Summary of potential environmental hazards associated with Underground Coal Gasification (UCG)

The main technical challenges with regards to UCG arise because the conditions under which the gasification reaction takes place are complex, naturally variable and difficult to monitor. This, combined with potential environmental hazards, which are summarised below, creates risk.

However, currently, there several factors limiting a robust assessment of the risks associated with UCG:

Environmental impact data

Data on the environmental impacts of UCG is limited, particularly from trials relevant to the proposed target coal seams under the Firth of Forth, a crucial aspect of which is their great depth (~800-1300m) as increasing the depth of UCG is considered to be the most effective way to mitigate risks. The best available environmental data come from USA trials of the late 1970s and 1980s, but these were conducted on shallow coal seams (<200m depth). The most relevant examples are the deep (> 500 m) European trials (e.g. El Tremedal, Spain), however, environmental impact data from these are either absent or limited[11].

Maturity of UCG technology

While major trials have taken place for more than fifty years and there are dozens of current trial projects around the world, no commercial UCG project has been demonstrated[1] and there remains significant technological and knowledge gaps[1,17].

Furthermore, a recent International Energy Agency report[17] emphasises that experience and expertise from closely related fields have limited applicability to UCG, and that the techniques and technologies proven in small-scale pilot trials do not necessarily transfer linearly to commercial-scale projects as new aspects such as the greater cavity size, multiple panels and increased length of operations likely present additional challenges.

Regulatory framework

Currently, we are considering our regulatory controls and it is likely that The Water Environment (Controlled Activities) (Scotland) Regulation and Pollution Prevention and Control (Scotland) Regulation 2012, amongst others, may apply. SEPA is working with Scottish Government and other regulators including the Coal Authority, Health and Safety Executive and

1 The Yerostigaz UCG facility in Angren, Uzbekistan, (majority-owned by Linc Energy) has been operating for over 50 years and could be considered commercial as it consistently produces 1 million m^3 of syngas per day (according to Linc Energy). However, it uses old, full depreciated equipment, the consistency and quality of syngas produced has not been a critical factor, it probably doesn't meet the environmental standards of OECD countries, and there have been no moves to scale-up the operation[17].

Potential hazard	Details and environmental concerns	Influencing factors	Example(s)	Relevance to Scottish context
Groundwater pollution	- Consistently identified as the primary environmental concern. - Pollutants include: - Organic compounds (e.g. Phenols, PAHs, BTEX) - Inorganic compounds (e.g. ammonia, nitrogen, cyanides) - Soluble gases (e.g. hydrogen sulphide, carbon monoxide, heavy metals) - Naturally Occurring Radioactive Material (NORM). - Changes in pH can also occur - Risk depends on the potential for pollutant migration and the presence of receptors. - Waste coal ash left in situ after decommissioning poses permanent risk of	- Inadequate site selection - Inadequate decommissioning - Groundwater flow altered post-operation - Excess cavity/well pressure - Inadequate monitoring - Inadequate process control - Well blockage - Fire/explosion - Damage to monitoring or production boreholes/wells - New pathways created due to cavity collapse and thermal/mechanical alteration of surrounding rocks - Faults/natural pollutant pathways - Intersection of historical mines	**Hoe Creek I, II & III, USA** (late 1970s, 3 shallow depth (~50m) trials): - Significant long-term groundwater pollution due to over-pressured cavity[2,3]. **El Tremedal, Spain** (1997, ~550m deep): - Main environmental impact was to groundwater and was calculated to be similar to underground tungsten mining[9] **Former Soviet Union[14,15,17]** (various trials): - Groundwater contaminants, resulting from gasification during the late 1950's and early 1960's, found to be widespread and	- Developments are likely to be at >800m depth, making examples from shallow (<500m) settings less informative. - The Coal Authority would not permit developments that have potential for intersecting historical mine-workings. - Groundwater at proposed sites is likely to be permanently unusable because it is naturally saline.

	groundwater pollution. - There are uncertainties over contaminant: - generation - persistence - transport		persistent, even up to five years after production had ceased. - Phenols were found within an aquifer which extended over an area of 10 km^2 - There were significant gas losses due to leakage, and it was common for between 5% and 25% of the gas formed to be lost from the underground gasifier **Experimental Mine "Barbara", Poland** (2013, a 30m deep engineered reactor): - Heavy metals, ammonia and cyanides found in effluents and groundwater near the site[13].	
Surface water pollution	**-** Surface waste water can originate from: - process water - gas treatment - cavity flushing water - Pollutants include	- Inadequate site selection - Natural or anthropogenic features (e.g. faults, fissures, boreholes) may create hydraulic connections to the surface	Risk of surface incidents due to inadequate surface infrastructure and treatment/disposal of waste should be similar to conventional surface	- Developments are likely to at >800m depth, making uncontrolled hydraulic connections from the cavity to the surface

	(same as above?) - The quality of waste water can vary significantly and rapidly	- Inadequate treatment/disposal of extracted waste water - Inadequate surface infrastructure, including materials, maintenance, procedures and protection systems - Excess well pressure due to: - Inadequate monitoring - Inadequate process control - Well blockage - Fire/explosion	industries **El Tremedal, Spain** (1997, ~550m deep): - 240 tonnes of coal gasified -The influx of groundwater into the cavity was much larger than expected, resulting an excess of produced water with elevated contaminant levels. This was a major technical and economic problem, although no local surface water contamination was detected[11]. **Carbon Energy, Bloodwood Creek, Queensland, Australia** (2008 to present, ~150m deep): - An injection well blockage caused pressure to spike well above hydrostatic pressure, resulting in the emission of process water through	highly unlikely, except in the case of damaged boreholes. **-** Discharge of waste water is likely to be into the marine environment because of its proximity to proposed sites and the huge dilution potential.

			the flare[1].	
Air emissions	- Pollution of air with: - Unburned hydrocarbons - NOx - H_2S and SO_2 - CO - Fly ash - Particulates and heavy metals - Mist formation (from cooling) - Dust deposition - Greenhouse gas (GHG) release: - CO_2 - CH_4	- Inadequate: - Monitoring - Site selection - Process modelling - Construction emissions - Emissions imbedded in materials - Flaring - Refining/combustion of syngas - Venting during start-up - Fractures or old mine workings - Fugitive (escaped) gases due to: - Leaking/damaged underground and surface infrastructure - Excess well pressure - Fire/explosion - Well blockage - Combustion of syngas	- **Linc Energy, Chinchilla plant, Queensland, Australia** (2007-2013, ~150m deep): workers suffered ill health due to “uncontrolled leaks” of syngas[4]. In 2007, a coal tar blockage caused a chamber fire, Linc Energy increased injection pressure causing well casings and overburden to crack and allow syngas to escape to the surface[5]. - Lifecycle climate impacts are estimated (from few studies and limited evidence) to be less carbon intensive than electricity generation from coal but more than from natural gas[6,7,16]. Large uncertainties remain.	- Regulation of emissions to air will depend on whether PPC 2012 applies to UCG and what other activities occur on site (e.g. gas processing or combustion for electricity generation). - CCS has been proposed for sites in Scotland, which would reduce lifecycle GHG emissions. However, CCS is still in its infancy, with only one commercial full-chain project in operation in the world today.
Underground explosion	Concerns include: - Water environment/air pollution from - Highly over-	- Inadequate: - Monitoring - Site selection - Process modelling - Inadequate process control	- **Experimental Mine “Barbara”, Poland** (2013, a 30m deep engineered reactor):	

	pressured cavity - New pathways in rock fractures - Damaged boreholes - Damaged surface infrastructure - Subsidence - Induced seismicity	- Temperatures too high - Too much gasification agent - Too slow gas collection - Damaged wells (ignition and production) - Material defect/installation error - Induced seismicity	cracks developed causing gases to leak and create explosive accumulations, igniting due to high temperatures[8]. - **El Tremedal, Spain** (1997, ~550m deep): malfunction of ignition system and failure of temperature measurement system resulted in accumulation of methane and a subsequent explosion. The injection well was damaged and the decision made to terminate the trial[7,12].	
Cavity collapse	Concern: - New pollutant/air pathways in rock fractures - Impacts to surface or groundwater hydrology - Surface subsidence - Damaged surface infrastructure - Damaged well casings Details:	- Uncontrolled gasification - Poor structural integrity of overburden - Disturbance of historical coal mines - Inadequate: - Monitoring - Site selection - Process modelling	Experience may be drawn from longwall mining. **Hoe Creek III, USA**[2] (late 1970s, shallow depth (~50m) trial): cavity collapse caused serious groundwater pollution and subsidence could be seen at the surface.	- Developments are likely to at >800m depth, greatly reducing the likelihood and impact of surface subsidence **-** The Coal Authority has stated that licences will normally only be issued in offshore areas and onshore areas where it

	- Surface subsidence risk deemed to be low if mitigated through site selection, e.g. - Deeper target coal seam - High structural integrity of overburden - Subsidence expected to be ~1/3 of coal seam thickness, with 98% of height loss occurring within 7 months[16].			can be demonstrated that the surface is suitable for piloting UCG. Hence, it is unlikely that surface infrastructure will be at risk.
Seismicity	Concern: - Pollution to the water environment and air via: - New pathways in rock fractures - Damaged boreholes - Damaged surface infrastructure - Explosion from gas accumulation via new pathways	- Stresses imposed by the cavity remaining after combustion - Cavity collapse - Proximity to existing faults - Use of hydraulic or explosive fracturing to link wells - Inadequate: - Monitoring - Site selection - Process modelling	No instances found in the literature but this may be from lack of reporting or monitoring. It is expected that induced seismicity will be small compared to mining and dam construction, for example.	
Groundwater depletion	Concern: - Supply shortage for other water users - Impacts to ecology	- Size of operation - Local hydrogeological conditions	The Independent Scientific Panel report on UCG pilot trials in Australia found that in some instances there is a	If Water Environment (Controlled Activities) Regulations (2011) apply, then groundwater depletion

	Details: - Due to use of water in reactor - Rate of water supply into the reactor affects the product gas composition - Impact is expected to be small but uncertainties remain.		need for external injection of water into the cavity to maintain appropriate hydrostatic pressure. It also recommended that a minimum distance is set between UCG and other activities that require different hydrostatic operating conditions (e.g. Coal Bed Methane).	would be prohibited.
Uncontrollable fire	Concern: - Pollution to the water environment and air - Cavity collapse Details: Risk decreases with greater target coal seam depth.	- Requires uncontrolled air/oxygen source to gasification cavity, via: - Faults/fractures/subsidence - Damaged borehole casings - Shallow target coal depth - Inadequate: - Monitoring - Site selection - Process modelling	No instances found in the literature but this could be from lack of reporting and the short duration of most projects. Analogous experience may be drawn from traditional mining activities.	- Developments are likely to at >800m depth, greatly reducing the likelihood of an uncontrolled air/oxygen source to the cavity occurring. - Developments will be occurring below the water table, making both oxygen ingress and uncontrolled combustion unlikely.

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