International CCS Policies and Regulations

WP5.1a/WP5.4 Report

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1. Introduction

Key challenges facing the large-scale deployment of CCS include technology, costs, financing, public acceptance and legal and regulatory issues. This report is concerned with the regulatory and legal issues facing CCS deployment in China. The report reviews the status of CCS regulation worldwide covering the various stages of a CCS project life cycle including carbon dioxide (CO_2) capture and CO_2 transport in addition to the injection and post-injection phases.

The deployment of CCS on a large scale is associated with risks. These risks are mainly due to the fact that CCS involves storing millions of tonnes of CO_2 per year with the possibility that the injected gas may spread over a large area and the subsurface pressure could be felt from very far locations. Regulatory frameworks that manage health, environmental, financial, and property risks and liabilities associated with CCS are considered by many to be required if CCS is to be adopted on a large scale. In order to gain public acceptance of CCS and achieve investors' commitment, these regulatory frameworks should be globally consistent and nationally coordinated[1].

CCS regulation needs to consider the capture, transport and injection/storage components of CCS. Regarding capture, currently emerging policies and regulation consider the concept of capture readiness, incentivisation, and IPR & technology transfer in addition to environmental impacts and safety issues related to the operation of the capture plant. CO_2 transport regulation considers routing of the CO_2 pipeline, ownership and liabilities. According to the International Risk Governance Council (IRGC), the area where there is greatest and most urgent need for CCS regulatory requirements is the storage of CO_2[1]. They recommend that a regulatory system for CO_2 storage should:

- Manage risks and liabilities
- Balance the competing needs of all players in a CCS project
- Address financial issues
- Address issues of climate change commitments
- Address ownership and access and property rights
- Obey the requirements of international treaties

The regulatory framework developed should encourage responsible operation and investment[2]. Policies should consider the availability of geological data and public acceptance. Emerging regulation on CO_2 storage is considering injection site characterisation and certification, site operation and closure, monitoring and verification requirements, long-term liability, ownership, and safety and environmental risks.

Over the past two years, there has been strong activity worldwide in developing CCS regulation. The following section gives an update on emerging CCS regulation and its implementation in several countries, followed by a discussion of how these developments can be relevant to the development of CCS regulation in China.

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[1] http://www.irgc.org/Expert-contributions-and-workshop.html

[2] http://www.irgc.org/IMG/pdf/Workshop_Report_Regulation_of_Carbon_Capture_and_Storage_March_15_and_16_2007_Washington_final.pdf

2. Current Status of CCS Regulation

In this section, updates on recent developments in CCS regulation from different countries are given. Some of the regulations discussed here are amendments to existing regulations while others are proposals for drafting CCS regulations based on existing experiences. Information from the different regulations and proposals reviewed are scanned and summarised in table format in several categories including CO_2 capture, CO_2 transport, site exploration and characterisation, site certification, classification of CO_2, risk assessment, access and property rights, site closure, post-closure and transfer of responsibility, measurement, monitoring and verification (MMV) requirements, and financial Issues.

The section starts with a brief review of amendments in international treaties and then focuses on regulation developed in the EU, the UK, the Netherlands, Norway, the US, Australia and Canada.

The regulatory frameworks and guiding principles considered in this analysis are given in Table 1 below.

Table 1: Major regulatory frameworks reviewed in the current section.

Country	Regulatory frameworks reviewed
EU	• EU Directive 2009/31/EC (on CO_2 storage) • EU Directive 2008/1/EC on Integrated Pollution Prevention and Control • Council Directive 85/337/EEC of June 1985 on EIA, which is to be applied to CO_2 transport.
UK	• UK Energy Act 2008
US	• IOGCC Guidelines • American Clean Energy and Security Act • EPA Guidance under the Underground Injection Control Programme 2007 • State regulations from Wyoming, North Dakota and Montana
Australia	• Australian Regulatory Guiding Principles • The Offshore Petroleum Amendment (GHG Storage) Act 2008 • Australian Greenhouse Geological Sequestration act 2008 • Queensland Greenhouse Gas Storage Act 2009-08-28 The Barrow Island Act of 2003 related to Gorgon

2.1 International Treaties

In 2007, CCS was accepted as a climate change mitigation option within the Kyoto Protocol[3]. In addition, legal barriers to the storage of CO_2 in geological formations under the seabed have been removed through modifying the London Protocol and the OSPAR Convention. In 2006, amendments to the London Protocol allowed and regulated the storage under the seabed of CO_2 from capture processes. In 2007, the contracting parties under the OSPAR Convention also adapted amendments that allowed the storage of CO_2 under the seabed.

[3]http://www.ieagreen.org.uk/presentations/Overview%20of%20Global%20CCs%20position.pdf

2.1.1 Marine Treaties

There are several pieces of legislations on the protection of marine environments and these will have a bearing on CCS regulatory activities. The most important of these legislations is the United Nations Convention on the Law Of the Sea (UNCLOS) 1982 which provides protection for all marine areas. Another is the London Protocol 1996 which replaced the London Convention of 1975 and whose purpose is to protect marine environments and prevent dumping of waste at sea.

2.1.1.1 The London Protocol

The London Protocol prohibits dumping waste in marine environments except for certain substances. CO_2 was not listed as one of these substances, which posed an obstacle for storing CO_2 under the seabed. In November 2006, the Protocol was amended and in 2007 it entered into force.

The amendment inserted a new category permitting the storage of CO_2 from CO_2 capture processes thus removing ambiguity and introducing the obligation for regulation. A further amendment sets the guidelines regarding impurities in the CO_2 stream and the requirements before a permit for storage is granted.

Under the London Protocol, which was agreed in 1996[4], all dumping is prohibited (except for acceptable wastes on the so-called "reverse list"). Amendments to Annex 1 of the Protocol[5] (Resolution LP1) considered 'that carbon dioxide capture and storage is one of a portfolio of options to reduce levels of atmospheric carbon dioxide' and noted that 'regulating such action is within the scope of the London Protocol'. The amendment emphasised that this resolution is restricted solely to carbon dioxide sequestration in sub-seabed geological formations and stated that guidance on the means by which sub-seabed geological sequestration of carbon dioxide can be conducted in a manner that is safe for the marine environment, over the long and short term, should be developed as soon as possible.

The new amendments entered a clause for allowing the sequestration of CO_2 from capture processes and stated that 'carbon dioxide streams' may only be considered for dumping, if:

- Disposal is into a sub-seabed geological formation
- They consist overwhelmingly of carbon dioxide (incidental associated substances derived from the source material and the capture and sequestration processes are allowed)
- No waste is added for the purpose of disposing this waste.

A further amendment to the London Protocol would be required to allow for trans-border transport of CO_2[6].

2.1.1.2 The OSPAR Convention

The OSPAR (Oslo-Paris) Convention regulates polluting activities in the sub-seabed and subsoil. The OSPAR Commission recognised CCS as an important option in the portfolio of measures to mitigate climate change and so the Intersessional Correspondence Group (ICG-CO2), formed by the OSPAR Committee meeting in 2006, agreed in the same year that in order to facilitate and regulate the placement of CO_2 in sub-seabed geologic formations, there was a need for amendments to Annex II and Annex III to the OSPAR Convention. The group agreed on the wording of

[4] http://www.imo.org/home.asp?topic_id=1488
[5] http://www.imo.org/includes/blastDataOnly.asp/data_id%3D16639/5.pdf.
[6] Parliamentary Office of Science and Technology, POSTNOTE 335: CO_2 Capture, Transport and Storage, June 2009.

possible amendments to these Annexes and that the wording should be consistent with the London Protocol amendment.

In 2007, the parties to OSPAR introduced amendments to allow for CO_2 storage in sub-sea bed geological formations provided the CO_2 stream consists overwhelmingly of CO_2. The amendments require that specific CO_2 guidelines be applied before issuing storage permits. The placement of CO_2 into the water-column of the sea and on the seabed was ruled out because of the potential negative effects. The amendments to the OSPAR Convention are yet to be ratified and so are still not in force.

The OSPAR guidelines focus on the process of CO_2 injection and post-injection at depths of more than 500 m. Guidleines are provided for site selection and characterisation, risk assessment and monitoring requirements. OSPAR guidelines state that the monitoring techniques described in IPCC Special Report on CCS (IPCC, 2005) and the Guidelines for National Gas Inventories (IPCC, 2006) should be followed.

2.1.2 Clean Development Mechanism

The Clean Development Mechanism (CDM) allows developed nations to pay for emissions reduction projects in developing countries and in return gain credits that they may put towards their own emissions targets. It has been suggested that CCS should be included within the CDM, which will enable operators to generate credits in a cost-effective manner.

The CDM Executive Board met in 2008 to consider whether CCS should be included in the CDM. However, concerns about project boundaries in case of trans-boundary projects were raised. Other concerns included leakage and accounting for the energy penalty. A final decision has not been made yet regarding the inclusion of CCS in the CDM.

2.2 CCS Regulation in the EU

The EU Directive (Directive 2009/31/EC) on the geological storage of CO_2 was adopted by the European Council on April 6, 2009 and entered into force on June 25, 2009. The Directive sets out a regulatory regime for permitting of exploration and storage. The Directive applies to projects with intended storage of more than 100 ktonnes of CO_2. The Directive gives Member States until 25 June 2011 to transpose it into their respective national laws.

The European Commission (EC) stated that Directive 2008/1/EC of the European Parliament (January 2008) is suitable for regulating the risks of CO_2 capture to the environment and human health. They recommended that this should be applied to the capture of CO_2 streams.

Moreover, the EC stated that it is of the view that the Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment should be applied to the capture and transport of CO_2 streams.

The 2009/31/EC Directive gave criteria for selection of storage sites, exploration permits; storage permits (application procedure, conditions, content, and the requirement for the EC to review permits, and changes and withdrawal of permits). It also discussed operation, closure and post closure obligations including CO_2 stream acceptance criteria, monitoring, reporting by operator, inspections by authority, and measures in case of leakage, transfer of responsibility, financial security, and financial mechanisms. The Directive also gave insight into third party access including access to network and storage sites and dispute settlements. Finally it gave information on reporting by Member States to EC, trans-boundary cooperation and penalties. Details of the EC 2009 Directive (mainly on CO_2 storage) are given in Table 2B below. Table 2A gives a brief overview of CO_2 capture and CO_2 transport-related regulation in the EU.

Directive 2003/87/EC establishes a scheme for GHG emission allowance trading. This Directive is used for regulating the liability for climate damage by requiring surrender of allowances. However, CCS is excluded from this Directive but Member States have an opt-in option under Article 24 where CO_2 stored will be counted as not emitted. In the revised EU-ETS Directive (Phase 3), CCS is listed in Annex 1 and so will be fully included in EU-ETS from 2013. Under the revised Directive, as stored CO_2 is considered not emitted, there will be no free allocations given to CCS installation no matter what the sector is. From 2013 onward, no free allowances will be given to the electric sector but auctioning will be the rule. If CO_2 leakage appears during phase 3 of the EU-ETS, then restitution of allowances is required.

Moreover, the Directive states that, any electricity producing facilities, including CCS installations, will not be awarded free allocations. Free allocations may be given to very efficient power companies that produce heat for district heating systems and industry operations.

Several European countries are adapting their existing laws to facilitate CO_2 storage[3]. Norway is looking at permitting operations under existing Petroleum and Pollution Control Acts (see section 2.2.3). Poland is looking to change its Mining Act. Germany will adapt oil and gas exploration laws for offshore storage and Mining Act for onshore storage. Details on current status of CCS regulation in the UK and in the Netherlands are given in Sections 2.2.1 and 2.2.2, respectively.

2.2.1 The UK

In 2008, the UK Energy Bill has received Royal Assent[7] and now contains complete provision for the offshore storage aspect of CCS. The resulting Energy Act provides a framework for licensing, enforcement and registration of storage sites. In the UK, most storage sites are expected to be offshore and so the Energy Act focusses on offshore storage.

The UK Energy Act introduces a regulatory framework for the licensing of offshore storage aspect of CCS. The Act asserts the rights of the Crown to an Exclusive Economic Zone (EEZ), which is estimated at 200 nautical miles. For companies willing to undertake CO_2 storage within the EEZ, a lease or a rental payment will be required from the Crown Estate.

The Act introduces a regime based upon licensing and complies with the EU Directive. This means that activities relating to the CO_2 storage require a licence from the relevant authority. These activities also include the exploration and operation of the storage site. The Energy Act also provides details relating to storage permits and details of the content of these permits. The Act recommends that the Secretary of State (or the Scottish Ministers if storage is in Scotland) grant storage permits. A permit may include provisions relating to financial security regarding future

[7] Royal Assent is the last step or hurdle in the legislative process; the final step after which an Act becomes a Law.

(operational, closure and post-closure) obligations. The Energy Act leaves details concerning the nature of these requirements for later regulations. The Act introduces a detailed section relating to assignment of inspectors by the Secretary of State for inspection of storage sites.

The Energy Act also draws on the Petroleum Act 1998 concerning abandonment of offshore sites to CO_2 storage installations. Plans and approvals are prescribed under the 1998 Act, which requires persons seeking to abandon an offshore site to provide an 'abandonment programme'. Table 3B gives an overview of the UK Energy Act 2008 in relation to CO_2 storage.

A brief description of regulation related to CO_2 capture (mainly Carbon Capture Readiness, CCR) and transport in the UK is given in Table 3A. The UK Government has responded to its consultation on “Carbon Capture Readiness” announcing that from April 2009, new coal power plants in the UK with power output of more than 300 MW will be required to demonstrate capture readiness by leaving suitable space for capture facilities. This goes beyond the CCR requirements in Article 33 of the EU Directive 2009/31/EC which requires plants to leave suitable space *only if* an authority is satisfied that: suitable storage sites are available; transport facilities are technically and economically feasible; and it is technically and economically feasible to retrofit for CO_2 capture.

According to the UK Government, assessment of capture readiness in the UK is to be done as part of the process of granting development consent under section 36 of the Electricity Act 1989. The UK Government is currently consulting on a new regulatory system, which requires all newly built coal power plants to capture at least 20-25% of their emissions as soon as they start operation. Upgrade to full capture capacity is then expected within five years of CCS being proven technically and economically feasible[8].

[8] http://www.ucl.ac.uk/cclp/ccsdedlegnatoverview.php

Table 2A: EU Regulation on CO_2 Capture and Transport

Category	Regulation
CO_2 Capture	• Capture will be regulated by inclusion in the Integrated Pollution Prevention and Control Directive[9]. • According to this Directive, all capture plant operators will need to get a permit. • According to this Directive, public consultation will be required and operators will be required to use best available techniques for capture • An Environmental Impact Assessment will be required and an Environmental Statement must be prepared. An environmental Impact Assessment has to be undertaken in the capture permit process in order to investigate the level of impurities in the CO_2 stream in addition to other environmental impacts. The composition of the CO_2 stream should be verified before injection. • Carbon Capture Readiness (CCR) requirements are defined. Installations must be able to fit capture technology at a later date. It must be ensured that there is suitable space set aside for capture plant, that there are suitable storage sites, that transport infrastructure is available and that the process is economically feasible. • CCR provisions will be reviewed in 2015 by the Commission, which may lead to replacing CCR with new schemes that require CCS from the beginning. • Directive 2008/1/EC of the European Parliament (January 2008) is suitable for regulating the risks of CO_2 capture to the environment and to human health
CO_2 Transport	• Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment should be applied to the transport of CO_2 streams • No permit is required but EIA must be undertaken according to national procedures and requirements. • Third party access to pipeline networks: Operators will only be permitted to refuse access to transport networks on the ground of lack of capacity. They may wish to add capacity if third party is willing to pay. • Member States will resolve disputes. • The Directive lays down conditions for resolving cross-border disputes.

[9] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:024:0008:0029:en:PDF

Table 2B– Summary of EU Directive 2009/31/EC on CO_2 Storage

Category	Regulation
Exploration Permits	• Member States should ensure that exploration permits are provided before exploration commences. • Monitoring tests may be included in the exploration permits • Period for exploration should not exceed period necessary to undertake the exploration it is granted for. However, extension may be granted if exploration has been done according to permit. • The holder of a permit is the only party allowed to explore the potential storage area. • Holder of exploration permit has preference over other applicants when it comes to granting of storage permits.
Site Characterisation	• Member States retain the right to determine areas from which storage sites may be selected. • Member States, which will allow storage in their territory, shall undertake an assessment of the storage capacity available in parts or the whole of their territory. • Suitability for storage of CO_2 will be determined through characterisation and assessment of site. • Characterisation and assessment of storage sites should be taken in three steps: - **Data collection**: Sufficient data must be collected to construct a volumetric and 3-D-earth model of storage site. The following data should be collected at least: geology and geophysics, hydrogeology (especially presence of groundwater), reservoir engineering (pore volume calculation and ultimate storage capacity), geochemistry (dissolution rates, mineralization rates), geomechanics (fracture pressure, permeability), seismicity, presence and conditions of man-made pathways such as wells and boreholes. The following should be documented: domains surrounding storage site which may be affected by CO_2 storage, population distribution in region, proximity to natural resources, activities around storage area (for example oil or gas exploration or groundwater extraction), and proximity to potential CO_2 sources and adequate transport networks. - **Building 3-D static geological earth model**: Using data collected above, a single or several 3-D models should be developed using computer reservoir simulators. Models should characterise geological structure, flow properties, fracture system characterisation, area and vertical extent of storage site, pore space volume amongst other parameters. Uncertainty of the models should also be included. - **Characterisation of storage dynamic behaviour**: Based on dynamic modeling using time-step simulations of CO_2 injection into storage site using the static model developed above. The following factors should be considered: possible injection rates and CO_2 properties, short and long-term simulations, pressure and temperature of the storage formation, a real and vertical extent of CO_2 vs. time, CO_2 trapping mechanisms, etc.

Table 2B – Continued

Category	Regulation
Site Certification and Storage Permits	• A geological storage site should only be selected if under the proposed conditions no risk of leakage and no health and environmental risks exist. • Conditions - No storage site is operated without permit - Only one operator per site - Procedure for granting of permits should be open to all entities with the necessary capacities and are based on transparent, published and objective criteria - Priority should be given to the holder of the exploration permit. • Priority in granting the storage permit should be given to the holder of the exploration permit. • In early stages of implementing the Directive, all storage permits should be made available to the EC in order to ensure consistency amongst all EU Members. This is thought to 'enhance public confidence'. • Permits should be withdrawn if leakage or irregularities are detected. The responsible authority should either issue a new permit or close the storage site. During this process, the responsible authority will be legally responsible for the site and any costs incurred should be recovered from the previous operator. • Operational, closure and post-closure obligations should be defined at the certification stage. This includes monitoring and reporting requirements as well as remediation following any leakage. • Operators must provide financial provision to ensure that all terms of the Directive and the issued permit are adhered to. • Application to Storage Permit: Storage permits should give information on - Name and address of operator and Precise location of storage site, - Requirements for storage operation and total quantity authorised, - Reservoir pressure limits and Maximum injection rates and pressures, - Requirements for composition of CO_2 stream, - If necessary, further requirements for injection and storage to prevent irregularities - Approved monitoring plan in addition to obligation to implement the plan and requirements for updating the plan - Requirement to notify authority in case of leakage and the corrective measures plan that will be undertaken in case of leakage - The conditions for closure - The approved provisional post-closure plan - Provisions on changes, review, updating and withdrawal of the storage permit - Requirement to establish and maintain financial security

Table 2B - Continued

Category	Regulation
Scale of Projects	• Applies to any project with more than 100 kilo tonnes of CO_2
Risk Assessment	• No injection should be allowed unless risk assessment and mitigation strategies is undertaken • Risk analysis of CO_2 composition including corrosive substances of the streams must be undertaken. • Risk assessment is a requirement for granting the storage permit • Must include details of the risks, their probability and mitigation procedures in case of occurrence.
Classification and Composition of CO_2	• The composition of the CO_2 stream should be verified before injection. • A CO_2 stream should consist mainly of carbon dioxide. No waste or other matter may be added. Incidental impurities from the source capture or injection processes and substances used for MMV should be below levels, which will adversely affect the integrity of the storage site or transport infrastructure. Impurity levels should not pose risk to environmental or human health or breach existing legislation. • No injection should be allowed unless risk assessment is undertaken regarding the composition of CO_2 streams. • A register must be kept of properties and quantities of CO_2 streams delivered and injected including composition of these streams.
Access, Property Rights and Ownership	• Member States must ensure potential users have access to storage site. • Access rights criteria should be transparent, published and clear.
Site Operation and Closure	• The operator of the storage site should accept and inject CO_2 only if an analysis of the streams including corrosive substances has been undertaken and that the analysis shows that contamination levels within the criteria given in the Directive. • Member States should ensure that site operators monitor CO_2 injection and storage according to a monitoring plan based on specific requirements. • This monitoring plan should be submitted to and approved by the authority in place before injection starts. • For offshore storage under the seabed, the monitoring plan should also consider the specific conditions in the marine environment. • Obligation on the operator of the storage site to take corrective measures in case of leakage. If the operator does not take these corrective measures, they should be undertaken by the authority and costs recovered from the operator. • Storage site should be closed upon request from operator if all conditions in the permit were complied with. • After closure, operator should remain responsible for site maintenance, monitoring and control according to a closure plan submitted to and approved by the responsible authority. This should remain the case until responsibility is transferred to authority.

Table 2B - Continued

Category	Regulation
Post-closure, transfer of responsibility and Liability Issues	• Liability for environmental damage is regulated under an existing regulation (Directive 2004/35/EC of the European Parliament of 21 April 2004). • Liability to climate damage is dealt with by including storage site in Directive 2003/87/EC, which requires surrender of emission trading allowances for any leaked emissions. • Responsibility will be transferred from operator to authority when evidence is shown that all CO_2 will permanently and completely remain contained. Operator should submit report to authority for approval of the transfer. In the early phase, all such reports must be made available to the EC after receipt by the responsible authority. • Liabilities other than those related to the phases of injection, closure and the period after transfer of responsibility should be dealt with at national levels. • After transfer of liability, monitoring should be reduced but should include leakage detection and should be intensified if leakage is detected. In this case no recovery of cost from the previous operator can be obtained. • Financial provisions should be made to allow for closure and post-closure obligations and to deal with corrective measure due to leakage or other irregularities. • Member States should ensure that operators provide financial security before injection is started. • After transfer of responsibility, national authorities may have to bear monitoring costs associated with CO_2 storage. In this case, operators need to provide financial contributions before transfer takes place. • This financial contribution should cover monitoring costs for a period of 30 years. It is the responsibility of Member States to determine the level of this contribution.

Table 2B – Continued

Category	Regulation
MMV	• Monitoring plan for operation and post-closure phases must be submitted with permit application. • Monitoring plan must include: parameters to be monitored, monitoring technology to be used and rationale, frequency of application, monitoring locations and rationale for spatial sampling. • Operator must carry monitoring of injection facilities and surrounding environment • This must be observed by Member States • Comparison between observed and modelled behaviour should be undertaken • Monitoring should detect CO_2 migration, leakage and any significant irregularities. • Monitoring should provide information on adverse effects on surrounding environment in particular ground water or human populations. • Assessment of whether stored CO_2 will be permanently contained must be included in monitoring • Monitoring networks should be updated in the short and long-term • All monitoring information should be reported in the reporting period to the authority. • Reports should include information on composition of streams and quantities injected. • Member States should ensure the organisation of routine and non-routine inspections of all storage sites. • Inspections should include visits, assessing MMV operations and checking all records. • Continuous monitoring should be undertaken of the following: (1) fugitive CO_2 emissions at the injection facility, (2) CO_2 volumetric flow rate, temperature and pressure at injection well heads, (3) chemical analysis of injected material, (4) reservoir temperature and pressure (to determine phase behaviour) • Data collected must be collated and interpreted and the observed results must be compared to behaviour predicted from dynamic simulations. If significant deviation is observed, the simulation model should be re-calibrated based on data from the monitoring plan. • Post-closure monitoring must be based on information collected and modelled during implementation of monitoring plan above.
Financial Issues	• Member States should ensure that proof that adequate provisions can be established by way of financial security. • This should include closure and post-closure requirements and must be valid and in place before injection starts. • Financial security should be periodically adjusted to take account of changes in risk of leakage and estimated costs of all obligations arising under the permit. • Proof of financial security and maintenance should be reported periodically. • Financial security must remain valid after site closure.

Table 3A: CO_2 capture and transport regulation in the UK.

Category	Regulation
CO_2 Capture	• Starting April 2009, new coal-fired power plants with a rated electrical output of 300MW or more must demonstrate capture readiness (CR), that is, to leave suitable space for the installations of capture facilities at a later date. • Carbon Capture Readiness requirements are defined[10] • Environmental standards within the capture plant boundary may be enforced using existing legislation such as the Pollution Prevention and Control Act and Hazardous Substances Regulations. • Same regulations that apply to refineries and natural gas extraction fields will apply.
CO_2 Transport	• Transport of small quantities of CO_2 by road or rail is covered under existing regulations. • For on-shore transport of large volumes of CO_2 via pipeline, licensing is required by the Secretary of State under the Pipeline Act of 1962. • Use of existing pipelines will also require re-licensing procedure to change pipeline specification since material transported is CO_2 not natural gas. • Re-compressors along the pipeline will be licensed by local authorities.

Table 3B - The UK Energy Act 2008

Category	Regulation
Exploration Permits	• Exploration activities require a license • A licensing authority may grant a license for exploration of a controlled place with the view of using it for CO_2 storage.
Site Certification and Storage Permits	• A licensing authority may grant a license for storing CO_2 (whether for permanent disposal or as an interim measure) and for transforming a natural feature in a controlled space for the purpose of storing CO_2. • The 'Licensing Authority' is either the 'Secretary of State' or the 'Scottish Ministers' depending on where storage site is located. • Licensing Authorities (1) may make provisions about circumstances for granting or terminating licenses, (2) may prescribe requirements for granting such licenses, and (3) may make regulations regarding the content of these licenses • The Secretary of State must maintain a register containing prescribed information related to licenses.
Scale of Projects	• Covers any controlled space or the transformation of a controlled space for the purpose of CO_2 storage including EOR.
Site Operation and Closure	• The Secretary of State may appoint persons to act as inspectors to assist in carrying out the functions of the Secretary of State as described by the Act in relation to the operation of the storage site. • Provision about closure of a CO_2 storage facility should be included in license. • Provision about obligations of a license holder between closure of a storage site and termination of the license.

[10] http://www.decc.gov.uk/en/content/cms/consultations/ccr_consultati/ccr_consultati.aspx

Table 3B - Continued

Category	Regulation
Post-closure, transfer of responsibility and Liability Issues	• Part 4 of Petroleum Act 1998 applies in relation to a CO_2 storage installation. • Scottish Ministers have authority for storage sites in Scotland. • Existing legislation under the Petroleum Act 1998 requires operators to retain future liability and to bear costs of decommissioning. • The EU Environmental Liability Directive will be applicable in the UK • Provision about the circumstances in which financial security may be released (in whole or in part) should be provided in licenses. • Provision about the circumstances in which financial security (which may be provided by way of a trust or other arrangements) may be required should be included in license. • Provision enabling the licensing authority to review the license in specified circumstances or at specified intervals should be given in a license. • Provision enabling the licensing authority, after consulting the license holder, to modify the license in specified circumstances (with or without the consent of the license holder) should be included. • A license may authorize, in such circumstances and subject to such conditions as are specified, the transfer of the license to another person (or the inclusion of another person as a joint license holder).
Financial Issues	• Licensing authorities may 'make provisions about financial arrangements to be made in relation to a closed carbon storage facility on or after the termination of a license relating to the facility'

2.2.2 The Netherlands

The Netherlands government is currently considering issues related to CO_2 storage regulation based on its existing regulatory system. The Netherlands has many gas reservoirs where production has ended. In order to store gas or CO_2 in any of these empty reservoirs, a storage license is needed. However, gas companies still hold production licenses for these reservoirs and so granting a storage license for site operators becomes impossible[11].

Amending the Dutch Mining Act of 2003[12] so that the government can withdraw some of the production licenses where there are no more activities is one of the options being considered. However, it is believed that in most cases, the companies interested in CO_2 storage will be gas companies who can inject CO_2 in their existing gas fields. One option is to give storage licenses to existing gas producers. However, a complex situation arises if these licenses are given to different operators while the production licenses still hold. In this case assessment of the value of remaining gas to transfer licenses may be difficult.

Regulators in the Netherlands are considering modifying the Mining Act 2003. Stakeholders are currently being consulted to identify problems and solutions for storage in gas reservoirs offshore.

2.2.3 Norway

Norway regulates permits through the Norwegian Pollution Control Act[13]. According to this Act, CO_2 emissions from industrial plants are considered to be pollution and a company that emits large amounts of CO_2 must obtain an emission permit. The 'Pollution Control Authority' may impose conditions to prevent these emissions as

[11] IEA, Legal Aspects of Storing CO_2, 2008.
[12] http://www.nlog.nl/resources/MBREngels22feb2005_2.pdf
[13] http://www.regjeringen.no/nb/dokumentarkiv/regjeringen-brundtland-iii/md/260597/260604/t-1300_pollution_control_act.html?id=260605

with the new gas-fired power plant at Mongstad, which is required to install CCS by 2014[14].

Currently an emission permit for fossil fuel companies does not include the transport and storage of CO_2. The Sleipner project was granted a permit under the Norwegian Pollution Control Act. Because of the risks of leakage, the storage of CO_2 is considered pollution and so requires a permit. In the case of Sleipner, an environmental impact assessment of storing CO_2 in the offshore saline aquifer had to be prepared before the permit was issued. According to Hallennstvedt[10], there is a need for dedicated legislation on the storage of CO_2 in Norway, which will form a basis for a permit system where authorities can set conditions and regulate the responsibility regarding inspection and supervision of leakage. It is a possibility that the existing Pollution Control Act can serve as a reference for this new CCS regulation.

The Pollution Control Act provides information on several topics relevant to CCS regulation including requirements in a permit application, withdrawal of permits, the responsibility of the authority, duty to provide information, right of inspection, closure and stoppage of operations and liability.

Another relevant regulation in Norway is the Petroleum Act. The oil deposits in the Norwegian territorial seas are owned by the Norwegian State. CCS as part of petroleum activities, whether for EOR purposes or for permanent storage under the continental shelf, is regulated by permit under the petroleum Act[10].

Norwegian power plants that install CCS will be required under the Norwegian Greenhouse Gas Emission Trading Act (and under the EU-ETS) to submit quotas equivalent to their remaining emissions. Stored CO_2 will be considered as non-emitted but leakage may occur from capture, transport and storage, and so there will be a need to clarify the responsibility for leakage in Norwegian law (which is currently not regulated) [10].

2.3 CCS Regulation in the US

Matson (2007)[15] suggests that most of the legal and regulatory structure required for CCS in the US already exists under EOR regulation, but that the post-EOR injection phase and post-closure “storage” phase are not addressed by EOR regulation. He suggests that the way forward is to adapt this legal and regulatory regime for CCS, filling the gaps and repairing the flaws. The past few months have witnessed significant activity in CCS-related regulation in the U.S. A summary of recent Acts is given in Table 4.

The discussion that follows introduces the Interstate Oil and Gas Compact Commission Guidelines (IOGCC) Guidelines, the American Clean Energy and Security Act, and the EPA proposal.

[14] N. Hallenstvedt, Current CCS Regulation in Norway, April 2008. http://www.ucl.ac.uk/cclp/pdf/CCS_in_Norway_April2008.pdf

[15] http://www.colloqueco2.com/presentations2007/ColloqueCO2-2007_Session4_1-MARSTON.pdf

Table 4: Recent CCS-related Federal regulation in the U.S.

Legislation	Description
American Clean Energy and Security Act	• Passed by House of Representatives on 26 June 2009 • Companion Bills currently at various stages in the Senate. (Overall Act won't be implemented until the US Senate approves it)
Carbon Capture and Storage Early Deployment Act (Boucher Bill)	• Introduced 24 March 2009, currently in committee • Provides for a referendum of relevant industries to incorporate a CCS Research Body to raise and distribute funds to CCS programmes.
Carbon Capture and Sequestration Programme Amendments Act	• Introduced 7 May 2009 • Would establish a demonstration programme for CCS. • Has been partly incorporated within the American Clean Energy Leadership Act so may not proceed.
American Clean Energy Leadership Act	• Introduced 16 July 2009, awaiting consideration by Senate • Provides a regulatory framework for CCS as well as financial assistance for demonstration programmes.
Carbon Storage Stewardship Trust Fund	• Introduced July 22, 2009 • Provides for long-term Federal stewardship of storage sites accompanied by a trust fund to meet costs and liabilities.
EPA proposal	• Federal requirements under the Underground Injection Control (UIC) Program for CO_2 Geological Storage
Interstate Oil and Gas Compact Commission Guidelines	• Published September 2007. • Detailed rules based on EOR, acid gas injection and natural gas storage regulation. • Includes ownership, permitting, verification, monitoring, and liability. • Legal and Regulatory Guide for States. States will choose whether or not to adopt IOGCC models, modify them or just ignore them. • H_2S, NO_X and SO_2 impurities remain covered by existing regulation. • The regulator is the "state" regulatory agency not the "federal" Environmental Protection agency

2.3.1 The Interstate Oil and Gas Compact Commission Guidelines[16]

The IOGCC guidelines were published in 2007. They give guidelines based on existing EOR, acid gas injection and natural gas storage regulation. The guidelines refer to a CO_2 facility defined as the unit where CO_2 is captured, a geological storage unit (GSU) defined as the subsurface reservoir and the CO_2 storage project (CSP) consisting of both the capture facility and geological storage unit.

A permit application must

- Have "necessary and sufficient" property rights
- Define boundaries
- Provide full technical evaluation
- Give details of public safety and emergency response plan, worker safety plan, corrosion monitoring and prevention plan, leak detection and monitoring plans (for all wells and surface facilities as well as the GSU).

[16] The Interstate Oil and Gas Compact Commission Task Force on Carbon Capture and Geologic Storage : "Storage of Carbon Dioxide in Geologic Structures A Legal and Regulatory Guide for States and Province" (September 25, 2007) (http://www.iogcc.state.ok.us/docs/MeetingDocs/Master-Document-September-252007-FINAL-(2).pdf)

After the permit is issued, authorisation for each CO_2 storage site must be obtained for each injection well according to existing rules. Underground sources of drinking water must be identified and special drilling practices followed. Standards for casing, tubing, corrosion, and cement must be followed to ensure isolation from underground water. Downhole safety shut-off valves must be included. The guidelines also refer to reporting requirements.

In terms of operational standards, the IOGCC state that worker safety plans must be provided, leak detectors must be installed at all subsurface and injection wells (with semi-annual testing), inspection records must be kept for five years. Other recommendations include quarterly operational reporting of pressures, temperatures and volumes and corrosion monitoring.

Considering the closure phase, a monitoring plan must be submitted for the State Agency for approval. According to the IOGCC guidelines, the operator remains liable for the storage site after injection stops for ten years (or other period). Each well is bonded and the bond is released when the associated well is plugged. Responsibility for monitoring remediation is passed to state or federal agency CSP operator and CO_2 generator released from further liability.

2.3.2 American Clean Energy and Security Act

The American Clean Energy and Security Act[17] was passed by the House of Representatives on 26 June 2009. Subtitle B of the Act deals with regulation related to the CO_2 capture and storage. Details related to the capture utility are given in Table 5A while storage-related details are given below.

- The Administrator must establish a coordinated approach to certifying and permitting geologic sequestration of CCS.
- In achieving that, the Administrator must reduce redundancy with the requirements of the Drinking Water Act.
- Less than two years of enacting this Act, the Administrator must introduce regulations to protect health and the environment by reducing the risk of leakage.
- Regulation should include (i) a process to obtain certification, (ii) requirements for monitoring, (iii) requirements for record keeping and reporting, (iv) public participation in the certification process, and (v) sharing of data between states, Indian tribes and the EPA.
- Requirements for maintaining evidence of ‘financial responsibility for remedial and emergency response, well plugging, site closure, and post injection site care’.
- The Administrator may establish financial responsibility using several options including insurance, guarantee, trust, standby trust, letter of credit, etc.

2.3.3 Environmental Protection Agency Guidance Under the Underground Injection Control Programme, 2007[18]

The US Environmental Protection Agency provided guidelines in 2007 followed by a proposal in 2008 for developing CCS regulations in the US. The guidelines have been developed under the EPA’s authority provided by the Safe Drinking Water Act (SDWA). The EPA’s proposal is to create a new category of well (Class VI) under its existing Underground Injection Control (UIC) Program with new federal requirements to facilitate the “permitting of the injection of CO_2 for the purpose of GS”.

[17] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h2454ih.txt.pdf
[18] http://www.epa.gov/fedrgstr/EPA-WATER/2008/July/Day-25/w16626.pdf

Underground injection wells are regulated under the authority of the Safe Drinking Water Act (SDWA). The SDWA is designed to protect the quality of drinking water sources in the U.S. and dictates that the EPA issue regulations for State programs that contain ''minimum requirements for effective programs to prevent underground injection which endangers drinking water sources.'' States and territories may apply to the EPA to have primary enforcement responsibility of the UIC Program. In order to obtain permission from the EPA, these authorities must meet minimum federal requirements including construction, operation, monitoring, reporting, and closure requirements.

The proposal included details of the technical requirements for site characterisation, requirements for corrective action, Injection well construction and operating requirements, mechanical integrity testing requirements, pressure monitoring requirements, record keeping and reporting requirements, well plugging post-injection Care, and site closure requirements and financial responsibility and long-term acre requirements. Further details are given in Table 5B.

According to Beveridge and Diamond PC[19], the EPA will face difficulties in regulating CO_2 storage under the UIC program, which is designed specifically for contamination of drinking water. More complex issues such as underground property rights and long-term liability for environmental impacts other than ground water contamination are not addressed by the EPA proposal. They believe that 'it is likely that interested parties will push for a more suitable and comprehensive regulatory structure involving DOE and state agencies.'

2.3.4 Other US Federal Regulation on CCS

The U.S. Congress has passed the American Clean Energy and Security Act 2009 in June 2009. Subtitle B of the Act focuses on CCS. It discusses several provisions including financing, deployment and regulation of CCS[20]. The Boucher Bill[21] was introduced into the House of Representative in 2008 but has been recently incorporated in the American Clean Energy and Security Act 2009 and so is unlikely to proceed.

The Department of Energy Carbon Capture Sequestration Program Amendments Act of 2009[22] has been under consideration but has recently been incorporated into the American Clean Energy Leadership Act (released in July 2009).

2.3.5 State Regulation on CCS

Several States have introduced regulation proposals to encourage and incentivise the deployment of CCS. A full list is available on the UCL CCLP website[23].

The IOGCC guidelines concluded that States are best suited to regulate geologic sequestration of CO_2 and proposing a model state statute and regulations[23]. Many of the petroleum-producing states have regulations that address enhanced oil recovery, natural gas storage, and acid gas disposal, that cover many of the same issues that will arise in the context of long-term storage of CO_2.

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[19] http://www.bdlaw.com/practices-128.html
[20] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:h2454ih.txt.pdf
[21] http://www.westgov.org/wieb/meetings/boardsprg2009/briefing/ccseda_summary.pdf
[22] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_cong_bills&docid=f:s1013is.txt.pdf
[23] http://www.ucl.ac.uk/cclp/ccsdedlegnatoverview.php

Wyoming was the first US State to pass CCS-specific legislation. House Bill 90[24] gives the Wyoming Department of Environmental Quality (WDEQ) the responsibility to issue permits for CO_2 sequestration. This creates a regime separate from CO_2 injection for EOR activities. The Wyoming legislation provides a framework on the basis of which the WDEQ will be able to develop permitting criteria and requirements. It is proposed that this regime will operate with the EPA UIC drinking water framework presented in section 2.3.3.

According to House Bill 90, permit applications must include proof of financial security, detailed site characterisation, monitoring plans and details for post-closure monitoring and verification. A working group is to convene in order to (1) determine suitable financial mechanisms and (2) define the post-closure care period.

The Bill states 'the right to mine or drill for resources has legal precedence over the right to store carbon gas underground.' It also states that 'whoever injects carbon gas underground remains legally responsible for it forever.'[25]

North Dakota (Senate Bill 2095 on CO_2 geological storage and Senate Bill 2139 on subsurface pore space ownership) and Montana (Senate Bill 498 on Laws for CO_2 geological storage) recently joined Wyoming in adopting legislation to facilitate CO_2 storage. The main issues with these new bills is ownership of the subsurface and liability. In North Dakota and Montana, just as in Wyoming, the ownership is given to the surface owner.

In Montana, liability to the storage site remains with the operator until 30 years after closure. Liability is then transferred to the State subject to compliance obligations and approval by the Montana Board of Oil and Gas Conservation. In North Dakota, a "Certificate of Completion" is issued 10 years after storage site closure after which liability is transferred to the State.

[24] http://legisweb.state.wy.us/2008/Enroll/HB0090.pdf
[25] http://www.greatfallstribune.com/article/20090627/NEWS01/90627001/New-Wyoming-laws-address-carbon-storage

Table 5A: Summary of U.S. regulation related to CO_2 capture and CO_2 transport

Category	Regulation
CO_2 Capture (*IOGCC guidelines*)	• CO_2 is defined as direct emission stream with a purity of at least 95%. • CO_2 is not currently defined in federal air regulations as a pollutant. While SO_2, NOx and contaminants should remain regulated as pollutants for public health, CO_2 should not be defined as a pollutant. • Existing state and federal regulations dealing with permitting, operating and emission standards can be easily modified to address CO_2 capture technologies.
CO_2 Capture (*based on the American Clean Energy and Security Act*)	• A utility which is required to have a permit (and is authorised to derive 30% of its annual heat from coal or petroleum coke) and which has initially (meaning that the operator has received a Clean Air Act preconstruction permit but administrative review of such permit has not been exhausted) been granted that permit on or after January 1, 2020, shall achieve an emission limit that is a 65% reduction in emissions of the CO_2 produced by the unit, as measured on an annual basis, or meet such more stringent standard as the Administrator may establish pursuant • In determining compliance with this subsection, the Administrator shall assume an energy penalty of the CO_2 capture system of no greater than15% • If a utility is initially permitted after January 1, 2009, and before January 1, 2020, must, by the applicable compliance date established under the Act (see below), achieve an emission limit that is a 50% reduction in emissions and assuming an energy penalty of no more than 15%. • The compliance date is the earliest of the following: 1. January 1, 2025 or 2. Four years after the date the Administrator issues a determination that there are in commercial operation in the United States electric generating units equipped with carbon capture and sequestration technology that, in the aggregate (i) have a total of at least 4 Gigawatts of nameplate generating capacity of which (a) at least 3 Gigawatts must be electric generating units; and (b) up to 1 Gigawatt may be industrial applications, for which capture and sequestration of 3 million tons of carbon dioxide per year on an aggregate annualized basis are considered equivalent to 1 Gigawatt; (ii) include at least 2 electric generating units, each with a nameplate generating capacity of 250 megawatts or greater, that inject carbon dioxide into geologic formations other than oil and gas fields; and (iii) are capturing and sequestering in the aggregate at least 12 million tons of carbon dioxide per year, calculated on an aggregate annualized basis. • If the deadline for compliance with paragraph 25 (2) is January 1, 2025, the Administrator may extend the compliance date by 18 months.

Table 5A - Continued

Category	Regulation
CO_2 Transport (IOGCC guidelines)	• Well-established regulatory frameworks related to CO_2 transport and so this will necessitate limited need for additional state regulation. • Federal agencies will ultimately need to address open access issues for CO_2 pipeline.
CO_2 Transport (general)	• CO_2 pipeline is generally regulated by the States not by the Federal Government. • In the US, jurisdiction over the "safety of CO_2 pipeline" resides with the Office of Pipeline Safety (a branch of the Department of Transportation). The OPS sets minimum safety standards on the transportation of hazardous liquids including CO_2. OPS regulates interstate pipelines and certifies states to undertake intrastate pipeline regulation and enforcement activities. Under OPS, there is no federal general certification of pipeline construction or rates (pricing) regulation and there is no protection from the entry of competing CO_2 pipeline (unlike with natural gas pipeline which are subject to siting and rates regulation under the Natural Gas Act of 1938). • The Natural Gas Act of 1938 vests in the Federal Energy Regulatory Commission (FERC) the authority to issue "certificates of public convenience and necessity" for the construction and operation of interstate natural gas pipeline. FERC is also charged with authority over the siting of natural gas export/import facilities as well as rates of natural gas transportation. FERC has also jurisdiction over regulation of oil pipelines. • FERC has explicitly rejected jurisdiction over CO_2 pipeline siting and rates (as with the Cortez Pipeline case)[26] • Jurisdiction over the regulation for pipelines other than gas, oil or water resides with the Surface Transportation Board (STB) (previously the Interstate Commerce Commission, ICC). • The ICC has previously rejected jurisdiction over the Cortez Pipeline • According to WRI, under the Mining Leasing Act, CO_2 pipelines in the US may be subject to access and rate conditions imposed by the Bureau of Land Management when they cross Federally owned land (in addition to regulation by individual states). • The WRI US CCS guidelines recommend that existing industry experience and regulation for pipeline design and operation should be applied to future CCS projects. • The Carbon Dioxide Pipeline Study Act of 2007 (S.2144), which would require the secretary of Energy to study the feasibility of, constructing and operating a network of CO_2 pipelines for CCS, was not passed and did not become a law.

[26] Vann and Parfomak, CRS Report to for Congress: Regulation of CO_2 Sequestration Pipeline: Jurisdictional Issues, 2008. http://www.cnie.org/nle/crsreports/08Apr/RL34307.pdf

Table 5B: Summary of the U.S. EPA Underground Injection Control Programme.

Category	Regulation
Exploration Permits	*Significant details are given on site characterisation and storage permits but not exploration permits as with the EU Directive*
Site Characterisation	• While initial assessments indicate there are many geologic formations in the U.S. that can potentially receive injected CO_2, not all can serve as adequate CO_2 Geological Sequestration (GS) sites. • Operators must submit maps and cross sections of the Underground Sources of Drinking Water (USDW) near the proposed injection well. • Operators must submit data to demonstrate that the injection zone is sufficiently porous to receive the CO_2 without fracturing and extensive enough to receive the anticipated total volumes of injected CO_2. • Operators must submit geologic core data, seismic survey data, cross sections, well logs, and data that demonstrate the lateral extent and thickness, strength, capacity, porosity, and permeability of subsurface formations. • The following data must also be collected in order to characterise a site: porosity, geophysical, geochemical and geomechanical data including fracture, proximity to groundwater reservoirs, injection pressures and rates, reservoir pressures, seismicity data, CO_2 composition, etc. • Mechanical integrity of injection well must be maintained. • Automatic shut-off valves must be installed at surface and also down the injection hole.
Site Certification and Storage Permits	• Information submitted for permit applications should include maps of the injection wells, the “Area of Review” (AoR) as determined through computational modeling, all artificial penetrations within the AoR, maps of the general vertical and lateral limits, maps of the geologic cross sections of the local area, the proposed operating data and injection procedures, proposed formation testing program, and stimulation program, well schematics and construction procedures, and contingency plans for shut-ins or well failures in addition to demonstration of financial responsibility to plug the well, and to provide for post-injection site care, and site closure. • Plans that should be included in permit application (1) monitoring plan (EPA believes site monitoring is site-specific and plans must be included up front to allow Director to undertake assessment of monitoring techniques proposed), (2) corrective action plan, (3) post-injection site care and site closure plan
Scale of Projects	• Pilot scale projects under new Class VI Program, also applicable for EOR and EGR under Class II Program.

Table 5B-Continued

Category	Regulation
Risk Assessment	• Risk assessment procedure required • Must be submitted to Director before consideration of Storage permits • Must be updated periodically • Must include assessment of potential leakage pathways (using simulations (potential magnitude of leakage, parameters affecting leakage (e.g. reservoir pressure, temperature, injection rate, etc.)
Classification of CO_2	• Owners or operators will need to characterize their CO_2 stream as part of their permit application to determine if the injected material is considered hazardous or not (this depends on coal type, composition, plant technology and operating conditions, pollution control technologies used, etc.)
Access, Property Rights and Ownership	• Not discussed in the EPA proposal. However, the IOGCC recommends that states should consider the potential need for legislation to clarify and address issues related to the ownership of the storage site (pore space) and payments for use of these storage sites.
Site Operation and Closure	• Operators must limit CO_2 injection pressures, except during well stimulation, so that injection does not initiate new fractures, propagate existing fractures in the injection zone, or cause movement of injection or formation fluids that endanger USDWs. During injection the pressure in the injection zone must not exceed 90 percent of the fracture pressure of the injection zone. • Hydraulic fracturing techniques used in EOR, EGR or ECBM would be acceptable provided integrity of confining systems is unaffected. • Once the operators provide documentation that demonstrates that the models predicting CO2 movement are consistent with monitoring results and that there are no longer risks of endangerment to USDWs, they could request that the Director authorize site closure. • Once closure approved by Director, operator must submit report within 90 days. • The report should provide documentation of injection and monitoring well plugging; copies of notifications to State and local authorities that may have authority over future drilling activities in the region; and records reflecting the nature, composition, and volume of the injected carbon dioxide stream. The report should provide information to potential users and authorities on the land surface and subsurface pore space regarding the operation. • No injection depth is specified in case some operators want to inject CO_2 as gas.
Post-closure, transfer of responsibility and Liability Issues	• EPA considers three distinct options for determining post-injection period (1) establishing a fixed period, (2) allowing a performance-based approach based on pressure decay measurements, and (3) a combination of fixed period and performance-based standard. • A default 50-year post-injection period before transfer of responsibility is suggested. • During the 50-year period, the operator is required to submit periodic reports providing monitoring results and updated modelling results as appropriate until a demonstration of non-endangerment to USDWs can be made. • The Director is allowed to increase or decrease the 50 years period. • The Director would determine that the post-injection site care period has ended and authorize site closure when the following have occurred: (1) All information required of post-injection and site closure plan received; (2) Data demonstrate that there is no threat of endangerment to USDWs.

Table 5B-Continued

Category	Regulation
EOR Experience	• Experience with CO_2 injection for EOR includes the use of acid-resistant cements. Cements with a reduced Portland content are more resistant to acid because they contain less calcium carbonate ($CaCO_3$). • There are technical challenges associated with geological storage in depleted oil and gas reservoirs. Injection volumes, operation conditions, and formation pressures for CO_2 injection will differ from those of traditional EOR/EGR operations.
MMV Requirements	• MMV techniques are site-specific and must be stated at the beginning before permits are granted. • Owners or operators of Class VI wells (i.e. wells for CO_2 injection) must report semi-annually to the permitting authority, on the physical and chemical characteristics of injection fluids, injection pressure, flow rate, temperature, volume and annular pressure, annulus fluid volume added, and the results of plume tracking, and atmospheric/soil gas monitoring. • "Area of Review" (AoR) modelling revisions; any updates to the information on the type, number, and location of all wells within the site AoR; and information on additional corrective action performed or planned based on AoR re-evaluations must be submitted by operator to Director immediately as changes occur. • Recordkeeping must be maintained throughout operation and for 3 years after closure (following the post-injection period). • Automatic shut-off valves must be installed down-hole in addition to at the surface. • Corrosion must be monitored. This is currently done by exposing some samples to a side stream of the injected fluid and these samples are periodically removed and weighed against original samples and a corrosion rate calculated. • Operators must monitor internal mechanical integrity of their injection wells by continuously monitoring injection pressure, flow rate, and injected volumes, as well as the annular pressure and fluid volume. • The proposal suggests "Continuous internal mechanical integrity monitoring of geological storage project injection wells", instead of "periodic testing" (which is required for most other types of deep injection wells). This is important because of the corrosive nature of geological storage waste streams. • Any other additional tests can be requested by the Director. • External mechanical integrity testing should be done at least once a year. • For external mechanical integrity testing, current methods can be used such as a tracer survey or a temperature or noise log or any other method approved by the Director.
Financial Issues	• Operators must demonstrate and maintain financial responsibility, and have the resources for activities related to closing and remediation of geological storage sites. • Proposal recommends that rule only specify a general duty to obtain financial responsibility acceptable to the Director, and will provide guidance to be developed at a later date that describes recommended types of financial mechanisms that owners or operators can use to meet this requirement. • Operators must demonstrate financial responsibility for corrective action including injection well plugging, post-injection site care and site closure, and emergency and remedial response using a financial mechanism acceptable to the Director • The Director would determine whether the financing mechanism submitted is adequate to pay for well plugging, post-injection, site closure, and remediation activities. • After end of post-injection period, operators and owners do not need to provide proof financial assurance or security. This will be when the Director approves the post-injection site care and closure plan. • Operator should periodically update costs for post-closure activities and based on corrective measures in the area and should submit cost adjustments to Director. • EPA will publish guidance for financial responsibility soon. Currently Financial assurance is typically demonstrated through two broad categories of financial instruments: (1) Third party instruments, including surety bond, financial guarantee bond or performance bond, letters of credit (2) self-insurance instruments, including the corporate financial test and the corporate guarantee.

2.4 CCS Regulation in Australia

Australia has been active in modifying existing regulation to facilitate the deployment of CCS. The Australian Regulatory Guiding Principles provide general guidelines for a CCS regulatory framework in Australian provinces. The Offshore Petroleum Amendments (Greenhouse Gas Storage) Act 2008 introduces modifications to the existing petroleum regulations to accommodate GHG storage offshore. In 2008, Victoria Legislative Assembly introduced the Greenhouse Gas Geological Sequestration Act 2008, which deals with onshore storage. Draft regulations are currently open for public submission and they are expected to be in place by January 2010. Recently, Queensland introduced the Greenhouse Gas Storage Act 2009; this has not entered the legislation yet.

2.4.1. Australian Regulatory Guiding Principles[27]

The objective of the Australian Regulatory Guiding Principles is to achieve a consistent regulatory framework for CCS activities in each Australian jurisdiction. Six issues are fundamental:

- *Assessment and certification processes*
  Should be consistent with agreed national protocols and procedures. Existing regulations should be used and amended where necessary.
- *Access and property rights*
  Surface and sub-surface rights should provide certainty to rights holders on their entitlement and obligations. Rights should be based on established legislation. When granting rights, governments should give consideration to land use planning issues that may arise.
- *Monitoring and verification*
  Regulation should provide for appropriate MMV requirements enabling the generation of clear, timely and accurate information, which is publicly accessible. Regulation should provide a framework to establish with accuracy gas location and amount captured, transported, injected and stored and the net abatement of emissions, which also include detection of leakage.
- *Post-closure and long-term Liability*
  The Guidelines state that current common law should continue to apply to liability issues for all stages of CCS. Government's consideration of the post-closure phase should aim to minimise exposure to health, environmental and financial risks for project operators, governments and future generations.
- *Financial issues and incentivisation*
  The guidelines state that for all stages of a CCS project, established existing legislation should be used in preference to new regulations. Also they state that regulations should consider appropriate financial instruments for the management of risk related to post-closure liabilities.

2.4.2. The Offshore Petroleum Amendment (Greenhouse Gas Storage) Act, 2008[28]

The Offshore Petroleum Amendment Act was developed to be consistent with the regulatory Guiding Principles. This purpose of this federal legislation is to ensure safety of storage and to give operators the confidence regarding access and entitlement to offshore storage formations. The amendments are targeted at defining the boundaries within which storage companies in the future can operate in order to protect the interests of existing oil companies. The Act also provides regulatory

[27] http://www.ret.gov.au/resources/carbon_dioxide_capture_and_geological_storage/Pages/ccs_legislation.aspx
[28] http://www.comlaw.gov.au/ComLaw/Legislation/Act1.nsf/0/413D01D98514999CCA25750D007CA95A/$file/1172008.pdf

framework to ensure projects meet health, safety and environmental requirements. The Act proposes that an "Injection License" be granted to operators to inject greenhouse gases. A comprehensive site plan needs to be developed in order for a license to be granted. At the end of the life of the site, decommissioning reports must be submitted to the appropriate Minister with MMV plans for the post-closure period. Further details of the main elements of the "Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2008" are given below in Table 6.

Amendments to the Offshore Petroleum Act were passed in 2006. The new amendments:

- Give regulators power to remediate
- Establish mechanisms for interactions with other resource users, especially petroleum
- Establish long term liability framework
- Define property access and property rights
- Define approvals process to ensure secure storage

2.4.3. Australian Greenhouse Geological Sequestration Act 2008[29]

The Australian Greenhouse Geological Sequestration Act was introduced by Victoria Legislative Assembly on Sep. 9, 2008. It is similar to the EU 2009 Directive in that it is specific to the storage component of CCS. This Act is, however, focused on onshore storage. It provides a detailed permitting regime for sequestration of "greenhouse gases". CO_2 is the only gas named in the Act as the case with the different Australian federal and state CCS regulations. The Act included details of amendments to existing Acts including the Water Act 1989, National Parks Act 1975, and Catchment and Land Protection Act 1994. More details of the Act are given in Table 7.

2.4.4 Queensland Greenhouse Gas Storage Act 2009[30]

The Act is intended to facilitate GHG storage in Queensland and to amend existing regulations including the Coastal Protection and Management Act 1995, Dangerous Goods Safety Management Act 2001, Environmental Protection Act 1994, Electricity Act 1994, and the Aboriginal Land Act 1991 in addition to other amendments. The Act emphasises that all storage sites in land are the property of the State and gives details regarding "GHG exploration permits" (tendering procedure, requirements, renewals, transition to "GHG Lease") and defines a maximum 12-year period for exploration permits. The Act also discusses "GHG Injection and Storage Leases" (tendering, development plans, approval, amendments to development plans, "surrender" applications and requirements). Relationships between different authorities and parties are also defined.

2.4.5 The Barrow Island Act of 2003[31]

The Barrow Island Act 2003 of Western Australia was intended to ratify and authorise the implementation of an agreement between the State and the Gorgon joint venture (1) to allow the offshore production of natural gas, (2) to allow land use for gas processing (under the Land Administration Act 1997) and (3) to make provisions for the underground disposal of CO_2 produced during gas processing on Barrow Island and for incidental purposes. The Act states the Petroleum Pipelines Act 1969 applies to pipelines on Barrow Island. The definition of "pipeline" was modified to include a "pipeline for the conveyance of carbon dioxide to a place on Barrow Island for the

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[29] http://www.ucl.ac.uk/cclp/pdf/Greenhouse_Gas_Geological_Sequestration_Act_2008.pdf
[30] http://www.legislation.qld.gov.au/LEGISLTN/ACTS/2009/09AC003.pdf
[31] http://www.ucl.ac.uk/cclp/pdf/Barrow_Island_Act_Western_Australia_2003.pdf

purpose of disposing of the carbon dioxide in underground reservoir or other subsurface formation."

According to the Barrow Island Act, injection of CO_2 for the purpose of disposal is subject to ministerial approval. A penalty of Australian $50,000 will be charged in case of violation. Requirements for the Minister's permit application procedure are given including size, location, rate of injection, volume, CO_2 composition, duration of proposed injection, methods proposed for injection, and capability of the underground reservoir to confine the stored CO_2. Data available and fees should be supplied with the application.

Table 6: Australian Offshore Petroleum Amendment (GHG Storage) Act 2008

Category	Regulation
Exploration Permits	• An exploration permit allows the storage operator to conduct all exploration activities outlined in their work program. • It will require the release of certain information; • It will be subject to fees (to cover the cost of administration) • It will be valid for a term of **six years** provided conditions are met. • After six years without conversion to a CO_2 storage retention lease or CO_2 storage injection and storage, the total area of the CO_2 storage exploration permit will be relinquished. • In the event that an owner of a CO_2 storage exploration permit finds a suitable storage site but will not take delivery of the CO_2 storage stream for some time, the exploration permit can be converted into “CO_2 storage retention lease”. • A “CO_2 storage retention lease” may be granted for a period of five years and extended further.
Site Characterisation	• Must test integrity of storage site including sealing, geological setting, etc. • Must specify - Source and composition of substance to be injected - Rates of injection, range of rates - Injection pressures, total amount injected
Site Certification and Storage Permits	• Actual GHG injection will be regulated through an “Injection License” • Obtaining the license requires a comprehensive site plan.
Scale of Projects	• Applicable to Commercial scale projects in Australia • Offshore applications • Excluding EOR
Risk Assessment	• Risk assessment must prove that injection will be carried out in a manner that ensures that the site is secure. • Must outline location for storage of CO_2 • Must detail risks and remediation strategies. • Processes for identification, assessment and management of risks must be described in the site plan.
Classification of CO_2	• The Act refers to GHG in general rather than CO_2. It states that the GHG definition will initially mean CO_2 with any substances incidentally derived from capture and transport.
Access, Property Rights and Ownership	• To follow existing regulation in the Offshore Petroleum Act 2006 with minor changes relating to the duration of permits and size of projects • Protection of CO_2 storage operators must satisfy the regulator (ultimately the Minister) that there will be no significant impact on petroleum rights before the license is granted. • The regulating authority will allow most CO_2 storage exploration in or near petroleum titles to proceed but will have to carefully weigh the risks of granting CO_2 storage injection licenses close to petroleum titles (i.e. petroleum titles that are in force before the CO_2 storage legislation comes into force). • The holder of a CO_2 storage title will not have rights to any discovered petroleum.

Table 6 -Continued

Category	Regulation
Site Operation and Closure	• At the end of lifetime of site, "decommissioning reports" must be submitted to appropriate authority with MMV plans. • Holder of license will not be free from liability until a "site-closing certificate" is issued. • Site closing certificate will only be issued after a thorough assessment of migratory behaviour on injected CO_2. • Suggestions for MMV must also be submitted • Source and composition of GHG, rates of injection, injection pressures, total amount injected must be recorded Closure activities must include plugging wells, removal of equipment and assurance that GHG will not leak.
Post-closure, transfer of responsibility and Liability Issues	• Transfer of liability from operator to government at the end of "closure assurance period" is discussed. • This period is given as a minimum of 15 years but is project-specific
MMV	• Monitoring should investigate CO_2 migration, leakage, and any significant irregularities. • Monitoring should include ground water • Assessment of whether stored CO_2 will be permanently contained must be included in monitoring • All monitoring information should be reported in the reporting period to the authority in charge.
Financial Issues	• Operator incurs expenses during closure. • If Authority incurs costs, they can bill it to previous operator. • Minister has the right to direct operator to obtain insurance against liabilities and expenses during the post-closure period.

Table 7: Australian Greenhouse Geological Sequestration Act 2008 introduced by Victoria Legislative Assembly on Sep. 9, 2008

Category	Regulation
Definition of CO_2	Only GHG named explicitly in Bill.
Exploration permits	- Regulation discusses requirements for exploration permits, renewal procedures and requirements for preparation of injection plans
Site selection, characterisation and licensing and site operation	- Regulation defines Injection permit, Injection and monitoring licenses, and GHG Sequestration Formation Retention Lease - Permission is only given when no danger to human health or environment exists and when "Minister" is satisfied all conditions are met. - Community consultation and local government involvement will be a requirement for obtaining injection licenses. - Regulation outlines need and conditions for reporting and documentation, regular inspections, penalties, GHG registers
Closure	- Act introduces criteria and conditions for acceptance of closure
MMV	- The act introduces provisions for proscribing monitoring and verification requirements - Australian EPA to administer monitoring and verification
Post-closure and long-term stewardship	- Act defines a period of 15 years for transfer of liability. - The Act introduces provisions to manage public health and environmental risks including long-term liabilities
Ownership	- The Act establishes Crown ownership of all sub-surface geological storage formations in Victoria. - On cancellation of a license, the Crown will become owner of injected GHG.
Financial Issues	- Rehabilitation bond, which is decided on by Minister.

2.5 CCS Regulation in Canada

In Canada there are well-developed EOR/EGR regulations[32]. Several EOR operations, including CO_2 flooding, are active in Alberta and Saskatchewan. In addition, there are regulations in place for gas disposal in deep saline aquifers and depleted hydrocarbon reservoir in Alberta and British Columbia. There is extensive operational experience with the separation, capture, transportation and injection of these gases and, more importantly, a regulatory framework dealing with the permitting, operation and abandonment of these operations already exists.

This framework may be expanded to cover the permanent storage and the post-abandonment stage of CO_2 storage operations, including monitoring and remediation. Issues that need to be considered in modifying existing regulation, include financial issues, incentivisation, liability and ownership and access rights. The Canadian government owns most, but not all, of the subsurface and so issues of ownership and access rights need to be considered carefully. Federal and provincial governments in Canada are working towards producing a coherent regulatory framework, much of which already exists.

Canadian regulation of CO_2 storage will also benefit from the existing regulation on disposal of acid gas (such as H_2S) in geological aquifers[9]. Sulphur dioxide, a flammable poisonous gas, has been stored in aquifers to avoid air pollution since 1989. Before acid gas injection can begin, applicants must meet regulatory requirements, including selection of reservoir and reservoir property characterisation. Licensees with interests in the wells are subject to continuing responsibility for the management and control of the well and they must report financial information to the Alberta Energy and Utilities Board, which compares the assets and liabilities of the licensee. If the licensee's liabilities exceed its assets under the Board's assessment, the licensee must place a security deposit for the difference in the form of cash or a letter of credit. All licensees must pay into a general fund, which is used to fund the abandonment stage.

2.6 Summary of Emerging Regulatory Frameworks on CCS

Regulatory Frameworks on CCS have been and are currently being developed worldwide. A common practice is that these regulations are based on existing legislation, which can be amended to cover issues related specifically to CCS. Current regulation on air pollution control and environmental impact assessment can be adapted to cover CO_2 capture. Moreover, existing transport pipeline can be modified to cover CO_2 transport. Regarding CO_2 storage, typically, existing non-CCS regulations cover permitting, construction, operations and abandonment of sites. However, issues related to post-closure (e.g. long-term liabilities and financial responsibility), and monitoring and verification requirements are not usually covered. Moreover, ownership and property rights, which differ from one country to another, will need to be addressed in new CCS regulation.

Existing EOR regulations are useful in dealing with issues related to exploration permits for CO_2 storage sites. Countries who have established industries in oil and gas extraction, already have well-developed regulatory frameworks covering pipeline transport, acid gas injection, disposal and storage, groundwater protection as well as enhanced oil and gas recovery. A strategy that several countries have adopted in

[32] IEA (2007), Legal Aspects of Storing CO_2: Update and Recommendations, http://www.iea.org/textbase/nppdf/free/2007/legal_aspects.pdf

deploying demonstration projects is by amending these existing frameworks to facilitate CO_2 storage. It seems that this is an efficient way in the short-term while more comprehensive regulation is being developed at the national level. However, existing petroleum regulations may need to be adapted to deal with emerging health and safety issues arising from CO_2 storage.

Several lessons can be learnt from emerging regulatory frameworks. According to emerging guidelines, in order to ensure environmental integrity, CCS regulation should be based on a site-by-site assessment and should include risk assessment and site characterisation and simulation, supported by monitoring. The development of these regulations is based on technical and scientific evidence and is based on learning from existing regulatory developments.

Table 8 summarizes the information available for the EU, US and Australia in several categories. The information in Table 8 is based on all the documents reviewed above for each of the three countries. It is seen that the regulatory frameworks are similar in emphasising the important areas of regulation. In all three countries, gaps exist in the areas of IPR and in providing specific information on monitoring requirements (e.g. acceptable parameter ranges and accuracy of instruments) and the tolerable composition of the transported/injected CO_2 stream.

Table 8: Review of regulatory frameworks on CCS (*based on documents in Table 1*).

Category	EU	UK	US	Australia
CO_2 capture discussed?	√	√	√	x
CO_2 transport discussed?	√	√	√	x
Details on exploration permits given?	√	√	√	√
Details on site characterisation given?	√	√	√	√
Site Certification and Storage Permits	√	√	√	√
Risk Assessment details given?	√	√	√	√
Classification of CO_2 referred to?	√	√	√	√
Details of CO_2 composition given?	x	X	x	x
Access, Property Rights and Ownership discussed?	√	√	√	√
Site Operation and Closure discussed?	√	√	√	√
Limits on injection pressure specified?	x	X	√	x
Details of parameters to be monitored post-closure given?	x	X	x	x
Post-closure, transfer of responsibility and Liability Issues discussed?	√	√	√	√
Transfer of responsibility period recommended?	x	X	√	√
MMV requirements given?	√	√	√	√
MMV specifications (accuracy of instruments and acceptable parameter ranges)?	x	X	x	x
IPR issues addressed?	x	X	x	x
Financial Issues addressed?	√	√	√	√

3. Applicability of Current CCS Regulation to China

The potential importance of CCS in China is highlighted by the rapid economic growth accompanied by rapid energy and electricity demand, and plentiful coal reserves. Climate change has become a very important issue for the Chinese Government. The State Council issued China's National Climate Change Program (CNCCP) in 2007 setting a goal for reducing GHG emissions by 20% by 2020 and including CCS as a key area in GHG reduction[33]. CCS was also integrated into 'The Outline for National Medium and Long-term S&T Development Plan towards 2020' as a leading edge technology[34]. In China's National Policy and Action towards Climate Change, CCS was identified as part of new technology development and combined with R&D of clean coal technology. Several pilot projects are underway and CCS R&D in China is currently accelerating. The Ministry of Science and Technology (MOST) has been working on a Guide for CCS, which determines the aim of CCS R&D in 2020 and 2030 and identifies major tasks and near-term projects on CCS[29].

One of the barriers to the deployment of CCS projects in China is the lack of regulatory experience with underground injection. One option for China is to focus its efforts on developing CCS technology to reduce costs and energy penalties, before addressing policy and regulatory barriers. Alternatively, regulation can be developed in advance or in parallel to facilitate the deployment of CCS technology.

The current section makes use of the international experiences and the Chinese situation to identify relevant existing regulation in China that might be amended to facilitate the deployment of CCS. This is then followed by a discussion of additional regulatory issues that should be considered in developing comprehensive CCS regulation in China as can be learnt from other countries' experiences. The review below is undertaken in the three main categories of CCS; i.e. capture, transport, and storage.

Sustainability aspects associated with CCS are addressed in Appendix B. This Appendix highlights some of the main issues that could be considered under the environmental component of a sustainability appraisal of any future CCS project.

3.1 CO_2 Capture

For all capture technologies (post-combustion, pre-combustion and oxyfuel capture), the cost and energy penalty are the major concerns. Apart from energy penalty, the capture technology will result in other non-CO_2 environmental impacts including air emissions, water consumption and solid waste[35]. The following existing Chinese legislation can be used to address the relevant environmental impacts.

[33] Liu Y., China's Policies and Actions on Carbon Capture and Storage (CCS), Presentation at the IRGC/ Swiss re Conference on Regulating and Financing Carbon Capture and Storage, 7-8 November 2007, Zurich.

[34] http://ec.europa.eu/environment/climat/pdf/china/China%20Policies%20and%20Actions%20on%20CCS.pdf

[35] WRI Guidelines, 2008

3.1.1 The Environmental Impact Assessment Law[36].

This law, adopted in 2002, requires that companies submit an EIA plan before construction commences “so as to propose countermeasures for preventing or mitigating the unfavourable impacts and make follow-up monitoring.” The EIA Law is a fundamental law in China for all projects with unfavourable impacts on the environment. The Law states that an EIA statement should include an assessment of the atmospheric pollution the project is likely to produce and its impact on the ecosystem, and should also identify preventive and corrective measures. It also states that the EIA statement shall be submitted, according to the specified procedure, to the administrative department of environmental protection concerned for examination and approval.

According to the EIA Law, the EIA plan is submitted to the competent administrative department in charge of environmental protection for examination and approval. In case a department is assigned for the project, this department will do the EIA preliminary evaluation and will then pass it to the administrative department responsible for environmental protection. The examination and approval of the reports of the impacts imposed by a marine project upon the marine environment are made according to the relevant provisions of the Law of the People's Republic of China on Protecting the Marine Environment.

3.1.2 The Prevention and Control of Atmospheric Pollution Law[37].

The purpose of this Law is ‘to prevent and control atmospheric pollution, protect and improve China's environment and the ecological environment, safeguard human health, and promote the sustainable development of economy and society’. The Law mandates that no industrial production facilities that cause environmental pollution shall be built in places that need special protection, as designated by the State Council. The State Council and the local governments at various levels must incorporate this Law into their national economic and social development plans.

According to this Law, the administrative department of environmental protection under the State Council must establish national standards for the discharge of atmospheric pollutants. The provinces, autonomous regions and municipalities should directly establish their local discharge standards under the Central Government guidance. Provinces are also allowed to set standards which are more stringent than those defined by the Central Government.

If CO_2 becomes listed as an atmospheric pollutant, the accompanying air emissions from industrial sources with CCS facilities would need to comply with this Law. The Law could also provide a legal basis for preventing and controlling non-CO_2 emissions from additional CCS facilities.

In addition, legal liabilities are also dealt with within the Law by imposing a fine on refusing to report, refusal to on-site inspections, failing to operate the installations for the treatment of air pollution, or dismantling the units without approval from the responsible authority. The Law discusses liability in detail and may be useful in drafting CCS-related liabilities.

[36] http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/03/environmental-impact-assessment-law.doc
[37] http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/03/air-pollution-control-law.doc

3.1.3 The Prevention and Control of Solid Waste Pollution Law[38].

The purpose of the Law is to prevent and control solid waste. This Law can provide a legal base for preventing and controlling solid waste from CO_2 capture facilities. The responsibilities of operators and the liabilities are defined in this Law. Solid waste from CO_2 capture facilities might be categorised as industrial or hazardous waste (WRI CCS Guidelines, 2008), which is covered by the current Prevention and Control of Solid Waste Pollution Law.

3.2 CO_2 Transport

Due to the risks associated with CO_2 pipeline transport (including impurities, operational parameters including temperature and pressure, and pipeline design), safety regulation is required. The National Standards of CO_2 composition for Industrial Uses sets the criteria for food additive liquid CO_2 and for industrial use in the chemical industry. These regulations refer to the volume of CO_2 and water content and they can serve as a legal basis for CCS regulation but with different standards since they apply to food grade CO_2.

Another regulation, which can be useful in relation to CO_2 transport, is the “Safety Management Regulation for Dangerous Chemicals”. According to this regulation, dangerous chemicals include explosives compressed gases and flammable gases. The regulation covers the transport of dangerous chemicals and, since, CO_2 from CCS processes falls under the category of compressed gas, this regulation may provide a legal base for risk management related to CCS transport.

3.3 CO_2 Storage

Chinese oil and gas companies are experienced in enhanced oil recovery (IEA, 2007). PetroChina has undertaken experiments on EOR in several oil fields in Daqing, Shengli, and Liaohe since the 1960s[39]. China has a well-established EOR regulation. It is very likely that near-future CCS deployment will be for EOR applications and so existing regulation may be used. However, amendments will be required in several areas including long-term liabilities, financial issues, injection site locations, and injection criteria. In the short and medium term, existing EOR regulation could be slightly modified to speed up demonstration of CCS while more comprehensive legislation and amendments related to liabilities and financial issues can be left for long-term deployment. This has typically been the approach taken in other countries.

As the purpose of EOR is to drive oil out rather than to store CO_2 permanently (as with CCS applications), the management of CO_2 stored and the associated safety concerns are not covered by existing EOR regulation. As the case is with regulation in other countries, the definition of “CO_2 storage” needs to be clarified in future CCS regulation.

The Marine Environmental Protection Law[40] in China may be relevant to CO_2 storage in the sub-sea bed. The purpose of the Law is to protect marine environment and resources, maintain ecological balance and safeguard human health. It applies to internal sea as well as territorial sea in China. It also covers waste disposal within and beyond the sea areas of China. All institutions engaged in navigation, exploration, exploitation, production and scientific research must comply with this Law. According

[38] http://www.ccchina.gov.cn/en/NewsInfo.asp?NewsId=5377
[39] http://www.un.org/esa/sustdev/sdissues/energy/op/ccs_egm/presentations_papers/li_ccs_china.pdf
[40] http://www.novexcn.com/marine_environemental_prot.html

to this Law all relevant departments under the State Council and governments of coastal provinces and autonomous regions may, under the Central Government, establish special marine protection measures. The Harbour Superintendency Administration of the People's Republic of China is responsible for overseeing, investigating and dealing with the discharge of pollutants into the sea.

In the China Marine Environmental Protection Law, no reference is made to CCS. If this Law is to be extended to cover CCS, clearer definition of CO_2 will be required. In the London Convention, which China has ratified in 2006[41], CO_2 from capture processes is defined as an industrial waste. Amendments to the Marine Environmental Protection Law in China may be made after CCS is defined.

3.3.1 Site Exploration, Characterisation, and Storage Permits

An important aspect of CCS regulation in China is likely to be site selection, exploration, characterisation and issue of storage permits. China has extensive experiences in issuing geological permits for oil and gas exploration, radioactive waste disposal in addition to permits for EOR, enhanced coal bed methane, and hydropower projects.

The existing EOR regulation will be an important cornerstone in the regulation for early deployment of CCS in China. The EOR approval process can pave the way for the overall approval process for other storage options.

3.3.1.1 Exploration Permits

The regulation on Environmental Protection and Management for Oceanic Oil Exploration and Development may be useful in developing regulation for CCS exploration permits. This regulation emphasises the importance of Environmental Impact Assessment (EIA) and defines the requirements for such an assessment, which may be relevant for CCS EIA activities. In addition, several Chinese provinces adopted provincial regulations for the management of oil exploration production based on an environmental perspective. IEA has been made mandatory for all projects. These regulations may have a big impact on CCS site selection, characterisation and permitting in the sub-seabed. However, because of existing marine laws (section 3.3.3) and because of the London Convention, which China has ratified, the injection of CO_2 into the water column in China will most likely be prohibited. Requirements under the London Convention are discussed in Section 2.1.1.1.

The Mineral Resources Law defines the conditions for exploration and can be useful in developing regulation for exploration permits, which will then lead to storage permits. This Law provides a powerful means for the Chinese Government to regulate mining activities. The same principles can also be applicable to CCS exploration permits, which are of the most importance in developing CCS projects.

3.3.1.2 Storage Permits

If CO_2 is categorised as hazardous waste, then the Hazardous Waste Law, where operators are asked to obtain permit before they store their waste may be helpful. The Law provides information on requirements for obtaining such permits including remediation plans.

[41] http://www.imo.org/includes/blastDataOnly.asp/data_id%3D23513/2-1.pdf

The EIA Law in China requires that an EIA be completed before project construction commences[42]. It is possible that CCS storage will fall under this regulation in which case an EIA would be mandatory for all permitting of storage sites. Procedures such as third party verification and public hearings are some of the important procedures governed by the EIA Law.

Currently, the main authority responsible for permitting large projects in China is the National Development and Reform Commission (NDRC) guided by the State Council. It is thus anticipated that the NDRC will be responsible for all exploration and storage permits related to CCS. However, the NDRC may require assistance from several other organisations due to the complexity of CCS projects.

The regulation of CCS in China may require an energy authority as well as an environmental authority. As part of the NDRC, the National Energy Bureau (NEB) is the central decision maker on energy projects and may serve as the authority responsible for CCS project approval approving both exploration and storage permits. The Ministry of Environmental Protection (MEP) is likely to be responsible for EIA during application for a storage permit. It may also be responsible for monitoring issues. The Ministry of Land and Resources (MLR) is expected to be responsible for land and sea exploration permits.

3.3.2 Liability

Long-term effects and safety/liability issues are discussed in the "Prevention and Control of Radioactive Pollution Law"[43]. The purpose of this Law is to protect the environment and human health by preventing, controlling and monitoring radioactive pollution. The Law assigns responsibilities and corrective measures for radioactive waste management. The Law is observed by State Council. The roles of the Central Government, operators and local governments are outlined in this Law. Licences should only be awarded after EIA has been undertaken. Issues of disposal site selection, fee administration, site monitoring and transport of waste are discussed in the Law.

Because it is comprehensive, this Law may be used as the framework for future CCS regulation. This is due to the several similarities between the "Law on Prevention and Control of Radioactive Pollution" in China and what CCS regulation is required in the near future as evident from regulatory developments in other countries.

In this Law, the selection of radioactive material disposal sites is based on EIA and evaluation of geological factors and is subject to State Council approval. Local governments should provide assistance and support for the operation and monitoring of sites. The site characterisation procedure, site selection criteria, licensing procedure and responsibilities of different parties can be translated for CCS regulation. However, the timescales for radioactive waste are different from those for CO_2 and so liabilities and monitoring requirements may need to be clarified in a new CCS regulation. Moreover, due to uncertainties with CCS storage, there may be higher risks. Finally, as CO_2 storage sites are much larger than radioactive waste storage sites, the management systems will be different.

In China, regulations assign legal liabilities to the private sector. However, if the private sector bears the entire liability in a CCS project, the wide spread of CCS in China will be unlikely. On the other hand, if the public sector bears full financial

[42] International Environmental Law Committee, August 2008. http://www.abanet.org/environ/committees/intenviron/newsletter/aug08/IELC_Aug08.pdf
[43] http://www.asianlii.org/cn/legis/cen/laws/pacorpl507/

liability, the precautions undertaken by storage site operators in the short-term will be affected. It is thus important that liability in CCS projects is shared between the public and private sectors.

3.4 Other CCS Regulatory Requirements in China

As mentioned above, EOR regulation in China can be very useful in developing CCS regulation for demonstration projects regarding permitting and characterisation. However, issues related to health and safety may need to be addressed by the new regulation.

For the long-term deployment of CCS, existing regulation can be useful in developing dedicated CCS regulation for CO_2 capture, transport and long-term liability. However, regulation is required in several areas as discussed below.

Several research groups have been developing guidelines on CCS regulations. A summary of the work of some of these groups is given in Appendix A.

3.4.1 Classification of CO_2

The stored CO_2 can be classified as either an industrial product or a waste product. The classification of CO_2 is important because industrial projects are, usually, subject to less stringent regulations than waste disposal projects. The presence of impurities will affect the capture, transport and storage processes and also the trapping mechanism within the reservoir and the capacity for CO_2 storage. Contaminant such as H_2S may need to be classified as hazardous thus resulting in different requirements for injection from when the stream is pure CO_2. Current CCS regulatory frameworks do not define allowable concentration of impurities.

3.4.2 Access, property rights and ownership

Property rights are intended to define who has or will in the future have access to a CCS project site. Definitions of property rights will depend on the national and international laws in place.

For effective operation, the operator of the storage site needs to be able to manage third party access to the site and prevent others from damaging the site.

Issues addressed by emerging regulatory frameworks include impacts on land use titles and the use of property law to regulate ownership. Many countries have legislation that gives legal rights for third parties to share the use of particular infrastructure with the owner.

Issues, which are considered in relation to ownership and property rights, include (IEA, Legal Aspects of Storing CO_2, 2008)

- **Ownership of the Subsurface**

In the US for example the sub-surface is owned privately while in Europe and Australia, the government owns the subsurface, which should be the one who gives rights of access.

- **Ownership of the injected CO_2**

Ownership of the CO_2 injected is important because it influences liabilities and responsibility for monitoring of the substance.

- **Ownership of the equipment used on site used for injection**

An issue that is considered is whether the equipment on the surface is a property of the landowner or the injection site operator. It is important for site operators to maintain ownership of injection equipment for insurance purposes.

- **Transnational issues**

For projects that cross country borders, issues of long-term liability, monitoring and access issues are considered by regulation.

- **Mineral rights and access to minerals**

Mineral rights and access to minerals needs to be addressed to prevent interference with other ownership and access rights (See for example section 2.2.2 on the Netherlands).

3.4.3 Site closure

Site closure is different from decommissioning of equipment and plant, which is only one component of site closure. It is very likely that site closure will include obligations to reduce residual risk associated with the site. As with other worldwide regulatory frameworks, a post injection period where the operator will continue monitoring on a daily basis may be required before closure. In emerging regulatory frameworks, site closure addresses long-term monitoring of the site, ownership of the CO_2 and financial issues. The period during which the operator still remains responsible for the storage site is also described in some of the frameworks.

3.4.4 Measurement, monitoring and verification requirements

Emerging regulatory frameworks usually outline the monitoring requirements during operation, the reporting requirements by the operator and the procedure for inspections by the authorities and climate change administrators. These emerging regulations also distinguish MMV standards during the operation of the site from those required in the post-closure phase. Such standards are likely to cover the collection of data on leakage, stored CO_2 and seismic activity. The collection of such data is important for updating the risk assessment plan, mitigation strategies and GHG accountancy (in order to provide proof of the amount of CO_2 stored).

Performance modelling from existing projects can be used to develop a generalised framework for MMV. Monitoring tools can change from one site to another but the general framework will provide consistency.

Emerging regulatory frameworks agree in the requirement that MMV techniques are outlined in the application for storage permits. Techniques used during the operational phase and those used during the post-closure phase may be different from those used in the site selection and characterisation phase.

3.4.5 Financial Issues

Financial issues include insurance and the provision of funding for liabilities and costs in the post-closure period in addition to changes in ownership during the operational phase. Costs include decommissioning costs, possible remediation costs in addition to site monitoring costs. Moreover, as with emerging regulatory frameworks, financial security is required to cover for liabilities arising from leakage of CO_2 if it happens. In order to ensure financial responsibility exists for a given project, insurance funds or government trust funds can be, for example, established[44].

Because of the long time horizons for CO_2 storage, it is currently impossible to obtain insurance for the entire post-closure project period[31]. There are no existing examples of insurance instruments that provide liability protection for decades or centuries. In

[44] IOGCC, 2005

the mining and petroleum industries, trust funds or bank guarantees are used to cover liability costs.

4. Summary and Conclusions

- Several regulatory frameworks on CCS have been or are in the process of being developed worldwide. These frameworks mainly focus on regulating CO_2 storage. All emerging regulations are similar in that they focus on issues related to exploration and storage permits, site characterisation, risk assessment, monitoring and verification requirements and post-closure liabilities and financial responsibility.

- Several lessons can be learned from the development of these frameworks.
  - Emerging worldwide regulatory frameworks on CCS are typically based on amendments to existing regulations.
  - The classification of CO_2 is one of the important issues that CCS regulation needs to deal with.
  - Gaps still exist in several areas including providing specific information on monitoring requirements (e.g. acceptable parameter ranges and acceptable accuracy of instruments used for MMV) and the tolerable composition of the transported/ injected CO_2 stream. For example, the EU Directive states that CO_2 composition should be verified before injection is started but does not state what levels of impurities are tolerable.
  - While emerging worldwide regulations acknowledge the importance of long-term management of storage sites, they fail to identify what parameters need to be managed and for how long.
  - Different frameworks agree that operational l data should be collected and analysed throughout the project and integrated in the reservoir model and simulations. Different regulations also agree on the need to recalibrate risk models periodically based on operational data as it becomes available.
  - These regulations tend to agree that MMV techniques are project specific and should not be specified by regulation.

- Review of Chinese laws reveals that there are several laws that can potentially be useful in drafting CCS regulation:
  - For CO_2 capture, the ‘Environmental Impact Assessment Law’ in China can be relevant for ensuring the safety of CCS projects. Moreover, the ‘Prevention and Control of Atmospheric Pollution Law’ can provide a legal basis for preventing and controlling non-CO_2 emissions from additional CCS facilities. The ‘Prevention and Control of Atmospheric Pollution Law’ also discusses liability in detail and may be useful in drafting CCS-related liabilities. The ‘Prevention and Control of Solid Waste Pollution Law’ can serve as a legal basis for drafting regulation related to preventing and controlling solid waste from CO_2 capture facilities.
  - Considering CO_2 transport, the ‘National Standard of CO_2 Composition for Industrial Uses’ and the ‘Safety Management Regulation for Dangerous Chemicals’ can be useful in regulating the safety and risk management of CO_2 transport.

- For CO_2 storage, existing EOR regulation can be useful but amendments will be required in several areas including long-term liabilities, financial issues and injection criteria.
- The ‘Prevention and Control of Radioactive Pollution Law’ in China may be used as the framework for future CCS regulation especially relating to liabilities, site selection and site monitoring.
- A crucial requirement for amending existing regulation is to define CO_2.
- If EOR regulations are amended, the management of CO_2 stored and the associated safety concerns need to be covered since the purpose of EOR is to enhance oil recovery rather than store CO_2.
- The regulation on ‘Environmental Protection and Management for Oceanic Oil Exploration and Development’ and the ‘Mineral Resources Law’ can both be adapted for developing regulation on CCS exploration permits.
- The ‘Hazardous Waste Law’ where operators are required to obtain permits before they store waste may be useful in drafting CCS regulation if CO_2 is defined as waste.

- There are areas where CCS regulation may need to be drafted specifically for CCS:
  - The classification of CO_2 is important because it will define what existing regulation can be most relevant depending on whether CO_2 is defined as a waste or as an industrial product. Impurities present in the CO_2 stream may influence its definition.
  - Issues related to the ownership of the subsurface, ownership of the injected CO_2 and access rights are important. In addition, mineral rights and access to minerals needs to be addressed.
  - The responsibility of the operator to the storage site after closure should be addressed by CCS regulation. This will include defining a ‘transfer-of-responsibility’ period.
  - Identifying the parameters to be measured and monitored and the acceptable accuracy of instruments used is important. However, no restrictions should be imposed on what techniques are to be used and operators should be able to select their own monitoring techniques as long as they meet criteria set by regulation.
  - Financial issues are important for addressing liabilities and post-closure costs. Financial responsibility and commitment should be provided initially in the application for storage permits. Financial issues should cover the operation of the site (including change of ownership) and the closure and post-closure periods.

- The regulation of CCS in China may require both an energy authority and an environmental authority. The main authority responsible for permitting CCS projects in China is likely to be the National Development and Reform Commission (NDRC). The National Energy Bureau, which is part of the NDRC, may be responsible for issuing exploration and storage permits while the Ministry of Environmental Protection may be responsible for EIA and monitoring issues.

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Appendix A: Current Research on CCS Regulation

This Appendix gives description (and results) of current and recent projects on CCS regulation.

A1. CCSReg

CCSReg[45] is a US collaborative project working with stakeholders and experts to facilitate the rapid adoption of a CCS regulatory environment in the US. The project consists of Carnegie Mellon University, Vermont law School, University of Minnesota and Van Ness Feldman. CCSReg is still underway and is expected to publish a series of policy briefs on CCS regulation.

The main findings to-date from CCSReg are summarised below:

- An adequate regulatory framework for CO_2 transport infrastructure does not yet exist. The project recommends that Congress resolve this issue as soon as possible to provide project sponsors with greater certainty in time for deployment of CCS on a commercial scale.
- Legal use of deep geological formations for sequestration and adequate financial, regulatory, and liability arrangements for long-term stewardship of sequestration sites are two most important issues which have not been addressed by the EPA (the US Environmental Protection Agency) proposal[46] on CCS regulation because it has been developed under authority provided by the Safe Drinking Water Act.
- While in most parts of the world, deep subsurface resources are owned by governments, in the US, ownership of these resources is undefined. They propose a federal solution rather than state-by-state solution.
- During injection, site operators must be required to pay into a fund that will cover long-term stewardship costs and other remediation costs that may be needed in the future. Again they recommend a federal system because this will be cheaper than a state-by-state system.
- The entity granting site certification and injection approval should be different from that responsible for long-term stewardship to avoid perverse incentives.
- While liability during the injection period can be managed using existing mechanisms, long-term stewardship will require new managing mechanisms.

A.2 International Risk Governance Council (IRGC)

IRGC47 is an independent organization with the objective to help in the understanding and management of risks which impact human health and safety. The "Regulation of Carbon Capture and Geological Storage" project within IRGC consists

[45] http://www.ccsreg.org/
[46] http://www.goodwinprocter.com/~/media/7CB2EE8B07CD47C0A2C3BB83290C9FF6.ashx
[47] http://www.irgc.org/

of several workshops with contributions from several countries including the Australian Greenhouse Office (Australia), the Statoil Research Centre (Norway), BP International, Carnegie Mellon University (US), Massachusetts Institute of Technology (MIT), and the Scottish Centre for Carbon Storage (UK). Contributions of experts in the area of CCS regulations are provided on the IRGC website[48]. A policy brief has been published by IRGC based on these expert consultations.

Recommendations included the following:

- A full portfolio of full-scale CCS demonstration projects should be implemented as quickly as possible with great government support which will incentivise such projects
- The development of a regulatory framework will encourage such projects and reduce risk.
- Such projects will provide scientific as well as technical answers to key legal concerns, will operate transparently with data available publicly, will try several technologies, and will be subject to comprehensive and comparative assessment.
- Site selection requirements must be dealt with rigorously in the regulatory framework, as poor performance in the early stages of CCS will give the technology a bad reputation.
- Early CCS projects should be regulated under modifications of existing regulations. Results from early [projects can be used to create a general CCS regulatory framework to manage commercial deployment.
- Development of CCS regulations should include details on public engagement and education, site selection criteria, general MMV techniques, standardisation of modelling techniques, modification to existing regulation, arrangements of long-term liability, and creation of financial incentives.
- An independent review group with strong skills in project evaluation and decision analysis should be formed to provide a comprehensive summary of results from early CCS projects worldwide.
- Development of CCS regulation is necessary but not sufficient for CCS deployment. Economic and political barriers must also be addressed.
- A climate regime is required before a regulatory framework on CCS is finalized.

A3. World Resources Institute

The World Resources Institute[49] (WRI) has published a set of guidelines for carbon dioxide capture, transport and storage[50]. According to WRI, the CCS guiding principles are

- Protection of human health
- Protection of ecosystems
- Protection of underground natural resources including water
- Ensuring market confidence in emissions reduction through appropriate GHG accounting
- Facilitating cost-effective and timely deployment of CCS

The WRI CCS Guidelines are targeted at ‘those involved in the development and implementation of CCS projects’ and at ‘those who are new to CCS who seek to understand how to responsibly conduct projects’. According to the WRI, the

[48] http://www.irgc.org/Expert-contributions-and-workshop.html
[49] http://www.wri.org/
[50] http://pdf.wri.org/ccs_guidelines.pdf

guidelines provide a benchmark for potential operators, financiers, insurers or regulators in evaluating potential project plans and understanding best CCS practices. Moreover, policymakers can use these guidelines to establish regulatory and investment frameworks to enable responsible CCS deployment.

A main conclusion of the WRI CCS Guidelines is that each CCS project will be unique and a 'team of qualified experts will be needed to design and operate each project'.

The WRI document provides guidelines for site selection and characterisation and for determining injectivity. It is recommended that operators should obtain porosity and permeability measurements from core samples collected on site and that this data should be made public. Guidelines for determining capacity should be based on site-specific data (CO_2 density at projected reservoir conditions of pressure and temperature). Capacity estimation should include both primary and secondary targets and calculations should include estimates of the pore volume that is expected to be utilised. The guidelines also provide recommendations of estimates of 'phase-relative permeability' i.e. (CO_2-brine).

The WRI guidelines also recommend that MMV requirements should not prescribe methods OR tools and that they should focus on key information required for each injection well and for the whole project. This includes

- Injected volume
- Flow rate or injection pressure
- Composition of CO_2 stream injected
- Spatial distribution of CO_2 plume
- Reservoir pressure
- Well integrity
- Determination of any measurable leakage

Operators should have the flexibility to select the appropriate technique that will be deployed at each storage site as long as these techniques provide the resolution set by MMV requirements. MMV plans should be submitted as part of the site permitting process and should be updated as needed during the project. Monitoring area should be based on knowledge of the regional site geology, overall site-specific assessment and sub-surface flow simulations. This monitoring area should be modified as data obtained during operation is obtained.

The WRI guidelines also provide recommendations on risk assessment, CO_2 composition, injection pressures, post-closure, transfer of responsibility, and monitoring duration requirement. Further details are given in reference 17.

A collaborative project between WRI and the Laboratory of Low Carbon Energy (LCE) at Tsinghua University was launched in January 2008 and will last for two more years. The objective of the project, which is funded by the US Department of State and the Asia Pacific Partnership (APP) on Clean Development and Climate, is to develop and draft CCS guidelines for China. The project will compare the different geology and regulatory environments in the US and China.

A4. The Carbon Capture Legal Programme at UCL

The Carbon Capture Legal Programme (CCLP)[51] at University College London (UCL) was established to provide a source of comprehensive information on CCS. The CCLP promotes informed discussion and analysis by decision-makers in government, industry and the wider community. The CCLP acted as a co-host for the launch of the International CCS Regulators' Network in Paris and continues to work with the IEA to further its work in this field.

A5. International CCS Regulators' Network

In 2004, the IEA launched a project to inform and engage regulators and experts on legal aspects of CCS. In 2008, the IEA launched the International CCS Regulators' Network[52]. The Network aims to provide a forum for potential CCS regulators and give them the opportunity to consider solutions for challenges they face in developing a CCS legal and regulatory framework.

[51] http://www.ucl.ac.uk/cclp/
[52] http://www.iea.org/textbase/subjectqueries/ccs_network.asp

Appendix B: Initial Appraisal of Sustainability of CCS in China

This Appendix presents an initial high-level assessment of some of the sustainability issues associated with future CCS projects in China. The initial intention of this work under NZEC WP5.4 was to examine a wide range of possible environmental, economic and social impacts of wider deployment of CCS in China. However it quickly became apparent that economic impacts could not be satisfactorily addressed without a fuller understanding of the way CCS will be financed in China, and that social impacts are almost always location-specific. For these reasons, this initial appraisal focuses only on environmental impacts.

In recent years, many researchers have studied the environmental impacts of CCS. These impacts are usually evaluated for a specific scenario and a specific project based on available data. The impact categories typically considered include climate change, air pollution, resource consumption (including water) and waste production in addition to landscape, biodiversity, and land use. Results are compared to a counterfactual and, for quantifiable categories; the comparison is performed on a standardised g/kWh basis.

This Appendix presents a preliminary high-level assessment of the potential environmental impacts that may result from the construction of a CCS project in China. Since coal is the major fossil fuel for electricity generation in China[53], the current discussion only considers the impacts from coal power plants with CCS.

The report considers CCS technology in general (whether pulverised coal, PC, using amine scrubbing, or Integrated Gasification Combined Cycle, IGCC, using pre-combustion capture with physical absorbents such as Selexol). Comparison is made to a counterfactual. The counterfactual in this report is taken as a situation where no CCS is installed on an advanced coal power plant in China.

This report provides initial screening and can provide a reference for future in-depth assessment of a specific project (capture, transport and storage) built in China. For a more detailed quantitative study of the environmental impacts of a power plant with CCS in comparison to the counterfactual, the following data is required:

- Data on location of power plant, storage site and transport network
- Type of storage (EOR, EGR, saline aquifers, etc.) and technical parameters related to the injection and storage process (for example, energy consumption.)
- CO_2 pipeline specifications (length, diameters, material of pipe, etc.)
- Power and capture plant performance data (lifetime, availability and capacity factor, efficiency, coal source and composition, emission factors, CO_2 capture efficiency, solvent requirements, etc.).

Typical Chinese data should be used for the quantitative analysis to be meaningful. The construction, operation and decommissioning phases should be considered. The operation phase should include upstream (i.e. coal mining and transport as well as other resource production and transport) and downstream process (i.e. waste disposal and post-treatment).

The categories considered for the current study are given in Table A1. The rest of the report gives brief details of some of the categories related to climate change, air quality, resource consumption and waste production.

[53] http://www.cd4cdm.org/Publications/ElectricityTargetsDCpost2010.pdf

Table A1: Criteria for environmental sustainability and impact assessment. Comparison is against an exactly similar hypothetical plant without CCS.

Criterion	Indicator	Reference to CCS	+ve or -ve
Impact on local environmental quality	Will the policy or project lead to a decrease in the emissions of any of the six **greenhouse gases**?	Yes	+ve
	Will it affect, or be affected by, vulnerability to the predicted effects of climate change e.g. flooding?	No	+ve
	Will it lead to increase in the emissions of **air pollutants**?	Possible	-ve
	Will it increase solid **waste production**?	Possible	-ve
	Will it increase **water pollution**?	Possible	-ve
	Will it involve **visually intrusive** construction works?	Possible (during pipeline construction)	-ve
	Will it involve re-locating people from their residence areas?	Possible (during pipeline construction)	-ve
	Will it involve demolition or modification of historic buildings?	No	+ve
	Will it impact on a location in such a way as to change its sense of place or identity in any other way?	No	+ve
	Will the policy or project lead to increase in exposure to noise of sensitive buildings such as schools and hospitals?	No	+ve
	Will it lead to an increase in the number of people affected by existing noise?	No	+ve
Change in usage of natural resources	Will the project reduce community access to resources	No	+ve
	Will it lead to increase in **consumption of natural, non-renewable resources**, including land?	Possible	-ve
	Will it increase the **use of energy**?	Yes	-ve
	Will it increase the **use of water**?	Yes	-ve
	Will it lead to a loss in local **biodiversity**?	Possible	-ve

Impacts on local environmental quality

Will the project lead to a change in the emissions of greenhouse gases, for instance by consumption of fossil fuels? In comparison to a counterfactual where CCS is not present, much lower GHG emissions will be produced and so the environmental impact is positive.
Operation of capture plant: CCS is a technology for reducing CO_2 emissions, the major contributor to global warming. Depending on the capture technology, it is possible to capture 85-95% of CO_2. However, since CCS is associated with an energy penalty, it requires additional usage of fossil fuels to deliver the same electrical output. This, consequently, leads to an increase in upstream greenhouse gas (GHG) emissions resulting from additional coal mining and transport activities and also from methane leakage as a result of coal extraction operations. As a result, a process capturing 90% of CO_2 from a power plant is in reality reducing life cycle GHG emissions by 70-80% (Odeh and Cockerill, 2008). These figures will be slightly different depending on the nature of mining activities in China. For example, mining in China may be associated with higher or lower methane leakage, higher/lower energy consumption and different coal transport scenarios. Operation of transport and injection/storage facilities: Emissions from transport and storage may result from leakage. Experience, however, shows that the probability of CO_2 leakage from pipelines or storage sites is very low. Construction activities: GHG emissions may also result from capture plant, pipeline and injection platform construction activities. Previous studies (Odeh and Cockerill, 2008), however, show that such emissions contribute to less than 1% of total life cycle GHG emissions.

Will it lead to increase in the emissions of air pollutants? In comparison to a counterfactual where CCS is not present, and based on a standardised g/kWh basis, some air emissions may increase while others may decrease depending on the specific operational parameters.
Operation of capture plant: The use of coal leads to the release of small amounts of volatile organic compounds (VOCs), aldehydes, carbon monoxide, heavy metals, particulate matter and ammonia. These may not be captured in the CO_2 capture process (for example the amine process is designed to capture acidic gases). Gases such as SO_2, NOx in addition to particulate matter (PM) are captured by the amine process. Whether the emission of these gases is increased or decreased (again on a g/kWh basis) will depend on removal efficiencies (i.e. how advanced the upstream SO_2, NOx and PM removal technologies) and also on the energy penalty of the capture process. The Chinese policy is to build advanced supercritical power plants with advanced pollution control processes and so high removal efficiencies are expected. The actual result will need to be investigated for a specific project in China. Additional emissions from the capture process may result from the use of chemicals to capture CO_2. For example, in the amine process ammonia and MEA may be released into the air, albeit in very small amounts. This needs to be evaluated for a specific project in China. Operation of transport and injection/storage facilities Air emissions from the transport and storage of CO_2, including emissions arising from the construction phase, are negligible.

Will it increase solid waste production? In comparison to a counterfactual where CCS is not present, and based on a g/kWh basis, waste production will increase.
Operation of capture plant: Waste from the counterfactual includes bottom ash from the boiler and electrostatic precipitation (ESP) unit and slag (from the boiler). However, power generating companies in China and worldwide are experienced at utilising this waste and transforming it into useful products such as construction materials. Due to lower energy input (because of the capture energy penalty), the rate of waste production (g waste per kWh electricity produced will increase). Additional waste may also result from the capture plant depending on the technology used. For example, with the MEA capture process, waste results from the degradation of MEA and other side reactions (Rao et al., 2004). The MEA waste may contain organic compounds, ammonia and traces of several inorganic species including potassium, sodium, arsenic, selenium and aluminium compounds. The amount of waste produced from the MEA process is approximately 6 kg per tonne of CO_2 captured. However, methods are available for removing and cleansing the flue gas before it enters the capture plant thus reducing the volume of waste generated in the capture plant itself. Operation of transport and injection/storage facilities: No major volumes of waste are expected to be produced from CO_2 transport and storage. Construction activities: Construction waste will be produced during the construction phase as a result of drilling and the use of drilling fluids.

Will it increase water pollution? In comparison to a counterfactual where CCS is not present, water pollution may increase if solid waste enters surface or underground water systems.
Operation of capture plant: Water pollution is caused by the reclaimer waste entering the water system or by air emissions dissolving in water and entering the water cycle. Unless treated, it is expected that the reclaimer waste will lead to increased water pollution. Operation of transport and injection/storage facilities: Water may be displaced from CO_2 storage aquifers into adjacent aquifers leading to pollution. Concentrated CO_2 may enter local surface waters if a leak occurs. Such leaks will, however, be temporary since once they are detected, steps will have to be taken to tackle them. Construction activities: Possible groundwater disturbance and extraction may occur during the construction phase. During the construction of injection platforms, contamination of groundwater may occur leading to increase in pH and heavy metal concentrations. Similarly, during CO_2 pipeline construction, disturbance to soil and groundwater flow and level may occur.

Change in usage of natural resources

Will it lead to increase in consumption of natural, non-renewable resources, including land? In comparison to a counterfactual where CCS is not present, and based on a g/kWh basis, the consumption of natural renewable resources will increase.
Operation of capture plant: Since CCS is associated with an energy penalty; there will be higher consumption and mining of coal. Large amounts of limestone will be required in the FGD process (for SO_2 removal). On a g/kWh basis, the amount of absorbent used for SO_2 removal (for example limestone which is the dominant process in China) consumed will increase in comparison to the counterfactual without CCS (an increase

of 30%, Koornneef et al., 2008, Odeh and Cockerill, 2008). Additional material and resource requirements in the MEA process itself include those of the absorbent (MEA), sodium hydroxide (NaOH) for solvent regeneration in the reclaimer and activated carbon for removal of long-chained polymeric compounds resulting from MEA side reactions.

Construction activities: The construction of the CCS plant (including transport and injection) will require large amounts of steel and other construction materials.

Additional mining of coal will lead to increased land use in comparison to the counterfactual case. The additional land requirement of a power plant due to CO_2 capture facilities is expected to be minor in comparison to that required by the power plant itself. However, current research is investigating methods for minimising land use when CCS is added to existing power plants as well as when new power plants are built. Installing CO_2 transport pipeline in the ground will cause temporary take of land and other ecological impacts.

Will it increase the use of energy?

In comparison to a counterfactual power plant without CCS, the consumption of energy will increase.

CCS will be associated with an energy penalty. Energy from the power plant will be required to operate the capture plant and CO_2 compression. For the amine process, energy will be required by the flue gas fan (10%), by the CO_2 compressors (25%), in the absorbent regeneration process (60%) and for absorbent pumping (figures based on model developed for UKCCSC at the University of Reading). Additional energy may also be required if the MEA waste is to be treated and reclaimed. For IGCC power plants, considerable energy will be required to run the air separation unit (ASU) to produce oxygen and in the CO_2 compressor. Regardless of the capture technology, compressors may be required along the transport network to re-compress CO_2. Moreover, CO_2 injection will also require additional energy.

Will it increase the use of water?

In comparison to a counterfactual where CCS is not present, and based on a g/kWh basis, the consumption of water will increase.

Water consumption may increase by more than 100% for the PC plant with CCS and 30% for IGCC with CCS[54]. For example, for the amine process, water is required for (1) cooling flue gas before it enters the absorber, and (2) for preparation of the amine make-up solution. For PC plants with post- combustion capture, water is required for cooling the flue gas in the direct contact cooler (DCC) as it leaves FGD. For the amine process, the absorption column must operate at a temperature of ~ 50° C.

Water will also be required in pipeline and injection platform construction activities. These requirements are, however, small in comparison to the full life cycle requirements of water.

[54] http://www.westcarb.org/Anchorage_pdfs/Ghose_%20SiteSelection.pdf

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