Scoping the environmental impacts of Carbon Capture, Transport and Storage

Explanatory note

For development projects that require Environmental Impact Assessment (EIA) under the EIA Directive (97/11/EC, as amended), a scoping exercise is often undertaken early in the planning stages. This can help the project to be designed to avoid or minimise negative environmental impacts, and provides an opportunity to incorporate positive environmental enhancements. Early consultation with all interested parties, including the Environment Agency, is an important part of scoping. Even if a project does not require EIA under the relevant legislation, a scoping exercise can support applications for other relevant consents or authorisations.

The Environment Agency is a statutory consultee to the EIA process in England and Wales, under the Town and Country Planning (EIA) (England and Wales) Regulations 1999, and more recently under the Infrastructure Planning (EIA) Regulations 2009. To support developers and other proponents through EIA scoping, we have produced a number of scoping guidelines, covering individual development categories, providing project-specific scoping guidance for key issues under our remit (available on http://www.environment-agency.gov.uk/research/policy/33013.aspx).

Our scoping guidelines promote a good practice approach to scoping as part of the EIA process, which in some respects goes beyond the statutory EIA requirements. When scoping a project, developers or their consultants should be satisfied that they have addressed all potential impacts, as well as the concerns of all organisations and individuals with an interest in the project.

This scoping guideline provides information on the most likely potential environmental impacts of Carbon Capture, Transport and Storage (CCS chain), focusing specifically on the environmental issues under the Environment Agency's remit. Each project should be considered on a case-by-case basis, to determine the full range of environmental issues (beyond those covered here) that may need to be addressed. The detailed characteristics of each proposal and site will determine the potential for impacts.

Our guidance is based on the main legal requirements on EIA stemming from the EC Directive and expected future UK Regulations. We recommend that developers seek independent legal advice to ensure that the proposed development is carried out in compliance with the requirements of this and any other relevant legislation, relating to planning as well as to pollution control.

The following scoping guidance notes, also published by the Environment Agency and available from our website, may also be relevant to various aspects of CCS projects:

A1 Construction work
D3 Petro-chemical industry – offshore developments, including exploration
D4 Petro-chemical industry – onshore developments, including exploration
E2 Pipelines (oil and gas)
G3 Chemical manufacture, processing and storage
I5 Thermal power stations
I7 Windfarms (onshore and offshore)

Contents of this Scoping Guideline

1 Introduction

1.1 This guidance note, in conjunction with the others listed on the previous page, seeks to help developers and other interested parties identify the potential impacts of Carbon Capture, transport and Storage (CCS) projects on the environment. The list of impacts presented is not exhaustive, and we recommend that a full site investigation into positive and negative impacts should be undertaken by individual developers on a project specific basis. Early consultation with the Environment Agency and other relevant organisations will enable the identification of environmental issues and constraints and the avoidance of sensitive areas, thus reducing the need for redesigning and mitigating avoidable impacts at a later stage.

Background to development type

1.2 Carbon capture and storage (CCS) projects are considered an option for reducing human emissions of carbon dioxide (CO_2) to the atmosphere. Stationary large sources of CO_2 (such as coal and gas fired power stations, steel and aluminium plants, and cement manufacturing plants) are the focus of the technology. The process is broken down into three components: (1) Capture of CO_2, (2) CO_2 transport, and (3) geological storage of the captured CO_2. Each is discussed below.

1.3 C**apture of CO_2** can be undertaken on power plant combustion emissions and industrial processes. Capture aims to produce a high-purity stream of CO_2 suitable for transport and subsequent storage.

1.4 There are three main approaches to capturing CO_2 from fossil fuel utilization;

- Post-combustion usually utilises a liquid solvent to capture CO_2 from the flue gases of primary fuel combustion.

- Pre-combustion undertakes gasification of the primary fuel in air or oxygen to produce a saturated synthesis gas, and further reaction through a shift reactor to produce a gas comprising of mostly CO_2 and Hydrogen. After separation the hydrogen can be utilized for power generation and the CO_2 exported.
- Oxyfuel primary fuel combustion uses pure oxygen resulting in a stream of flue gas consisting mainly of water and CO_2.

1.5 This guidance focuses on power plant combustion utilising post and pre-combustion methods, although some of the impacts will also be relevant to industrial processes and oxyfuel capture.

1.6 **Transport of CO_2** will be necessary when the capture plant is not directly above the storage location. CO_2 transport via pipeline is likely to be the dominant method, although shipment of CO_2 is also feasible in some situations within the UK. Pipeline transport will usually require the CO_2 to be compressed into its dense phase (i.e. liquid or supercritical phase) to allow for efficient flow. Pipeline and shipping transport of CO_2 are covered within this guidance document.

1.7 There are three geological **storage options for CO_2**: oil and gas reservoirs, deep saline formations and un-mineable coal beds. All three options occur in sedimentary basins in both onshore and offshore locations, and involve injection of dense phase CO_2 into a geological formation.

1.8 This guidance focuses on geological formations with emphasis on depleted oil and gas reservoirs, although some of the impacts identified will be relevant to saline aquifers and un-mineable coal beds.

1.9 Impacts are identified as being related to the separate parts of the project highlighted above and as interlinking impacts that need to be addressed. Distinction is made between the individual project impacts, interlinking impacts and on- and offshore operations.

Important considerations for CCS

1.10 Current practitioners and developers have highlighted some important considerations that require attention when proceeding with the planning of a CCS development. These issues are highlighted in points 1.9 and 1.10.

1.11 The largest risk stemming from CCS operation is the potential for leakages of CO_2 during the operation and post closure phases. This can have large health and safety as well as environmental repercussions. In most instances health and safety would be the primary focus, with environmental impact being considered a secondary concern.

1.12 Leakages can arise throughout the CO_2 system, although leaks from the transport system or geological storage are likely to pose the greatest impacts. Pipelines can suffer leakage from failure through corrosion, external physical damage (e.g. puncture from vehicles or anchors), and leakage through inappropriate sealant materials. Propagation fractures from an initial flaw could release a large quantity of CO_2. Large-scale storage leakage may result from injection well failure, well blow-outs and from abandoned wells. In the instance of a large leak of CO_2 the safety considerations would likely outweigh the environmental considerations, as the CO_2 could form a heavier than air cloud with concentrations high enough to cause immediate harm to people and fauna (i.e. >10% in air by volume). Valleys and low-lying ground would be at particular risk from a large CO_2 release. Smaller scale storage site leakages could result from geological faults and fractures or leaking wells. These smaller leakages are more likely be very low volume, being more gradual and diffusive, and may go undetected. They may pose environmental issues to soil, water and flora through acidification. Unplanned or accidental CO_2 releases may take a variety of forms and scales.

1.13 Health and safety is a concern also with regard to the large chemical inventories and usage expected on the capture plant site. For most effective results, health, safety and environmental considerations of CCS projects should not be decoupled in the planning stages. Considerations of site selection, layout and infrastructure positioning are important for safety considerations under abnormal conditions. Some capture plants may be subject to the Control of Major Accidents and Hazards (COMAH) regulations, and pipelines likely to be assessed through a Major Accident and Hazard Risk Assessment. With the appropriate up front risk assessment and management, CCS should operate effectively, safely and in an environmentally responsible manner.

Phases of development

1.14 The pre-operation phase is essential for establishing appropriate design of the entire chain to allow for efficient operation and reduction of risks associated with CO_2 releases. If CCS facilities are retrofitted to existing infrastructure, this will need to be tested during the construction phase to make sure it is fit for purpose. Care will need to be taken during construction of capture facilities onto sites that are operational (e.g. power plant). Testing of existing pipelines should fully assess their ability for CO_2 transport. Utilisation of existing infrastructure (onshore or offshore) should assess its capacity for the life extension beyond its original design. New developments will have construction related issues similar to their traditional counterparts.

1.15 CO_2 is introduced into the system during the operation phase. CO_2 will be captured and compressed into a high purity stream that may contain impurities dependant on the fuel type used. The compressed CO_2 stream will be passed to the transport system. Long pipelines may require further compression. A shipping transport option may require storage tanks at the capture site or close to the shore and additional compression at the eventual storage location. On arrival at the storage site additional compression may be needed and testing of the CO_2 stream properties. During operation steady state operation is required to keep CO_2 flowing through the system. Start/stop operation (through disturbance to the system, maintenance requirements or to achieve short term increase in power station output) may involve venting of CO_2 and its associated impurities.

1.16 Post closure of the system will require the decommissioning of the capture and transport systems. The storage location will be required to be sealed. Monitoring will be required for to demonstrate the competence of the storage site to hold the CO_2. Therefore, it is likely the infrastructure surrounding the injection facility will not be decommissioned until this is demonstrated (this will be a certain time after injection ceases, where by responsibility is passed back to the state).

2 Development Control and EIA

Development Control

2.1 Carbon Capture, Transport and Storage developments are likely to require either planning permission under the Town and Country Planning regime, or Development Consent by the Infrastructure Planning Commission, if they are Associated Developments to new power plants covered by the relevant Energy National Policy Statement.

Environmental Impact Assessment (EIA)

2.2 The new EU Directive 2009/31/EC on the geological storage of carbon dioxide will need to be implemented in Member States by June 2011. UK regulations and provisions are under development to meet with this target. Amongst them the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 are being amended to accommodate the changes to the EU Directive 85/337/EEC on which they are based.

2.3 Specifically, EU Directive 2009/31/EC amends Annex I and II of the EU Directive 85/337/EEC, to include the need for EIA of CCS facilities. Annex I projects require EIA under all circumstances. Annex II projects require EIA subject to thresholds set by Member States, the sensitivity of the locations they may affect, and the significance of any potential environmental impacts of the project.

2.4 Annex I has been amended to include, at Point 16, under "pipelines with a diameter of more than 800 mm and a length of more than 40 km", those for "the transport of carbon dioxide (CO_2) streams for the purposes of geological storage, including associated booster stations".

2.5 Annex I has also been expanded to include:

Point 23: "Storage sites pursuant to Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide"; and

Point 24,. "Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to Directive 2009/31/EC from installations covered by this Annex or where the total yearly capture of CO_2 is 1.5 mega tonnes or more."

2.6 Annex II has been amended to include, under Point 3:

(j) Installations for the capture of CO_2 streams for the purposes of geological storage pursuant to the Directive 2009/31/EC from installations not covered by Annex I to this Directive."

And to replace item (i) from point 10 with;

"(i) Oil and gas pipeline installations and pipelines for the transport of CO_2 streams for the purposes of geological storage (projects not included in Annex I)."

2.7 It is expected that future CCS projects in the UK will fall under these Directive amendments and under corresponding UK regulations once these are issued, and will require EIA.

2.8 Whether or not a formal EIA of a proposed project is required, the Environment Agency and other statutory consultees and regulators may request environmental information concerning the proposal prior to releasing the relevant permits. An EIA may provide the most appropriate method for a developer to collate the necessary information.

3 Potentially significant environmental effects

3.1 The EIA Directive requires the EIA to *'identify, describe and assess…the direct and indirect effects of a project on the following factors: human beings, fauna and flora; soil, water, air, climate and the landscape; material assets and the cultural heritage; [and] the interaction between the [above] factors*.' Socio-economic issues, health and safety in the workplace, material assets and cultural heritage are also considered in EU Guidance on Scoping (ERM, 2001a). This Scoping Guidance Note focuses on the potential impacts of CCS on the environmental topics for which the Environment Agency is the principal competent authority – namely fauna and flora specifically related to aquatic environments, soil, water, air, climate, and material assets associated with flood risk and coastal erosion management. Environment Agency advice on these issues is presented without prejudice to the advice of other relevant authorities (e.g., Local Authorities, Natural England, Health Protection Agency), which should also be consulted.

3.2 CCS activities have the potential to affect the environment in many ways. They can differ widely in terms of their mode of operation and location, and key issues are likely to vary from site to site. Therefore, we recommend that expert advice on detailed technical issues be obtained. The issues arising for all environmental receptors will change over time throughout the construction, operational and decommissioning phases. Developers and site operators should therefore consider the impacts arising from all aspects of the development activities.

3.3 Potential impacts are discussed here in broad terms only as their nature and intensity will depend on the physical characteristics of the project and the composition of any polluting materials. An EIA of proposed CCS activities should take these factors into account in assessing potential impacts on the environment.

3.4 The following paragraphs should be read in conjunction with Table 1, at the end of this Guidance Note. The table provides a summary of the activities involved in the preparation and ongoing management of CCS, and the impacts arising from them.

Water Environment

3.5 Surface water hydrology can be affected by the additional abstraction requirements of the capture plant, leading to reductions in the river water flow.

3.6 Surface water quality could be affected during the pre-operation/construction phase through discharges from pipeline testing, earthworks and accidental spillage. During the operation phase surface water could be affected by wastewater discharges from capture plant activities and cooling. The receiving environment could potentially be polluted during the operation phase by suspended solids from site runoff, and through disturbance to contaminated land and accidental spillage and leaks of substances used in the capture process onsite. Surface water may also be affected by all activities in the CCS chain through a potential leak of CO_2, causing surface water acidification.

3.7 Groundwater hydrology can be affected through the construction and physical presence of the pipeline and capture plant. This could divert the course of groundwater flow, potentially having implications for surface water and aquatic ecology.

3.8 Groundwater quality could be affected in the event that leaks and spills that may occur onsite were allowed to seep into the ground and infiltrate into the groundwater. In an abnormal release of CO_2 from the transport system or storage site during operation or post closure, the groundwater could become acidified, which could lead to leaching of trace metals from surrounding matrix. Injection of CO_2 into the storage formation could lead to the displacement of brines, which can pollute groundwater on contact.

3.9 Coastal and seawater quality can be affected during seabed modifications potentially required for the installation of pipelines and infrastructure for offshore storage. Such modifications can lead to sediment disturbance and releases of pollutants. Spills and leaks from construction machinery can also impact water quality.

3.10 Sea bed preparation and additional construction of pre-existing offshore platforms for offshore storage could re-suspend potentially contaminated cuttings from previous well drilling operations left on the seabed around the platform jacket base. Offshore injection operations can affect the water quality through the requirement of oily water discharges and the use of chemicals. Injection also has the potential to displace large quantities of paleowater that may be hypersaline or of low quality.

3.11 Abnormal releases of CO_2 from offshore pipelines during operation or storage sites during operation or post closure have the potential to acidify surrounding seawaters.

Land

3.12 Soil quality may be affected through disturbance of contaminated land on previously industrial sites during construction and decommissioning of the capture plant. During operation of the transport system or storage site or post closure of the storage site, abnormal releases of CO_2 could reduce soil pH, resulting in oxygen-depleted soils and mobilisation of heavy metals. This would reduce soil quality, potentially resulting in toxic conditions for flora.

3.13 Over very long time scales there is potential for geologic structures to be altered through injection of CO_2. In the short term (until temperatures reach equilibrium) there may be an impact in the thermodynamic and chemical properties of the storage formation. This could incite seismic activity and potential ground heave or soil cave-ins.

Air and Climate

3.14 Local air quality can be affected during construction activities through the production and suspension of dust, having implications for local receptors. Fuel usage by machinery and equipment, shipping vessels and helicopters during the construction and operation will also cause emissions to the local environment.

3.15 Releases from the CO2 stream during pipeline operation could allow for deposition of CO2 stream impurities into the surrounding environment (although it is expected that many of these will have been removed upstream). CO2 releases would cause local air quality reductions, being worst during calm weather conditions. Utilization of shipping vessels (during construction of offshore infrastructure and/or operation of shipping transport) will result in emissions to air with local air quality impacts. Capture plant operation may produce a variety of air emissions depending on the technology and fuel used. Solvents may also be released into the receiving environment. Stop/start operations (as a result of maintenance, to achieve short term increase in power station output or in emergency situations (e.g. leak)) requiring venting and flaring may increase transitional emissions, and may require CO2 and sulphur dioxide (SO2) to be released. Local air quality changes may have implications for humans and flora and fauna.

3.16 Fugitive emissions of CO_2 may be experienced from inadequate seals and fittings along the CCS chain. The specification of CO_2 in the pipeline will have to meet certain minimum quality limits to allow for an environmental case to be made for releases.

3.17 The capture, transport and storage of CO_2, a greenhouse gas, aims to mitigate the effects of climate change, having a global benefit. However, any large release or failure of the system during operation or post closure may have local detrimental effects.

Ecology

3.18 In proximity of aquatic environments, the physical footprint of the infrastructure may cause aquatic habitat and species loss. Construction and operational noise may disturb aquatic species. Seawater contamination outside of agreed limits may impact aquatic ecology. Cooling water discharges may have a thermal impact on receptors in the receiving environment. A release of CO_2 either through venting or an accidental event during operation or post closure can cause the formation of solid CO_2 particles through depressurisation and resulting cooling. Solid particles could build up to form a pipe work plug or external to the pipeline cause significant solid CO_2 deposition. As solid CO_2 is at -78oc, its formation can cause harm to flora and fauna. Offshore spills from operation may contaminate the seawater having impacts for aquatic ecology.

Human Environment

3.19 Construction may disturb agricultural land onshore, and fishing grounds offshore. Recreational activities in proximity of rivers or coastal areas may be affected by nearby construction activities, potentially having a negative short term impact. Public concern may occur over routine releases from capture plants, accidental releases from pipelines and CO_2 storage onshore.

3.20 The capture process may involve the use of a large inventory of chemicals and flammable gases. Pre-combustion capture can involve the production of large quantities of hydrogen, introducing risks such as detonation explosions. Any significant release of CO_2 along the chain has the potential to accumulate in dips or slumps on the surface in calm weather conditions. This poses a risk for humans in the affected area, potentially causing fatalities, due to asphyxiation.

Additional impacts

3.21 General waste will be generated through the construction and operation phases of the project. There may in some cases be additional capture waste generation from degradation products of solvent usage.

3.22 Resource use will increase as a result of;

- Large resource use associated with the feedstock requirements of the capture plant in terms of chemicals and fuel.
- Abnormal CO_2 contamination of drinking water and oil and gas reservoirs may eliminate these resources from future usage.

3.23 Energy requirements throughout the entire chain of CCS will cause additional emissions associated with the energy consumed. Initial feedstock transport and waste disposal (up and down stream emissions), can be large due to the scale of operation. Capturing and compression of CO_2 have the largest energy requirements within the chain. Additional compression and reprocessing for injection, if required, will also have associated emissions, with large pollution potential with offshore fuel use. Emissions have local and regional implications

4 Mitigation Measures

4.1 Although strictly not considered during the Scoping stage of EIA, a discussion of potential mitigation measures is provided here, as mitigation at an earlier, design stage of a project is a much more effective approach than “retrofitting”, or introducing post-construction measures.

Construction

4.2 Careful site selection, design and layout of the capture facility and transport route of CO_2 would be the initial mitigation to reduce environmental impacts. The pre-operation and construction phase is crucial in detecting potential leak pathways. Developers should undertake a careful and extensive investigation of the storage site. Thorough risk assessments should be utilized to enable safety to be built into the project design. To minimise the potential for significant impacts as a result of leakage, pipeline route selection is key to avoiding large population densities and sensitive sites. For new builds, onshore pipeline length should be minimised by utilising coastal sites for capture, and by building pipeline networks. Application of the Construction Code of Practice or Construction Environmental Management Plan should manage and reduce construction related impacts.

Operation

4.3 It is likely capture plants will be subject to COMAH assessment due to the large inventories of chemicals required. Applying this technique should reduce environmental risks. Additionally, environmentally benign chemicals should be selected. To reduce risks associated with CO2 leaks from pipelines, developers should deploy a management/safety plan that sets out monitoring, inspection and operational requirements as well as emergency response procedures. Pipeline monitoring options include internal inspection, external corrosion checks and leak detection (where possible) and regular foot, air and ship patrols. Storage sites will also require monitoring throughout operation and post closure, techniques available include; seismic monitoring, side scan sonar and CO2 detectors. Early detection of a leak should initiate planned remediation to stop the leak and treat the damage.

Decommissioning

4.4 The post closure phase will require removal of infrastructure and on surrender of an environmental permit the original condition of the site must be restored. A decommissioning plan would help avoid pollution and contaminated land risks. Reuse of infrastructure should be assessed. The storage site will require long term monitoring and verification to ensure the CO2 remains in the storage media and to allow for early remediation where required.

Protecting the water environment

4.5 Selection of the site for the capture facility should be undertaken with the water resources of the area in mind if water cooling or pre-combustion (for the shift reactor) are to be undertaken. In areas with limited water resources, alternative cooling methods should be considered e.g. air cooling. Efficiency of design should be maximised to reduce water requirements and technological advances should be used where available.

4.6 Surface water quality can be maintained through treatment of wastewater to remove suspended solids, and other contaminants. Best practice mitigation measures against on site activities should be employed to reduce surface water impacts e.g. the use of temporal ditches, traps, bunding of storage tanks.

4.7 Seawater quality reductions through chemical use can be reduced through selecting chemicals based on environmental impact criteria and conducting full chemical risk assessments.

Soil Protection

4.8 Soil quality issues, in relation to contaminated land can be reduced through the physical removal of contamination offsite or mapping and demonstrating the contamination will not leach out.

Protecting the air environment

4.9 Air quality impacts from dust can be reduced through standard dust mitigation measures, e.g. wetting, sheeting, washing and vehicle speed reductions. Good communication with local residents should also be carried out. Capture plant design can allow emissions from operation to be reduced. Combining an appropriate vent stack height with venting velocities should be adequate to prevent thresholds for certain emissions being reached. Using low nitrogen oxides (NOx) burners or introducing catalytic reduction technology can reduce NOx emissions. Careful design should allow for flexibility to be built into the system and buffers could be placed along its length to allow for continuous operation and reduction of stop/start emissions. Seals must be of an appropriate material to avoid explosive decompression and fugitive emissions along the CCS chain.

Protecting Ecology

4.10 Noise impacts to marine ecology can be reduced through careful seismic practice (for offshore monitoring) and restricting vessel movements. Spills into the aquatic environment can be reduced through training of offshore platform personnel, regular inspection and maintenance and using absorption material.

4.11 Required site clearance and construction should be undertaken outside seasonal breeding periods and habitat enhancement and creation should be considered. A Code of Construction Practice will raise staff awareness.

Protecting the Human Environment

4.12 Hydrogen storage in small containers will reduce risks, and appropriate roof design for dispersion will remove the containment risk. Careful onsite gas management will reduce risks of fire. Appropriate venting design will decrease venting issues.

Reducing Waste issues

4.13 Recycling opportunities should be maximised and markets, where available, should be utilized for ash and spent catalysts. A waste management plan should be produced to reduce waste mismanagement.

Reducing Energy Requirements

4.14 CCS technological efficiency is expected to increase over time and therefore the current most efficient technology should be used. Further research is and should continue to be undertaken to increase efficiency opportunities. Efforts should be made to integrate the energy requirements of CO2 capture and compression with the power plant. Alternative options should be considered to decrease up and downstream emissions, e.g. the use of natural gas reduces transport fuel usage.

5. References and Further Reading

DNV, (2009), Mapping of potential HSE issues related to large-scale capture, transport and storage of CO_2, 2008-1993 Available from www.ptil.no/getfile.php/PDF/Ptil%20CCS%202008.pdf, last viewed 1/08/2010.

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Table 1: Summary of key potential impacts of CCS activities.

The activity is highlighted in bold, preceded by a code for the corresponding part of the chain (key below), with the associated impacts stated as bullet points.

Activity Key:

(CP) = Capture Plant **(S) = Storage**
(T) = Transport **(EC) = Entire chain**

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
WATER	**Surface water hydrology & channel morphology**		**(CP) Abstraction** • Decreased river water flow. **(CP) Site Drainage** • Increased site run off	
	Surface water quality	**(CP) Earthworks** • Pollution from suspended material • Disturbance of contaminated land and subsequent pollution of water courses. **(CP) Materials Management** • Pollution from spills and leaks **(T) Used pipeline testing** • Pollution from contaminants	**(CP) Process discharge** • Impacts of water chemistry from temperature changes and contaminants in discharges **(CP) Materials Management** • Pollution from spills and leaks **(CP) Site drainage** • Possible pollution from contaminated runoff **(EC) Abnormal CO_2 release near a watercourse** • Water acidification	
	Groundwater hydrology	**(CP) Earthworks** • Alteration to groundwater flow	**(CP) Abstraction** • Decreased groundwater flow. **(T) Buried pipelines** • Permanently alter groundwater flow	
	Groundwater quality		**(CP) Materials management** • Contamination from spills or leaks of chemicals and solvents	**(S) Abnormal CO_2 leakage** • Acidification of groundwater • Contamination from

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
			(S) CO_2 Injection • Contamination from displaced brines **(S) Abnormal CO_2 leakage** • Acidification of groundwater • Contamination from mobilized metals • Contamination from CO_2 stream impurities	mobilized metals • Contamination from CO_2 stream impurities
	Seawater hydrology and seabed morphology	**(EC) Offshore earthworks** • Seabed and geology alterations		
	Seawater quality	**(EC) Offshore earthworks** • Re-suspension of contaminated cuttings pile causing seawater pollution **(EC) Materials management** • Spills and leaks from construction vessels	**(S) Offshore CO_2 Injection** • Discharge of contaminated oily water • Discharge of hypersaline paleowater **(S) Offshore well maintenance** • Contamination from chemical use in well workovers **(S) Abnormal CO_2 release/leak** • Seawater acidification Contamination from reaction with contaminated cuttings pile	**(S) Abnormal CO_2 release/leak** • Seawater acidification • Contamination from reaction with contaminated cuttings pile
LAND	**Soils**	**(CP) Excavation and earthworks** • Contamination through disturbance of contaminated land.	**(EC) Abnormal CO_2 release** • Soil acidification through infiltration • CO_2 accumulation in soils displacing air and asphyxiating roots of vegetation	**(CP) Plant removal** • Contamination through disturbance of contaminated land **(S) Abnormal CO_2 release** • Soil acidification through infiltration

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
	Geology		**(S) CO_2 injection into formations** • Induced seismisity, cavins or ground heave though alterations in thermodynamic and chemical properties	
	Local air quality	**(CP) Onsite activities** • Dust generation **(EC) Use of machinery, vehicles and shipping vessels** • Emissions from fuel usage	**(CP) COAL combustion emissions** • Releases of dioxins, mercury and arsenic in ash • Releases of NOx, SOx, particulates and ammonia **(CP) General capture emissions** • Releases of CO_2, NOx, SOx, hydrocarbons, particulate matter, VOCs, and heavy metals • Solvent releases from flue gases • CO_2 separation efficiency requires some impurities to be removed, potentially having air quality improvements **(CP) PRE-COMBUSTION hydrogen combustion** • Nitrogen use increases NOx releases **(CP) Operation stop/starts** • Additional transitional emissions **(T) Abnormal pipeline rupture** • Release of high pressure CO_2 • Deposition of CO_2 stream impurities; H_2S and heavy metals **(T) CO_2 Shipments** • Emissions through heavy fuel oil usage **(EC) Venting for maintenance/system failure**	

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
			• Emissions of CO_2 and SO_2 **(EC) Powering machinery** • Associated emissions of NOx, SOx, CO, CO_2, CH_4, NMVOC **(EC) Fugitive emissions** • Releases from compressor seals, flange and fittings and seams.	
AIR	**Regional/global air quality**		**(EC) Normal system operation** • Power generation whereby CO_2 is captured, transported and stored therefore positive mitigation against the greenhouse effect **(EC) Abnormal system failure/rupture/conventional generation** • Releases of CO_2 undermining project aims and contributing to the greenhouse effect	**(S) Abnormal CO_2 release** • Releases of CO_2 undermining project aims and contributing to the greenhouse effect
FLORA & FAUNA	**Aquatic ecology**	**(S) Offshore earthworks** • Noise and seismic disturbance to aquatic ecology • Contamination impacts from re-suspended contaminated material **(S) Onshore/offshore Materials management** • Harm to aquatic flora and fauna from machinery/vessel fuel and chemical spills and leaks **(S) Intertidal zone earthworks** • Disturbance, or loss of	**(CP) Discharge** • Alteration of habitat through temperature or water chemistry **(S) Offshore materials management** • Harm from spills and leaks from offshore vessel entering the water column **(S) Abnormal offshore pipeline/storage site CO_2 releases** • Seawater acidification impacts on aquatic ecology can be fatal • Loss of sensitive deep sea species • Harm to calcium carbonate producing organisms	**(S) Abnormal offshore storage site CO_2 releases** • Seawater acidification impacts on aquatic ecology can be fatal • Loss of sensitive deep sea species • Harm to calcium carbonate producing organisms • Harm to subsurface microbial communities

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
		aquatic flora and fauna	• Harm to subsurface microbial communities	
HUMAN ENVIRONMENT	**Agriculture and Fisheries**	**((T) Earthworks and excavations** • Disturbance to agriculture **(S) Offshore earthworks and excavation** • Disturbance and interference to fishing grounds from vessels and exclusion zones **(S) Offshore installation** • Damage to fishing nets through dropping of construction materials		
HUMAN ENVIRONMENT	**Health and safety**	**(CP) Earthworks and excavations** • Construction site safety required • Retrofitting on active sites poses a particular set of health and safety issues **(T) Pipeline laying** • Construction site safety in areas with public access – crossing roads and footpaths in open countryside	**(CP) PRE-COMBUSTION Capture** • Risk of fire from use and production of flammable gases, Natural gas, syngas and hydrogen **(CP) Large chemical usage** • Risks from spills and leaks **(CP) Compression of CO_2** • Hazardous substance in supercritical phase **S) Onshore Storage negative publicity** Concern over CO_2 safety **(EC) Venting high pressure CO_2** • Human injury from vent stream containing solid CO_2 particles **(EC) Abnormal CO_2 releases**	**(S) Onshore abnormal CO_2 releases through storage leakage** • Human exposure to high density CO_2 from accumulations at the surface or in basements (may potentially occur only if onshore storage is allowed) can be fatal above concentrations of 7-10% • Crater formation

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
			through pipeline rupture or storage leakage • Human exposure to high concentrations of CO_2 from accumulations at the surface or in basements can be fatal above concentrations of 7-10% • Crater formation	
	Other Impacts/Issues	**(CP) Waste generation** • Liquid and soils wastes from onsite construction potential pollution impacts with careless management	**Waste generation** (CP) Capture process • Solvent and flue gas degradation products requiring special disposal (CP) COAL use for PRE-COMBUSTION • Ash waste and slag generation (CP) Onsite operation • Liquid site drainage waste and solid maintenance waste **Resources** (CP) Large feedstock requirements • Large resource usage (T) CO_2 solidification in pipeline • Necessary relaying generates additional construction impacts and material usage **(EC) CO_2 releases** • Contamination of drinking water reduces usage capability **(EC) Entire chain additional energy**	**Resources** **(S) CO_2 releases** • Contamination of drinking water and oil and gas reservoirs reduces usage capability (but only if onshore storage is allowed) Contamination of oil and gas reservoirs reduces usage capability

		Activities and potential impacts		
Potential receptors of impact		**Pre-operation/Construction phase**	**Operation phase/ On-going site maintenance**	**Post-Closure/ Decommissioning phase**
			requirements • Transport of capture feedstock • CO_2 capture process • CO_2 compression (initial and additional requirements • Reprocessing before injection = All require fuel usage and release emissions	