cooking. Global annual production of DME is around 10Mt, most of this from China.[31]

Coal-to-Olefin technology is new and largely limited to China. Chinese capacity has risen from almost nothing in 2010 to around 12Mt/yr in 2015. Over 45 Coal-to-Olefin plants are planned in China by 2019, with a combined total output capacity of over 28Mt/yr.[32]

3.4 Environmental risks

Coal wagons belonging to Shenhua Group at Xinghuo Railway Station, Beijing, China

3.4.1 Coal mining impacts

Coal Chemical industries consume very large amounts of coal. This coal must be mined, cleaned and transported before it is gasified or used for the plant operation. The damaging impacts of coal mining on health and the environment have been well documented.

Coal mining (surface, underground and mountain top removal) causes major health impacts including cancers, heart disease, strokes and chronic lower respiratory diseases.[33] Pollutants including cadmium, selenium, arsenic, copper, lead, mercury, ammonia, sulphur, nitrates, nitric acid, tars, oils, fluorides, chlorides, sodium, iron and cyanide can contaminate watercourses while dust particulates create air pollution.[34] Wastewater from the coal mining and the cleaning process must be treated to reduce environment harm when disposed of. Forests and ecosystems are often destroyed to make way for surface coal mines or during mountaintop removal, and underground mining can cause surface subsidence.[35]

Very large amounts of coal are required for all Coal Chemicals processes. A 2010 study highlighted that

Sasol's ICL plant in South Africa consumes 36.2Mt/yr of coal (the equivalent to around three 4GW power stations) and produces 15,000bbl/d. This leads them to estimate that approximately 1 tonne of coal is required to produce approximately 1-1.4 barrels of synthetic fuel.[36]

CTG also requires large amounts of coal. The coal-based SNG plant in Chifeng, Inner Mongolia produces 4 billion m^3/yr of SNG and consumes 22.9Mt/yr of lignite.[37] With these figures, we can estimate that 1 tonne of coal produces around 175m^3 of SNG at this plant.

3.4.2 Greenhouse gas emissions

CTL is extremely carbon intensive. Research from 2008 indicates that CTL emits nearly twice as much CO_2 (just under 1 tonne of CO_2 per barrel) compared to conventional diesel production (at around half a tonne of CO_2 per barrel) on a well-to-wheel basis.[38] Other estimates of ICL calculate that approximately 80-110% more CO_2 is emitted than conventional fuels if the CO_2 is vented.[39]

Capturing the carbon emissions during CTL has been posed as an option, particularly with DCL technology where hydrogen sulphide and carbon dioxide can theoretically be co-captured and stored.[40] ICL also potentially offers opportunities for GHG mitigation as additional syngas from the process can be used to generate additional synthesis fuel.[41]

However, CCS technology has failed to reach commercial viability, as documented in section 2.4.1.2 on Carbon Capture and Storage. And even with CCS, CTL production-chain emissions will always be higher than for conventional petroleum-derived products, in large part because of the mining process to extract the coal,[42] as well as from the energy required for the conversion process. Further, it will not be possible to capture most of the carbon emissions, as fuel will ultimately be burnt where it cannot be sequestered – in vehicle engines.

Emissions from CTG are 20-108% higher than from conventional natural gas depending on end use.[43] Each cubic metre of SNG emits around 7.9kgCO_2 in its full lifecycle, compared to pipeline natural gas and liquefied natural gas (LNG) that emit around 2.2 and 2.5kgCO_2 respectively.[44] If SNG is used to generate electricity, life-cycle emissions are around 36-82% higher than conventional coal-fired power.[45]

Other CTC processes emit similarly high levels of GHGs. In terms of life cycle emissions, each tonne of coal-derived methanol is responsible for about 5.3tCO_2 compared to 1.7tCO_2 from natural gas-based methanol.[46] Olefins are similarly carbon intensive – for the same amount of olefin output, coal-derived olefins are responsible for 7 times more CO_2 than naphtha-based olefins and 9 times more than ethane-based olefins.[47]

Acland Coal Mine in the Darling Downs region, Queensland, Australia

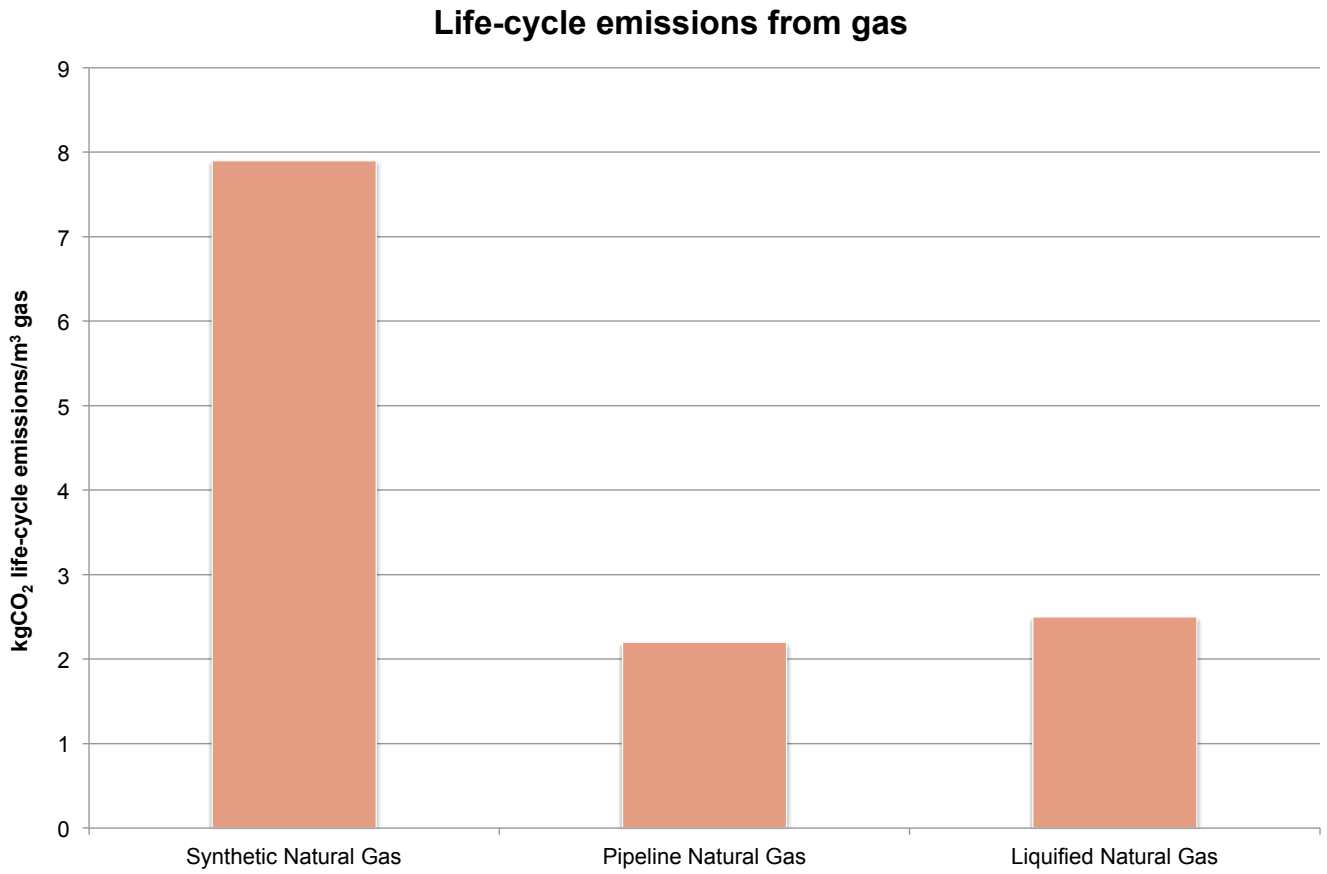

Figure 2: Life-cycle emissions from gas[48]

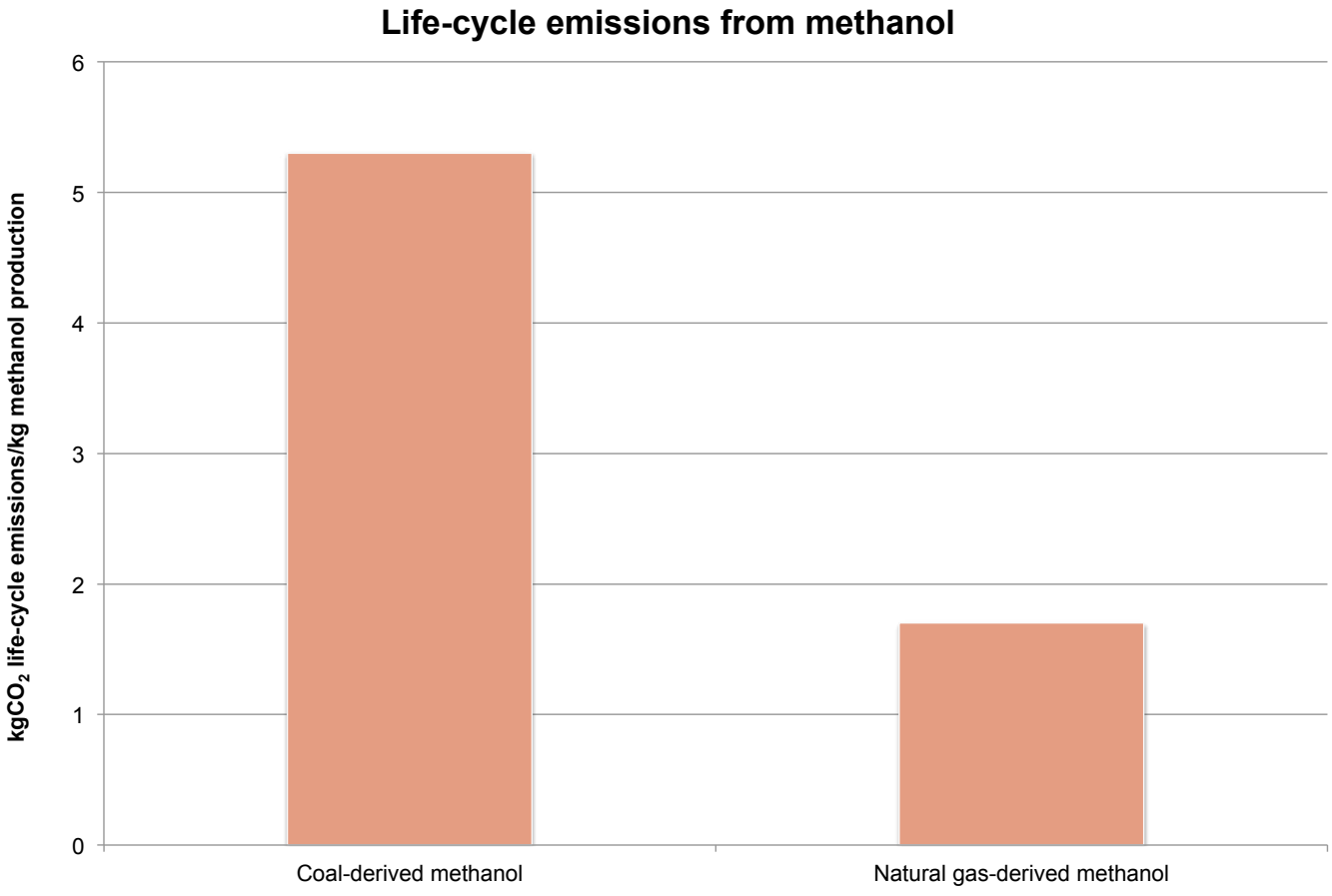

Figure 3: Life-cycle emissions from methanol[49]

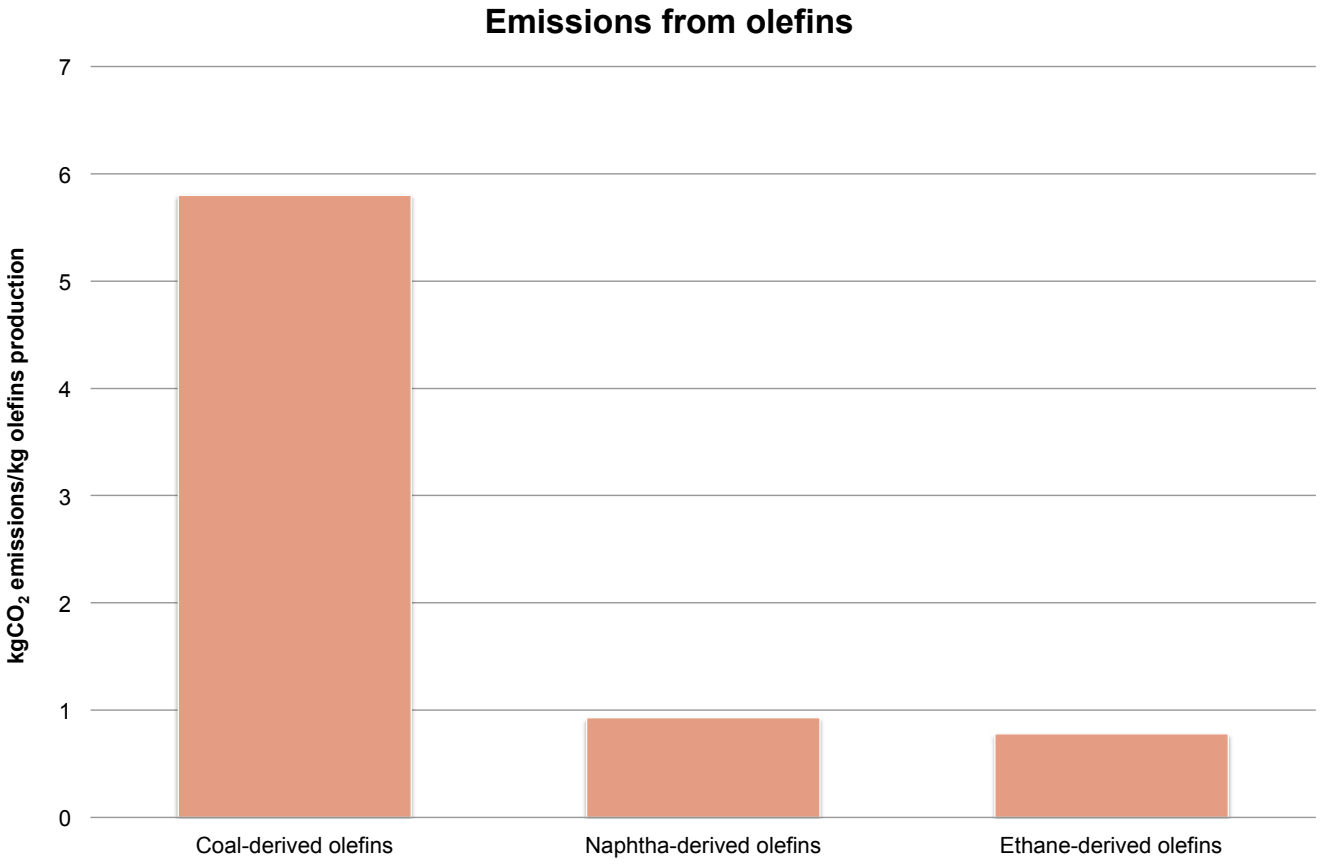

Figure 4: Emissions from olefins[50]

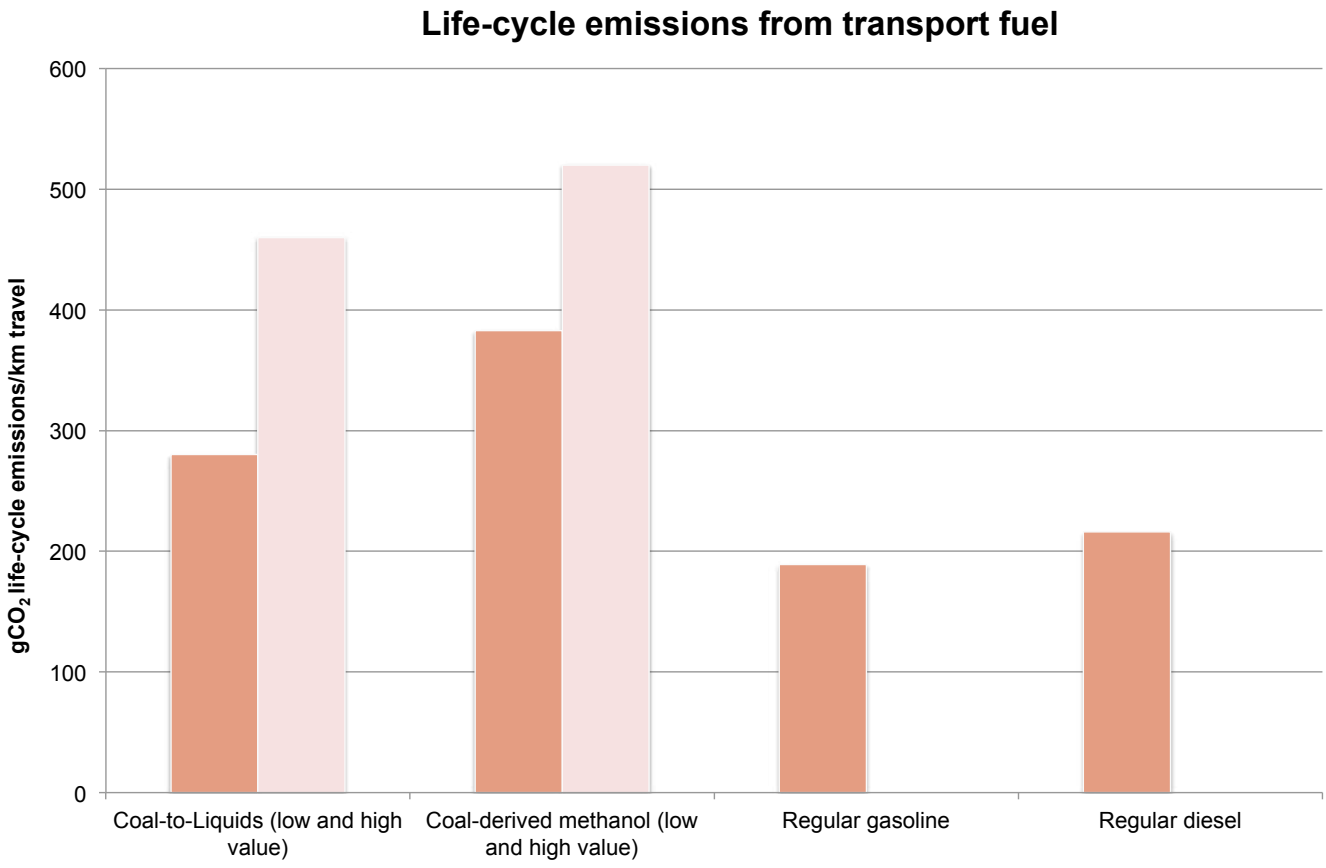

Figure 5: Life-cycle emissions from transport fuel[51]

3.4.3 Climate change

The climate change consequences of shifting towards significant production of Coal Chemicals would be extremely serious. As already outlined in the section on UCG and climate change, continuing to exploit coal at current levels would blow the world's chance of staying under 1.5°C of warming.

China's plans for large-scale development of CTG have potentially global consequences. 2013 analysis indicated that if the 40 projects that were in the planning and construction stages in 2013 became operational around 110GtCO_2 would be emitted over the next 40 years.[52] China's carbon dioxide emissions in 2011 were around 9Gt.[53]

In terms of CTL, even a partial transition from conventional oil to low-quality carbon intensive coal-derived liquid fuels could raise climate change emissions by several Gigatonnes of carbon per year by mid century, depending on the level of transition.[54] These emissions would lock in dangerous levels of warming and use up the world's carbon budget to stay under 1.5°C.

3.4.4 Water consumption

Coal Chemicals processing requires huge volumes of water. The water-intensive nature of the industry is one of the reasons why the Chinese Government has recently stalled its huge Coal Chemical plans.

Though water consumption varies depending on plant design and specification, DCL and ICL are very thirsty processes. Water is used for cooling, cleaning and the CTL process. There are estimates that 1 tonne of oil produced from DCL requires 8-9 cubic metres (m^3) of water, and ICL requires 12-14m^3. Other estimates put DCL and ICL approximately on a par, with 1 tonne of oil requiring between 5-12m^3 of water.[55]

For SNG, one cubic metre of SNG is estimated to require approximately 6-12 litres of water.[56] The Great Plains Synfuels CTG plant consumes 9.24 million m^3 of water every year.[57]

According to estimates of Chinese Coal Chemical industries, every tonne of coal-derived ammonia requires 27m^3 of water[58] and every tonne of methanol requires around 20m^3 of fresh water.[59]

Many of China's demonstration and planned Coal Chemical projects are located in areas of water scarcity.[60] Shenhua has come under recent scrutiny for the high water consumption of its DCL project at Ordos, Inner Mongolia. The project consumes approximately 14.4 million m^3 of water annually, and is accused of having a devastating impact on the local environment – the water level has dropped by around 100m in some areas, decreasing vegetation cover and causing difficulties for local herders and farmers.[61]

3.4.5 Waste from syngas cleaning

Raw syngas from coal gasification contains an array of toxic substances including sulphur, hydrogen chloride, ammonia, hydrogen cyanide, ash and trace metals such as mercury, arsenic and selenium. Though different Coal Chemical products will require different compositions of chemical substances, generally these toxic elements must be removed and disposed of before the syngas can be processed into liquid fuels, Synthetic Natural Gas or further chemical products. The treatment of these toxic substances requires significant volumes of water (for water washes), and creates contaminated wastewater and other wastes including metal adsorbents requiring specialist treatment.[62]

According to the former UK Department of Energy and Climate Change (2009), ensuring that contaminants in syngas are removed in 'an environmentally friendly, cost effective' way is a 'major technical concern.'[63]

3.4.6 Waste disposal

At the only commercial SNG plant in the Western world, the Great Plains Synfuels SNG plant, around 11.36m^3 of wastewater is produced every minute.[64] A portion is recycled, a portion is evaporated in ponds, and a portion is used in ash treatment that is then put into landfill. The remaining wastewater that cannot be processed or cleaned is injected in to deep wells.[65] Deep well injection has proven highly costly due to the construction of 130 monitoring wells to check for leaks into surrounding groundwater.[66]

At the Shenhua CTL project in Ordos, a Greenpeace investigation has revealed potentially illegal dumping of wastewater from the industrial process, resulting in contamination of the local environment with harmful carcinogenic compounds.[67]

3.4.7 Air Pollution

Annual emissions at the Great Plains Synfuels plant (2014 data)[68]	
Pollutant	**Tonnes/year**
SO_2	3463.36
NO_2	2934.92
NH_3	880.42
CO	2023.75
PM_{10}	169.19
$PM_{2.5}$	29.94
VOC	347.45
Methanol	307.43
Toleune	2.25
Phenol	5.42
Catechol	0.83
PAH total	30.35
Xylenes	2.22
Benzene	3.82
Acetonitrile	3.75

Table 2: Air pollution from Great Plains Synfuels Plant

Harmful air pollutants are emitted during CTG production. Pollutants include emissions of $PM_{2.5}$ as well as ammonia, nitrous oxides, and sulphur dioxide[69] that together can form secondary aerosol, a major component of fine particulates that cause respiratory health problems when breathed in. Long-term and short term exposure to $PM_{2.5}$ are linked to severe health impacts including cardiovascular problems, childhood respiratory diseases, adverse birth outcomes and possible neurodevelopment and cognitive function outcomes as well as other chronic disease conditions such as diabetes.[70] Exposure to nitrous oxides and sulphur dioxides have been linked to respiratory diseases, with children particularly sensitive. The World Health Organisation recommends that the annual mean concentration in air of $PM_{2.5}$ should not exceed 10 micrograms (one-millionth of a gram) per cubic metre (μg/m^3), and the 24-hour mean should not exceed 25μg/m^3.[71]

During the early years of the Great Plains Synfuels SNG plant, air pollution standards were continuously broken. They remained that way until 2002 when, faced with a US$1.3 million fine from the North Dakota Bureau of Health, the plant operators installed a wet electrostatic precipitator that brought emissions down.[72]

In China, the average $PM_{2.5}$ concentration from Chifeng, a coal-based SNG plant located in Inner Mongolia, was 68.8μg/m^3 between January and March 2014. This is more than two times the safe 24-hour mean.

3.5 Conclusion

The development of the Coal Chemicals industry poses many risks. Mega projects in China suck surrounding ecosystems dry with massive water consumption while yet more coal is mined, processed and transported. Wastes require careful disposal to safeguard the health of the local population and the environment. In terms of climate change, Coal Chemicals emit huge amounts of GHGs that threaten to further destabilise the earth's climate.

The following case studies from South Africa, the US and China document the companies involved that are pursuing these industries, and highlight where Coal Chemicals development is likely to take place in the future.

Eskom coal in the Mpumalanga province, eastern South Africa

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CASE STUDIES

Australia: Underground Coal Gasification

By Kat Moore, Friends of the Earth Australia

1. UCG overview

Australia has seen a growing unconventional gas industry emerge in recent years, in addition to long running coalmining operations for domestic use and export. This industry is most advanced in the state of Queensland, which has also been the location of a number of Underground Coal Gasification (UCG) test projects.

Australia has enormous brown and black coal resources. At present, 37.3% of the Australian landmass is covered by coal and gas licences and applications, totalling around 2.8 million km^2 - an area almost 13 times the size of Great Britain.[1]

The energy industry has targeted all forms of unconventional gas resources, but the most significant activity has focused on Coal Seam Gas (CSG) resources.[2] The CSG industry is rapidly expanding: by 2013 the industry reported a total of 5,072 wells, 4,842 in Queensland and 230 in New South Wales.[3]

The development of large-scale infrastructure for the transport and processing of CSG has increased the viability of underground gasification proposals. In this sense, UCG has been a secondary stage in the development of unconventional fossil fuel resources in Australia.

All forms of onshore unconventional gas have been strongly opposed by communities across the country.

2. Previous trials

Australia has been home to three UCG pilot projects, all of which took place in the state of Queensland in the north east of the country. All of them have ended in charges of environmental damage. These were Cougar Energy's 2010 Kingaroy pilot project; Carbon Energy's Bloodwood Creek site in the Surat Basin, south east Queensland, which operated from 2008-2012; and Linc Energy's Hopeland site, operational between 1999-2013.[4]

The Darling Downs agricultural region in Queensland, Australia has experienced rapid development of Coal Seam Gas and Underground Coal Gasification

All three projects were located in the inland region of South Eastern Queensland, to the west of the capital Brisbane, an agricultural area where the threat of unconventional gas drilling (especially CSG) has already caused considerable concern about impacts on the environment and groundwater in particular. All three were test projects, which did not proceed to commercial production, and all faced major opposition from local communities.

2.1 Cougar Energy

Cougar Energy's pilot program ran from March 2010 to January 2011. The company was ordered to cease its trial due to the release of water contaminated with benzene and toluene into nearby boreholes, and its failure to notify the Department of Environment and Resource Management (DERM; the state government authority charged with environmental compliance in Queensland) of the contamination.[5] It was subsequently found guilty of three breaches of the Environmental Protection Act 1994 and fined A$75,000, as well as being ordered to pay A$40,000 in legal and investigation costs.[6]

When asked if Cougar Energy would be permitted to operate in Queensland in the future, acting director general of the DERM Terry Wall said 'certainly not in respect of Underground Coal Gasification'.[7]

2.2 Carbon Energy

Carbon Energy's pilot project, operating from 2008-2012, was intended to trial a specific UCG process which involved oxygen injection, developed by the company in conjunction with the federal government's scientific research organisation, the CSIRO, and to test the quality of syngas produced by the technology. The company states that its purpose is 'to produce clean energy and chemicals feedstock from Underground Coal Gasification (UCG) syngas'.[8]

In 2012, Carbon Energy was found to have released contaminated water, and was charged with 'disposing of processed water by irrigating it to land without approval'.[9] Similar to the Cougar Energy case, the company was fined A$60,000. Its executive officer, Andrew Dash, was fined an additional A$2,000 for a breach of environmental conditions and failure to notify the department. Carbon Energy was also ordered to pay A$40,000 in legal and investigation costs.[10]

2.3 Linc Energy

Linc Energy's site at Hopeland was the longest-running trial of the three. The facility trialled five different gasifier operations and in 2008 constructed a pilot Gas-to-Liquids (GTL) plant. In 2016, Linc Energy was charged with five counts of 'willfully and unlawfully causing serious environmental harm' at the Hopeland site between July 2007 and December 2013.[11] The charges relate to allegations that large quantities of gas, including hydrogen, hydrogen sulphide and carbon monoxide, escaped the wells and polluted the surrounding area. A 314km^2 'excavation exclusion zone' was imposed, where landowners were not permitted to dig below two metres.[12] Workers at the site reported health issues such as heart palpitations, stinging eyes and headaches, and sometimes had to drive a number of kilometres off site before their personal gas detector would stop registering.[13]

Hopeland locals are pursuing a class action against Linc Energy for loss of land value resulting from the alleged contamination.[14] Linc Energy went into voluntary administration in April 2016, and in May 2016 it was announced that the company is going into liquidation. There is a risk that the company will avoid clean-up costs (estimated to be around A$30 million[15]) as a result of this.

3. Current situation

On the back of these three disastrous trials, the Queensland state government announced a ban on UCG in April 2016.[16] Legislation to put the ban into effect is planned by the end of 2016.[17] Environmental groups including Friends of the Earth Australia, are watching this process closely.

Despite the loud warning of the Queensland projects, there are currently two projects being planned in South Australia.

3.1 Leigh Creek Energy Project

Leigh Creek is a small coal mining town located about 550km north of Adelaide. The Leigh Creek Energy Project (LCEP) is intended to fill the gap in gas demand as well as employment left by the closure of the Alinta Energy surface coal mine, which operated at Leigh Creek for over 100 years, ceasing operation in November 2015.[18]

The company running the project, Leigh Creek Energy, was previously called Marathon Resources.[19] It plans to use UCG to exploit the coal seam and feed the resulting syngas into the eastern Australian gas pipeline network. The company is aiming to produce commercial quantities of gas by the 2018-19 financial year, and to be operational for 30 years on an 80 petajoules (75.8 Bcf) per annum base case scenario.[20]

The LCEP has been granted a Gas Storage Exploration Licence, which if progressed to a Gas Storage Licence would enable the project to store gas on-site.[21] This is in addition to the existing options of transporting the gas to the Gladstone liquefied natural gas and port facility, enabled by the planned construction of a 125km gas pipeline, which would connect into the South Western QLD pipeline,[22] or using it in a proposed gas fired power station, a joint venture with the Shanghai Electric Group.[23] Additional uses include the project's own energy needs, and nearby mines including BHP's Olympic Dam, and Oz Minerals' Prominent Hill.[24]

3.2 Arckaringa UCG & Coal Chemical

Arckaringa Coal Chemical Joint Venture Co is a joint venture between Sino-Aus Energy Group and Altona Energy, with the aim of developing a UCG site and Coal-to-Liquids plant.[25] Altona Energy is touting its Arckaringa project as a '21st century clean-technology operation' due to their planned use of Carbon Capture and Storage technology, and states that it has already selected a potential long-term storage site nearby.[26]

It was announced in April 2016 that Sino-Aus has paid the final A$1.4m of its initial financial contribution to the project, its total contribution now sitting at A$5.4m.[27] Operations are due to commence in the second half of 2016.[28]

4. National Regulatory Framework

UCG is still a reasonably young technology in Australia, its trials having been restricted to Queensland thus far, and therefore of little concern to the Federal or other state governments. Approval of onshore fossil fuel exploration and commercial production is the responsibility of the state governments.

The primary regulatory concern is that whilst CSG is managed either under petroleum or coal legislation, UCG is categorised as mineral - thereby leading to potential licence and exploration overlap and a level of competition between the two industries.[29] This is not, however, necessarily a bad thing for those opposing these developments as it has led to proponents of UCG attempting to undermine the social licence of CSG companies in order to gain support.

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South Africa: Underground Coal Gasification and Coal-to-Liquids

By David Hallowes, groundWork (Friends of the Earth South Africa)

1. Eskom's Underground Coal Gasification pilot plant

Eskom's UCG pilot plant at Majuba Power Station started up in 2007. In 2014, Eskom said that the 'first pilot' was producing 15,000m^3 of gas per hour and consuming 100 tonnes of coal per day. It was intended that this would be ramped up to 75,000m^3 an hour to co-power Majuba.[1]

Eskom also developed an alternative plan to use the gas to fire a large combined cycle gas turbine (CCGT) of 2,100MW capacity. Eskom says the Majuba coal seam contains 400-500Mt of coal over an area with a 10km diameter. UCG applied to this area would provide enough syngas to run the CCGT plant for its lifetime.[2] However, the plant was shut down in 2015 and its future is uncertain.

1.1 History

The very large Majuba Power Station (4110MW) was the last of a string of plants built by Eskom in the final decade of the apartheid regime. It was completed in 1992 but the first of its six units was only commissioned in 1996.

Like all Eskom's power stations, Majuba is built on top of a coal resource. The coal, however, turned out to be unmineable because the coal seam is fragmented and disrupted by dolerite intrusions. The coal supply therefore has to be trucked in by road at the rate of some 42,000t a day.[3]

Meanwhile, Eskom was looking for ways to use the Majuba coal resource – a seam 300m underground and 3-5m thick. In 2001, it identified UCG as the best option and, following various studies, it started construction in 2005 using technology licensed to Ergo Exergy, a Canadian corporation. The gasification process was started in January 2007 and the gas was fed into a small generator. Eskom then expanded production to mix the gas with coal to co-fire one of Majuba's six units in 2014.[4] This initial firing was very brief – scarcely an hour on one account – and the rest of the gas was flared.

The original intention was for the UCG plant to scale up to provide 30% of Majuba's energy (equivalent to 4.5Mt of coal a year).[5] Eskom subsequently considered the alternative of building a separate gas-fired power station at the Majuba site.

In its 2015 Integrated Report, however, Eskom reported a ZAR 1.05 billion (around US$70,290,643) impairment on the UCG project, and 'as a result of funding constraints, a capital project reprioritisation was undertaken, leading to approval of the closure and rehabilitation of the project'.[6]

Meanwhile, prospecting for coal bed methane (CBM) from the same coal seam is being undertaken on adjacent land by Kinetico Energy, an Australian company.[7] Kinetico suggests several potential uses, including co-firing with coal at Majuba and use in the production of petrochemicals.

In their public documentation, neither Kinetico nor Eskom mention the other project and so say nothing about whether CBM, which involves fracking the coal seam, is compatible with UCG. When questioned, Eskom responded that mining rights are assessed "to ensure minimal impact to the overall system which includes adjacent mining projects".[8] The Department of Mineral Resources (DMR) issues mining rights and it is unlikely that it has the capacity to make that assessment.

1.2 Future plans and developments

The UCG plant was shut down in late 2015 and its future is uncertain. Officially, all options for using the gas are being investigated and 'shutting down and rehabilitation forms part of the research methodology'.[9] However, the UCG has not been running for several months. Eskom is not providing capital and the on-site offices are all but empty. It seems unlikely that it will re-start.

1.3 Air, water and ground pollution

Eskom repeats the industry line that UCG is an 'advanced clean coal technology'. Compared with conventional coal fired generation, Eskom claims significant reductions in particulate and sulphur and nitrous oxide emissions, and that carbon emissions may be reduced depending on geology and coal quality. Eskom even claims that 'UCG creates a cavity that could potentially sequester its own CO_2'.[10]

Compared with conventional mining, Eskom says UCG eliminates physical extraction of coal and hence reduces the disturbance of land. It also 'shortens the coal value chain' from mine to power station, eliminating coal handling and transport.

The key motivation, however, is to expand reserves: 'Almost three quarters of the country's coal resources are presently regarded as conventionally un-minable, but could be extracted using UCG technology.'[11] At 1.8 tonnes of CO_2 per tonne of coal, that would mean emissions of anything between 80 and 160GtCO_2 from UCG depending on whose estimate of the conventional coal reserve one believes.[12]

Nevertheless, 'Eskom intends to also explore the potential to apply for Clean Development Mechanism (CDM) funding, once the pilot plant research is complete and emissions performance has been confirmed.'[13]

Underground, the coal burns at 1,200˚C and heats the rocks 'some 40m above the coal seam'. Eskom treats this as negligible because of the depth. It nevertheless expects 'gradual' subsidence at the surface, 'as per any underground mining operation', of some centimetres per year.[14] However, if the project is implemented with largescale production burning a cavity over a wide area, it will take time for the full impact to show.

Yet even a few centimetres surface slumping indicates more severe slumping underground and the likely collapse of ground into the cavity 300m below. That in turn may create new pathways for the movement of groundwater above and into the cavity, resulting in acid mine drainage and contamination by metals and salts. At the surface, water will pool in the depressions created by slumping. This will reduce the surface runoff of clean water into rivers as pooled water percolates into the groundwater and is contaminated in the process. The damage is irreversible.

Gasification consumes water 'in the coal seam and in the immediate surrounding strata' to produce hydrogen. Eskom says aquifers closer to the surface, as well as surface water, will be monitored 'to ensure no impact …' Should monitoring detect an impact, however, it is likely to be too late to prevent irreversible harm.

Eskom follows standard industry practice, discussed above in section 2.4.2, to address the risk of 'contamination of aquifers and water bodies with UCG products'.

1.4 Government support and regulation

The departments of Mineral Resources (DMR) and Energy (DoE) have expressed strong support for the development of UCG.[15] Eskom is a state-owned enterprise. Under apartheid it determined government policy on power and today remains central to policy making. Beyond UCG, government has guaranteed ZAR 350 billion (US$23.2 trillion) of Eskom debt for its 'new build' programme.

UCG is yet to be regulated. The Mineral and Petroleum Resources Development Act (MPRDA) Amendment Bill provides for prospecting and mining rights for UCG.[16] The Bill was passed by parliament in 2015 but the president sent it back without signing it into law. The Bill is once more making its way through parliament.

The pilot was developed without regulatory approvals. It developed an environmental management plan in 2014 and received a mining right in 2015. It is yet to obtain a water use licence. Eskom says an application cannot be made until the Department of Water Affairs promulgates regulations for UCG.

2. Sasol's Coal-to-Liquid and Coal-to-Chemical processing plants

Sasol produces a very wide range of products adding up to 20 to 25Mt/yr. Liquid fuels production capacity at the Secunda site is equivalent to 150,000 barrels a day crude oil throughput.

2.1 History

Sasol was created by the apartheid government as a state-owned corporation in 1950. South Africa has very little crude oil and Sasol was initially established

to protect the balance of payments. With the increasing isolation of the apartheid regime, the dominant motivation became securing a domestic supply of feedstock.

To build its massive Coal-to-Liquids (CTL) plants, Sasol needed open greenfield sites on top of huge coal fields, a copious supply of water, enormous capital investments and cheap labour.

With these plants came the creation of whole new towns. Sasolburg was built to house the workers for the Sasol 1 plant in the early 1950s, and the town of Secunda was built in the 1980s to house workers for the plants Sasol 2 & 3. Both towns were designed as garden cities but with environmental racism built in: the white towns with tree lined avenues were built upwind of the industrial site while the black townships were put directly in the prevailing path of pollution.

Sasol was heavily subsidised from the start. The state paid the escalating capital costs of Sasol and covered its losses. The plant started producing liquid fuels for sale in 1955 but operated at a loss until the 1970s 'oil crises' drove up the price of crude. The apartheid regime, meanwhile, was increasingly nervous about energy security and instructed Sasol to build Sasol 2. Following the revolution in Iran, a major supplier of oil, it called for Sasol 3.

The state, however, could not afford this expansion. It privatised and listed Sasol although it retained a considerable shareholding. To attract private capital, the state guaranteed profits. As the oil price collapsed in the mid 1980s, Sasol's production was heavily subsidised through a 'fuel equalisation fund'. At the same time, Sasol diversified its products and turned the Sasolburg plant to chemical production: fertilisers, explosives, waxes, solvents, phenols, olefins, polymers and more.

With the democratic transition, Sasol escaped its confinement to South Africa and went global. It listed on the New York Stock Exchange and expanded into Africa, Europe, the Middle East, China and the USA.

2.2 Future plans and developments

Sasol has undertaken various expansion projects in the last decade. It has recently constructed two new 10Mt/yr coal mines at Secunda to replace old mines. It says it is 'prioritising gas-based growth in South Africa and North America' to 'assist' a transition to a low carbon economy. It is expanding gas production in Mozambique and plans to expand gas-fired power production for its own consumption or sale.[17]

2.3 Environmental issues around air pollution and water use

CTL is the dirtiest and most energy intensive way to make fuel or chemicals. To produce 21Mt of product,

Protests against Sasol during the COP17 climate talks in South Africa in 2011

Sasol's plants consume about 40Mt/yr of coal and emit around 70Mt GHGs (CO_2e), more than the total emissions of Sweden in 2012.[18] Table 1 shows figures reported by Sasol.[19]

Table 1: Production and emissions (thousand tonnes)

	Production	CO_2e	NOx	SO_2
2015	20,855	69,772	157	208
2014	22,050	72,275	159	223
2005	24,152	75,372*	166	222

**** In 2013, Sasol reviewed its data and concluded that GHG emissions since 2000 were five million tonnes less than previously reported. If this is believed, emissions in 2005 were 70.3 Mt – less than in 2014 and only marginally more than in 2015 despite substantially higher production.***

The reduction in emissions from 2014 to 2015 is largely the result of reduced production. The intensity of GHGs actually increased. According to Sasol, this is because it sold a plant in Germany and excluded joint ventures where it is not the operator. This suggests statistics from low emitting plants were used to 'dilute' continued high emissions at Sasol's home plants. At 3.35 tonnes CO_2e per tonne of product, Sasol's 2015 emissions intensity is in fact higher than the 3.12 it reported in 2005.

Reduced production also accounts for lower emissions of sulphur dioxide (SO_2) and nitrogen oxides (NOx). Over the decade since 2005, there has been little or no improvement. More substantial improvements were made before 2005 when Sasol switched from coal to gas for the feedstock at the Sasolburg Chemical Industries. The corporation also tried to claim CDM credits for this but failed since the switch to gas was planned to compensate for depleted coal reserves well before the Kyoto Protocol was adopted.

Sasol is notorious for very high emissions of volatile organic compounds (VOCs), revealed by groundWork and community air monitors in 2000 but previously denied by Sasol.[20] In 2015, Sasol reported VOC emissions at 46.5 kilotonnes (kt). This is hardly better than the 47kt reported in 2009 when Sasol set a target of reducing VOC emissions to 10kt by 2020. Before 2009, Sasol reported emissions of 'non-methane hydrocarbons', rather than VOCs, of around 200kt. This suggests that some 150kt emissions have been disregarded in reporting due to a change in categories.

Leaks, fires, explosions and other incidents regularly add to the routine emissions from 'normal' operating. For example in 2005 there was a series of accidents that left 15 dead at Sasol's chemical plants.[21]

Sasol uses water on a massive scale – up to 150 million m^3 in recent years across all of its plants in South Africa – and produces around 35 million m^3 of liquid effluent laden with metals and salts. This does not include the impact on groundwater through acid mine drainage from its coal mines. The scale of waste is considerable. It produces around 500kt waste, over 300kt of which is hazardous. Leachate and spillages from waste dumps, pits and ponds adds to water pollution. Sasol's coal mining operations affect over 470km^2 of land each year: open cast mining simply destroys the land, while underground mining causes slumping and drains groundwater.

Demonstrators protest the term 'clean coal' used by Sasol during the COP17 climate talks in South Africa

2.4 Government support and regulation

Like Eskom, Sasol enjoys an insider track on energy policy and planning. As one example, it is a long-standing member of the South African delegation to the UNFCCC.

Support is also provided through which prices are regulated or not. Fuel prices are regulated using a formula based on crude oil prices and supposed costs of transport. This gives Sasol very high returns when oil prices are high but threatens losses at low prices. The price of chemicals is not regulated. Sasol enjoys market dominance in upstream bulk chemicals and, somewhat to government's chagrin, uses it to impose 'import parity pricing' – i.e. it sells at international prices plus the notional cost of transport and handling.

Throughout its history, Sasol has been protected by weak environmental regulation. groundWork and the Centre for Environmental Rights (CER) reviewed the state of air quality regulation and corporate compliance in 2014. They concluded:

> *'Government is allowing the air quality regime to collapse. The evidence in this report points to the conclusion that this is the intention: monitoring stations are not maintained; relevant health statistics are not collected; the half-hearted attempt to develop a functioning air quality information system, as required by law, is abandoned; no attempt is made to build capacity in any of the spheres of government and, where it has been developed, it is destroyed; pollution control budgets are inadequate; the law is offset; non-compliance is being legalised; and the DEA is evidently under instruction from other ministries.'* [22]

Eskom power plant, South Africa

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p. 39: "Eskom and surroundings" by Megan Lewis, groundWork South Africa is used with kind permission.

US: Underground Coal Gasification, Coal-to-Liquids and Coal Gasification for electricity

By Lukas Ross, Friends of the Earth US

The US has the most abundant coal reserves on earth – and nearly all of them need to stay in the ground to keep warming below 2°C, let alone the 1.5°C called for in the Paris climate agreement.[1] But even as US coal faces structural decline in the face of rising costs, cheap alternatives, and new regulations, this politically-connected industry is not going to disappear without a fight. In order to compete, it is promoting investment in experimental and other less traditional coal technologies, including Underground Coal Gasification, Coal-to-Liquids, and Coal Gasification for electricity. Although attempts to mainstream these technologies have often floundered, costing investors and sometimes taxpayers billions, the political clout of coal means that many of these projects are lightly regulated and eligible for considerable state and federal subsidies. (See also the review of UCG history in Table 1, section 2.2 Brief history).

1. Underground Coal Gasification

During the US energy crisis of the 1970s, UCG was entertained as an alternative to energy imports from the Middle East. The idea was that the syngas produced through the process could be a new source of power and a feedstock for everything from petrochemicals to liquid fuel. The newly established Department of Energy funded many of the original pilot projects, but mixed results and dropping oil prices meant that the practice was never pursued on a commercial scale.[2]

Even if crucial equity considerations are ignored, scientists estimate that only 5% of US coal reserves can be extracted on a 2°C carbon budget – and even less to maintain 1.5°C. But UCG has the potential to radically expand the amount of economically exploitable coal by between 300-400% in the US alone by reaching coal seams that are inaccessible through conventional mining methods.[3]

1.1 Risks of water contamination

The Fort Union Formation is an underground seam in Wyoming's Powder River Basin, the region already responsible for 40% of US coal production, mostly on public lands. Linc Energy, an Australian company positioning itself as a global UCG leader secured a 'research and development' license for a project in 2014, with the hope of eventually expanding it to commercial production.[4] The potential for growth is theoretically high. A report from the Wyoming Business Council suggests that 74% of all the coal deeper than 150m – roughly 278Gt – is appropriate for gasification.[5]

In order to proceed with the project, Linc secured an exemption from the federal Safe Drinking Water Act, effectively giving the company permission to pollute water from a perfectly drinkable aquifer. This was a controversial step in Wyoming, where the arid climate and declining supplies of groundwater set the stage for competition between different consumers. The gasification process produces pollutants like benzene, xylene, and toluene, with no guarantee that contamination would be limited even to the water supply that Linc has been given permission to pollute.[6] The precedent is incredibly troubling. Earlier projects funded by the Department of Energy in Wyoming resulted in water contamination, and a project run by Linc in Australia similarly led to water contamination – resulting in both a class action lawsuit from landowners and criminal charges against the company.[7]

In May 2016, Linc Energy's subsidiary US companies filed for bankruptcy in the US courts[8] and Linc Energy also filed for bankruptcy in Australia.[9] Linc highlighted the decline in oil prices as well as a series of unsuccessful drilled wells.[10] The company is thought to have assets of between approximately $50 million and $100 million and liabilities of between $100 million and $500 million.[11]

2. Coal-to-Liquids

In the US, the idea of Coal-to-Liquids has captivated coal state politicians from both the main parties. As recently as 2007, it was possible for Barack Obama, then a Senator representing the coal state of Illinois, to join Kentucky Republican Senator Jim Bunning in proposing a package

worth a potential US$8 billion to try to subsidize a domestic liquid coal industry into existence. Neither the proposal nor the ultimate goal were successful.[12]

When the price of oil first spiked in the mid 2000s, liquid coal was presented as an answer to rising fuel prices and the perception of declining conventional crude reserves. At one point in 2008, the RAND corporation suggested that by 2030 CTL could provide 3 million barrels of fuel per day, or roughly 15% of domestic demand at that time.[13] But none of the projects floated during this period ever made it much past the drawing board.

2.1 Lack of commerciality

Medicine Bow was a CTL plant proposed for Carbon County, Wyoming. A project of DKRW Advanced Fuels, it was supposed to turn coal into a gas, turn the gas into a liquid, and trap the associated carbon dioxide for either underground storage or enhanced oil recovery. To get the project off the ground DKRW sought a variety of subsidies, including development bonds from the state of Wyoming, federal tax credits for 'advanced' coal projects, and a federal loan guarantee for US$1.75 billion.[14]

Only so its construction permit would not expire, DKRW began construction in 2010, but the project never really got beyond the stage of poured cement. Arch Coal, the second-largest coal company in the US, bought a minority stake in the project and loaned it US$44 million, but a 2013 report to investors show that Arch accepted a US$57.7 million loss on the entire venture.[15] The Chinese state-owned Sinopec Engineering Group, which was hired as a construction contractor, was forced off the job by DKRW in 2014 - a move that an analysis from JP Morgan concluded was actually a major favour to Sinopec.[16]

After numerous delays and failure to secure financing, DKRW now concedes that low oil prices have made the project unviable.[17] Although this is a convenient excuse, the truth is that Medicine Bow was defunct well before the price of oil collapsed in late 2014.

Adams Fork Energy is a proposed CTL plant in Mingo County, West Virginia. Led by New York-based TransGas, the planned facility was supposed to produce 18,000bbl/day of gasoline while consuming over 6,800t of coal.[18] But similar to Medicine Bow, the project never managed to secure financing for its estimated US$3 billion price tag, in spite of the significant political support the project garnered from then-Governor, now-Senator Joe Manchin. Although TransGas insists the project is still viable and could be completed by 2019 or 2020, the site has been dormant for over five years and never made it past the poured concrete stage.[19]

3. Coal Gasification for electricity

Burning coal for electricity is one thing. Turning coal into a gas and burning the gas for electricity is something else. The technology isn't new, but it is emerging as one of the leading strategies for the struggling coal industry to rebrand itself as clean. So far, the results are dubious.

Building a new Coal Gasification facility remains one of the most expensive sources of electricity, and the process of purifying the produced gas not only requires huge quantities of water, it causes water to be contaminated with pollutants like nitrates, selenium, and arsenic.[20]

Part of the argument for gasification is that it is easier to pair with Carbon Capture and Storage (CCS). But like gasification, CCS is expensive and untested, and adding the two technologies together makes an already expensive proposition prohibitive.

3.1 Spiralling costs and high subsidies

Kemper is an Integrated Gasification Combined Cycle (IGCC) power plant in Kemper County, Mississippi. It is a project of Southern Company, one of the largest investor-owned utilities in the US. The plant is designed to burn syngas made from low-quality lignite coal, but paired with CCS it purports to capture 65% of the associated carbon emissions, making it roughly as clean as a natural gas power plant.[21]

Although Kemper would be the first utility-scale CCS project in the US, the economics of the project have long been in question. Throughout its life, the estimated cost of the project has more than doubled to a current tally of US$6.7 billion.[22] The partially finished plant has been burning natural gas since 2014, but construction cost overruns forced Southern Company to record massive losses of US$868 and US$365 million respectively in 2014 and 2015.[23] The project is now under investigation by the Securities and Exchange Commission (SEC), the federal agency in charge of regulating fraudulent investment practices.[24]

When Kemper does eventually begin gasifying coal, it will be thanks in no small part to subsidies from taxpayers and electricity consumers. In its annual report to investors, Southern Company reported that the Kemper project had received a grant from the Department of Energy worth US$245 million. If and when it begins actually sequestering carbon it is expected to be eligible for a per ton tax credit for capturing CO_2 and either storing it underground or using it for oil production (see below). The facility was also eligible for a series of advanced coal investment tax credits established in 2005, but because of delays US$279 million worth had to be rescinded.[25]

But the largest subsidy will come from regular consumers paying their electricity bills. Although legal wrangling continues, Mississippi regulators granted Southern Company a 15% rate increase to help cover the costs of the plant.[26]

The Texas Clean Energy Project in Penwell, Texas is another facility like Kemper designed to gasify coal and trap CO_2 emissions. Like Kemper, it has a price tag that keeps rising, ballooning from US$1.9 billion in 2010 to a current estimate of US$3.9 billion.[27] Also like Kemper, the project benefits from significant taxpayer subsidies – although ongoing delays have put those incentives in danger.

The project was theoretically eligible for US$450 million in grants as part of the Clean Coal Power Initiative, a federal program established in 2002 to fund advanced coal technologies and financed in part through money from the 2009 stimulus. The funds were supposed to be doled out in four separate stages, but a recent report from the Department of Energy Inspector General showed that the agency had improperly given the facility US$101 million ahead of schedule. The project never secured financing, and it seems unlikely to now, but an estimated US$116 million has already been lost and at least another US$220 million could still be at risk.[28]

4. Carbon Capture and Storage – another Big Oil giveaway?

Besides delays and prohibitive costs, both Kemper and Texas Clean Energy Project have something else in common – a plan to sell captured CO_2 for enhanced oil recovery, a practice that involves pumping CO_2 and other injectants underground to extract hard-to-reach oil reserves. The oil industry is looking to expand EOR as part of its growth strategy, but the challenge is that in many regions natural seams of CO_2 are running low, and so oil companies are looking for a stable alternative supply – something they hope carbon captured from coal plants can supply.[29]

Building continues at the Kemper County Coal Gasification Plant, Mississippi, US

In fact, the Great Plains Synfuels plant in North Dakota, which gasifies coal to produce synthetic natural gas and other chemicals, captures an estimated 3MtCO_2 per year, which is then piped to Canada for EOR.[30] If it ever comes online, the Texas Clean Energy Project intends to sell captured CO_2 to oil producers in the nearby Permian basin, while Kemper plans to net US$50 million in additional revenue selling CO_2 for nearby oil extraction, as well as other byproducts.[31]

This is a problem. The climate benefits of using the emissions from one fossil fuel to enable the extraction of another are dubious. When the lifecycle emissions are calculated for extracting coal, burning it at a CCS facility, and using it to extract oil that might otherwise be left in the ground, it can result in as much as 4.7 tonnes of CO_2 emitted for every tonne pumped underground to stimulate extraction.[32]

5. Billions in subsidies for extreme coal

Research and Development funding is available from the federal government for both coal and CCS through the Department of Energy. In 2016[33] alone US$430 million has been allocated – an increase of US$30 million from the previous year and US$60 million more than President Obama requested in his annual proposal to Congress.[34]

Tax credits are available for a variety of so-called advanced coal projects, and can be worth as much as 30% of the overall value of the project. These incentives are expected to cost taxpayers US$1 billion between 2014 and 2018. Another tax credit is available specifically for CCS for every tonne of CO_2 captured by a power plant or other industrial emitter. It is worth an inflation-adjusted US$20 per tonne if the CO_2 is stored underground, and US$10 per tonne if it is used as part of EOR. Over the same four-year time period, the cost to taxpayers is expected to reach $700 million.[35]

Loan guarantees are available for CCS and other coal projects through the Department of Energy. Medicine Bow was close to acquiring one, although it ultimately fell short (see above). This program subsidizes the risk of private lenders, forcing taxpayers to foot the bill if a project fails and the borrower defaults.

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UK: Underground Coal Gasification

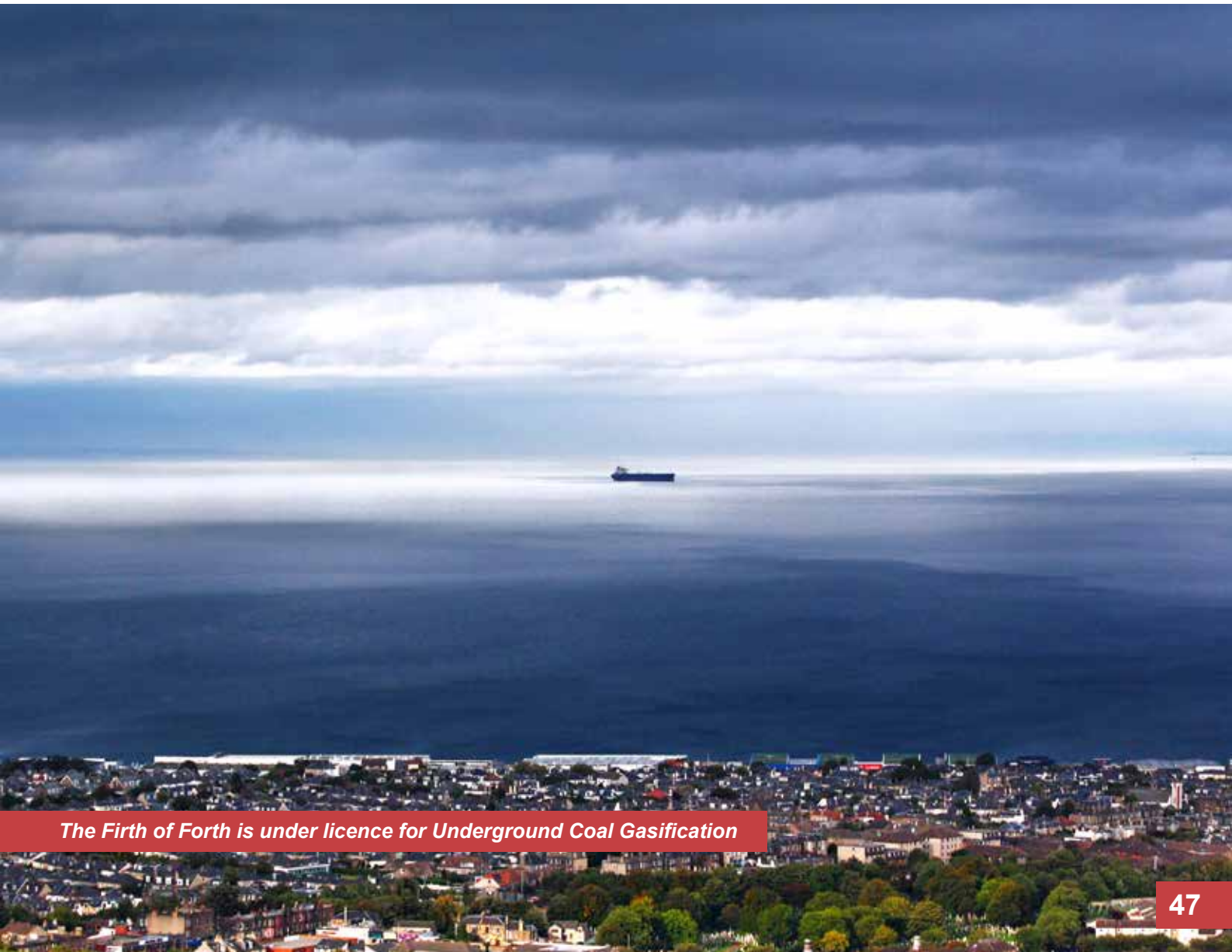
In the UK, two energy companies own a total of 19 licences for near offshore, coastal areas. However, to date there are no UCG test or commercial projects underway, and in October 2015 the Scottish Government announced a moratorium on the technology.

1. History of UCG in the UK

The chemist and inventor William Ramsay is credited with being an early pioneer of UCG, arguing in 1912 that UCG could help alleviate the smog that formed in most cities from burning coal.[1] Earlier proponents of the technology included Siemens, Betts and Mendeleyev who argued that UCG would make underground mining unnecessary and would not produce ash and other hazardous pollutants.[2]

Early trials of UCG in the UK were undertaken in Durham in the 1920s.[3] Thirty years later further trials took place in Newman Spinney in Derbyshire and Bayton in Worcestershire. However the late 1950s saw the cheap availability of oil in the UK, prompting the National Coal Board to abandon further UCG development on economic grounds.[4]

The next significant wave of interest from the UK in the technology was in the 1990s, when the government collaborated with Spain and Belgium to trial a deep UCG project in El Tremedal, Spain. The trial was designed to test UCG at depths of more than 550m as well as directional drilling techniques that were being developed.[5] The pilot project ran into severe difficulties on its third test phase when an aquifer situated above the gasifying coal seam flooded the gasification cavity, causing a blowback of phenolic liquor that passed to the surface under pressure and exploded, coating the UCG site with toxic residue.[6]



The Firth of Forth is under licence for Underground Coal Gasification

2. Current activities

2.1 Companies and Licences

Two companies hold a total of 19 UCG licences in the UK.[7] Cluff Natural Resources (CNR) is the most active UCG company in the UK, owning 9 licences across the UK. CNR is owned by multi-millionaire Algy Cluff who made his fortune in African gold mining and North Sea oil. The company is registered in London and also holds 5 offshore oil and gas licences in the North Sea.[8]

Five Quarter Ltd was a spin-off company from Newcastle University and owned 10 UCG licences across the UK. On 1st March 2016 Five Quarter Ltd ceased trading, citing changing global market conditions, a decrease in North Sea activity and 'considerable uncertainty' about the UK Government's energy strategy.[9]

The 19 licences are all offshore around the UK coast and include:

- 6 licenses in Scotland
- 11 licences in England
- 2 licences in Wales

6 out of 10 licences owned by Five Quarter expire in December 2016. As Five Quarter has ceased trading, there is a possibility that the other 4 licences that expire in January 2018 may be sold on as assets.

2.2 Case study: UCG project at Kincardine, Firth of Forth, Scotland.

CNR's 'flagship' UCG project was planned for the Kincardine licence area, Scotland. Development into a commercial operation would represent the first off-shore UCG project in the world, at depths that have been tested only a handful of times.

2.3 Feasibility of Kincardine site

An initial feasibility study carried out in 2014 by Belltree Group on behalf of CNR estimated the coal resource at the Kincardine site suitable for UCG. It calculated that the Upper Hirst coal seam holds a mid-case value of 17Mt of coal suitable for UCG, and the Wester Main coal seam holds a mid-case value of 26Mt of coal suitable for UCG.

If all the coal estimated in the mid-case scenario were burnt, nearly 120Mt of CO_2 would be emitted.[10] This is more than twice Scotland's annual carbon emissions, or another 13.5 years worth of emissions from the recently-closed Longannet coal-fired power station.

The Belltree report highlighted extensive historic mining activity in the licence area that may pose a 'high risk of rockhead and surface instability and loss of fluid circulation at drilling locations' under the surface,[11] complicating UCG operations.

2.4 Use for syngas

CNR planned to sell the produced syngas as a feedstock to either the petrochemical industry or for electricity production. CNR has said that 'using UCG will also enhance the UK's ability to service its own domestic and industrial demand' and the produced syngas is a 'particularly valuable petrochemical feedstock for industry.'[12] It has also highlighted the potential to feed power stations in close proximity – for example the (now closed) coal power station at Longannet or a proposed Integrated Gasification Combined Cycle power plant at the Ineos plant in Grangemouth.[13]

2.5 Cluff's plans put on hold

2015 proved a difficult year for CNR. There were public calls from many community and campaign groups for UCG to be included in the Scottish Government's 2015 moratorium on unconventional gas, with a debate on the topic tabled for the governing Scottish National Party's October 2015 Conference. In response to the growing pressure, CNR announced in its August 2015 Interim Results report that work on a planning application for the Kincardine site was to be postponed, including an Environmental Impact Assessment, until 'after such time as the political situation is more certain.'[14]

Despite the announcement of a moratorium on UCG in Scotland in October 2015 CNR continued to state that the preparatory work including 'site selection studies, modelling and design work' were still developing for Kincardine.

However, in January 2016, CNR suggested that it was now focussing on its North East of England licenses.[15] By May 2016, CNR confirmed that it had written off the £337,000 value of its nine UK licenses, shifting its attention to conventional North Sea assets instead.[16]

Demonstrators span the iconic Forth Road Bridge to protest against UCG in Scotland

3. Regulatory framework and environmental monitoring

UCG is licensed by the Coal Authority, which is an executive non-departmental public body sponsored by the former Department of Energy and Climate Change. Coal authority licensing and Health and Safety Executive powers remain reserved to the UK Government at Westminster

Environmental regulation however is devolved, with responsibility falling variously to the Environment Agency of England, Natural Resources Wales and the Scottish Environment Protection Agency. UCG operations fall under a number of environmental licensing regimes originating from EU law on industrial emissions, waste management and groundwater protection.

Perhaps the most significant of these in relation to UCG is the EU's Water Framework Directive which stipulates that Member States should protect all sources of groundwater, not only those aquifers that are potable. However, one controversial element contained in the WFD (Article 11(3)(j)) relates to the pollution of aquifers deemed to be in a 'Permanently Unsuitable Zone'. The PU Zone is defined as a block of strata 'where the water quality and/or yield are so poor that groundwater in that area cannot realistically be regarded as an environmentally or economically significant 'aquifer'.'[17]

Once a PU Zone is defined, UCG (or other oil, gas and mining) companies will not be penalised by the regulator if the zone is polluted through their activity. This apparent contradiction in the Directive is as yet untested.

Planning authority too lies with the devolved administrations in Scotland and Wales. This means that while licensing powers are in the hands of the UK Government, devolved Governments are ultimately able to determine whether or not UCG should go ahead in Scotland and Wales since UCG operations will require planning permission for above ground infrastructure. This is how the current moratoriums in Scotland and Wales are put into effect. The Scottish Government and Welsh Assembly also retain Marine licensing powers which potentially come into play with UCG planned in near offshore waters.

4. Level of government support

The UK Government has conducted reviews of UCG technology. The official Department of Energy and Climate Change (DECC) policy position to UCG was 'arguably… one of neutrality,' given the 'uncertainty of viability' involved.[18]

UCG was included in the UK Government's 'cleaner fossil fuels programme' that analysed different fossil fuel technologies and their compatibility with Carbon Capture and Storage (CCS). The then Department for Trade and Industry (and subsequent bodies) conducted a five-year review of the state of UCG that completed a report in 2004 entitled 'Feasibility Study of UCG in the UK.' It concluded:

> *'UCG, in conjunction with carbon dioxide capture and storage… to reduce carbon dioxide emissions, has the potential to contribute to the UK's energy requirements. However, there are hurdles that need to be overcome: key are economic viability of this technology compared with other cleaner fossil fuel technologies… and the environmental concerns with implications for planning permission. For any project to be able to get started, these challenging issues will have to be tackled beforehand. Major concerns cover uncontrolled combustion, escape of pollutants, groundwater contamination and subsidence.'*[19]

DECC had only ever discussed the possibility of UCG planned in conjunction with CCS. In November 2015, however, the UK Government announced that its

major four-year CCS competition that would award £1bn in funding to a successful CCS project would be cut.[20] Two sets of competitors – Shell and SSE's Peterhead project, and Drax's White Rose consortium – cancelled their projects as a result. The cut in funding led to Professor Paul Younger, a former non-executive (unpaid) director of Five Quarter, former advisor to the Scottish Government on unconventional gas and formerly a strong advocate of UCG, saying:

> *'I do not support unconventional gas development without at least a reasonable hope of CCS becoming available in the foreseeable future, and the recent shock announcement by the Westminster government has effectively dashed all such hope.'*[21]

In January 2014, DECC established a working group on UCG to examine current UCG licensing processes, past research and feasibility work, potential environmental impacts and other regulatory requirements.[22]

In Scotland, the Scottish Government has been more cautious in its approach to UCG. Following a moratorium on shale gas and coalbed methane extraction in January 2015, then Energy Minister Fergus Ewing announced a further moratorium on UCG in October 2015, appointing Professor Campbell Gemmell, a former CEO of SEPA to 'lead an independent examination of the issues and evidence'.[23]

In Wales, the Natural Resources Minister Carl Sargeant issued a notification direction in March 2016 to require 'any planning application connected to the gasification of coal must be referred to Welsh Ministers where local planning authorities are minded to approve them'.[24]

The Solway Firth on the border of England and Scotland is under licence for UCG

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China: Coal-to-Gas, Coal-to-Liquids and Coal-to-Chemicals

China is rich in coal resources and is a global player in coal production and processing. Much of the recent activity in the Coal Chemical sector have taken place in China.

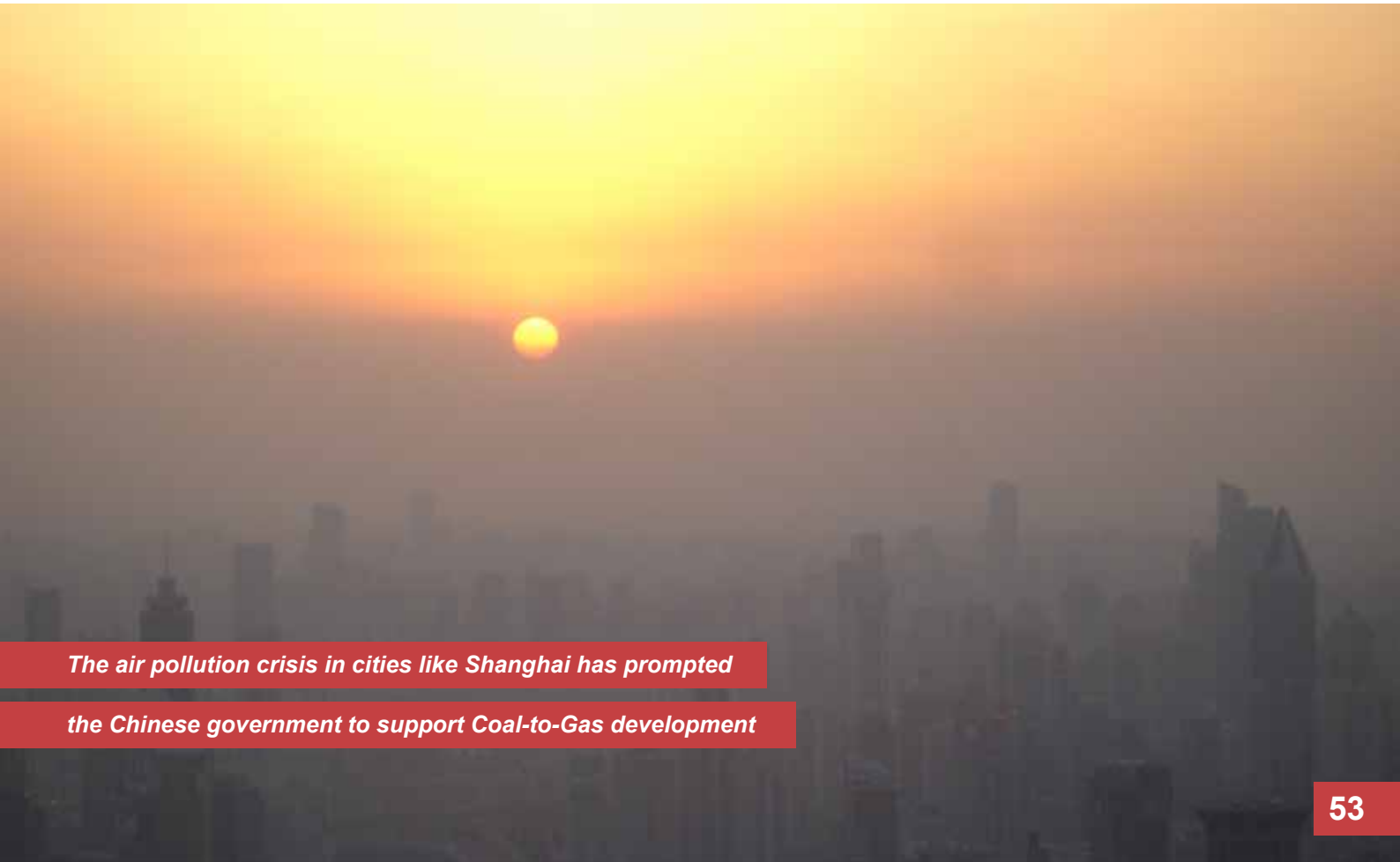
1. Coal-to-Gas

1.1 Recent activities

China's interest in Coal-to-Gas (CTG) has been growing in recent decades in response to the huge levels of air pollution in its eastern cities and industrial areas. There is increasing awareness of the health and local environmental impacts from the high levels of smog caused by burning coal for district heating and electricity. In response to the air pollution crisis, the Chinese Government published the Action Plan for Air Pollution Prevention and Control (2013-2017). It contains new policies such as a ban on new coal power plants in certain industrial regions, cuts in coal consumption and steel production, and higher targets for non-fossil fuel energy resources.[1] Gas in particular is being pursued as an energy source that emits fewer emissions of particulate matter and greenhouse gases (GHGs).

To meet this rising demand for gas, the Chinese government pursued CTG, approving nine large-scale SNG plants in 2013 that had a combined capacity of 37.1 billion m^3/yr.[2] By 2014, around 50 CTG plants with a combined capacity of 225 billion m^3/yr of SNG were being planned or constructed.[3] Many of the projects are located in the Northern provinces of Xinjiang and Inner Mongolia,[4] areas that are less populated than the urban sprawls of the southeast. Coal is gasified and the SNG is transported along thousands of kilometres of pipelines to the southeast consumers.[5] Similar to natural gas, the transported SNG can be used for industry, power generation, residential use, commercial use, heating, vehicle use and agriculture.[6]

Since 2014, however, the pace of CTG expansion slowed. There have been growing concerns around water scarcity, as well as climate change emissions, prompting the Chinese central Government to pull back from supporting CTG to the same level as pre-2014.[7] As well



The air pollution crisis in cities like Shanghai has prompted the Chinese government to support Coal-to-Gas development

as this, there were operational difficulties for the SNG industry. A major demonstration project, the Datang SNG project in Chifeng, Inner Mongolia suffered from severe operational delays between 2012-2013. In January 2014, an industrial accident took place at the same plant, causing the death of two workers and injuring a further four. Subsequently in 2014 severe corrosion was detected and the plant was shut for repairs for two months. There were additional difficulties in treating wastewater at the plant, and overall the plant's budget is several times higher than previously estimated.[8]

Nevertheless, the industry continues to develop regionally. As of December 2015, three plants are operating with a combined SNG output of 3.11 billion m^3/yr, four projects are under construction and around twenty other projects are at the planning stage – two projects in Inner Mongolia operated by Datang and Hui Neng, and one project in Xinjiang operated by Qing Hua.[9]

1.2 Air pollution and greenhouse gas emissions

China's push for CTG is at odds with the country's massive efforts to tackle climate change and transition to a lower carbon economy. To cut climate emissions, China is pursuing non-fossil fuels (projected to rise from 9.4% of total energy consumption in 2012 to 13% by 2017) as well as slowing its coal consumption.[10]

However, China's push for Synthetic Natural Gas risks compromising progress on reducing greenhouse gas emissions.[11] In 2014 around 50 CTG plants were being planned or constructed. Analysis indicates that if all of these projects became operational over 986MtCO_2 would be emitted,[12] just over the total annual emissions of Germany in 2012.[13] Though many of these projects are now anticipated to succeed to the operational stage, and the Chinese Government has pulled back financial support for these industries, there is a risk that regional governments will continue to expand these industries to pursue local economic development.[14]

As well as spiralling greenhouse gas emissions, an expansion of the CTG industry risks huge environmental impacts for the nearby population. A 2014 Chinese analysis[15] of the levels of air emissions produced from SNG production compared to natural gas concluded:

> *'using coal to produce SNG leads to a transfer of emissions from urban areas to rural ones which are situated close to coal mines. It is worrying as rural areas like Xinjiang and Inner Mongolia are characterised by the fragile environment due to the arid nature of both regions. The SNG production in those regions could lead to serious environmental problems.'*

2. Coal-to-Liquids

Similar to CTG, the coal liquefaction industry is growing steadily, with the majority of activity happening in the northern provinces of Inner Mongolia, Shaanxi and Xinjiang. Analysis by Greenpeace East Asia[16] from December 2015 states that there are at least five coal liquefaction plants (one DCL and four ICL) operating with a combined capacity of 2.34Mt/yr of fuel.

2.1 History

There has been growing interest in coal liquefaction since the 1970s. Companies like Yankuang Group and Shenhua Group particularly researched Fischer-Tropsch synthesis and undertook many trials and demonstration projects in the 1990s.[17] The 11th Five Year Plan (2006-2010) contained a vision of 'orderly advancement of demonstration projects to develop deep processing of coal and coal transformation industries, and the advancement of coal liquefaction demonstration projects.'

During the 2000s, the Central and regional governments approved dozens of projects to ease dependence on imported crude oil. The world's first DCL plant, operated by Shenhua group, was constructed with an operating capacity of 1.08Mt/yr, opening in 2010.[18] Shenhua's plant enjoyed financial support from the Central Government, notably the 1998 'Coal Replacing Oil Fund' of 11 billion Yuan (US$1.3 billion).[19] Further government support included innovation and research programmes with a special emphasis on CTL development.

2.2 Current activities

From 2008, there was a temporary halt in CTL activity. In August 2008, the NDRC ordered a stop to all except two CTL projects in China.[20] The two projects are owned by Shenhua and are located in Inner Mongolia and the Ningxia Autonomous Region. In 2011, the Chinese Government issued a ban on any CTL plant with an annual fuel output below 1Mt, and also made it harder for coal chemical projects to buy land.[21]

In 2014, after allowing some companies to restart development and construction, the Central Government's National Energy Administration directed local authorities to 'curb blind investment' in coal conversion projects, noting that some regional governments have been enthusiastically promoting development 'regardless of realities in environment, water resources, as well as technological and economic capabilities.' [22]

There are a number of reasons for China's policy reversal on CTL. First, the decline in oil prices in 2008 meant that many of the proposed projects became uncompetitive given extremely high production costs: coal liquefaction plants have massive start-up and construction costs and take at least three years to build. Second, the Chinese Government became increasingly anxious at small, uncompetitive CTL projects becoming a fragmented industry outside the power of the Chinese Government in Beijing – larger, state-owned projects like the Shenhua plants were easier to control.[23]

According to 2015 analysis by Greenpeace East Asia, around 13 CTL projects currently exist; 5 of these are in operation and a further 8 are in the construction and planning phases. Should the 8 become operational, the total combined capacity of the 13 projects would be around 20.7Mt/yr.[24]

2.3 Water scarcity

A third reason was due to increasing concerns around the levels of water required in the CTL process, and the impacts this would have on local environments. A 2013 analysis highlights that Shenhua's coal liquefaction plants in Ordos (including both its DCL and ICL lines) consume more than 10 million m^3 of fresh water per year, according to Ejin Horo county government[25] (for comparison, average water withdrawal for domestic use per person in China is 32m^3/yr).[26] The area has already been severely impacted by thirty years of intensive mining activity, resulting in a rapid decline of both surface and groundwater resources.[27] Local populations who use the land for agricultural purposes have been affected. The expansion of these industries into the arid regions of Xinjiang, Shaanxi and Inner Mongolia would create further stress on water resources.

Since 2015, the CTL industry has been developing, but with new environment guidelines in an attempt to reflect the issues around water. Draft guidelines were released in July 2015 by the National Energy Administration which state that projects will only be allowed in regions with sufficient water resources. Further, CTL plants will be allowed a maximum of 3.7 tonnes of coal for each tonne of liquid product produced.[28]

Though these new policies reflect progress in environmental awareness, existing mega-projects such as the Shenhua DCL plant still consume vast amounts of water that is unsustainable to the local environment. Besides water consumption, the huge coal use and subsequent CO_2 emissions make this industry unacceptable in terms of climate change.

3. Coal-to-Chemicals

China's expanding chemical sector includes some forty thousand different chemicals, with feedstocks including oil, gas and coal. This case study focuses on three chemicals – ammonia, methanol and olefins – which, in China, are predominantly derived from coal, and form the base feedstock for many other chemical products and processes. Charting their expansion highlights some of the historical trends in the Coal-to-Chemicals industry, as well as the huge carbon footprints of these chemical products.

3.1 History

China's Coal-to-Chemical industry saw huge expansion between the 1990s and 2007.[29] The first pilot project for methanol production was in 1995, when Ford Motor Company donated a methanol engine during the Sino-American Scientific Collaboration research project. The Chinese Government encouraged methanol production for automobile fuels from 1998-2008,[30] and its use grew, particularly in blending with gasoline.

3.2 Current activities

In 2008, the Chinese Government's enthusiasm for methanol waned, due to a growing preference for low-carbon fuels and concerns about national oil company profits.[31] Subsidies were cancelled and plans to standardise production were dropped. Nevertheless, the methanol industry continued to expand regionally and in 2009, China was the biggest producer of methanol, accounting for more than 20% of world production.[32] By 2011, this had grown to more than half of world

production of methanol.[33] In 2014, China produced 37.4Mt of methanol, with around 80% of this from coal.[34] The methanol can be further processed into olefins for plastics, rubbers and detergents.

Coal-to-Olefin technology is new and largely limited to China. Chinese capacity has risen from around nothing in 2010 to around 12Mt/yr in 2015. Over 45 Coal-to-Olefin plants are planned in China by 2019, with a combined total output capacity of over 28Mt/yr.[35] Shenhua and Datang operate Coal-to-Olefins plants in Inner Mongolia and Ningxia, and Tongliao Jinmei operates a plant that produces ethylene glycol from coal.[36]

Ammonia production is fundamental to China's chemical sector and is used for agriculture (to make fertilizer) and industry (e.g. to make nitric acid, used for dyes, fibres, plastics and explosives). Between 2000-2012, total ammonia production grew approximately 4% per year, from 33.6 to 54.6Mt, around a third of all world production.[37]

3.3 Energy and greenhouse gas emissions

The Chinese Coal-to-Chemicals sector consumes huge amounts of energy. In 2010 it accounted for 10% of the total energy consumption of all industries, estimated to be around 31.5Mt of coal equivalent.[38] Total energy consumption grew at an average rate of 4.68% between 1980 and 2010.

Carbon dioxide emissions for the chemical industry similarly grew between 1980 and 2010 by an average of around 3.37% annually. In 2011, the chemical industry emitted at least 450Mt of CO_2.[39] In response to growing emissions and international pressure, the Chinese Government has introduced measures to reduce carbon emissions – for example in the ammonia industry through more efficient technologies.[40] There has also been increased research into CCS technologies and their compatibility with the chemical sector. However, as of 2015, the only operating CCS projects in China's Coal Chemical sector are two small demonstration projects that capture less than 5% of CO_2 emissions, and CCS is not being built into the vast majority of Coal Chemical projects.[41]

4. The future of Coal Chemicals in China

China is currently embarking on two contradictory paths. Significant work has been done by the Government to cut both air pollutants and climate change emissions through policies to decrease coal use. Yet the approval of mega CTL, CTG and CTC projects threatens to reverse this progress, pushing China down a path of high carbon development. It remains to be seen whether China will build many more Coal Chemicals plants – the operating costs are huge, particularly in a context of low oil prices. In this context, is crucial that China stops approving new coal conversion projects and focuses instead on developing its growing renewable energy and low carbon technologies.

Ganjiaxiang industrial complex in Nanjing, China

Notes

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