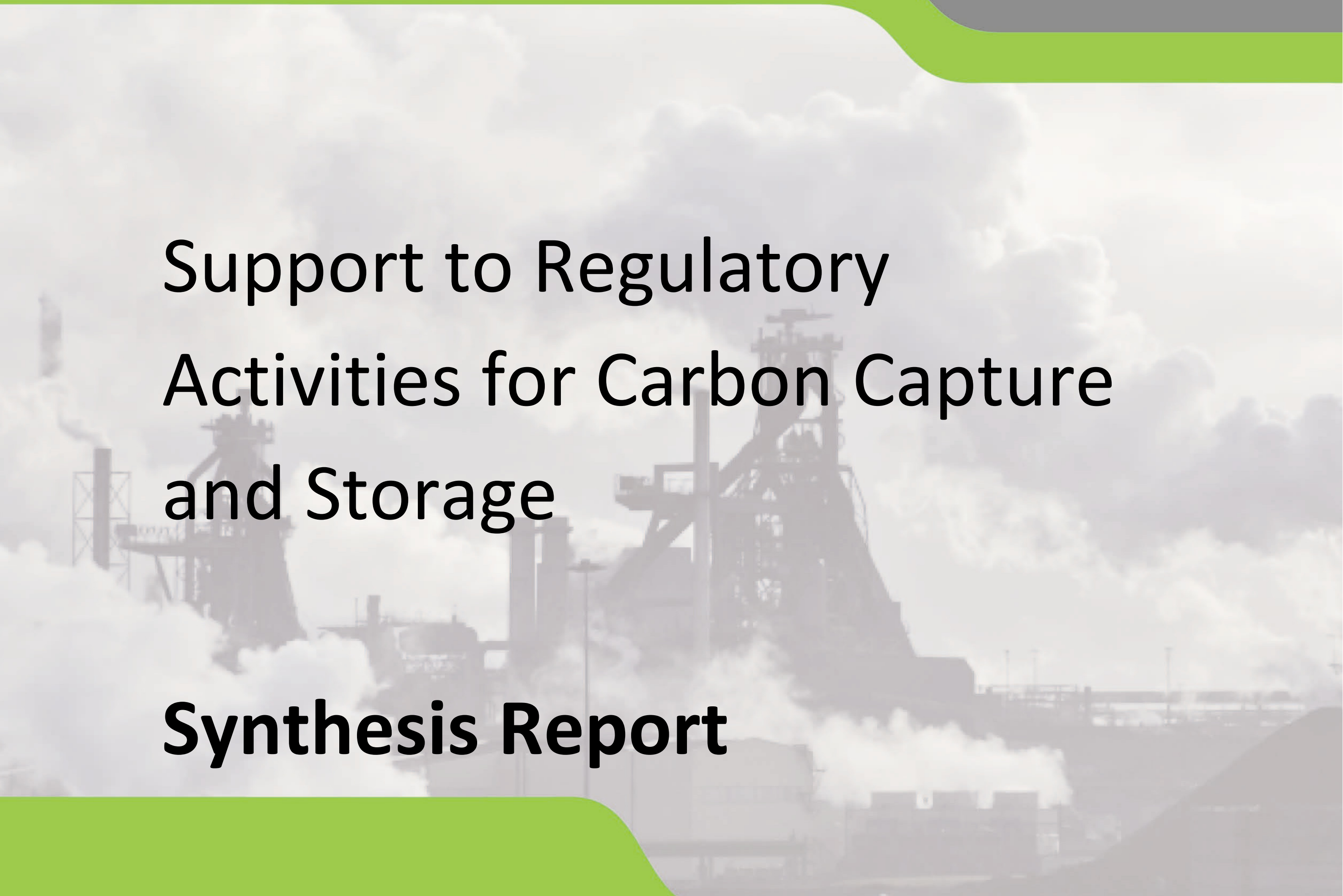
Support to Regulatory Activities for Carbon Capture and Storage



Support to Regulatory Activities for Carbon Capture and Storage

Synthesis Report

July 2009

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Introduction

This **Synthesis Report** presents the integrated findings of the **Support to Regulatory Activities for Carbon Capture and Storage (STRACO$_2$)** Project, designed to support the development of a regulatory framework for Carbon Capture and Storage (CCS) in the European Union. The detailed research for the Project is presented in the accompanying **Full Report**.

The STRACO$_2$ project covered the period January 2008 to August 2009. The project is financed by the European Union's Seventh Framework Programme (FP7). The objectives of the project include:

1. **Identifying Science and Technology development priorities** in multiple aspects of technical applications and regulations for specific themes including:
    - CCS technologies
    - Safety and liability of applications
    - Compliance and testing of technologies and projects
    - Cross-cutting technical themes

   This advances both the overall availability of CCS technologies and highlights the relevant issues for a regulatory framework.
2. STRACO$_2$ will **facilitate and increase Science and Technology cooperation** at the EU level. This will strengthen the link with other ongoing CCS research activities and form the basis for a future European Roadmap for CCS Research.
3. Through its research, STRACO$_2$ will **identify important issues for CCS-regulation** to be taken into account when developing a regulatory framework including: incentivisation schemes, financing mechanisms, international trade (and dialogue with associated international bodies), technology transfer and socio-economic impacts. This will help to address economic, social and infrastructural issues that may be associated with the large scale commercial deployment of CCS technologies.
4. STRACO$_2$ aims at establishing the EU regulatory framework as the basis for dialogue and priority setting with regulatory authorities in **China** with a view to furthering joint activities.
5. STRACO$_2$ will **facilitate and increase Science and Technology cooperation** at the international level with China by including Chinese partners in project activities.

The implementing consortium for the project includes the following research organisations in both Europe and China: Bureau de Recherches Géologiques et Minièrs, DEVELOPMENT Solutions, Netherlands Organisation for Applied Scientific Research TNO, Mälardalen University, Kungliga Tekniska Hoegskolan (Royal Institute of Technology), World Business

Council for Sustainable Development, the Administrative Centre for China's Agenda 21, Institute of Engineering Thermo-Physics, Institute of Policy and Management. **The views expressed in the Synthesis Report and Full Report are those of the consortium, and do not represent any official view of the European Union.**

CCS is designed to minimise the environmental impact of rising CO2 production through the capture and storage of CO2 in places other than the biosphere. It is a promising future technology for combating climate change and could be an important tool for reaching a low carbon economy over the next few decades. First generation CCS technologies have now reached a stage of development that allows for industrial scale demonstration in the future. In the European Union, this has been accompanied by increasing regulations in the area of CCS.

The STRACO$_2$ Project aims to support the development of CCS regulations in the EU and across the globe. The project also researches the possibility of using EU and international CCS regulation as a best practice study for CCS regulation in China. With research focusing on the applicability of European regulation to the Chinese political and economic situation, the project aims to build a basis for future EU-China cooperation and to support policy makers on CCS regulation. It will facilitate increased collaboration on CCS in the international context which is necessary for CCS to become an important instrument in the global fight against climate change.

The STRACO$_2$ main research phase started in July 2008 after the Stakeholder Needs Assessment was finalised. The work has been based on literature and project research undertaken by project partners coordinated through two Expert Working Group meetings between project partners in Brussels and three Expert Working Group meetings in Beijing during 2008. In addition, a research consolidation meeting took place in Beijing in December 2008 involving all project partners. Research consultations and dissemination occurred at the *STRACO$_2$ International Conference on CCS Regulation in the EU and China* in February 2009 in Brussels and the STRACO$_2$ international stakeholder workshops in Beijing (March 2009) and Brussels (April 2009), consulting the views of government, industry and academia in Europe and China.

The Synthesis Report compiles the findings of the projects five work packages from the Full Report, being:

- **WP3: Safety and Liability** (Chapter 1 – Lead Author: Ton Wildenborg – TNO)
- **WP4: Site Qualification and Certification** (Chapter 2 – Lead Author: Sandra Beranger – BRGM)

- **WP5: Incentivisation and Financing** (Chapter 3 – Lead Author: Peter Stigson – MU)
- **WP6: Crosscutting Issues** (Chapter 4 – Lead Author: Mårten Bryngelsson – KTH)
- **WP7: The International Dimension** (Chapter 5 – Lead Author: Zhang Jiu Tian – ACCA 21)

Each chapter in the Synthesis Report is presented in the following structure:

- **An overview of EU and international policies**
- **A review of current and past CCS projects and the results of a stakeholder survey**
- **The China applicability section, introducing policies and projects in China, and offering recommendations for future development and international cooperation**
- **Gap analysis and recommendations for future policy making and research and development (R&D)**

Further details regarding STRACO$_2$ and all project documents and activities are available via the project website: www.euchina-ccs.org

This synthesis report has been prepared for the ease of reference of stakeholders, providing an overview of each section of the full report, highlighting recommendations for policy and research and development needs. It should not be seen as a comprehensive presentation of results, but readers can refer to the Full Report for more detailed research. For the most part, the numbering in the synthesis corresponds with that in the Full Report. A table of abbreviations, glossary, annex and bibliography are contained in the Full Report.

Chapter 1

STRACO$_2$ Work Package 3
Safety and Liability

Final Report

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1. Safety and liability

1.1 Introduction

This section is a synthesis of the report resulting from Work Package 3 (WP3) of the EU-funded research project Support to Regulatory Activities for Carbon Capture and Storage, STRACO$_2$. The focus of this chapter is on safety and liability issues in CCS, and specifically how they are dealt with in CCS regulation. Before CCS can be applied on a large scale the legal and regulatory framework must provide clarity to all stakeholders.

Safety and liability are two crucial concerns of regulations dedicated to CCS. The objective of regulatory frameworks for industrial activities is to enable operations to be led in a safe way with respect to human health and the environment. Safety in this report is considered in the context of risk management, which consists of risk assessment, monitoring and corrective measures. In case of CO$_2$ geological storage, the unusual long time scales require addressing short-term impacts for current needs as well as the long-term impacts on future generations. Moreover, clarifying liabilities is commonly seen as a major requirement for CCS implementation and development, as industry will not start CCS operations without a definite vision on the extent of their liability.

This study aims to:

- Establish a comprehensive overview of the current debate and understanding of safety and liability issues related to CCS;
- Identify gaps in current research on CCS issues related to safety and liability; and
- Provide recommendations on actions on how to close the identified knowledge gaps.

The safety and liability study has focused on geological storage of CO$_2$, and not capture and transport.

1.1.1 Method

The study included a comprehensive overview of the current debate and arrangements on safety and liability issues. Existing regulation documents on CCS activities, established in 2007 and 2008, were reviewed to determine how safety and liability issues are addressed and to analyse differences in the regulatory requirements worldwide.

Stakeholders' opinions were analysed using the results of a survey held among different actor groups; legal and regulatory authorities, universities, research institutions, environmental NGOs and other organisations.

The progress and results of relevant EU and international projects were reviewed and analysed, in order to compare these results with the regulation documents and to formulate recommendations in relation to safety and liability issues.

Gaps in regulations, and recommendations for filling them, were defined based on the review of current EU and international projects as well as the stakeholder analysis.

1.2 Review of CCS policies

1.2.1 Introduction

This section aims to report how safety and liability issues are addressed in emerging regulations. Different existing policies were reviewed with respect to safety and liability issues. The policies reviewed refer to documents developed or adapted specifically to fit the needs of geological storage of CO_2.

1.2.2 Safety

Various time scales can be considered for CCS safety demonstration. Allowing for the aspects which make CCS different from other existing activities, the following section focuses on the storage aspects.

The policy review aimed to determine: the aspects relating to safety issues in the regulations developed for CCS; and which gaps can be defined in these policies for a safe and secure large scale deployment of CCS. The policies listed below are analysed in more detail in the full report.

1.2.2.1 EU and Member State Policies

Entity	Policy	Content
European Union	***European Union Directive on geological storage of CO_2***	Provides a legal framework for “environmentally-safe capture and geological storage of carbon dioxide (CO_2) in the EU”.
UK	***Energy Bill 2008***	A common regulatory framework for storage of CO_2. Applies to CO_2 storage in UK territorial waters from 0 to 200 nautical miles.

1.2.2.2 International Policies

Entity	Policy	Content
International	***London Convention 1972***	Regulates the use of the seas. Designed to protect the marine environment from deleterious impacts of human activities, particularly pollution by dumping of waste.
	London Protocol 1996	Replaced the Convention in the contracting States. Prohibited all dumping in the marine environment, except for some tolerable waste identified in the document. Amended to allow storage of carbon dioxide into sub-seabed geological formations.
	OSPAR Convention	Aims to protect the marine environment in the North-Eastern Atlantic Ocean. Constitutes a legally binding engagement for the Parties. Regulates the use of the sea and the disposal of waste or other matter. Amended to allow CO_2 storage in sub-seabed geological formations, excluding CO_2 injection in the water column.
USA	***Environmental Protection Agency (EPA) Guidelines 2007***	Federal-level guidelines for regulating CO_2 storage pilot projects under the Underground Injection Control program (UIC) Class V wells. In July 2008, the EPA submitted a proposal for regulating CCS projects under a new Class VI. This proposal is currently under discussion.
	Interstate Oil and Gas Compact Commission Guidelines 2007	At the State level, the Interstate Oil and Gas Compact Commission delivered guidelines for US States and Canadian provinces to regulate CO_2 storage.
Australia	***Regulatory Guiding Principles for Carbon Capture and Storage 2005***	The federal level Ministerial Council on Mineral and Petroleum Resources (MCMPR) endorsed these guidelines based on the analysis of three options: status quo, self-regulation and additional amendments to existing regulation.
	Offshore Petroleum Amendment Bill 2008	Released by the federal government to amend the petroleum regulation to allow CO_2 storage in offshore formations.
Japan	***Law relating to prevention of marine pollution and maritime disaster***	Amended in May 2007 to implement amendments of the London Protocol, to provide for offshore CCS in the Japanese exclusive economic zone.

1.2.2.3 Overview

The consulted texts differ in terms of status, scope and endpoints of interest. It results in somehow significant variations in their approach (e.g. USEPA documents focusing on drinking water neglect surface vulnerability; the London Convention/Protocol, the OSPAR Convention, the Australian Petroleum amendment or the Japanese amendments dedicated to offshore storage concentrate on the marine environment). However we can note a high degree of proximity between:

- the EU Directive, the London Protocol / London Convention and OSPAR Convention texts,
- the US EPA texts,
- the 3 other US texts, relating to State-level legislation.

The UK Bill differs from others as it enables each licensing authority to set its requirements.

1.2.3 Liability

1.2.3.1 Introduction

Liability concerns the operational, closure and post-closure phases of CO_2 capture and storage projects. The operational phase relates to the capture of CO_2 at the point source, the compression and transport to the storage site and the injection into a geological reservoir. The closure phase is the period in which the injection process has ceased but monitoring is still in place and before liability is transferred to another party, e.g. a governmental body, if applicable in the concerned country's legislation. In the post-closure phase CO_2 is stored for the long term.

The risks associated with CCS are relative to the large volumes of CO_2 that need to be injected and the long time frame during which CO_2 must be safely and effectively stored. Liability therefore must address the post-closure phase of the CCS life cycle. Potential risks associated with long-term storage include leakage, ground movement (with or without induced seismicity) and displacement of formation fluids. These risks can result in contamination of groundwater, local ecological damage, harm to human health and global environmental damage.

Different key issues of liability can be distinguished [ACCSEPT project, 2007]: Operational liability, in-situ liability, and climate liability.

Operational liability refers to liability in the operational phase of capture, compression, transport and injection of CO_2. Due to the short time frame of the operational phase, fewer regulatory issues arise with respect to operational liability.

In-situ liability involves post-injection liability. A legal framework is needed which addresses who is liable in case migration of CO_2 leads to impacts on public health and environment.

Climate liability is another type of post-injection liability and concerns negative impacts on climate change due to CO_2 leakage.

This section aims to determine: what aspects are related to liability issues in the regulations developed for CCS; and which gaps can be defined in the regulations concerning liability issues.

The methodology for this review is outlined in the full report.

1.2.3.2 EU and Member State Policies

Table 1- EU and Member State Policies Relevant to CCS

Entity	Policy	Content
European Union	***European Union Directive on geological storage of CO_2***	The liability issues in the Directive were reviewed for the operational, closure and post-closure phases of CO_2 storage. The Directive directly affects other European Directives and regulations which have been amended accordingly.
European Union	***EU Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage (ELD)***	The main objective is the application of the "polluter pays" principle. It establishes a common framework for liability with a view to preventing and remedying damage to the environment. Operation of storage sites has been added to the list of activities falling under the Directive on environmental liability.
The Netherlands	***Dutch Mining Act (amended 2003)***	The possibilities to regulate CO_2 storage are under discussion. A CCS Task Force established in 2008 will enable the development of conditions to stimulate implementation of large scale and commercial CCS in the Dutch energy sector. One goal is the amendment of the Dutch legal and regulatory framework enabling storage of CO_2 in geological reservoirs [www.senternovem.nl]. This applies to the Dutch Mining Act. However, liability issues are not yet addressed within Dutch legal frameworks.
UK	***Energy Bill 2008***	Similar to the EU Directive, for example with regards to long term liability, Enhanced Oil Recovery and CO_2 purity. Once implemented in UK policy, the EU Directive will override existing regulatory frameworks governing CCS.

1.2.3.3 International Policies

Table 2- International Policies Relevant to CCS

Entity	**Policy**	**Content**
International	***London Convention 1972 and 1996 Protocol***	An overview of the liability aspects as found in the London Protocol can be seen in the full report.
International	***OSPAR Convention***	An overview of liability issues as included in the amendment of the OSPAR Convention can be seen in the full report. The OSPAR regulation consists of a framework for risk assessment and management of storage of CO_2 streams in order to ensure permanent containment of CO_2 streams. Its focus is more on assessing and managing safety than on liability issues.
USA	***Environmental Protection Agency (EPA) Underground Injection Control (UIC) Program***	Provides a regulatory background to deal with the large amount of various waste materials that are discarded through underground injection. On the State level, several States have started to develop approaches to regulate CO_2 storage site operation which are at an early stage.
	Interstate Oil and Gas Compact Commission Guidelines 2007	Published general regulations concerning CO_2 storage which could be adopted by individual States.
Australia	***Regulatory Guiding Principles for Carbon Capture and Storage 2005***	One key area concerns liability and post-closure responsibilities. More specifically, a person or body is liable to pay monetary compensation (damages) potentially arising from leakage due to negligence[1] for injury to a person or persons (for instance, workers or members of the public) or for damage to property.
	Offshore Petroleum Amendment Bill 2008	Released by the federal government to amend the petroleum regulation to allow CO_2 storage in offshore formations.
Japan	***Law relating to prevention of marine pollution and maritime disaster***	Before commencing an offshore CCS project, a permit is needed. No information was found regarding long-term liability, although CDM projects have shown that Japan is interested in transforming the liability for monitoring the reservoir from the host country to the State after commercial projects are closed.

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[1] *Liability in negligence*: arises where a person or body has a duty to take reasonable care to avoid harm to a person or property and fails to do so.

1.2.3.4 Overview

Liability aspects are currently well addressed in amended, provisional and/or proposed legislation concerning CCS activities as well as in discussions relating to the development of legislation. Still, many questions need to be answered especially concerning long-term liability. Most of the legislation concerning liability of CCS activities is in the proposal phase and still under discussion. The current development of CCS legislation is, however, growing fast and the first acts are now in place.

The researched documents all consider liability issues in the operational phase as well as in the post-closure phase. In most of the researched legislation clear distinctions are made between the different phases of the storage life cycle and who is liable for certain events. In general, in the operational phase liability lies with the operator/owner of the permit for storing CO_2.

The liability issues arising from policies can be found in the Gap Analysis, and in more detail in the full report.

1.3 Analysis of stakeholder feedback

1.3.1 Questionnaire analysis

A stakeholders' assessment was performed in 2008 through a questionnaire concerning the Draft CCS Directive. Five questions referred to safety issues and four related to liability issues:

- What do you see as the biggest issues concerning safety?
- Which safety issues would have to be in the forefront for EU regulation on safety?
- What safety issue could be a barrier for stakeholders to invest in CCS research?
- How could this effect be reduced?
- Does the current Directive[2] contain any gaps in its safety issues concerning CCS?
- What issues concerning liability are the most important?
- Does the current Directive[2] contain any gaps in its liability issues concerning CCS?
- In which areas are there still needs for fundamental research on safety issues?

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[2] It should be underlined that the survey was carried out in 2008; therefore the answers to these questions refer to the Draft Directive proposed by the European Commission on 23 January, 2008.

- Which issues of safety and liability could prove problematic in the international legislation (e.g. OSPAR and LP)?

The majority of the stakeholders came from EU countries and are related to governmental authorities, universities, research institutions, environmental NGOs and other organisations. In total 49 questionnaires were analysed and the detailed results are presented in the full report.

1.3.1.1 Questionnaire main outputs

The most apparent result of this analysis is that, even when responding to questions regarding safety, liability matters are a major concern for stakeholders.

In the questions relating to safety issues, the topic highlighted as being of prime importance was monitoring, for which detailed requirements or guidelines as well as further developments are needed. Long-term containment was frequently referred to as a major concern, with a particular focus on wellbore integrity. Remediation and emergency measures are mentioned several times as needs for CCS safety. Finally, impurities in the CO_2 stream are raised as a problem that must be further addressed to ensure safety.

Beside technical arguments, public acceptance is described as a potential major caveat to CCS implementation.

To fill in the identified gaps related to safety, the stakeholders mainly expect regulation to bring the necessary precisions. They also require the development of standards or guidelines (e.g. for site qualification, risk assessment, monitoring, site closure), and highlight the need for information and transparency for the public.

Concerning liability issues the transfer of liability in time, to whom, for what period and for which cases, is seen as the most important topic that must be clarified in the Draft Directive. The identified gaps related to liability concerning the detail and clarity of the topic, especially the detail of post-closure obligation, liability duration and the actual handover of (financial) responsibility.

In general, there appears to be very few significant differences between the opinions of the various stakeholder types in their responses to the questionnaire.

1.4 Review of EU and International projects

1.4.1 Introduction

Research is available from EU and international projects concerning a wide variety of different CCS topics. In order to use this knowledge and compare results, an overview of several projects relating to safety or liability issues is presented. The projects listed below are reviewed in the full report.

Table 3- EU and International Projects

Project	**Relevance to STRACO$_2$ WP3 on Safety and Liability Issues**
ACCSEPT www.accsept.org	Dealt with the management of storage risks and liability.
CASTOR www.co2castor.com	SP3 "CO$_2$ storage performance & risk assessment studies" delivered useful information for STRACO$_2$ regarding safety and liability.
CO$_2$GeoNet www.co2geonet.com	2 sub-projects are particularly interesting on safety: JRAP 1: Cap rock seal capacity for CO$_2$ storage; and JRAP6: Risk assessment tools for CO$_2$ geological storage assessment
EU-GEOCAPACITY nts1.cgu.cz/geocapacity	Some results are relevant to the safety analysis, especially outcomes relating to site selection criteria (EU-GeoCapacity, 2008)
SACS and CO$_2$STORE http://www.co2store.org	One deliverable was a Best Practice Manual for CO$_2$ storage in deep aquifers (Chadwick *et al.*, 2007). These guidelines address various relevant technical concerns related to CO$_2$ storage.
Zero Emission Platform ZEP www.zero-emissionplatform.eu	4 publications provide useful information on safety and liability: *Strategic Research Agenda (SRA); Strategic Deployment Document (SDD); "CO$_2$ Use and Storage" – Contribution to the Strategic Research Agenda (WG2) (2006); Making Carbon Capture and Storage Happen in Europe: Markets, Policy and Regulation (2006).*
CAPRICE www.caprice-project.eu/	As the project objectives are very technical, relevance to STRACO$_2$ is limited.
EC MOVECBM www.movecbm.eu	The integrated risk assessment work performed is too technical to be of significance for STRACO$_2$ Work Package 3.
CO$_2$REMOVE www.co2remove.eu	The project's contribution to guidelines for safe and effective storage of CO$_2$ is very relevant. It also provides a framework for performance assessment and will result in an overview of monitoring systems. A report drafting guidelines for licensing of CO$_2$ storage in saline aquifers provides an overview of site qualification requirements, tackling numerous issues related to safety.
CO$_2$ Capture Project www.co2captureproject.org/	A major deliverable (CO$_2$ Capture Project, 2009) summarises guidelines for CO$_2$ storage; it addresses central aspects related to safety, e.g. monitoring, risk assessment and management, modelling, uncertainty management.
IEA GHG Weyburn-Midale CO$_2$ Monitoring and Storage Project www.ptrc.ca/weyburn_overv	Development of a workflow to guide all future aspects of CO$_2$ geological storage projects, including the technical research component of site characterisation, monitoring and verification, wellbore integrity and performance (risk) assessment, as well as the non-technical policy component, focussing on public communication

Project	Relevance to STRACO$_2$ WP3 on Safety and Liability Issues
iew.php	and outreach, regulatory issues and the business environment.
Geological CO$_2$ Storage Assurance at In Salah Algeria www.insalahco2.com	Research into the regulation and verification of CCS, the policy framework that considers the financial background and terms of cost-effective use of CCS and how to deal with long term liability.
CO$_2$SINK http://www.co2sink.org	Although one work package organises an integrated, cross-discipline methodology for risk assessment and management, work is highly site-specific. No public deliverable has been found reporting outcomes on that topic relevant to the STRACO$_2$ project.
FutureGen www.futuregenalliance.org	Significant work was done during the site characterisation and selection process, in particular in the Environmental Impact Statement for the four candidate sites. The documents relative to the offer and the selection's results and environmental volume for the selected site indicate the criteria that were evaluated and their ranking,plus the monitoring program used(FutureGen, 2006 & 2007).
Otway Basin Pilot Project http://www.co2crc.com.au/otway	Safety is a main focus of the project. The operator designed a comprehensive monitoring programme, which is well documented (CO$_2$CRC, 2008, Sharma *et al.*, 2008, Cook, 2008, Sharma & Cook, 2007, Perkins, 2006), providing useful lessons on safety issues.
CO$_2$QUALSTORE http://www.dnv.com/industry/energy	Although relevant to the safety aspects investigated (regarding long-term behaviour, remediation techniques, risk management), no technical outcomes are able to be analysed in STRACO$_2$ as the CO$_2$QUALSTORE guidelines will not be issued until October 2009.

1.4.2 Safety

The project review mainly focused on 10 past and current projects with very different status, scopes and objectives, from strategic RD&D planning (ZEP) to research projects or sets of projects (CO$_2$GeoNet, Carbon Capture Project) and pilot demonstrations (Otway, FutureGen). This leads to variability in how safety is addressed. The project review can be seen in the full report and is summarised in the Gap Analysis below.

1.4.3 Liability

A limited number of the researched projects discuss liability issues for CO$_2$ storage. In two projects (ACCSEPT and ZEP) liability results were obtained. Both projects focus on long term liability issues, presenting the most significant challenge for legislators. The relevant points are raised in the Gap Analysis and analysed in the full report.

1.5 China Applicability

1.5.1 Introduction

From the Chinese government's perspective, China looks to CCS as one of the promising technological options for GHGs emission reduction in the future.[3] CCS appears in *China's 11th Five-Year Plan under the National High Technologies Programme* and in the *National Medium- and Long-Term Science and Technology Plan Towards 2020*.[4] In China's *National Policy and Action towards Climate Change* released in October 2008, CCS was mentioned as part of new technology development. Combined with R&D of clean coal technology, due to the fact that coal dominates Chinese energy supply and will continue to do so in the foreseeable future, the importance of CCS technology is apparent. According to the official statement, China is willing to join the international community in developing CCS even without quantified emissions limitations under the Kyoto Protocol.[5]

CCS in China is still at a very early stage. The estimates of China's storage capacity vary widely from 150 Gt to 2,000 Gt.[6] The preliminary estimation shows that the potential storage sites include 46 oil & gas reservoirs with storage capacity of 7.2 billion tons of CO_2; 68 un-mineable coal beds with methane recovery, with a capacity of 12 billion tons of CO_2; and 24 saline aquifers with potential storage capacity of 1,435 billion tons of CO_2.

Current experimental projects include Enhanced Oil Recovery (EOR) projects, a micro-pilot Enhanced Coal-Bed Methane Recovery (ECBM) project in Shanxi province, and a demonstration project at the Yantai IGCC Plant.[7] The first post-combustion demonstration project in China was established and launched in mid 2008 by Huaneng Power plants.

In the near future, China will focus on relevant capacity building issues, and expect the Chinese CCS technology development roadmap to be planned in line with China's energy structure, such as (1) information sharing, exchange of professionals, and introduction of measures, tools and models, etc.; (2) the areas that can bring direct economic returns, for example, EOR; (3) Supporting the implementation of the Nation's key energy policies, such as enhanced coal bed methane (ECBM) exploitation and recovery with CCS. China will also rely more heavily on the international mechanisms with sufficient financial support to develop and demonstrate CCS technology.[8]

1.5.1.1 Methodology

Based on the international experiences and the Chinese situation, this section identifies the relevant existing legislation and regulatory bodies for further amendment; formulates the guidelines for a new legislative framework; and explores the innovative schemes such as public-private partnerships.

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[3] Fu, 2007.
[4] IEA, 2007.
[5] Fu, 2007.
[6] IEA, 2007.
[7] IEA, 2007.
[8] Fu 2007.

The safety and liability issues discussed in the following section will be addressed by CCS stages covering capture, transport, and storage.

1.5.2 Relevant policies

1.5.2.1 *National Strategy and Actions towards Climate Change*

The *National Strategy and Actions towards Climate Change*[9] highlighted CCS as part of the prioritised research and development areas of climate change mitigation technology, together with nuclear power and other clean coal technologies.

1.5.2.2 Technical Actions to combat Climate Change in China

CCS is considered a key technology to control CO_2 emissions and climate change mitigation, under the key tasks. Three key areas of carbon dioxide capture, utilisation and storage are identified as R&D, technology development roadmap, capacity building and demonstration.[10]

1.5.3 Safety related legislation

1.5.3.1 Capture

The available technologies for carbon dioxide capture include pre-combustion, post-combustion and oxy-fuel combustion capture. All three technologies employ similar processes, injecting finely ground coal through burners into a furnace for combustion, though they operate at different temperatures and pressures.[11] For combustion technology, the cost and energy penalty are major concerns. Capture technology with additional facilitation and process will result in other non-CO_2 environmental impacts, including emissions, water consumption, hazardous and industrial waste.[12]

Existing Chinese legislation is identified within which CCS could be incorporated and environmental impacts addressed.

Table 4- Chinese Legislation Relevant to Safety during Capture

Legislation	Content
Law of People's Republic of China on Environmental Impact Assessment (EIA)	This fundamental legislation in China applies to all construction projects and programmes with potentially unfavorable impacts upon the environment. Involves third party scientific review and incorporates potential environmental impacts as criteria in decision making. Safety of CCS should be ensured based on assessing potential environmental risks, and the confirmation and license from independent scientific review. This is the most accessible existing legislation for ensuring safety of CCS projects. Examples of integrating EIA into CCS projects are limited. Also, due to variations of EIA legislation in different countries, adaptation and adjustment should apply

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[9] Chinese Government, 2008.
[10] Chinese Government, 2007.
[11] WRI, 2008.
[12] WRI, 2008.

	within a regional context. A review of the Chinese EIA Law raised a number of points and issues needing further discussion and research, which are analysed in the full report.
Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (Order of the President No.32)	Air emissions accompanying CO_2 from industrial sources with CCS facilitation should comply with this law, which specifies the responsibilities of operators (units), local government and central government. Chapter III directly focuses on atmospheric pollution by burning coals. The Law set the major liabilities on operators with financial penalties, while liabilities set on the administrative department for environmental protection are limited.
Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution	Provides a legal basis for the prevention and control of solid waste generated from carbon capture, in which the responsibilities of different stakeholders, the procedure and the legal liabilities, are defined. The solid waste can often be identified as industrial waste or hazardous waste.

1.5.3.2 Transport

The main transport means of carbon dioxide include pipeline transport and ship transportation.

The risks of transportation of CO_2 are usually associated with the impurities issues of CO_2 properties; the operational parameters including temperature and pressure; and pipeline design including model application, uncertainty management and risk acceptability criteria.

Table 5- Chinese Legislation Related to Safety during Transport

Legislation	**Content**
National Standards for CO_2 Composition: GB6025-93	This standard addresses the industrial use of liquid carbon dioxide in chemical industry, cooling, shaping, etc. The regulations usually refer to the volume of CO_2 and the weight of contained water.
GB 10621-2006	Issued in 2006, this sets the criteria for the food additive liquid carbon dioxide.
Law of the People's Republic of China on Safe Production	The Law of the People’s Republic of China on Safe Production focuses on the training of workers, management responsibilities, emergency response and aids.
Safety Management Regulation for Dangerous chemicals	The “Dangerous Chemicals” referred to include explosive goods, compressed and liquefied gas (which includes Carbon Dioxide from CCS processes), flammable gas, flammable solid material, self-flammable material, etc. The Regulation covers the production, storage and utilisation of dangerous chemicals, the operation and transportation of dangerous chemicals, registration and emergency response.

1.5.3.3 Storage

Enhanced oil recovery and enhanced coal bed methane recovery projects are considered as promising for current and future CCS project deployment in China. The Chinese oil and gas industry has accumulated an extensive knowledge base regarding EOR applications.[13]

There is, however, a definition gap between "CO_2 storage" and "CO_2 injected" in China and worldwide. In EOR projects, the management of injected CO_2 is often missing, and the risks and safety concerns are underestimated, while the function of the oil driving rate is highlighted. The definition of "CO_2 storage" needs to be further clarified in future legislation.

Relevant existing legislation in China is identified in Table 6 below:

Table 6- Chinese Legislation Relevant to Safety during Storage

Legislation	Content
Marine Environmental Protection Law of the People's Republic of China (amended)	The EIA Law requires that the appraisal and approval of environmental impact assessment for marine projects should be carried out according to the Marine Environmental Protection Law. This may cover CCS activities when they are carried out on-shore and off-shore.
London Convention; OSPAR Convention	Since China has ratified the London Convention, the recent amendment of the London Convention which allows CCS storage in the sub-seabed geological formation is applicable in China, together with other criteria.
Law of the People's Republic of China on Prevention and Control of Water Pollution	Chapter V contains the regulation on under-ground water pollution prevention and control. Pollution and leakage prevention measures are required for under-ground activities. The protection of underground drinking water and the monitoring of groundwater is likely to become an important component of the future CCS regulation. CCS regulation should not conflict with the existing water law.
Law of the People's Republic of China on the Prevention and Control of Radioactive Pollution	The regulation covers the standard of pollution prevention and control, monitoring and supervision of radioactive pollution, and the responsibilities, operation procedure and emergency response for relevant activities and radioactive waste management. Long-term effects and the required safety and liability considerations of radioactive waste are similar to current CCS issues, although the potential environmental impacts and thermodynamics of carbon dioxide from CCS processes are different from radioactive waste. This regulation can provide a framework applicable to legislative procedure, scope and responsibility identification for future CCS regulation.

1.5.4 Liability

Traditionally, the regulations in China highlight the legal liabilities for the private sector or other operators, and to a lesser extent for the public sector. If the private sector bears entire liability, the potential unbounded liability will make widespread deployment of CCS

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[13] IEA, 2007.

unlikely. However, if financial liability is fully covered by the public sector, the precautions taken by storage operators in the short term would be affected.[14] Based on the fact that development of CCS is in very early stages and that industries are generally hesitant, it is important that the liability of CCS involves both the private and public sector; and to highlight both penalties and rewards for operators. Theoretically, the liability framework can rely on existing regulations, formulating new frameworks, insurance and new public-private partnerships.

1.5.4.1 Current liability regimes

Liability regimes implemented around the world usually divide the liabilities at different stages of CCS. Examples of such regimes have been discussed earlier, and include the Underground Injection Control (UIC) Programme adopted by the US EPA for demonstration CCS projects, the Australian CCS regulation system and the EU CCS Draft Directive.

1.5.4.2 Potential frameworks for China

Modifying existing regulations: The relevant legislation identified previously has developed a different series of legal liabilities. Liability issues for CCS should also highlight the balance of the penalties and rewards. And the responsibilities should be shared between public and private sectors.

Formulating a new framework: Existing regulation on radioactive pollution can provide a framework for the legislative procedure, scope and responsibility identification approach for future CCS regulation.

Insurance (for financial responsibilities in ensuring liability): Insurance and reinsurance, in practice, enter China for large scale investments like renewable energy, with the potential to apply to future CCS activities. However, it could be difficult to engage private insurance schemes with CCS regulation, as Chinese regulation is a command-and-control tool which seldom involves private insurance. Government involvement would be better for ensuring long-term liability considering the long-term effects and potential risks of CCS projects. If the national government were to take all financial responsibility it would reduce the level of precaution taken by operators, as they would not bear the costs of liability. Therefore, a private-public partnership could work for CCS liability in China.

1.6 Conclusion

1.6.1 Safety

Building on the lessons learnt from the examination of the various policies and projects reviewed, and from the stakeholders' feedback, this section seeks to identify the gaps in the

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[14] de Figueiredo, 2007.

regulations and/or in our understanding of CCS safety issues. We then deduce recommendations for future regulatory developments and R&D needs.

1.6.1.1 Overview

The policy review revealed significant differences between the texts with respect to safety aspects, mainly due to their varying nature and scope. However, some texts need to be completed by an additional regulation (*e.g.* the EU Directive will be transposed into national law in each of the Member States); moreover, the introduced frameworks suppose an application for licences, which must specify requirements for each individual project. In particular, technical criteria such as indicative or threshold values will be set in the permits, given site-specific considerations. Consequently, many policy texts themselves are vague. They rarely specify techniques, such as for monitoring. Level of detail is limited; burden of proof is on the operator. The documents assign goals to be met rather than the means to achieve them.

Several arguments explain this observation. First, the status of some documents (which presume an additional regulation, *e.g.* the EU Directive) justify their framework nature, and consequently their relatively poor level of detail. Second, many aspects related to safety are site-specific, such as risk scenarios to consider, potential targets, adequacy of monitoring techniques or operational parameters largely depend on site-specific conditions. This prevents from adopting detailed programmes at a generic level. Third, lack of experience about CO_2 storage hardens the establishment of such generic criteria. Given these two factors, we should avoid overprescriptive regulation, to accomodate technological and knowledge developments.

However, our questionnaire analysis demonstrates that stakeholders expect a CCS regulation to set precise requirements, commonly accepted standards, guidelines or even techniques, in the field of site characterisation, site closure, risk assessment, emergency measures, monitoring, etc. One reproach of the EU Draft Directive was lack of detail. There seems to be a gap between the content of the available regulatory texts and the stakeholders' expectations from them.

The projects reviewed do not offer solutions to all these identified gaps, particularly due to site-specific conditions. Risk assessment methods or corrective measures appear as knowledge gaps requiring further research. However, projects adequately fill in the gaps of regulatory documents on certain topics including site selection criteria or monitoring techniques and their capabilities. They rarely provide quantitative thresholds due to the site-specific nature of these issues, but probably provide sufficient knowledge to assess a site and design a project. In particular, operational solutions have been found to the majority of issues when considering a given site for designing pilot projects, as shown by the FutureGen and Otway projects.

1.6.1.2 Gap analysis for safety aspects

A number of topics were found recurrent in the consulted documents, such as the requirements for:

- Data describing the natural characteristics
- Identifying, monitoring and reporting major operational parameters
- Dealing with impurities in the CO_2 stream
- Using numerical simulations in the assessment of the future behaviour of CO_2
- Monitoring the site, especially the migration of CO_2 inside and outside the reservoir
- Submitting a plan describing the potential interventions in case an unexpected event
- Demonstrating the absence of significant risk before abandoning the site

Nevertheless, the way these items are addressed varies greatly among the documents. This is detailed in the full report. Some other subjects were far less frequently covered, such as:

- The explicit requirement for a risk assessment and details of how it would be performed
- The need to characterise the environment around the storage site
- The time scales to consider in the application
- The need to tackle uncertainties relative to the geological medium in the assessment
- The need to monitor the environment
- The need to monitor the effectiveness of any corrective measure taken

Globally, there are significant variations in the level of detail of the consulted documents. But their common point is that even the most detailed specify very few technical criteria:

- They do not make explicit which natural features make a good possible storage site
- What the right injection parameters are
- Most do not prescribe monitoring techniques and protocols
- They do they explain which risk assessment results are deemed acceptable
- They do not make clear how to build a corrective measures programme
- The time scales to address are not quantified
- The criteria for site abandonment remain vague
- No consensus can be found on the degree of purity required for the CO_2 stream

With this limited level of detail, the applicant has little technical guidance for proving the safety of its operations. The regulations foresee the issuance of a storage licence which will probably set the specific requirements. Indeed, this approach is justified by the site-specific nature of a CO_2 storage safety assessment. Moreover, given the lack of experience of CO_2

storage and the long-term fate of a storage site, it is difficult to set generic criteria. Regulations should also leave space for future technological developments.

The project review showed that certain project aspects adequately complement regulations on some topics such as monitoring: a number of techniques are developed and described that would meet the expectations of regulators. The projects do not prescribe generic protocols however, since it must be tailored to site-specific conditions. The same applies to site selection criteria: the projects bring valuable details on the necessary data to characterise a site, however, few quantitative thresholds can be found, as they depend on site conditions. The critical risk scenarios that must be considered also appear rather detailed in the projects, even though a systematic method for identifying them is not agreed.

On some other topics, the projects probably do not provide sufficient answers to the questions posed by regulations. Risk assessment standards or risk acceptability criteria are not available; no consensus appears on the time scale that must be considered in the risk assessment. The issues of impurities, potential impacts of a leakage on various kinds of receptors or corrective measures are not adequately understood or known and require further work. Nor do the projects deliver generic technical criteria for site abandonment.

1.6.1.3 Recommendations for safety aspects

The following recommendations to address safety issues were defined to resolve these gaps:

Recommendation 1:

It is recommended that a guidance document, to which regulations can refer to, be established as to provide a minimum list of the required characteristics:

- *parameters of the injection operations;*
- *physical and chemical properties of the injected fluid; these must include elements informing about its potential effects on the environment, in case of a leakage.*

As it was underlined for site characterisation, the developments of metrics or guiding approaches to assess the suitability of the foreseen operational parameters would be useful.

We recommend that well construction standards dedicated to CO_2 injection and storage be developed; based on the experience of the oil and gas industry and the future knowledge developments resulting from CO_2 storage operations. Regulations will possibly point towards these standards, which will leave space for future improvements due to technological developments.

Recommendation 2:

Regarding the importance of site specific considerations in the establishment of a site characterisation programme and the assessment of the suitability of a storage complex, we acknowledge that regulations cannot set detailed all encompassing requirements. Nevertheless, the *policy documents may refer to some form of guidance, as stakeholders expressed a desire for this in our opinion review.*

We therefore recommend that common reference documents be established, based on the research outcomes, to provide guidelines for site characterisation, under the form of:

- *an indicative list of the various characteristics that must be present*
- *a guidance on how to determine the area supporting the characterisation*
- *metrics or criteria helpful in the assessment of the site*

These guidelines should allow site-specific transcriptions and leave space for technical developments.

Recommendation 3:

We recommend that regulations explicitly require the characterisation of the surrounding environment of the storage complex. This would help the understanding of what the consequences of an unexpected behaviour of the storage complex could be, and therefore facilitate the safety assessment.

The provided data should be sufficient to identify which elements could be endangered by an undesired event, especially a CO_2 leakage. It should at least consider, when applicable, human, surface and/or marine ecosystems, natural resources and especially freshwater aquifers, as well as man-made structures.

Recommendation 4:

In order to ensure that CO_2 storage activities are led in a safe way, it appears necessary that a risk assessment be conducted to evaluate and manage the risks posed to human health and safety, to the environment, natural resources or any feature that could suffer significant damage from the CO_2 storage operations. Regulations should require this risk assessment and specify its endpoints of interest according to their own scope.

A framework for risk assessment as delivered in the London Protocol or OSPAR Convention annexes seems valuable. Similar guidelines could be helpfully referred to in other regulatory documents. The lack of standards for risk assessment was highlighted in the stakeholders' feedback analysis.

In the absence of an internationally recognised method, R&D must be pursued to develop the process(es) for assessing risk caused by CO_2 geological storage and then provide harmonised technical guidance.

Recommendation 5:

When it is compliant with its scope, a CO_2 storage regulation should specify that both short term and long term must be taken into account in the risk assessment.

Details about the duration addressed in the assessment depend on site specific conditions. Nevertheless, experience gained during early CCS projects will help guide the choice of adequate time *scales. We recommend that this knowledge be synthesised in some form. Regulations could possibly refer to the state-of-the-art to indicate the time period to adopt. The fact that risk events may continue beyond the end of the CO_2 plume displacement in the reservoir must be borne in mind.*

Recommendation 6:

Together with the requirement for a risk assessment, CO_2 storage regulation should explicit the types of risks that must be investigated at a minimum. This does not mean that it will exhaustively list generic risk scenarios applicable to all projects.

A framing of these risk types similar to what is adopted in the London Protocol / OSPAR Convention appears valuable, as standards for risk assessment seem desirable according to the stakeholders' opinion survey.

Recommendation 7:

We advise that:

- *more R&D is carried out*
- *experience from the early projects is exploited*

to determine what composition of the CO_2 flux is acceptable, to which extent it depends on the site conditions and whether a generic evaluation process can be proposed.

We recommend that regulations, or the frameworks they can refer to, underline the need for the risk assessment to handle the effects of potential impurities, either injected with the CO_2 or mobilised underground under its action.

Recommendation 8:

It is recommended that CO_2 storage regulations clearly expose what should be the outputs of numerical simulations. These outputs should be in line with the needs for performing the risk assessment.

R&D programmes must keep improving the calculation codes for simulating the behaviour of CO_2 in and potentially outside of the reservoir. Increasing accuracy, robustness as well as decreasing computation time will result in a better confidence in the predictions.

Technical developments in this field are essential. CCS-dedicated regulations should leave room for these improvements and avoid overspecifying the model(s) needed; instead, it should mention the state of the art or the Best Available Technologies as a reference for the modelling work.

Regulations should also highlight the value of an interactive approach between site characterisation, numerical modelling and monitoring. Stepwise implementation of this process should optimise the adequacy of the project's design and the quality of risk assessment.

Recommendation 9:

The need to address uncertainty should be emphasised in CO_2 *storage regulations. Uncertainty sources should be identified; sensitivity studies should be run for the various calculations, and the uncertainties surrounding the risk assessment results should be clearly and transparently expressed, so as to provide the regulator with an informed decision basis.*

Recommendation 10:

In our mind, the acceptability of a risk must be determined with regard to the potential consequences that it could engender. We recommend that risk management be guided by the principle of risk reduction to levels as low as reasonably achievable.

Metrics should be proposed at the international level as guidance for evaluating risk to the various targets. It could for instance take the form of thresholds relative to leakage fluxes.

To achieve that, further R&D work is needed to understand the potential impacts of CO_2 *and potential associated impurities on the environment, i.e. on the various targets, including the global response of ecosystems.*

Recommendation 11:

Looking for harmonisation at the international level, a guidance document could be developed describing the objectives of a monitoring plan, which elements to monitor and how to determine the area of review. This guidance, or regulations themselves, should stress the need to:

- *build a monitoring plan consistent with the risk assessment outputs*
- *monitor the environment to follow the impacts of the operations on fauna, flora and the environmental medium*
- *acquire a baseline before the beginning of storage activities*

Further R&D is expected to improve the monitoring techniques. Regulations should refer to the best available technologies for the design of monitoring programmes. A document should be established and periodically revised to synthesise the status of the various techniques and thus provide guidelines for building an adequate plan. This document could include data about the scope, accuracy, associated operational protocol and cost of the technologies.

Finally, CO_2 *geological storage regulations should explicitly require that the monitoring plan around a storage project (i.e. its objectives, the techniques and protocols employed) be submitted and validated by the competent authority. A periodic review of this plan appears valuable.*

Recommendation 12:

An appropriate contingency plan should embrace all aspects: prevention, correction, mitigation, remediation. For a safe implementation of CO_2 *geological storage, it is recommended that all regulatory frameworks require that the site operator prepares a plan for the case of any failure of the storage. The regulatory documents should stress the manifold composition of this intervention plan, as underlined above.*

This plan should be consistent with the results of the risk assessment and the monitoring programme, and be designed to bring a proportionate answer to the risks identified in the evaluation carried out for the specific site. It should clearly identify which action to take in response to which event.

The plan could usefully refer to standards or guidelines available from the oil and gas industry. Nevertheless, given the specifics of CO_2 *storage, further work is needed from the technical community to improve the knowledge of the potential impacts of* CO_2 *leakage and the potential actions to correct, mitigate or remediate* CO_2 *leaks and its effects. Our opinion review revealed that stakeholders consider emergency measures and remediation actions as an essential matter of regulation, as well as a topic for further R&D. A guidance document should be established referencing these measures and stating in which case to implement them. This would provide the operator with helpful guidelines to prepare its intervention plan, and the regulator with elements to check the validity of this plan. Regulations could contain a link to such a document.*

Recommendation 13:

We recommend that CCS regulations highlight the need for adapting the monitoring plan after measures have been implemented in reaction to an unexpected event, in order to monitor and report the effectiveness of these measures. This survey highly depends on the site, the issue encountered and the measures chosen, and could not be guided by a general document.

Recommendation 14:

The criteria for determining whether the operator is allowed to abandon the site will be highly site-specific, since it will depend on the natural characteristics and on the way operations have been carried out. Regulations should emphasise the need to demonstrate the consistency between the predicted behaviour and the monitoring results. They should also include in their requirements the implementation of a decommissioning plan for plugging wells, etc. Such a plan should be established in line with best practices; a document could be developed to synthesise these guidelines, to which regulations could refer.

Experience should also be gathered from the early projects to strengthen the understanding of the long-term behaviour of a CO_2 *storage site and to help in the interpretation of what is meant for demonstrating that the site can be abandoned.*

1.5.5 Liability

The gap analysis is built upon the previously established reviews of policy, projects and stakeholders opinions. The focus is on the EU CCS Directive while other researched policy documents figure as background information for the gap analysis.

1.5.5.1 Gap analysis for liability aspects

The following topics, the majority of which are related to the long time frame of CO_2 storage, seem not to have been clearly defined in the EU CCS Directive or other researched legislation:

- Development of financial security instruments and their effect on reducing investment risk
- Financing of long-term stewardship
- Return of unused deposits
- Uncertainty for Governments and stakeholders on how to prove permanence ("indefinite future")
- Duration of operators responsibility after closure until transfer to the State
- Responsibility for environmental damage: the producer of CO_2, the operator of the storage site or the State
- Setting the negligence standard for fault-based liability
- Sharing of liability where third parties are involved
- Relationship with national law regimes

1.5.5.2 Recommendations for liability aspects

Recommendation 1:

Stimulate market development of financial security instruments for ELD

In order to induce the market development and the implementation of financial security instruments the process of transposing the Environmental Liability Directive must be stimulated. Therefore the lack of data on remediation costs, and risk as well as lack of experience in underwriting and claims needs to be compensated.

Recommendation 2:

Define financing of long term stewardship

The CCS Directive states that Member States shall ensure that adequate provisions can be established (financial security or any other equivalent) by the operator to ensure that all obligations with respect to the storage permit can be met. The development of such an instrument can be stimulated by reducing uncertainty to all parties, by inducing knowledge on, for example, remediation costs and risk assessment. A balanced set of instruments must be made available as soon as possible so that investment risks of projects starting up will be reduced.

The CCS Directive states that a financial contribution is made by the operator for 30 years of monitoring after closure of the site, depending on site characteristics. This reduces uncertainty in possible financial risks. However, the contribution is set before transfer of liability and the possibility could arise that the costs of monitoring will be less than anticipated or could even exceed this contribution. A provision must be made available in which it is made clear what happens in case of such events.

Recommendation 3:

Specify the elements for reducing risk of potential leakage

The elements which reduce risks of potential leakage could be specified in terms of (technical) requirements and detail. This minimises liability and induces knowledge on details of containment of a storage site after closure and transfer. These terms could be established on a Member State level and based on existing legislation for risk assessment.

Recommendation 4:

Enable transfer of liability in national law

In order to reduce investment risk it is recognised that liability needs to be transferred to the State after closure of the storage site. However, it appears that several national laws do not approve of such a transfer. If it is not allowed in national law this could be solved by making an exception for carbon dioxide storage. Another solution could be to create a public-private partnership in order to *reduce investment risks and if the operator ceases to exist, the State takes over liability. Probably the State will have the largest share in order to reduce risks for the operator.*

Recommendation 5:

Create clear guidance for responsibility in case of long term potential events

Develop on a Member State level clear guidance on liability of long term potential events, e.g. leakage and the subsequent damage to the surroundings. All actors need to be addressed separately as well as how they are compensated and in case of what events.

1.5.6 R&D needs

The review of existing regulation, CCS projects and the stakeholder questionnaire revealed a number of recommendations for further research and development, which are detailed below.

1.5.6.1 Safety

Recommendation 1:

Risk assessment

To develop the process(es) for assessing risk raised by CO_2 geological storage and then provide harmonised technical guidance.

Recommendation 2:

Impurities

To determine what composition of the CO_2 flux is acceptable, to which extent it depends on the site conditions and whether a generic evaluation process can be proposed.

Recommendation 3:

Modelling

To keep improving the calculation codes for simulating the behaviour of CO_2 *in and potentially outside of the reservoir. Increasing accuracy, robustness as well as decreasing computation time will result in a better confidence in the predictions. Technical developments in this field are essential. CCS-dedicated regulations should leave room for these improvements and avoid overspecifying the model(s) needed.*

Recommendation 4:

Risk acceptability criteria

To understand the potential impacts of CO_2 *and potential associated impurities on the environment, i.e. on the various targets, including the global response of ecosystems.*

Recommendation 5:

Monitoring

To improve the monitoring techniques; regulations should refer to the best available technologies for the design of monitoring programmes. A document should be established and periodically revised to synthesise the status of the various techniques and thus provide guidelines for building an adequate plan. This document could include data regarding the scope, accuracy, associated operational protocol and cost of the technologies.

Recommendation 6:

Intervention

To further develop emergency measures and remediation actions; a guidance document should be established referencing these measures and stating in which cases to implement them.

Recommendation 7:

Risk management

Integration of site characterisation, risk assessment, monitoring and intervention into one logical scheme for risk management, which can be deployed during all stages of the storage lifecycle.

1.5.6.2 Liability

Recommendation 1:

Long-term liability

To identify and analyse the items which are subject to liability on the long term in terms of actions for assessment, monitoring, remediation, well maintenance etc.

Recommendation 2 :

Financial instruments

To develop financial instruments for financially securing different forms of liability with special reference to the long term.

Chapter 2

STRACO$_2$ Work Package 4
Site Qualification and Certification

Final Report

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2. Site Qualification and Certification: from a lifecycle perspective

2.1 Introduction

This section is a synthesis of the results from Work Package 4 (WP4) of the EU-funded research project Support to Regulatory Activities for Carbon Capture and Storage, STRACO$_2$. This chapter focuses on CO$_2$ storage capacity and site qualification and certification. For CCS projects, qualification can refer to a formal and structured process for demonstrating that a site will serve as a safe storage provided it is managed according to accepted and approved management plans.

The International Energy Agency, in its address to the Poznan summit in December 2008, stated that the priority is to develop standards for CO$_2$ storage site selection and permitting, CO$_2$ retention monitoring and verification and CO$_2$ pipeline transport health and safety.[15] It also indicated that governments should improve estimates of CO$_2$ storage capacity.

This chapter aims to:

- Establish a complete overview of the current procedures, systems and certification requirements related to site selection and qualification
- Identify knowledge gaps related to site qualification and potential in certification requirements accounting for technological, environmental, social and legal aspects
- Provide recommendations for concrete actions to close remaining gaps that have been identified related to site qualification and certification

2.1.1 Method

To address the above-stated objectives, the carbon capture and storage regulations published between 2007 and summer 2008 were reviewed to establish site qualification criteria and to analyse differences in the requirements worldwide. The past and ongoing main EU and international projects were reviewed and analysed to identify their recommended site qualification criteria, when available, and compare them with the ones stated in the regulations/guidance documents.

A stakeholder questionnaire was developed in order to identify the main concerns of legal entities, universities, research institutions, environmental NGOs, and other organisations regarding site qualification and certification.

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[15] Kerr, 2008.

The regulations and projects reviewed enabled the evaluation of the consistency and frequency of the appearance of criteria for site qualification, and to identify gaps in the site qualification and certification processes. The gaps and stakeholder concerns, provided the basis for recommendations regarding site qualification and certification. It should be noted that the gap analysis considered regulatory and guidance documents in the same manner, as well as on- and off-shore regulations.

The intended users of this chapter are operators, authorities and other stakeholders participating in the site selection, project planning and approval process of a CO_2 storage project.

2.2 Review of CCS policies

2.2.1 Introduction

CCS research, development and deployment are at different stages throughout the world. Similarly, CCS policies and regulations regarding site selection and certification are evolving at different paces depending on the region considered. This section aims at synthesising the CO_2 storage potential and the guidelines/regulations developed in different regions of the world.

The main aims of the policy review were to determine the storage potential in several countries considered as the main actors in CCS; state what a common best practice site qualification and certification would look like; and gaps in current policies if CCS is to be deployed on a large scale.

In order to be as inclusive and comprehensive as possible, storage potential estimates and policies were identified for comparison and analysis. These covered 14 countries, 2 international convention policies and 4 international networks. The methodology for this review is outlined in the full report.

2.2.2 General EU policies

2.2.2.1 EU legislation linked to the EU CCS Directive

This section focuses on briefly presenting the directives and regulations directly affected by the EU CCS Directive. Their domain of application, their goals and the amendments to allow/control CCS activities are stated in the full report.

Table 7- EU Legislation Linked to the EU CCS Directive

Legislation	**Aim**	**Amendments to allow for/control CCS activities**

Directive 85/337/EC on the assessment of the effects of certain public and private projects on the environment	Assessment of environmental impact of projects	To include pipelines for the transport of CO_2 for the purpose of geological storage; to include storage sites; to include installations for the capture of CO_2 streams for the purposes of geological storage.
Directive 96/61/EC now integrated into Directive 2008/1/EC concerning integrated pollution prevention and control	To avoid shifting pollution from one media to another (air, water, soil); to prevent and/ or minimise emissions into air, water, soil, to achieve a high level of protection for the environment as a whole.	Installations to include CO_2 capture installations for the purposes of geological storage.
Directive 2000/60/EC establishing a framework for Community action in the field of water policy	To improve the ecological health of inland and coastal waters and prevent further deterioration. There is a requirement for nearly all inland and coastal waters to achieve ‘good status’ by 2015.	To allow injection of CO_2 streams for storage purposes into geological formations which, for natural reasons, are permanently unsuitable for other purposes.
Directive 2006/12/EC on Waste	Ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment.	To **exclude** CO_2 captured and transported for the purpose of geological storage from the directive.
Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants	Reduce acidification, ground level ozone, and particles, throughout Europe by controlling emissions of sulphur dioxide (SO2), nitrogen oxides (NOx), dust (particulate matter (PM).	To ensure that combustion plants have suitable space on the installation site for the equipment necessary to capture and compress CO_2 and; have assessed availability of suitable storage site and suitable transport facilities and technical feasibility of retrofitting for CO_2 capture.
Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage	To establish a framework for environmental liability based on the "polluter pays" principle, with a view to preventing and remedying environmental damage.	The operation of storage sites is added in the list of activities where this directive applies.
Regulation (EC) No1013/2006 on shipments of waste	Establish procedures and control regimes for the shipment of waste, depending on the origin, destination and route of shipment, the type of waste shipped and the type of treatment to be applied to the waste at its destination.	The shipment of CO_2 for the purposes of geological storage is excluded from the scope of this regulation.

2.2.3 EU CCS Directive

2.2.3.1 Position and CO_2 storage potential

The European Union aims to have 12 large-scale demonstration projects for coal- and gas-fired power plants running by 2015, and recommends to include CCS in all new coal-fired power plants commissioned after 2020 and to have new plants commissioned before 2020 to be capture-ready.

The European areas identified as plausible geological storage areas are shown in the full report.

2.2.3.2 Guidelines and regulations for site qualification and certification

The final CCS Directive, published in June 2009, was reviewed according to the eight main phases of a CCS deployment project: screening, site investigation, well drilling and testing, site development plan, construction, storage operation, closure and post-closure.

The directive is further summarised in the full report.

2.2.3.3 Impact assessment of the EU CCS Directive

The impact assessment of the EU CCS Directive[16] considered the three components of CCS, i.e. capture, transport and storage. It concludes that capture presents similar risks to those of the chemical/power generation sector and therefore regulatory regimes already exist (Directive 96/61/EC). Similarly, CO_2 transport presents similar risks to natural gas transport and so will be regulated in the same way. For CO_2 storage, based on the stakeholder consultation, the impact assessment highlighted the main issues to be addressed for the regulating framework. Of the options considered for a regulatory framework, developing a free-standing framework in the form of a draft directive, was chosen as the most effective option for the regulating framework. A draft was issued on 23 January 2008 and the final version was adopted on 23 April 2009. It is presented in the full report.

2.2.4 CCS legislative status

The position, CO_2 storage potential, guidelines and regulatory documents related to site qualification and certification in Member States is analysed in the full report. Among EU Member States, the UK, France, Germany, Poland, and the Netherlands, have all taken positive steps toward developing CCS work, including initiating projects and drafting legislation. A more detailed analysis of these countries is detailed in the full report. Other

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[16] European Parliament, 2008a

countries reviewed include the United States, Canada, Australia, Norway, Japan, India, Brazil, South Africa and Kazakhstan.

Existing legislation relating to site qualification and certification from these areas and internationally is listed in Table 8 below.

Table 8- Legislation Relevant to Site Qualification and Certification

Title	Entity	Year of Publication
Directive 2009/31/EC of the European Parliament and of the council on the geological storage of carbon dioxide and amending Council Directives 85/337/EEC, 96/61/EC, Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. April 23, 2009.	Europe	2009
Energy bill – Chapter 3: Storage of carbon dioxide.	United Kingdom	2008
London Protocol - Risk assessment and management framework for CO_2 sequestration in sub-seabed geological structures. LC/SG-CO_2 1/7, annex 3.	International Convention	2006
London Convention - Final draft specific guidelines for the assessment of carbon dioxide streams for disposal into sub-seabed geological formations.	International Convention	2007
OSPAR guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formation. Reference Number: 2007-12.	International Convention	2007
US-EPA - Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells.	U.S.A.	2008
US-EPA - Using the Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects – UIC Program Guidance (UICPG # 83) March 2007.	U.S.A.	2007
Storage of Carbon Dioxide in Geologic Structures – A Legal and Regulatory Guide for States and Provinces – Task Force on Carbon Capture and Geologic Storage – 25 September 2007.	Interstate Oil and Gas Compact Commission (U.S.A. and Canada)	2007
US - Washington State Legislature – Chapter 173-218 WAC – Underground injection control program.	U.S.A. Washington State	2008

US – State of Wyoming, House Bill No. HB0090 – Carbon Capture and sequestration.	U.S.A. – State of Wyoming	2008
US – Kansas, Proposed regulation for the underground storage and sequestration of CO_2.	U.S.A. – Kansas	2009
Australian Regulatory Guiding Principles - Ministry Council on Mineral and Petroleum Resources.	Australia	2005
Australian Draft Offshore Petroleum Amendment (Greenhouse Gas Storage) Bill 2008. Overview	Australia	2008
Australia, State of Victoria. Greenhouse Gas Geological Sequestration Bill 2008.	Australia, State of Victoria	2008
Amendments of the Law relating to the prevention of marine pollution and maritime disaster.	Japan	2007-2008
Legal aspects of storing CO_2 – Update and recommendations.	IEA	2007
Environmental Assessment for CO_2 capture and storage.	IEA-GHG	2007
Permitting issues for CO_2 capture and geological storage.	IEA-GHG	2006
CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport and Storage.	World Resources Institute	2008
UNFCCC – Clean Development mechanisms – Proposed new baseline and monitoring methodologies.	UNFCCC	2008

2.2.5 Storage capacity

This section summarises the storage potential of several countries. Storage potential estimates for other countries are identified in the full report.

Table 9- Storage Potential of Various Countries

Country	Date of the source	Depleted oil fields ($Gt CO_2$)	Depleted gas fields ($Gt CO_2$)	Coal seams ($Gt CO_2$)	Deep saline aquifers ($Gt CO_2$)
UK	2003	2.6	4.9		240
Germany	2007	0.11	2.75	0.4-1.7	20 +/- 8
US and Canada		82.4 – 90.9		156.1 – 183.5	919 - 3378
Canada	2008	4.5			1000
India	2007	7		5	360

2.3 Analysis of stakeholder feedback

2.3.1 Questionnaire overview

This section aims at presenting the questionnaire results regarding site qualification and certification and the resulting main outputs. Given the relative number of respondents, it is not guaranteed that these results reflect the international CCS community point of view. The stakeholders are presented in the full report.

Seven questions were asked regarding site qualification and certification:

- What do you see as the main obstacle in site qualification and certification?
- Is there still a need for fundamental research on site qualification and certification and what research priority areas are needed?
- Which issues would have to be on the forefront for EU regulation and site qualification?
- Which issues of site qualification and certification could prove problematic at the international level?
- Which issues of site qualification and certification could prove problematic in future EU/China co-operation?
- Potential sites in the EU
- Potential sites in China

The results for each of these questions are presented in the full report.

2.3.2 Questionnaire main outputs

The respondents agreed that a sizeable number of obstacles still exist on the topic of site qualification and certification. Respondents did not agree on a single main obstacle from closure and post-closure, monitoring, site characterisation and storage permit, as all were seen as nearly equally important. An equally strong agreement seems to exist on the need for more fundamental research, especially in areas of technology and geography, but less so in the area of regulation. Questions of liability remain a major concern in terms of site qualification and certification. The importance of safety in site qualification for public acceptance of the technology was emphasised by the findings of the assessment.

The problem of common standards and their enforcement will be a major issue on the international level when the technology is deployed internationally and site characterisation and qualification will play an important role in these standards. While common standards were seen as a general problem on the international level, implementation and governance issues were named when asked about the EU-China level. At this level, liability and monitoring are once again major concerns for western stakeholders as was the question of how much the Chinese will be willing to agree to international standards and have them implemented, controlled and verified in their own territory, possibly by international bodies.

Therefore the main suggestions for areas the EU should concentrate on in future CCS regulation for site qualification and certification were: to ensure future co-operation between the EU and China on agreeing common standards and regulations, as well as supporting the development of China's ability to run CCS projects.

2.4 Review of EU and International projects

2.4.1 Introduction

This section aims at synthesising the main results or guidelines of CO_2 storage projects regarding site qualification and certification. It aims to define a common best practice for site qualification and certification based on the literature available in CCS projects and to highlight existing gaps for each stage of site qualification and certification.

To reach these objectives, the best international practices were identified and site qualification and certification guidelines applicable to CCS projects were synthesised and analysed.

2.4.2 CCS projects

The table below summarises the scope of the CCS projects presented in the full report.

The main results of this review regarding site qualification and certification are three guidelines and two reports, shown in the right-hand column of the table. All these documents are available on the internet.

All 13 studied projects cover the entire life-cycle of a CCS project. No document is available yet for four of the projects selected. This analysis is valid at the time this report is written (May 2009), but since most of the projects studied are ongoing, the analysis provided is subject to change rather rapidly.

Table 10- CCS Projects Worldwide

Projects	Financing	Zone	on-shore	off-shore	saline aquifer	hydrocarbon reservoir	coal bed	Project Scale	Comments/Objectives	Results regarding Site Qualification	Resuts regarding Site Certification	Results regarding Storage Capacity	Main document/guideline
ACCSEPT project	European 6th Framework Programme	Europe	x	x	x	x	x	Any	Dedicated to a gap analysis for CCS implementation in Europe: identification of the key issues	No technical results regarding site qualification and certification are provided			
CASTOR	European 6th Framework Programme	Mainly Europe and neighbouring countries	x	x	x	x	x	Any	Develop and validate all the innovative technologies needed to capture CO2 and store CO2 in a reliable and safe way	Provide lessons and recommendations for reservoir characterisation (WP 3.6.1 deals with "Criteria for CO2 Storage Site Selection and Site Management"), overburden and caprock properties, predictive flow modeling, monitoring plan and preventive and corrective actions	No specific result	No specific result	-
COACH	European 6th Framework Programme	Europe and China	x	x	x	x	x	Large-scale polygeneration energy facilities with options for coal based electric power generation as well as production of hydrogen and synthetic fuels, with CO2 capture and geological storage	Establish broad cooperation between China and the EU in the field of CCS	COACH deals with "Site qualification and certification" in the Work Package n°3, but no document is available		No specific result	-
CO_2ReMoVe	European Community + Private companies	Europe and neighbouring countries	x	x	x	x		Full-scale projects.	Develop innovative research and technologies for the monitoring and verification of CO2 geological storage	the project deals with methods for base-line site evaluation, monitoring, verification, performance. Moreover, it will develop a pragmatic and science-based catalogue of procedures for applying a performance-based regime for technical standards for geological storage of CO2, with particular relevance for Risk Acceptance Criteria	The project recommends a third party assistance in the quality assurance of the licensee's activities. No specific result for Site Certification	No specific result	Final documents and guidelines are not available
EUGeocapacity	European Community + Partners	Europe and China	x	x	x	x	x	Full-scale projects.	Assess the European Capacity for Geological Storage of Carbon Dioxide	The project provides the basic site selection criteria to evaluate and rank storage sites. It presents Decision Support Systems (DSS) and Geographical Information System	No specific result	The project defines the stepwise process of identifying storage potential and assessing storage capacity and deals with methodologies for calculating CO2 storage capacity in deep saline aquifers, hydrocarbons fields and coal fields	Final documents and guidelines regarding Site Qualification and Storage capacity are not available
SACS – CO_2STORE	European 5th Framework Programme	Europe	x		x			Large-scale storage of CO2: With 1MT of CO2 injected every year since 1996, Sleipner is the first commercial scale CO2 injection facility in the world. The 4 other case-studies are also commercial-scale.	The goal of these projects is to improve the understanding of CO2 injection in deep saline aquifers and to build upon Sleipner experience in order to assess new potential storage reservoirs in different sites in Europe.	The project provides the main geological criteria used for ranking potential sites during the screening phase with an estimation of the positive geological indicators. Moreover, it provides a methodology for site characterisation	No specific result	The project presents a CO2 storage capacity calculation for saline formation, mainly based on the methodology of Bachu & Shaw (2003)	Best Practice for the storage of CO2 in Saline Aquifers – Observations and guidelines from the SACS and CO2STORE projects. Edited and compiled by: Chadwick A., Arts R., Bernstone C., May F., Thibeau S., Zweigel P. 2007
UK-NZEC	Funded by the UK DECC	China	x	x	x	x	x	Any	Demonstrate advanced, near zero emissions coal technology through carbon capture and storage (CCS) in China (options for demonstration and build capacity for CCS in China)	NZEC is relevant to Site Qualification and Certification, and Storage capacity, mainly for the final conclusions, at the moment, no result from this project are available			-
CO_2GEONET	European 6th Framework Programme	World	x	x	x	x	x	Any	European Network of Excellence on geological storage of CO2	Project of development of a decision support tool system (DSS) associated with a Geographical Information System (GIS), that would aid project designers and regulators to assess information on potential environmentally sensitive areas in the site selection process	No specific result	No specific result	-
ZEP	Funded by EU and industries	Europe	x	x	x	x	x	Any	European platform reuniting the European Commission, European industry, NGOs, scientists and environmentalists. The goal is to enable European fossil fuel power plants to have zero CO_2 emissions by 2020.	Recommendations are regarding methods for the risk assessment process, risk scenarios, monitoring technologic gaps	No specific result	No specific result	-
FutureGen Alliance	USA government and industries	USA	x		x			Large-scale engineering laboratory and prototype plant for injecting a minimum of 1 Million Metric Ton (MMT) CO2 per year over the project Test Phase, the total storage capacity of all target formations in aggregate must equal or exceed 50 MMT of CO2	Design, build, and operate a first-of-a kind coal-fueled, near-zero emission power plant (275-megawatt prototype plant)	The Futuregen documents provide site identification and ranking process, an evaluation of each parameter (criteria) of the geological storage, a description of the criteria for each selected site (Environmental Information Volume). Moreover, the documents describe investigation and monitoring methods and techniques	No specific result	No specific result	Results of site offeror proposal – Proposal Evaluation – July21, 2006. Final Site Selection Report – December 18, 2007. Environmental Information Volume – Mattoon Site – December 1, 2006.
CO_2CRC OTWAY	Australia, supported by 15 companies and 7 government agencies	Australia	x	x	x	x	x	Pilot project, 100,000 T injected in 2 years	Demonstrate that CCS in Australia is technically feasible and environmentally safe, Facilitate research into new monitoring technologies, Offer opportunities for trial and experimentation	The project presents a site characterisation methodology that summarises the different scales of site assessment, the screening criteria, and the factors for ranking of prospective sites	No specific result	The project presents a CO2 storage capacity classification system with a methodology for storage capacity estimation in saline formations, in depleted oil and gas fields, and in coal seams. The methodologies are mainly based on DOE (2006) and CSLF (2007)	"Storage Capacity Estimation, Site Selection and Characterisation for CO2 Storage Projects" (CO2CRC, 2008)
CO_2 Capture Project	Energy companies and 3 governments (U.S. Department of Energy, Norges forskningsråd, European Union)	World	x	x	x	x	x	Large CCS operations	Synthesize key technical aspects and technological innovations used in the geological storage of CO2	The project deals with all phases of a geological storage: site selection, site characterisation, site development plan (basis of design), monitoring, closure	The project presents a framework for Certification of CO2 storage site	-	A Technical Basis For Carbon Dioxide Storage – January2009
CO_2 Qualstore	public/private (Joint Industry Project)	World	x	x	x	x	x	Large CCS operations	Develop a risk-based qualification procedure (guideline)	The project will deal with site selection, qualification criteria, qualification and verification process. But it is a new project launched in November 2008 and no technical document from this project are available			-

2.5 China Applicability

2.5.1 Challenges for the applicability of International and EU CCS regulatory experience to China

In the stakeholder needs assessment, European participants were asked to rank their views on future EU-China co-operation on CCS. European stakeholders saw the European experience as the first mover on CCS regulation as best practice for future Chinese regulatory approaches to CCS. Site qualification and certification issues were seen as the major stumbling blocks together with financing issues. Site monitoring was seen as a likely major problem for EU-China co-operation on site qualification and certification. It also became clear that deployment and regulation have to go hand in hand. Looking at the long regulatory process in China, it was felt that regulatory issues have to be addressed now if large scale demonstration plants are supposed to be ready in the mid-term.

2.5.2 Site qualification and certification issues in China

The qualification and certification of prospective storage sites in China is the fundamental issue of any regulatory approach to CCS. While the issues of capture and transport are widely seen as questions of the right choice of technology and financing, site qualification and certification is the decisive process for any storage approval.

To make CCS viable from a climate change point of view, the guaranteed storage of the captured CO_2 has to be ensured over a long period of time with near perfect closure. The German Environmental Agency proposes 0.01% of CO_2 leakage to ensure positive effects for fighting climate Change.[17]

The question of site qualification and certification must therefore take into account geological, environmental and social issues. The storage permit would be the central instrument of control for the Chinese government in regulating CCS storage in the future. It is assumed that China would build on its past experiences with issuing geological permits from oil and mining industries and waste disposal.

The selection and permitting process of sites in China is well established due to a sizable number of large hydropower projects, enhanced oil recovery (EOR) projects and similar

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[17] Boehringer, 2009

activities impacting large areas of land or natural resources, and the process of exploring, qualifying and permitting sites is well established.

While China is generally seen as having a large number of promising storage sites, there is currently no comprehensive knowledge on exact site locations and capacity, even in the relatively well-known areas of oil and gas exploration and coal seams. Additionally, there is very little knowledge of the conditions and locations of saline aquifers. Generally, the research into storage sites (see research by the COACH and NZEC projects) has a strong focus on the northern and north-eastern parts of China. While an all-encompassing survey for possible CCS storage sites in China has yet to be done, a rough estimate of storage sites can be seen in the full report.

Between December 2008 and May 2009, the $STRACO_2$ consortium conducted interviews with Chinese government institutions that are most likely to play a role in establishing early CCS regulation in China in the coming years. It was agreed that the project approval process under the NDRC will form the framework for regulation of CCS demonstration projects in China.

It is most likely that the permit for the construction and use of a storage sites for CCS would demand a multilayered approval process similar to the one used for other large projects with regional implications, similar to the construction of hydropower plants. A specific multilayered approval is needed that, besides the agreement of the NDRC to the project design, will also involve other considerations. The most important considerations are geological assessments, environmental impact assessments and perhaps even relocation assessments for the inhabitants of the area that have to be done with other large scale infrastructure projects. Only then could a permit for the installation of a storage site be issued.

This adapted process could roughly follow the draft German CO_2 Deposition Act permitting process. This process involves: 1. The Approval of the survey, 2. Approval of the CO_2 Deposition, 3. Site closure. These three steps, which are discussed in the following chapters, if integrated into the established frameworks, could comprise the project approval process for CCS storage sites in China.

Due to the historic development of the Chinese political and economic system, the permitting and approval of economic projects by government authorities is widespread and generally well established. However, the certification of environmental issues is comparatively new and the energy and environment institutions are currently in a constant process of reform. Therefore, the overview of relevant institutions below has to be seen as building on the current situation and will be subject to changes and reform in the coming years.

2.5.3 Potentially relevant institutions

This section provides an overview of the institutions that may most likely be responsible for the process of site qualification and certification. The report then examines the existing regulations of similar processes that could be transposed to site qualification and certification for CCS in China.

Table 11- Institutions Relevant to Site Qualification and Certification of CCS in China

Institution	Role
State Council National Development and Reform Commission (NDRC)	The most important authority for the permitting of large projects (i.e. with an investment of over RMB 100 million). Assuming that a storage site for CCS with its injection equipment and storage monitoring would be counted as part of the overall CCS project, including capture and transportation, it would surpass this threshold, making the NDRC's approval mandatory. The outline of any future storage permit would therefore have to be based on the NDRCs project approval procedure. NDRC is likely to be the relevant authority for questions of site qualification and certification assisted by environmental and geological agencies. The NDRC preferred adaptation of the mining law is seen as the central driver of the permitting process.
National Energy Administration (NEA)	Previously the Energy Bureau within the NDRC would be responsible for project approval, under the assumption that CCS would be categorised as a subject of energy policy. This has now become the responsibility of the National Energy Administration (NEA), which has replaced the Energy Bureau, and has become the central decision maker on energy projects in China and would likely have the final say on the overall project approval.
Ministry of Environmental Protection (MEP)	Responsible for the Environmental Impact Assessment to be undertaken during the application process for a storage permit. Although likely to be involved in the permitting process, the MEP currently has no jurisdiction over climate change issues, which reside with the NDRC's Leading Group on Climate Change. In the case of monitoring issues the MEP has developed the greatest expertise of all Chinese ministries so far, and it therefore is a relevant authority for monitoring storage sites.
Ministry of Land and Resources	Oversees the issues of land (and sea) exploration and use, and the required permitting. Responsible for supervising examination, approval, registration and licensing of the rights to

(MLR)	explore and mine mineral resources.
Ministry of Water Resources	Tasked with overview of saline aquifers and permitting their use, and would be involved in the permitting process.

2.5.4 Overview of relevant existing Chinese regulation

The process of qualifying and certifying storage sites in China can build on a number of established processes: 1) Regulations on oil exploration, EOR and Enhanced Coal Bed Methane (ECBM) project experience; 2) Mining laws of China; 3) Experience gained with the EIA law since 2003; and 4) Existing laws and standards on nuclear and hazardous waste.

2.5.5 Established mechanisms for exploration permit

Under the draft German CO_2 Deposition Act the survey approval or exploration permit, as it should be referred to hereafter, would have to be the first step for the final storage approval. The applicant would have to submit its formal preconditions as an entity but also a survey plan to reach the necessary approval. These mechanisms are obviously well established from earlier resource extraction surveying.

Relevant legislation is listed in Table 12 below:

Table 12- Legislation Relevant to Site Qualification and Certification of CCS in China

Legislation	**Content**
Regulation of the People's Republic of China on Environmental Protection and Management for Oceanic Oil Exploration and Development; The Implementation Measures of the Regulation	Plays an important role in the existing approval process for oceanic oil exploration. These regulations stipulate that an Ocean Environmental Impact Assessment is mandatory for oil exploration and extraction activities, this EIA report has to include: (1)Name of the oil field, geological location, scale; (2) Status of coastal environment and marine resources where the oil project is located; (3) Categories, components, amount and treatment measures of waste emitted during oil exploration; (4) EIA on marine environment including potential impacts on the surrounding coastal natural environment, marine resources due to marine oil exploration and extraction; potential impacts on fishing, shipping, and other marine activities; planned environmental protection measures to avoid or eliminate adverse impacts; (5) Unavoidable impacts, impact level, and reasons; (6)Measures to prevent major oil pollution accidents .
London Convention	China has ratified this Convention, which gives detailed site requirements for an EIA report on marine oil exploration, and is relevant to any potential CCS EIA report.

Provincial regulations for management of oil exploration	These exist for the management of oil exploration and extraction under an environmental perspective. Liaoning, Shandong and Gansu are a few of the provinces that have successfully made EIA mandatory for all project approvals, highlighting risk prevention and emergency response measures.
Mineral Resources Law of the People's Republic of China	Article 23 of the Mineral Resources Law, stipulates the conditions for exploration and requires every site qualification in its earlier phases of geological exploration to follow the relevant unified state plan (Mineral Resources Law, Chapter III Article 23).
Measures for the Registration Administration of Mineral Resources Exploitation	Regulates geological exploration.
Environmental Protection Law	Covers role of the environmental impact statement.
Environmental Assessment Law 2003; Amendment made for the EAL 2009 (not yet passed)	The Amendment will extend the scope of the project assessment to a regional or special assessment taking into account more regionally-oriented impacts that might be relevant for future storage of CO_2, demanding the assessment of large areas that might be impacted.

Chinese mining institutions have a long history of qualifying and certifying the use of underground resources. These are important for the exploration permits that would lead to storage permits. The responsible institution for the permitting of geological exploration in China which could oversee the early steps of site qualification is the MLR. Mining permits are the most powerful instrument of control by the Chinese authorities to regulate mining activities in China. The same would apply for site exploration permits of CCS projects as they would form the backbone of each CCS project approval process. Projects are unlikely to get an overall approval as long as no storage site exploration has taken place. These mining permits could serve as a blueprint for future permitting processes in the area of site qualification and certification.

The approval process could involve the feasibility study (in this case relating to storage capacity, sealing capacity, etc.), the seismological assessment and the EIA before the mining (storage) licence and the permit approval. This process is currently in use in other mining fields such as copper mining.

The certification and permitting of environmental impacts in China has recently developed quickly.

The Project Application Report for the NDRC which would form the basis of storage permits to be obtained, currently requires the EIA to be one of the first certificates to be submitted during application. The full environmental impact assessment report has to be completed prior to project construction for large and potentially heavy polluting projects. The EIA governs procedures that will be important for CCS site qualification and certification. The EIA Law also regulates the monitoring of the project and gives the MEP the authority to withdraw the EIA permit in case of clear irregularities.

2.5.6 Laws and Standards applicable to the storage permit

Liang and Wu (2009) call for new laws to be made as long as CO_2 is not considered hazardous waste, meaning that these regulations, which are well established in China, do not apply to CCS. However, even assuming that hazardous waste regulations would not apply to CO_2, the lessons learned from this regulation should be incorporated.

In the draft German CO_2 Deposition Act, the following preconditions are given[18]: Injection Plan; Monitoring Plan; Security Plan; Preliminary closure plan; Financial security for possible damage, and emission trading liabilities.

The necessary conditions of the site include that there shall be no adverse consequence for soil, ground water, surface, surface waters, sea or atmosphere. While the aforementioned practices are already giving an encompassing framework for storage site qualification and certification, the following standards are likely to play a role in detailing guidelines for the storage permit.

As EOR is one of the most promising storage possibilities for the near-term future, the established process of application for EOR will be one of the most important regulations in the early deployment of CCS in China. The EOR approval process can also set a precedent for the overall approval process for other storage options.

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[18] Boehringer, 2009.

Table 13- Legislation Relevant to the Storage Permit

Legislation	**Content**
Hazardous Waste Law	While under international experience CO_2 is not qualified as hazardous waste, the experience gained from this law might be useful for permitting storage. Article 17 would apply giving individuals and units that plan to store hazardous waste the responsibility to obtain a storage permit first.
Law of the People's Republic of China on the Prevention and control of Radioactive Pollution	Similar differences obviously exist in the questions of material quality and reactivity with other elements between CO_2 and nuclear waste, however, this law has already established a site selection plan for solid radioactive waste disposal. The approval by the MEP is reliant on geological factors, the proven need for disposal and the successfully passed EIA. This law also includes the local authority, which can serve as an example for future CCS storage site regulation.
GB 18597-2001 Standard for Pollution Control on Hazardous Waste Storage	Formulated for the purpose of implementing the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste, this standard aims to prevent the environmental pollution caused by the storage of hazardous waste, and to enhance the supervision and regulation of the storage of hazardous waste. Within the Chapter 6, the site selection and design guideline of storage installations of hazardous waste are outlined. The GB 18597-2001 standard could be useful in outlining the future location of any CCS storage site.

2.5.7 Site closure procedures

The last critical point in the storage process is the closure of the site. The project permitting process should stipulate a third step to be certified during the application process. When applying for the overall project permit, the applicant should submit a definite closure plan, aftercare plan, security and monitoring plan including during injection and after injection for long term security.

Experiences from storage plans from the Gansu nuclear waste storage facility were named by Chinese experts interviewed as possible best practice experiences in China.

2.5.8 China Applicability Conclusions and Recommendations

Site Qualification and Certification constitute an area where the transfer of knowledge and regulatory experience between the EU and China could be very beneficial for the development of CCS regulation in China. China already has an existing framework of the project approval process that can be used for CCS.

China will have to adapt laws like the Mining Law and the Environmental Impact Assessment Law to make them applicable to the relevant issues of CCS. It is in this regard that future co-operation between the EU with its advanced level of regulation could be beneficial for China. This co-operation would be beneficial both on the Union and Member States level.

The draft German CO_2 Deposition Act might be an especially interesting set-up for the Chinese permitting process with its threefold approach to exploration, storage and closure permits. For exploration and surveying, future regulation could build on existing mining and oil exploration law, guiding the exploration and surveying of prospective storage areas. These would have to be adapted for specific use. For example, the duration of the permit would have to cover the whole period of activity on the site, plus the liability phase for the storage site (above 20 years in the EU directive) until the handover to the Chinese state.

Recommendations to the EC:

Establish a dialogue on CCS regulation with all Chinese government institutions mentioned in this research to mirror the multilayered approach necessary for the CCS site qualification and certification.

Include Member States as the main actors in specific CCS regulation, being the most important dialogue partners for the Chinese side. The German Authorities should be approached first after the draft German CO_2 Deposition Act is passed.

Recommendations to the Chinese Government:

It will be important for China to start adapting existing laws to the requirements of CCS as soon as possible as major demonstration projects are in their planning phase and the discussion and legislative process in China could take up to three years.

Adapt major laws, like the mining law, to the needs of CCS, learning from European and international experiences already undertaken in this field.

2.6 Conclusions

The main objective of this STRACO$_2$ work package four was to map the current understanding of site qualification and certification for CO_2 capture and storage. A special emphasis has been put on storage sites, as experience in other domains can be transposed and used for CO_2 capture and transport.

After reviewing the capacity estimates in various countries, the starting point of our analysis has been a review of regulatory and guidance documents dedicated to CCS. This survey collected amendments to international conventions on the use of the sea domain, ratified texts, proposals under discussion, or guidance documents established specifically for CCS in Europe, the USA, Australia and Japan. The status, scope, and contents vary widely from one text to another. As a consequence, they address the phases of a CCS project lifecycle differently.

Our policy review has been completed by a stakeholder survey to identify what is expected from regulation regarding site qualification and certification. According to this feedback, each phase of a CCS project was seen as equally important and more fundamental research was required, especially in areas of technology and geology. While common standards were seen as a general problem at the international level, implementation and governance issues were named when asked about the EU-China level.

This survey was further completed by the review of past and on-going relevant EU and international projects, including a network and a platform, to identify their developments and recommendations in terms of site qualification and certification.

This work enables the identification gaps and provides recommendations regarding storage capacity estimates, site qualification and certification from different perspectives. These findings are summarised below.

2.6.1 Gap analysis

2.6.1.1 Gaps regarding storage capacity

In the past, a variety of methodologies were used to estimate storage potential. Since 2007, the CSLF[19] and CO_2CRC[20] have published their methodologies, which are relatively similar to each other and are now widely used. However, the estimates obtained before these publications cannot be compared since they do not specify which type of storage capacity they refer to (theoretical, effective or practical capacity). The second main gap lies in the lack of information/data associated to the sub-surface, especially for storage in saline aquifers. Finally,

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[19] CSLF, 2007.

[20] CO_2CRC, 2008.

the documents reviewed do not specify the relative role of each trapping mechanisms in terms of capacity, and most of them do not give an accuracy of the estimates required.

2.6.1.2 Gaps regarding site qualification

As in the previous chapter on safety and liability issues, the topics found recurrent in the documents consulted over site qualification and certification issues were:

- data describing the natural characteristics of a site
- indicating, monitoring and reporting major operational parameters
- dealing with the matter of impurities in the CO_2 stream
- using numerical simulations in the assessment of the future behaviour of CO_2
- monitoring the site, especially the migration of CO_2 inside and outside the reservoir
- submitting a plan describing the potential interventions in case of an unexpected event
- demonstrating the absence of significant risk before abandoning the site

Nevertheless, the way these items are addressed varies greatly among the documents and some topics were far less frequently stated, such as:

- site screening
- the need to create models early in the site investigation process and update them regularly
- the time scales to consider in the application
- standards for well injection design, drilling, testing and maintenance
- the definition of the area, elements and parameters to monitor
- the monitoring of the efficiency of any corrective measure taken
- routine and non-routine inspections
- best practices regarding plant and equipment decommissioning

Globally, the most significant variations lie in the level of detail of the consulted documents. Their common points are that each step of a CCS project has agreed objectives and that their techniques, values, thresholds and methods are rarely given. Most do not prescribe screening criteria, nor modelling or monitoring of protocols, methods and techniques. Similarly, very few documents address the criteria and methods for site abandonment and the time scales vary greatly.

2.6.1.3 Gaps regarding site certification

Site certification is rarely mentioned in the literature review. The few projects and organisations that do mention it include the certification agency DNV, the CO_2 capture project,

CO_2ReMoVe and CO_2Qualstore. However, the term has different meanings from one project or document to another.

2.6.2 Recommendations

2.6.2.1 Recommendations regarding capacity estimates

Recommendations regarding capacity estimates:

It is recommended to:

- *test the applicability of the proposed methodologies (CSLF, 2007; CO_2CRC, 2008) in the different settings and at various scales*
- *specify the methodology and information used to calculate the estimates (including accuracy of the information)*
- *build on experience acquired worldwide to further refine capacity estimates, assessing* CO_2 *storage capacity at different scales, different storage types, involving different trapping mechanisms, and different types of capacity (from theoretical to matched)*
- *gather data to properly assess the storage capacity estimates in a given environment*
- *qualify and possibly quantify more precisely the cause(s) of the reduction of the storage capacity from theoretical to effective and to practical*
- *quantify the relative importance of the different trapping mechanisms in different settings, at different times and scales*
- *based on field experience, qualify/quantify the costs increase due to further data collection, simulations, etc. compared to the benefit of capacity estimate refinements*

Updates should be conducted regularly in order to take into account recent sub-surface knowledge, technologies and modelling improvements.

2.6.2.2 Recommendations from a CCS project lifecycle perspective

Recommendations are made in three main areas: guidelines and standards, regulations and research and development. Although they interact, they have been separated for clarity purposes in this section.

Recommendations for Guidelines and standards

The need for guidance documents and standards for potential operators and the competent authorities was identified. We advise building on experience from early CCS projects in order to develop guidelines/standards for:

Site screening

It is recommended to define an accepted and validated methodology to conduct site screening in each country. This methodology could be based on the regional geology, the resources usage, beside CCS, the distance between the source and sink, the likely impact on the industry / environment (health, ecosystems), a preliminary risk assessment of the storage project, etc.

It is recommended to use existing data from the oil and gas industry, in particular for depleted reservoirs and sites close to oil and gas producing fields.

A Geographic Information System (GIS), potentially combined with a multicriteria analysis, seems to be the most suitable tool to summarise the results and highlight the most suitable storage sites agreed list of site selection criteria and a reference guideline document enabling a party to be able to answer the four main questions to investigate when assessing the storage potential and within a pre-defined domain.

The criteria in the site screening phase in all projects, regulatory frameworks and guidance documents reviewed are summarised in the full report, which could be a basis for building the above mentioned methodology.

Site characterisation/investigation

*It is recommended to develop an **agreed list of site selection criteria and a reference guideline document enabling a party to be able to answer the four main questions to investigate when assessing the storage potential** and collecting data necessary to identify which sites perform effectively and safely:*

*-**what data** is required to assess a storage complex's potential and to characterise it (for example: storage complex characterisation: which parameters, what level of detail and/or accuracy is reasonable to obtain, potential leakage pathways: which pathways and which level of details are reasonably possible to obtain, potential receptors: which receptors and sensitivity of the receptors)*

*-**how** can this data be collected (possible methods of acquisition and/or dissemination, their advantages and drawbacks, their accuracy), and how can the data be transferred to the competent authorities to contribute to the general increase in sub-surface knowledge*

*-**where** should this data be collected: how to define the area of review and the "buffer" area to ensure a safety zone if the CO_2 stream is to move differently from the predictions*

*-**what level of accuracy is acceptable:** How is the data interpolated? How are the heterogeneities in the sub-surface considered? Which level of accuracy is considered sufficient? What is the variability?*

The criteria regarding site investigation and characterisation available in the literature reviewed are summarised in the full report.

Modelling

It is recommended to develop a ***reference guideline document and good practices on computer simulation*** *to include:*

-the construction of a ***conceptual model***

-the ***data inputs****: which field data needs to be/can be collected, to what degree of accuracy (and consequences in the accuracy of the outputs), which ones need to be estimated using literature review / trial and error*

-the ***codes*** *that are available/currently developed (for geological modelling, hydrogeological modelling, geochemical modelling, geo-mechanical modelling, heat-transfer modelling and coupled codes), their advantages and limits in different settings*

-the ***results/outputs*** *that can legitimately be expected, their degree of accuracy, their potential for improvement if more field data/monitoring results are collected, the consequences of the accuracy in the risk assessment*

-the ***benefits of developing a model at an early stage*** *of a CO_2 storage project and updating the model as more data is collected*

CO_2 injection well drilling, testing, maintenance, plugging

It is recommended to develop ***standards for CO_2 injection well drilling, testing and maintenance,*** *as well as for active, inactive, or abandoned well locations, evaluation and plugging when needed. These standards will minimise risk of leakage and help develop a certification framework.*

Monitoring

It is recommended to develop a ***reference document regarding storage site monitoring****, specifying*

-how to define the ***area*** *to be monitored? How often to re-evaluate it?*

-how to design a ***monitoring program****?*

-which ***elements*** *(injection facility, injection well, environment, storage complex, etc.) can be / need to be monitored? which* ***parameter****(s) / indicator(s) to follow/monitor for each element?*

and, for each of the parameters to monitor:

-what are the ***best available technologies*** *to monitor these parameters?*

-what is their ***accuracy****?*

-what is the appropriate ***frequency of monitoring****, or, if site specific, which elements to consider to determine the frequency (or revise it)?*

Inspections

It is recommended to develop a ***standard for routine and non-routine inspections*** *in Europe so that the inspections are carried out by a third-party in a similar manner at all EU sites. This standard could answer the following questions, among others:*

-What to inspect? Which parameters?

-What to report? How?

-What to do in case of non-compliance?

-What is the reasonable frequency of non-routine inspections?

Irregularities

A guidance document should be developed *addressing the following issues:*

-potential irregularities

-potential impact(s)

-potential remediation/mitigation (as a function of time and the impacts that occurred and that could occur)

Further research is necessary to put together such a document.

Plant and equipment decommissioning

It is recommended to develop a standard document specifying ***what a closure plan should include*** *and the* ***best practices for decommissioning plant and equipment****. From a technical point of view, it is advised that:*

-given the central importance of plugging and well abandonment, technical standards for plugging CO_2 *injection wells and ensuring storage integrity be developed in the future*

-post-closure well material performance (including potential for corrosion of metal casing or tubing by CO_2*) be further researched under realistic laboratory and/or field settings*

-long-term behaviour and impact of CO_2 *on reservoir fluids and rocks be further researched*

Closure and post-closure monitoring plan:

Given the absence of homogeneity between the documents, it is recommended that post-closure monitoring be revised and a ***reflexion be conducted on****:*

What are the objectives of post-closure monitoring?

What / Which parameters should be monitored? Which technology should be used?

What to do in case of significant irregularities, if the predictions do not fit the observed plume behaviour?

How long and how often should the site be monitored? Which criteria should be decisive for the end of the monitoring?

Who should finance the monitoring?

Recommendations for Regulations :

Besides references to such guidelines that could be established, it is recommended that regulations stress the needs for:

-characterising and monitoring the environment around the storage site*, which implies acquiring a monitoring baseline prior to storage operations*

-site investigation permits

-references to well drilling, testing and maintenance standards

-submission of the geological data *to the competent authorities in order to enrich sub-surface knowledge*

-addressing ***property rights***

-addressing ***potential conflicts*** *between storage operators in the same storage or adjacent storages that unpredictably become one*

-addressing ***the cross-boundary storage issues***

-addressing ***the link and responsibilities between the*** ***CO_2*** ***emitter, transporter and storage operator and compensations for surface property owner*** *in case of damages*

-monitoring throughout all phases of the project's life-cycle*: before, during and after the injection, and determining when/under which conditions the monitoring can be stopped*

-preparing preventative and corrective measures plan*, gathering several kinds of measures (protection, correction, mitigation, remediation); and monitoring the efficiency of any corrective measures taken. It is recommended that the risk assessment be linked to the corrective measures plan: for each potential impact, a mitigation measure should be developed*

-routine and non-routine inspections, *that favour compliance of the operator,*

-an ***accurate and precise understanding of the site*** *before transition from the closure to the post-closure period. Since modelling is the only available option to anticipate the future of a site, comparing the actual and modelled behaviour of the* *CO_2* *plume and providing regular updates of the model is key*

-a ***report comparing environmental status before and after injection****. In particular, this document should highlight the plume location and behaviour*

-site registration*: it is important that future generations be informed of the plume location(s), well locations, geology and potential mitigated impacts*

-site certification *(see below), including consistent requirements for storage licence (in case of potential trans-boundary storage especially)*

-public information/participation/consultation*: this aspect may have been underestimated in some countries and may be a barrier to CCS acceptance*

Finally, regulations should emphasise the need for consistency between site characterisation, numerical modelling, risk assessment, monitoring, and corrective programmes since these phases form an iterative process that will end with site closure and decommissioning.

Research and development

Pursuing R&D in numerous areas is necessary to achieve the above stated objectives. In particular, progress is desired in the following:

-long-term behaviour and impact of CO_2 on reservoir fluids and rocks

-the fate of other substances in the CO_2 stream and their effects

-potential risks from displaced brines and their effects

-long-term integrity of wells

-post-closure well material performance (including potential for corrosion of metal casing or tubing by CO_2)

-monitoring tools and technologies

-CO_2 storage numerical modelling tools

-potential corrective measures

In addition, development of early CCS projects and additional research should help to clarify:

-an acceptable CO_2 stream composition

-the monitoring locations of the CO_2 stream quality and quantity

-the conditions / timescale for abandonment of a CO_2 storage site

2.6.3 Recommendations regarding site certification

Recommendations regarding site certification:

It is recommended to define the term "certification". We suggest that it refers to the validation by a third-party of key milestones of a CCS project's lifecycle. Based on the definition adopted, an adequately robust certification system should be developed. It could take into account some of the recommendations outlined in the above paragraphs.

Chapter 3

STRACO$_2$ Work Package 5
Financing of, and economic incentivisation mechanisms for CCS

Final Report

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3 Financing of, and economic incentivisation mechanisms for CCS

3.1 Introduction

This chapter synthesises the results from the Work Package 5 (WP5) of the STRACO$_2$ project. It focuses on financing of, and economic incentivisation mechanisms for CCS.

The cost gap between CCS and non-CCS operations is currently high, which represents a major challenge for the commercial success of the technology. Although research, development and demonstration (RD&D) will eventually reduce this gap, financing will remain a major issue in whether to deploy CCS - only overridden by administrative policies making CCS mandatory.

These novel aspects mean that CCS investments are associated with large uncertainties regarding their future economic circumstances, which depend heavily on climate and energy policy developments, aforementioned results of research, development, demonstration and deployment (RDD&D), energy prices and public acceptance. Parallel to this, the technology is capital intensive both in terms of direct and operating costs. This adds further to CCS being associated with high investment risks, which mean that first-movers will require special incentives to bridge the higher costs and risks that they will face compared to later projects.

This study has a strong actor focus due to having utilised a stakeholder survey. The actors in WP5 are mainly policymakers, insurance and financial institutions, and industry. What policymakers must accomplish in order to incentivise CCS is to implement policies that reduce costs and risk. Looking at policymakers' options, the policy instruments at hand can roughly be divided into: those that reduce the costs of CCS facilities and operations, and those that provide an added value of engaging in CCS. The study will argue the former is more effective in the early stages of technological maturity and should complement the latter which is more appropriate once the technology is more commercially viable. For this reason the analysis will be separated into these two categories. Looking strictly at financing and incentivisation options, however, does not provide a comprehensive overview of the methods by which different stakeholders can be encouraged to engage in CCS. Such an analysis must inherently also include reflections on disincentives, as to provide an overview of policy obstacles, or barriers.[21] It is important to identify which risks that stakeholders identify as impeding their willingness to engage in CCS activities most.

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[21] This terminology used within the study signifies whether a factor impedes investments, i.e. an obstacle, or whether it effectively blocks investments, i.e. a barrier.

The risk focus is also fundamental in light of the 2008 global economic developments, where investment risks have been firmly placed in the limelight. Which of these risks are most important for CCS investors, and which policy initiatives could be used to bridge them to establish improved or favourable investment conditions, are important aspects for policymaking aimed to finance and incentivise CCS investments, and are analysed in the questionnaire.

The study's objectives include:

- Establishing an overview of the current policy mechanisms promoting CCS
- Identifying technical and non-technical issues preventing CCS being included into the Clean Development Mechanism and the EU Emission Trading Scheme
- Providing recommendations for concrete actions to close remaining knowledge gaps that have been identified
- Developing recommendations on potential CCS policies
- Identifying stakeholder opinions on potential CCS policies and provide suggestions to compromise differences in opinions
- Providing input and disseminating knowledge on financial aspects of CCS (e.g. financing mechanisms)

  Highlighting good policy practice to facilitate China policy suggestions

3.1.1 Method

The study is based on literature and questionnaire surveys. A survey of scientific publications provides a theoretical background to policy theory, CCS policies and issues, and stakeholder opinions. Public documents provide insight into State policies and publications from various stakeholders as well as providing CCS and policy opinions. Other media are utilised to acknowledge the large amount of opinions that are expressed through channels other than scientific and official State documents.

3.2 Review of Incentivisation and Stimulation Policies

Specific CCS policies are relatively scarce due to the technologies' state of development. Policies that affect CCS (e.g. geological, energy and climate policies) are however abundant. In fact, much of the work on establishing CCS policy regimes lies in clarifying the role of CCS in already existing policies. Important policy lessons can be expected in the short-term due to EU and G8 (including China, India and South Korea)[22] goals to deploy 12 (by 2015) and 20 (by 2010) full-scale CCS operations respectively.

3.2.1 General EU policies

Although the EU is currently in the process of developing specific CCS policies on incentivising CCS through the amendments of the EU-ETS, there are a number of other policies that could potentially promote investments in CCS RDD&D through making CCS mandatory. The section also examines relevant policies from the risk analysis and policy obstacle perspective.

Table 14- General EU Policies Relevant to Incentivisation of CCS

Legislation	Aim	CCS and potential obstacles
The 2001 Large Combustion Plants Directive	Aims at gradually reducing the annual emissions of sulphur dioxide and oxides of nitrogen from existing plants. Focus on emissions from combustion plants exceeding 50 MW thermal.	Does not currently include carbon dioxide.
The 2008 Integrated Pollution Prevention and Control Directive	Pollution prevention from industrial activities through implementing technical standards in operational permission processes.	Does not currently include CCS.
The Community guidelines on State Aid	Regulates state aid within the EC	CCS is only marginally dealt with, though it specifically addresses aid to CCS in industrial-scale demonstration plants up to 2015.

3.2.2 Draft Directive on the Geological Storage of Carbon Dioxide

While the draft CCS Directive does not provide any incentives for CCS investments, it does provide some potential disincentives, or policy barriers. Potential disincentives for companies engaging in storage activities include the initial provision that the purity of the gas stream should *consist overwhelmingly of carbon dioxide* and that *all available evidence* should indicate

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[22] This is formulated as a support by the G8 (and China, India, and South Korea) Energy Ministerial meeting in Aomori, Japan, in June 2008, for the IEA and CSLF recommendations to the G8 Summit in Hokkaido, Japan, July 2008. See http://www.cslforum.org/documents/pgtg_ResultsG8-IEA-CSLFWorkshop0408.pdf and http://www.enecho.meti.go.jp/topics/g8/g8sta_eng.pdf.

that the storage is sealed *for the indefinite future*, which would have resulted in elevated investment risks. These and other relevant aspects were also identified by the EP, who in a draft report on the CCS Directive, suggested a number of amendments aimed to reduce bureaucracy and legal risks, and to increase regulatory clarity.[23] These recommendations for amendments were not uncommonly motivated by lessening risks for actors to engage in CCS activities.

Some issues, however, remain in the Directive as adopted by the Parliament.[24] For example, if leakage would occur, the Directive stipulates that the storage permit is withdrawn and that the relevant authority thereafter issues a new permit *or* closes the site, with no guidance on which decision that business could expect. The costs incurred in such events should be recovered from the operator. These two aspects together pose a significant financial risk, which is made worse as the possible occurrence of such events is unforeseeable.

The conclusion is that the regulatory certainty will increase in time but that this will take time as CCS is a new technology and the fact that lessons and precedents for storage may be long in coming due to the storage timeframe. This should be compared to any short term goals for CCS deployment and the risks facing investors in such activities.

3.2.3 Amendments to the EU-ETS as to improve and extend the system

Unlike the incentives for CCS investments, the EU-ETS has a focus on providing incentives for CCS investments. So as to improve the effectiveness, efficiency, and scope of the EU-ETS, the European Commission published suggestions for amending the scheme in a post-2012 perspective.[25] The amendments are positive in that they prolong the trading period to 8 years and contribute to better harmonisation of the EU policy environment. This increases transparency and predictability, which may lead to higher policy acceptance and reduced policy risks. The three most important amendments in the context of CCS are the clarification of its role in the scheme, the rules on auctioning versus free allocations, and the funding of CCS through the new entrants reserve.[26]

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[23] European Parliament, 2008.

[24] The Directive has been endorsed by the Parliament and now awaits the formal adoption by the Council in 2009. See http://www.europarl.europa.eu/ for the text adopted at the sitting of 17 December 2008.

[25] COM(2008) 16 final.

[26] The text included in the study was as approved on the sitting of 17 December 2008. See http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+20081217+SIT+DOC+WORD+V0//EN&language=EN.

The inclusion of CCS in EU-ETS and clarifying the role of technology therein is important, especially as this study will show that ETSs are the main instruments discussed for promoting CCS.

3.2.4 Positions and policies of individual EU institutions

The EU identifies CCS as playing an important role in its future energy system, and CCS has thus developed as a central element on EU climate and energy agendas. The current state of play is to facilitate a framework that ensures that:

- there are no essential policy barriers to deploy CCS
- that CCS is deployed in an environmentally safe and reliable fashion
- that newly constructed fossil fired power plants facilitate space for future CCS retrofits.

A European Industry Initiative on CCS will provide a needed arena for dialogue between private and public CCS stakeholders. Different communications to a large extent acknowledge the specific CCS investment conditions. There is, however, a gap in how this is transposed into actual policy decision. It is important that the EU now remain committed to the outlined initiatives to provide for a framework that will be effective and accepted. It is also a positive development that there are discussions on a stronger inclusion of non-power industry perspectives, which this study will show is lacking.

The specific positions on CCS will be strengthened in the short term due to ongoing discussions on the draft CCS Directive and EU-ETS amendments. No institutional obstacles to a positive CCS development within the EU can therefore be identified, although it is advisable that EU policymakers remain committed to testing CCS through installing a funding mechanism for demonstration plants. In addition, the EIB has instruments to contribute to the specific conditions and risks related to CCS investments in the shorter-term, although the situation is less favourable for commercial projects, that is at present more dependent on long-term operational profitability.

3.2.5 Positions and policies of individual Member States

Member States (MS) generally lack specific CCS policies which are aimed towards incentivisation and/or financing. Due to the wide range of policies that affects CCS, and the few policies specifically targeting the technology, this section will not provide a full policy overview, but will focus on explicit CCS policies as well as positions on the legislative processes regarding the suggested CCS Directive and EU-ETS amendments. A specific policy initiative that stands out is the UK technology competition on CCS, which provides some policy lessons. While a number of MSs have carbon dioxide taxes, we have only been able to identify one country, Sweden, that offers tax deductions for stored or sequestered gas volume. From a CCS position, no MS is against the technology *per se*, but there is some opposition to the suggested funding scheme.

Table 15- Examples of Specific CCS Incentivisation Policies in Member States and the EU

Country	Policy	Scope	Legislative progress
GERMANY	**Subsidy**[27]	COORETEC supports R&D on capture technologies (50 % support for industries)	In force
NETHERLANDS	**Subsidy**[28]	R&D on underground storage of carbon dioxide	In force
SWEDEN	**Subvention**[29]	Full carbon dioxide tax deduction for sequestered carbon dioxide	In force
UK	**Subsidy / Technology competition**[30]	Support for a single post-combustion CCS operation (≥300MW)	In force
	Subsidy[31]	The Hydrogen, Fuel Cells and Carbon Abatement Technologies Demonstration Programme have funds earmarked for CCS	In force
	Subsidy[32]	Environmental Transformation Fund aimed at promoting RDD&D of low-carbon technologies	Proposal in legislative process
EU	**Emissions trading (EU-ETS)**	Possibility for opt-in CCS from 2008-onwards	Proposal in legislative process
	Subsidy	EU-ETS auctioning revenues earmarked for climate investments	Proposal in legislative process

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[27] Innovation Norway and Gassnova, 2008. International CCS Technology Survey (Issue 3), Available at http://www.innovasjonnorge.no (Accessed 6 November 2008)
[28] http://www2.oecd.org/ecoinst/queries/index.htm (Accessed 4 November 2008)
[29] The Swedish Energy Code (1994:1776, Chapter 9, §4)
[30] http://www2.oecd.org/ecoinst/queries/index.htm (Accessed 4 November 2008)
[31] Innovation Norway and Gassnova, 2008. International CCS Technology Survey (Issue 3), Available at http://www.innovasjonnorge.no (Accessed 6 November 2008)
[32] http://www2.oecd.org/ecoinst/queries/index.htm (Accessed 4 November 2008)

3.2.6 International CCS policies

This section provides an overview of international policy regimes on CCS. The countries studied have been selected in view of implementing relevant policies and/or facing similar challenges as China which could potentially be dealt with through large-scale implementation of CCS.

Policies in a number of non-EU countries are identified in Table 16 below, and their positions detailed in the full report.

Table 16- International CCS Policies

Country	**Policy**	**Scope**	**Legislative progress**
Australia	**Regulatory Guiding Principles, November 2005**[33]	CCS offshore and continental	In force
	Draft Offshore Petroleum Amendment (Greenhouse Gas Storage) Bill[34]	Pipeline transportation, injection and storage offshore, property rights and access, safety management, risk identification and monitoring	Under discussion
	Subventions	RD&D through a Low Emissions Technology Demonstration	In force
	Subvention	Start-up of a Global CCS Institute	Under discussion
Brazil	**None specific to CCS**[35]	Not relevant	Nothing planned
Canada	**Regulatory regimes for oil and gas**[36]	Capture/compression + transportation + injection	In force
	Federal Air Emissions Regulations, 2008[37]	Regulation of GHG emissions + incentives for building ”CCS ready” + compliance options	Planned to come into force 1 Jan 2010

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[33] http://www.ret.gov.au/resources/Documents/ccs/CCS_Aust_Regulatory_Guiding_Principles.pdf

[34] http://www.ret.gov.au/resources/Documents/ccs/os_Petroleum_Amendment_Bill_2008.pdf; http://parlinfoweb.aph.gov.au/piweb/browse.aspx?path=Legislation%20>%20Current%20Bills%20by%20Portfolio%20>%20Resources,%20Energy%20and%20Tourism%20portfolio; http://www.ret.gov.au/General/Resources-CCS/Pages/GHGStorageLegislation.aspx

[35] International Energy Agency, October 2008. CO_2 capture and storage. A key abatement option.

[36] http://www.iea.org/Textbase/work/2008/ccs/pdfs/PanelII_2_Canada_LarryHegan.pdf

[37] http://ec.gc.ca/doc/virage-corner/2008-03/541_eng.htm; http://www.ec.gc.ca/doc/virage-corner/2008-03/pdf/pres_eng.pdf; http://environment.alberta.ca/1319.html

	Provincial Climate Change Plans[38]	Regulation of GHG	In force (Alberta, British Columbia, Saskatchewan)
India	**None specific to CCS**[39]	Not relevant	Nothing planned
Japan	**Marine Pollution Prevention Law, 1970, amended May 2007**[40]	Storage	In force
Norway	**Pollution Control Act**[41]	All activities that may cause pollution ⇒ capture, transport and storage of CO_2	In force
	Energy Act[42]	Electricity production, transmission and distribution⇒ capture of CO_2	In force
	Petroleum Act[43]	All petroleum activities ⇒ capture, transport and storage of CO_2	In force
	CO_2 levies Act[44]	CO_2 emissions from petroleum activities on the Continental Shelf ⇒ capture, transport and storage of CO_2	In force
USA	**US EPA-Clean Air Act**[45]	Capture	In force
	US Department of transportation[46]	Transport	In force
	Safe Drinking Water Act[47]	Injection and storage (health and safety regulations)	In force
	Underground Injection Control Program[48]	Injection (part of the SDWA)	In force
	S.2191-Lieberman-Warner Climate Security Act[49]	Cap and trade system Incentives for CCS implementation	Proposed

From the international situation, it is clear that there are large differences in the progress of CCS policies. The policy efforts that are currently being undertaken include a broad span of

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[38] http://www.iea.org/Textbase/work/2008/ccs/pdfs/PanelII_2_Canada_LarryHegan.pdf
[39] International Energy Agency, October 2008. CO_2 capture and storage. A key abatement option.
[40] http://www.iea.org/Textbase/work/2008/ccs/pdfs/PanelII_4_Japan_Maeda.pdf
[41] http://www.regjeringen.no/en/doc/Laws/Acts/Pollution-Control-Act.html?id=171893
III/Miljoverndepartementet/260597/260604/t-1300_pollution_control_act.html?id=260605
[42]http://www.nve.no/admin/FileArchive/379/The%20Energy%20Act.pdf
[43] http://www.npd.no/regelverk/r2002/Petroleumsloven_e.htm
[44] http://www.npd.no/regelverk/r2002/CO2_-_avgiftsloven_e.htm
[45] http://www.epa.gov/air/caa/
[46] http://www.access.gpo.gov/nara/cfr/waisidx_02/49cfr195_02.html
[47] http://www.epa.gov/ogwdw/sdwa/index.html
[48] http://www.epa.gov/safewater/uic/index.html
[49] http://www.govtrack.us/congress/billtext.xpd?bill=s110-3036

initiatives – from reducing investment risks in pipelines, network activities, Public-Private Partnerships and investment funds. Canada, Norway, and the USA can be expected to provide important policy lessons in the short-term as a result of planned and recently implemented policies. These countries, as well as Brazil, can also be expected to provide investor lessons, as a result of the projects that planned within these countries. It is thus recommended that the specific policy measures included here are monitored in relation to their capabilities to promote investments. However, due to a lack of experiences at present it is difficult to provide robust examples of "good policy" within this analysis.

3.2.7 CCS within the Clean Development Mechanism

The international policy aspects also include the potential role of the Clean Development Mechanism (CDM) under the Kyoto Protocol as a potential instrument for a global large-scale dissemination of CCS technologies. The UNFCCC/SBSTA (2008) has conducted a stakeholder survey to support the decision-making process on the inclusion of CCS in the CDM, but no conclusion has yet been reached.[50] Within the debate, there are positive and negative stakeholder groups. The former group (including, for example, China) points to the large potential for CCS in emission abatement scenarios.[51] A strong advocate in this group is the IEA, which made CCS in the CDM their core question in their presence at the COP/MOP4 in Poznan, partly through backing a new CCS Methodology issued by Shell. The adversaries (including, for example, Brazil) mainly base their negative position on CCS potentially slowing down investments in renewable energy technologies and that an inclusion of CCS would reduce the attractiveness for other projects (renewable energy and energy efficiency).

The CDM could potentially be an effective tool in promoting both CCS projects and policy development in developing countries. Looking at the CDM framework – based on evaluated methodologies and contributions to sustainable development – it is, however, not recommended that the CDM is used for this purpose until CCS has been more tested and storage permanence is proven. This is a direct result of current controversies of including CCS in the CDM, potential conflicts in positions on CCS and sustainable development, and difficulties in establishing robust methodologies. These issues could possibly be overcome by RDD&D, providing a potential within the CDM in a post-2012 perspective. A longer-term perspective with stringent emission caps would also reduce the risk, whether plausible or not, of destabilising the carbon markets through large volumes swamping the carbon markets and

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[50] For further and updated information from UNFCCC on this issue, we refer to http://cdm.unfccc.int/about/ccs/index.html.

[51] de Coninck, 2008.

forcing increased regulation of CER utilisation. Regardless of which position is taken by the international community, the trade-offs between CCS uncertainties and action to reduce carbon dioxide emissions should be considered.

While it is not recommended to include CCS in the CDM due to uncertain sustainability aspects, the situation would be different with more strict technology transfer or direct funding mechanisms without such considerations. One such alternative are Nationally Appropriate Mitigation Actions (NAMAs). However the issues that are raised above, and in Chapter xx on cross-cutting issues, may still be argued to question the *appropriateness* of CCS. Moreover, suggestions for legal texts indicate that NAMAs should share modalities with CDM.[52] Thus, the objection on sustainability concerns could be transferred.

3.3 Analysis of stakeholder feedback

3.3.1 Questionnaire analysis

This section will provide an overview of stakeholders and their opinions on financing and incentivisation policy processes, a full version of which can be found in the full report.

The policy analysis of WP5 as well as the STRACO$_2$ project in general has a strong actor focus due to drawing heavily from the stakeholder questionnaire as well as wanting to focus on acquiring up-to-date stakeholder investment perspectives. So as to provide a basis for the analysis, this study provides a conceptual framework for positioning the four main stakeholder groups included in the analysis – governments, financial and insurance institutions, and business. Public ownership occurs in all four groups. The following questions were asked:

- Which are the biggest obstacles to the commercial success of CCS at the moment?
- Which regulatory measures should be taken to facilitate investing in CCS technology?
- Who should take the lead in financing pilot projects and early applications of CCS?
- Please state why?
- Should CCS become part of the EU-ETS?
- Which stakeholders are the most important financers of CCS in the longer term?
- What, if any, problems/barriers exist in the draft CCS Directive by the EC?

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[52] FCCC/KP/AWG/2009/L.2.

- What, if any, problems/barriers exist in the CCS amendments of the EU-ETS directive suggested by the EC?
- What is your view on other regulatory activities in the EU related to CCS (synergies, barriers, opportunities etc.)?
- If you have invested in CCS activities, what was the main driver?
- What, if any, are the main regulatory (policy) barriers for investing in CCS technology?
- What requirements do you put on policy makers to:
  - Initiate, maintain, or increase participation in CCS RD&D?
  - Invest in CCS applications?
- What is your key message to policymakers in order to promote an increased business interest in CCS activities?

3.3.2 Questionnaire main outputs

The majority of the respondents identified several obstacles to investing in CCS. Although some policies are implemented today, they are not enough to promote RD&D activities that can test the technologies, bring down investment risks, prove the legal system, and contribute to the commercialisation of CCS. The key issue here is which measures should be promoted to facilitate investments. Three issues were singled out as being most important, i.e., to:

- introduce financing for demonstration plants to promote rapid commercialisation
- provide long-term, stable, and predictable incentives, preferably through a carbon price
- provide clarity of post-injection liability transfer

The fact that the private sector is engaged in CCS for strategic business reasons, despite a lack of present or long-term policy support, is identified as presenting a gap between current progress and the desired developments of the CCS markets. This situation should be seen by policymakers as a signal that the implementation of policies can be effective from day one. There are clear signs of actors venturing in on the developing market for the production of CCS equipment, resulting in a lack of producers and competition not being an obstacle of major concern. The implementation of CCS by the power producers and industry is, however, identified as associated with larger risks and thus making less progress in terms of positive market signals. The results also imply that policymakers should start addressing the gap between the power industry and non-power industry sectors as well as carbon dioxide emissions from biofuel.

3.4 Survey of Policy lessons

So as to utilise previous research in relevant areas, this section will provide an overview of policy lessons and suggestions provided by implemented policies, relevant research and deployment projects as well as in literature. Due to the shortcomings of experience, and hence, the lack of lessons to be learnt from the few CCS policies that have been implemented, this section includes only provisional results, especially in terms of international policies.

3.4.1 Lessons from international policies

There is little to learn in terms of evidence-based policy lessons that have contributed to positive CCS development. Nevertheless one policy initiative that can be singled out is the *UK technology competition on CCS*. Whether this policy will be successful and, more specifically, whether it will be more successful than other CCS policies, remains to be seen. The initiative can be criticised for having been associated with unpredictable policy management and being narrow in scope. Importantly, looking at the former, this has led to CCS projects in the pipeline being postponed. Nonetheless the narrower scope can be seen as a positive element as it provides clarity and support for stakeholders and technologies that the policy covers.

The main conclusion is that national policies on financing and incentivisation of CCS are in their infancy and policy lessons are thus largely nonexistent. Any policy guidance or investment support would be a step forward – seeing as all CCS investments at this stage contribute to reduced investment risk in the longer term and aid in proving the viability of the technologies involved.

3.4.2 Lessons from CCS research projects

Previous research projects on the deployment of CCS draw on the work of a large number of experts from a wide range of disciplines. Two additional projects whose findings will be relevant in relation to STRACO$_2$ are the UK-China Near Zero Emissions Coal (NZEC) and the Co-operation Action within CCS China-EU (COACH) projects. These are not included here as they are ongoing.

The table below presents the CCS deployment projects and lessons learned for incentivisation:

Table 17- CCS Deployment Projects Relevant to Financing and Incentivisation

Project	**Relevance to STRACO$_2$ WP5 on Financing and Incentivisation**

CO_2 Capture Project www.co2captureproject.org	The project supports the findings that risks and disincentives are two important factors in determining the investment climate for CCS (CO_2 Capture Project, 2007).
European Technology Platform for Zero Emission Fossil Fuel Power Plants (ETP ZEP) www.zero-emissionplatform.eu	The main conclusions, expressed in relation to the EU Flagship Programme, are that the industry should bear the majority of risks and costs of CCS operation, but that "first movers" should share this risk with the EU (ETP ZEP, 2008b). Details of how the costs should be shared through funding support are considered urgent and a number of viewpoints are provided.
DYNAMIS www.dynamis-hypogen.com	The sub-project, "SP6 Societal anchorage of a HYPOGEN demonstration"studies market environment, financial options, legal and regulatory environment, and public perceptions of deploying a future HYPOGEN plant. The project identifies that uncertainty over EU-ETS in a post-2012 perspective is an investment barrier.
ACCSEPT www.accsept.org	The project team concludes that the provision of incentivising is needed for the development of CCS. The proposed mechanisms are a link between CCS and the EU ETS, or the Kyoto Protocol's flexibility mechanisms, and particular measures such as capital grants or guaranteed returns on investment. Poor quality and quantity of information on costs of CCS is considered a clear disincentive for investors in CCS. EU-level policies to consider include a portfolio standard, an emission standard for power production, or an obligation to capture and store CO_2 from all fossil-fuel-fired power production and other large point sources.

The two apparent conclusions that can be drawn from related CCS research projects is that they all identify that financing and incentivisation policies are necessary for demonstration and commercialisation of CCS, as well as seeing that this process is associated with a number of significant risks and disincentives. In terms of including CCS in the CDM opinions vary.

In terms of discussions of policy support for CCS the projects include a diverse set of instruments although all focus on emissions trading as the key instrument. In this context it is argued that measures should be taken to facilitate allocation procedures that are harmonised, more transparent, and longer-term. At current, the EU-ETS is seen as establishing substantial investment obstacles. The latter is also discussed in relation to policy regimes in general and suggestions range from 15-20 year policy horizons.

The need for RD&D to develop a sound knowledge base that can contribute to lowering investment risks is also highlighted. The risk profile is seen to develop positively over time, meaning that private business can assume the risk of commercial projects, while demonstration projects will need public risk sharing facilities.

Combining these two points, the situation where investment decisions are taken many years ahead of commissioning emphasises the need for rapid policy initiatives to accomplish this within a timeframe that may support the current deployment goals. This supports a policy focus on financing upfront costs, rather than operational incentives, as emissions trading at current is not regarded as providing a sound investment and operational financial conditions.

3.4.3 Lessons from CCS deployment projects

This section draws lessons from CCS deployment projects that were selected based on a rating of boiler size, capture volume, planned commissioning date and information availability. The focus of the analysis is on financing structures, stakeholder opinions, as well as investment opportunities and obstacles. The section also analyses CCS projects that have been postponed or cancelled, so as to provide insight into deployment barriers that may occur within a project cycle.

As China has a rapidly growing consumption and extraction of LPG (approx. 18.9 Mt/Yr)[53], we have included analyses of carbon dioxide separation projects in natural gas extraction operations. Research has shown large variations in the carbon dioxide contents of Chinese gas fields (Hao et al., 1996), meaning that the abatement potential thereof varies.

Table 18 presents the CCS deployment projects and lessons learned for incentivisation:

Table 18- CCS Deployment Projects and Lessons Learned for Incentivisation

Project	Relevance to STRACO$_2$ WP5 on Financing and Incentivisation
Mongstad, Norway (R&D)*, Post-combustion	Strong government involvement (investment and cover of additional operating costs resulting from carbon capture) was required to launch the project and secure participation of private partners. The innovative (early starter) and generic character of the project (test facility of CO_2 capture for a range of concentrations in flue gas) convinced EU surveillance authorities to allow state aid.
Weyburn-Midale, Canada Commercial, EOR (gas from industrial source)	An EOR operation enables testing and development of storage at much reduced cost. In addition to strong governmental financing, private investors are willing to pay (limited) participation fees provided that the issue of intellectual property is well addressed.
Kårstø, Norway (R&D)*, Post-combustion	A fully public-financed demonstration plant is needed to promote CCS and support the risks with regard to performance and costs.

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[53] Data based on Jan-Jun production statistics from http://www.chinaoilweb.com (Accessed 12 September 2008)

Snøhvit, Norway Commercial, Separation and EGR	A tax rate of 42 €/ton carbon dioxide makes it profitable to capture, transport and store the carbon dioxide from a nearby gas field and allows for a consortium with a 36.5% participation from the private sector.
Schwarze Pumpe, Germany R&D, Oxy-fuel	A fully state-owned company can use its long-term investment horizon to start a small-scale focussed demonstration project that can be later expanded through collaboration with private partner(s).

3.4.4 Lessons from restructured, postponed and cancelled projects

So as to provide information on negative policy lessons, we also reviewed five projects that have not been able to overcome one or more investment obstacles, rendering the projects postponed (dormant), cancelled or needing to be restructured. This analysis will thus focus on the background and causes of diversion from the initial project plans. The results underpin the argument that incentivising CCS is not only about providing financing options but also working to reduce a number of other policy, technological and scientific risks. It is furthermore evident that postponing and cancelling of projects due to lack of technical or financial feasibility may have different reasons – some of which can be expected and others that are due to developments during the project cycle. We argue that an important aspect is that negative evidence, based on the non-progression of the projects, influences decision-makers, and may increase the perceived investment risk in CCS among other stakeholders due to providing proof of investment uncertainties. This argument is to an extent substantiated by the ETP ZEP (2008a) which regards the 12 projects within the Flagship Programme as a method to “de-risk” investments through proving the viability thereof. Logically, failing to prove viability would conversely “up-risk” investments through the notion that available technologies, know-how and policy structure do not sustain such endeavours.

Table 19- Restructured, Postponed and Cancelled Projects

Project	Relevance to Financing and Incentivisation (Obstacles)
FutureGen , USA IGCC, Pre-combustion (275 MW) (Restructured)	Increased construction costs due to construction material price hikes and inflation
Halten CO_2 Project, Norway Post-combustion (Cancelled)	Less than expected return on EOR (in terms of revenue and oil-volumes)
Killingholme, UK IGCC, Pre-combustion (450 MW)	Amended policies eliminated financial support

Postponed	
Kwinana, Australia IGCC, Pre-combustion (500 MW) Cancelled	Feasibility study deemed storage site unsuitable
ZeroGen, Australia IGCC, Pre-combustion (120/400 MW) Restructured	Reduce investment risk (in terms of technology)

3.4.5 Lessons in literature – a survey

This section provides an actor-oriented overview of cost issues and how incentivisation, disincentivisation and financing of CCS have been covered in literature. Although not comprehensive, the survey includes both scientific and non-scientific (such as policy and position papers) material.

The literature survey covered studies by the following: McKinsey (2008); Sekar at al. (2007); Rubin et al (2007); Odenberger et al. (2008); Barbose et al (2008); Fuss et al. (2008); Blythe et al. (2007); Yang et al. (2008); Bachu (2008b); Wilson et al. (2007); Löschel and Otto (2008); Groenenberg and de Coninck (2008); Jepma and Spijker (2008); Kerr (2008); Otto et al. (2008); Watson (2008); Blanford (2009); EC (2008a); International Energy Agency and OECD (2008); Australian Business and Climate Group (2007) and; UNFCCC (2008).

In terms of the economics of CCS investments, there is a consensus that the high costs of investing in, and operating, a power generation facility with CCS poses a significant obstacle. Cost estimates for CCS operations vary from one study to another. Literature also provides insight into risks relating to investments in CCS, which include policy changes, carbon prices, energy and fuel price fluctuations, and technological risks associated with storage and permanence.

The literature study does not either provide tangible results in terms of experience-based lessons. One issue nevertheless can be identified as the main focus of identified policy barriers and obstacles being emissions trading as the main policy incentive. The literature identifies that there is a need for amended and/or complementary policy approaches to CCS.

The literature survey substantiates the findings of the project analyses and highlights a number of issues that form investment obstacles. One of the main issues in this context is the cost structure of CCS and utilising emissions trading as the main driver for a large-scale growth of

CCS through all stages of technological development. There is, as a result, strong support for adopting parallel policies that can help build a more comprehensive and effective policy framework. While different policy instruments can serve this purpose have been analysed, there is little emphasis on specific suggestions.

Integrated Gasification Combined Cycle (IGCC) appears to hold the greatest economic potential for CCS due to low capture costs. However, as IGCC, like CCS, has low maturity, the commercial potential of joint operations thereof may be postponed due to double risk premiums. This implies that while IGCC/CCS RD&D is of obvious importance, policymakers should also promote separate efforts as these may be easier to realise due to lower investment risk.

An increased cost range with CCS compared to non-CCS operations point towards an increased construction cost-risk, which has been further emphasised due to construction commodity price hikes.

3.5 Gap Analysis

3.5.1 Barrier/Gap analysis for the CCS policy developments

The analysis points towards several important and interrelated gaps in the promotion of CCS. First, there is a significant cost gap between CCS in the demonstration phase relative commercial applications. The second gap is the current discourse that to a large extent focuses on emissions trading, such as the EU-ETS, which is not expected to provide enough incentives in the current, early stages of maturity, to bridge the cost gap. This means that the commercialisation of CCS is not expected to match the deployment goals for full-scale and commercial operations. Looking at the deployment goals that exist and the estimated role of CCS in medium-term scenarios, there is a *third* gap based on a consensus that current policies will not support the stipulated deployment.

To fill these gaps, i.e., facilitating the desired development trajectory, additional policies will have to be implemented. These should be focused on basic R&D as well as demonstration activities, where the latter could be considered a pinnacle issue from the narrow timeframe in which the Flagship Programme should be accomplished. Policies supporting this development within the given timeframe (until 2020) would be most effective in the form of subsidies to the extent that such can be raised.

3.5.2 Knowledge Gaps

Another, *fourth*, gap can be identified in terms of knowledge. This is mainly attributable to the weak capacity base in analysing CCS components, investments conditions, as well as the full infrastructure. In terms of capture there is a need to increase R&D so as to explore which technologies will be most cost and capture effective under different operational conditions. This is important to avoid a lock-in of unfavourable technologies. In regards to transport, there are fewer gaps due to gas transports being more of an everyday business activity. Storage is the aspect of CCS that is associated with the largest gaps in knowledge. This is, inter alia, a result of a vast geological stratum, costly exploration of storage sites, long-term permanence, and tectonics. Increasing this knowledge in practice can remove certain gaps but storage analyses will generally have to be taken on a theoretical knowledge base.

In general terms, there is also a common gap between policymakers and business with regards to understanding of each other's viewpoints. In order to close this gap and to maximise available expertise, the arena for dialogue, and the dialogue itself, between the relevant stakeholders, need to be improved. Parallel to this, there is also a gap in the common terminology used among the stakeholders in the policy processes. Such lack of understanding could reduce the effectiveness and efficiency of the policy processes.

3.6 China Applicability Research

3.6.1 Introduction

With the rising environmental cost of China's rapid development, Environmental and Climate Change policies become an increasingly sensible option, both economically and financially. The country is therefore rapidly expanding and diversifying its financing and incentivisation mechanisms for more sustainable means of energy production.

Considering China does not have mandatory emissions caps, there is no compelling financial incentive or governmental regulation to reduce CO_2 emissions through CCS, which is necessary to compensate for the high additional costs of CCS. Moreover, since the overall public financial resources for CCS are limited, other climate change mitigation options such as renewable energy and energy efficiency are given priority for financing incentives.

The position of CCS in the overall climate change strategy and policy in China has a fundamental impact on the availability of financing incentivisation for CCS. Energy conservation is highlighted as a "basic national strategy" in China's Energy Situation and Policy, resulting in much greater focus on energy efficiency than CCS. In China's 11th 5-year plan, the energy conservation target is set as a 20% decrease in energy consumption per GDP in 2010 compared to the 2005 levels. The target is ambitious and requires a series of policy and financial instruments in order to be achieved. In the recent China's National Strategies and

Actions towards Climate Change, the energy conservation and efficiency improvement is again stated as a prioritised national strategy to mitigate climate change.

Renewable energy is also clearly stated as a priority to enhance China’s energy supply capacity in China’s Energy Situation and Policy report, once again taking a higher priority than CCS.

As CCS development is in its infancy, greater focus should be placed on financial incentivisation for demonstration plants in the short term to gain experience and acceptance for CCS in China. Once the technology is successfully demonstrated, seriously exploring financial incentives for commercial deployment is possible.

3.6.2 Chinese Stakeholder Structure

The most significant difference between Chinese and EU stakeholders is that central government in China will play a fundamental role if CCS becomes viable in terms of policy formulation, guiding CCS development, sourcing finance and providing incentives. The key governmental organisations potentially involved with financing and incentivising early CCS deployment include: Ministry of Finance (MoF); State-owned Assets Supervision and Administration Commission (SASAC) and; Development banks and Commercial banks.

Furthermore, since the uncertainty of CCS investment remains high, both in China and in the world, very few private financial institutions will be involved in CCS in China at the demonstration stage, therefore, the financing of CCS could depend on public financing institutes or international assistance. Among public CCS investors in China, resources including experiences, financial capacity and facilitations are mainly held by the state-owned oil companies such as Sinopec and PetroChina, and power companies like GreenGen. These actors are already engaged in CCS-related activities, and could be key to future CCS demonstration.

3.6.3 Political Incentivisation

While currently not a top priority, CCS is still regarded as a promising technology option for China to reduce emissions from its high dependency on coal generation power. CCS is identified as a key area of research and development in the recent China’s National Strategies and Actions towards Climate Change and Technical Actions to Combat Climate Change in China, and the earlier China’s National Climate Change Programme. According to officials contacted by the consortium during this project research, the inclusion of CCS into the twelfth Five year plan was under consideration. An inclusion into the main instrument of Chinese economic planning would obviously open many new opportunities for CCS financing in China. Examples identified were facilitation grants with low interest rates, bond financing and tax incentives through support from the NDRC and the MoF.

The most important aspect would be policy certainty. As the current position of Chinese government institutions does not openly prioritise technology, industries contacted by the consortium named policy uncertainty as a major hurdle for their investment.[54] Therefore, early regulation as well as policy prioritising will be beneficial to the development of CCS.

With CCS becoming incorporated in China's climate change strategy, any financial incentive mechanism or policy should be designed in a manner that considers other incentivisation models being developed around the world, but tailored to the Chinese context.

Liang and Wu argue for the need of a regulatory framework with reliable standards to incentivise investment into CCS.[55] For Liang and Wu this political certainty includes a guaranteed continuous flow of qualified CO_2. As CCS is a multilayered process regulation has to keep in mind that all parts of the CCS cycle must be operational at the same time. Cost would also be driven down by guaranteed high level support for international co-operation projects. Risk standards should become part of regulation.

3.6.4 Relevant Policies and Potential Incentive Schemes in China

Financial incentivisation schemes in China support key priority areas of renewable energy and energy efficiency. Exploring these climate change-friendly financing programmes currently utilised in China provides examples of approaches to potentially fund CCS demonstration plants. Specifically, a series of innovative green financing schemes have recently been developed and adopted for the energy conservation programme, which cover various tools such as research funding, taxation, fee-charging and pricing, insurance, emission trading, eco-compensation, government procurement and phasing out mechanisms. In the full report, a summary of promising financing incentivisation mechanisms explored through the Chinese perspective of applicability for CCS demonstration and subsequent deployment is presented.

3.6.5 Subsidies

A non-distortion subsidy approach to promoting clean development is to use feed-in tariffs which create regulatory advantages that fix a fee per unit of renewable electricity produced to compensate for the relatively higher costs of the projects in comparison with energy production based on conventional fossil fuel. The main two approaches are:

1. **Feed-in tariffs (FIT)**: a fixed amount of money (tariff) is paid for the electricity produced. The producer who receives a feed-in tariff effectively sells his electricity to the payer of the fee, usually national government.
2. **Feed-in premiums (FIP)**: a fixed fee (premium) is paid only to compensate for the financial gap of renewable electricity. With this approach, the electricity is sold separately on the regular market.

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[54] Talk between European industries and consortium researchers on ---April 2009, Beijing.

[55] Liang & Wu, 2009, p. 2424.

Liang and Wu see subsidies as the main driver of CCS investment in China until the technology becomes commercially viable.[56] In the long term this should then take the form of tax exemption, and banking and private investment subsidies could also take the direct form of pricing rights for clean energy companies. This view was also supported by Chinese industry when contacted by the consortium.

3.6.6 Taxation

China has been discussing the levying of environmental taxes for some time and some experts have called repeatedly for establishing a carbon tax. While it will be very difficult for CCS to take priority over other technologies as mentioned above, when it comes to subsidies and financial state aid,[57] a carbon tax would serve the dual purpose of making funds for CCS R&D available, but more importantly incentivising investment in demonstration projects assuming that stored CO_2 would be counted as non-emitted by the tax authorities.

Industry stakeholders active in China nominated a carbon tax as the main driver that would incentivise industries to invest in CCS demonstration plants. This finding is also backed up by the results of Liang and Wu.[58] The implementation of a carbon tax could be an efficient instrument to fund CCS demonstration plants. The revenue from the tax could be employed to fund CCS projects at the up-scaling phase and facilitate the consolidation of the technology. Alternatively, the Chinese government could use part, or all the revenue from the tax, to create a fund aimed at financing CCS projects. This approach is widely used throughout the EU at the MS level.

In China, the Government recently decided to increase the refined oil consumption tax rather than impose a new fuel tax as previously announced. The consumption tax is paid by refiners and importers who consequently pass the cost on to consumers. The tax is levied on seven refined oil products rather than just on the pump/retail price of petrol and diesel. Under the initial fuel tax scheme, tax revenues would replace road tolls as a means of financing motorway construction and maintenance works, with local governments receiving the necessary funds in proportion to local road use. Similar mechanisms are possible for CCS infrastructure if prioritised in the future.

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[56] Liang & Wu, 2009, p. 2426.

[57] Talks between $STRACO_2$ researchers and fiscal think tank June 2009.

[58] Liang & Wu, 2009, p. 2426.

3.6.7 International Financing

In September 2007, the EIB launched the €100 million Post-2012 Carbon Fund. The establishment of the Fund is one of the outcomes of current co-operation in the field of climate change between the EIB and three European national financing institutions: Instituto de Crédito Oficial (ICO), KfW Bankengruppe and the Nordic Investment Bank (NIB).The Post-2012 Carbon Fund is designed to support the market value of CERs produced after the expiry of the Kyoto Protocol in 2012.

The EIB agreed to provide a €500 million loan to China to underpin its efforts to mitigate climate change under China's Climate Change Framework Loan (CCCFL). The CCCFL is a large-scale, multi-investment scheme designed to support investment in projects in the energy and industrial fields to help reduce emissions. It is intended for a broad spectrum of project types including projects using renewable energy, energy efficiency, afforestation and CCS. Priority will be given to projects that: result in a significant reduction in greenhouse gas emissions; generate CDM carbon credits; and result in co-financing activities with other international or multilateral financial bodies.

Another source of funding for CCS technologies may be represented by multilateral development banks, like the Asian Development Bank (ADB). Such financing institutions can play a crucial role by providing funding, risk mitigation products and, they can also offer private capital flows by absorbing political risks so as to give greater certainty to investors.

3.6.8 Emission Trading Schemes

In China, the applicability of a carbon trading system for the funding of CCS plants, either for the demonstration or the full implementation stage, is not eligible for offset credits under Phase 2 of the Kyoto Protocol and China does not have a mandatory cap and trade system. Negotiations are underway regarding the inclusion of CCS in CDM. China has only recently allowed the creation of local voluntary frameworks that attempt to encourage domestic companies to take part in emission reduction schemes. Liang and Wu propose a national emission trading scheme to be established and used for CCS.

In terms of financing CCS plants through emission trading, another potential funding source is to allocate part of the revenue in the National CDM Fund under the Ministry of Finance, obtained from tax revenues on the sale of CERs. Alternatively, a floor price could be set for CO_2 as in the case of CDM certifications. This option would rely on the compliance of the Central Government to guarantee extra financial support for CCS or to create a specific fund for this aim. A floor price for CERs has been unofficially set by China’s Designated National Authority (DNA) in the past and, this mechanism has been flexibly employed by the Chinese authorities. The establishment of a set price for CDM carbon units has had some positive impacts on the market, most notably the provision of a financial incentive to invest in projects that are deemed particularly risky in nature.[59]

3.6.9 Existing Technology Research Platforms

Table 20- Existing Technology Research Platforms in China

Research Platform	Funding potential for CCS research
The National High Technology Programme (also known as 863 Programme)	Potential source of funding for CCS related research especially in the field of R&D of new technology and modernisation of the energy-generating sector. One of the central objectives of the Programme is to incentivise breakthroughs in key technologies for environmental protection and energy development to stimulate the sustainable development of Chinese society.
The National High Technology Programme	Could be useful for the initial phase of the CCS implementation pathway, which focuses on capability building strategies and small-scale demonstration initiatives.
National Basic Research Program (also called 973 Program) (MOST)	Unlikely to contribute significant financial reserves required for CCS demonstration. Generates studies of innovative scientific issues related to priority topics, including energy and resources and environment. Funding for projects is between 20-30 million RMB over a span of 5 years.
National Natural Science Foundation	Plays an important role in research and promoting strengthened CCS research if the government identifies it with priority status as was nominated by stakeholders.

3.6.10 Public-Private-Partnerships (PPP)

A PPP is based on the fact that the concerns of private investors associated with the long-term uncertainties and perceived risks associated with CCS may be alleviated by allocating demand risks to governments. Private investors would then be responsible for payment on the basis of carbon captures or performance targets that could eventually be recovered by sales of carbon credits or by raising electricity fees. Without public funding there will be little investment, especially in the context of first-movers. Government involvement as a funding body will ideally progressively downsize in the long term but is deemed crucial in the initial phases of funding. The prerequisite of PPP is that government ensures private investors achieve average profits.

3.6.11 Capture Ready

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[59] WWF, The Value of Carbon in China, 2008.

While Capture ready and the provision of infrastructure is not directly a way of incentivising or financing CCS in China, both are ways of lowering the costs and overcoming disincentivisation challenges for the speedy deployment of technology in China.

3.6.12 China Applicability Conclusions and Recommendations

Significant financial incentives are required to enable CCS for any type of project in China. International or Chinese governmental clean technology subsidies or grants will be required in order to incentivise the demonstration phase. If the demonstration proves successful, further incentivisation such as carbon financing, feed-in tariffs, PPPs, and favourable financing terms will be required for wide-scale deployment. Without such incentives or stringent regulation, the cost of attaching CCS to power generation projects in China will not be feasible.

To support regulation that incentivises CCS deployment in China, the consortium gives the following recommendations:

Recommendations to the EC:

Start a dialogue with all financial institutions on incentivising CCS, including the Research Institute of fiscal science on taxing, but also SASAC, commercial banks and the Grid companies on how to incentivise CCS in China, pointing to the first financing models in the EU.

Co-operate with Institutions like EIB, ADB, IFC and others to make loans available for CCS deployment in China.

Recommendations to the Chinese Government:

Make Capture ready mandatory for all new power plants from 2015 (assuming that demonstration plants work in China.)

3.7 Conclusion: Discussion and Recommendations

The discussion and recommendations of financing and incentivisation policies begin with a background on the importance of a common terminology to facilitate an effective and efficient dialogue. Against the background of CCS being a novel technology, this and other related aspects will be developed into policy implications and recommendations relating to investment risks. This aims to nominate which risks pose the main investment obstacles in theory and practise. It will also provide insight into how policies can be designed to reduce financial uncertainties of deploying technology. As risk management in many instances is paramount to facilitating investments, this study also analyses which risk-sharing between governments and business could incentivise deployment of CCS. Based on requests from the DG ENV, recommendations are first discussed in terms of novel policy approaches. Emissions trading is included seeing the dominant role thereof in discussions on financing and incentivisation policy. The discussion is concluded by recommending a stronger network to acknowledge the infrastructural challenges and multitude of stakeholders involved in CCS.

3.7.1 Main identified policy issues

3.7.1.1 Establishing a common understanding

All policy design and management processes should be based on a common terminology that provides a dialogue that is fully understandable to all included parties.

3.7.1.2 The main investment risks

The main subject of this section is to discuss different risks and how they affect investments in CCS. The risks included are mainly those that have been identified in the questionnaire (Section 3) and policy lessons survey (Section 4). This includes uncertainties in terms of policies, costs, technologies, interdependency and storage.

-***Higher costs and cost uncertainties of implementing CCS***
To promote investments in demonstration plants, businesses require some form of cost alleviation. This will in the short-term, and to some extent in the medium-term, have to be in the form of policies that mitigate upfront costs rather than operational costs. While both costs will be reduced with RDD&D, the upfront costs are identified as the greatest obstacle within the demonstration phase. In a longer-term perspective, when there is a functioning infrastructure and technologies with tested operational reliability, the policy focus should be on incentives. Current policies do not provide the desirable policy support to promote these investments.

-Policy uncertainty
Lack of financing and incentivisation policies is associated with absence of a long-term policy framework. There has also been a past risk of how present policies would be adopted so as to facilitate CCS (such as OSPAR, etc.). These policy issues have largely been dealt with, and in an EU context the issue has been largely resolved. In an international context the situation may still be an issue although a number of policy initiatives in this area have been identified.

-Storage as a long-term risk

Storage is accompanied by special risk conditions in that both liability and monitoring are long-term issues. A full infrastructure will reduce the operational risks but in the timeframe of commercialisation of capture, the longer-term risk can only be evaluated theoretically. Longer-term permanence will be a continuous risk that can only be mitigated by time, during which period some form of risk management must be offered to facilitate investments on a broad scale. Storage risk is also one of the main concerns in including CCS in the CDM and a more robust knowledge base on permanence should thus be promoted.

-Interdependency

Interdependency of the different stages of the CCS infrastructure imposes a risk for each stage, as each operator will be dependent on the others to carry out the operations. This establishes uncertainties when it comes to who should move first.

-Risk developments over time

While many risks associated with CCS can be mitigated over time others may increase. How the different risk profiles develop over time have implications for investors. The risk profiles include policy uncertainty, storage risk, infrastructure independency, technology maturity, joint risk profile and joint investment risk profile. These are detailed in the full report.

3.7.1.3 Policy recommendations

This section will primarily focus on policy approaches that have been less explored in previous CCS research. The recommendations are based on the analysed stakeholder views and literature. Suggestions include green bonds and feebates, while also include discussion on the difficulties of ETSs as the key policy measure. Not a policy instrument *per se*, but rather a policy process, are public-private partnerships which may, or may not, include policy instruments.

Recommendation 1*:*

Designing a long-term and predictable policy framework

All actors, including policymakers, identify long-term policies as essential. The uncertainties on the final economic, technical, and environmental effects of CCS means that the policy focus should be on RD&D until it is proven that CCS can be achieved in a safe, cost-efficient, effective way with secure long-term storage. This places special conditions on current CCS policies. They must be able to promote investments in high-cost forerunner projects possibly without assuring long-term support for the activities. Given the potential appointed to CCS by government funded organisations (such as IEA and IPCC), policymakers should include CCS in the policy roadmap so as to send a clear signal that CCS is feasible and viable. To *lessen the risk for the forerunners, governments should play an important role in funding demonstration projects.*

Recommendation 2*:*

Financing

While the study argues that governments cannot reduce emissions because they do not manage the emitting sources, this must not necessarily be the case for pilot and demonstration plants. The questionnaire indicates that industry called for governments to venture into technology deployment. While this could be possible in the shorter-term, it is definitely not an option in the long term where CCS is commercial. An important aspect of governments backing CCS investment is that it provides that policymakers are confident in the technology, which may promote followers from the private sector. Public and private investment and development banks have an obvious role in the financing of CCS. Public and private funding, and incentives, for RDD&D will be needed in the long-term.

Within the EU, a common investment vehicle is SICAV (Societe d'Investissement a Capital Variable). A SICAV company has high flexibility in its financial structure in that it can freely issue stocks within different funds categories, which opens projects up to various investors to partake in funding on different levels in a dynamic environment.

Another financing option is to promote and adopt bond initiatives on different regional and technology specific levels. Green bonds show tangible benefits – i.e. broad participation, potential for competitive environment in fundraising, and a long-term resource base.

Recommendation 3*:*

Financing and incentivisation through voluntary agreements

Another policy option could be to implement voluntary agreements (VAs) designed to promote investments in CCS. Such agreements are signed by a government and industrial entity, where the governments offer an investment incentive in return for the industries to carry out some form of activity. While there are different VAs depending on which role the industry plays in designing the contract, the type generally regarded as most effective are negotiated agreements where the industry in fully engaged in designing the contract.

Recommendation 4*:*

Incentivisation through refunded emission payment schemes (Feebates)

Several policies can be used for incentivisation and many have been tested and proven efficient in promoting renewable energy. One especially interesting instrument in a CCS context is feebates - or refunded emission payment (REP) schemes. These constitute a benchmarking policy which either imposes a fee or offers a rebate depending on how an operation compares to other operations in the scheme. While emission tax is imposed on all actors, feebates reward emitters that reduce emissions.

Recommendation 5*:*

Incentivisation through emissions trading

In the discourse of policy incentivisation mechanisms, emissions trading is the option that is most commonly discussed. But emissions trading schemes, such as EU-ETS, as identified in the literature survey, are not effective in promoting technology development and favouring "near market technologies". Additional obstacles can reduce effectiveness of a policy agenda with a narrow focus on incentivisation through emissions trading.

Recommendation 6*:*

Capture readiness

In preparing for a policy framework for CCS and so as not to establish obstacles for incentivisation and CCS implementation later on, policymakers should consider capture ready.

Recommendation 7*:*

Sharing risks and managing risk issues over time

As seen in the risk profiles, costs and risks do not always match. This opens up discussions on which risks that business should assume and which risks that governments should assume. Seeing the costs and the investments barriers that CCS stakeholders identify, we argue that policymakers should consider the potential for easy access to storage (to minimise infrastructural investments). In the storage sector, the governments could provide indemnity for the first operations based on performance contracts.

A public-private risk sharing option posed by Vattenfall,[60] *acknowledges the diverse stakeholders in CCS projects, noting supplier and industry co-ownership of capture facilities. This would mitigate risk by strengthening trust between different actors and in the delivered product.*

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[60] See https://www4.eventsinteractive.com/iea/viewpdf.esp?id=270005&file=%5C%5Cserenity%5CEP11%24%5CEventwin%5CPool%5Coffice27%5Cdocs%5Cpdf%5Cghgt%5F9Abstract00561%2Epdf (Accessed 19 January 2009)

Recommendation 8*:*

A network facility

In order to maximise the utilisation of early experiences and to handle the infrastructural interdependency risk, a network facility should be set up to exchange information on planned and anticipated technology, projects and infrastructural developments.

3.7.2 Measures to fill main knowledge gaps

The two main measures that should be considered by policymakers in an effort to promote CCS investments and reduce risks are RD&D on fundamental technology aspects as well as policy learning.

Recommendation 1*:*

RD&D on fundamental technology aspects

This is especially important in the short-term, as to bridge the gaps of technology-related knowledge capacity. An example of the need for this comes from the stakeholders who raised concerns of which capture technology will eventually be the most successful. Other aspects include infrastructural interdependency, long-term storage permanence, and full-scale CCS feasibility and viability.

Recommendation 2*:*

Policy learning

Policy learning, comprising the inclusion and consideration by policymakers of policy knowledge in the policy environment, is important in all policy processes. There is also a need for stakeholders outside of policymakers and business to learn about CCS infrastructure and policies.

Chapter 4

STRACO$_2$ Work Package 6
Cross-cutting issues, CCS consistency with EU's sustainability and industry strategies and policies

Final Report

Project Leader
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KTH

4 Cross-cutting issues

4.1 Introduction

This chapter is the synthesised result of the Work Package 6 (WP6) of STRACO$_2$. It deals with the crosscutting issues and more specifically the interrelationship between technology, environment, society, economic feasibility and regulatory design for CO$_2$ capture and storage (CCS). This chapter deals with policies and regulations to ensure that CCS implementation and use is in line with sustainable development as well as industry policy ambitions.

Two of the most important European Union (EU) strategies are the Lisbon Strategy and the EU Sustainability Strategy (SDS). The two strategies are often said to be complementary. While the SDS is primarily concerned with quality of life, intra- and inter-generational equity and coherence between all policy areas, the Lisbon strategy focuses primarily on competitiveness and economic growth and job creation.[61] This chapter gives an overview of CCS policies and initiatives in the EU compared to state of the art technology available, using Member State (MS) and international policy examples. The objective has been to gather knowledge about the EU experience and apply it to the Chinese process of developing a climate policy, a binding emission reduction target and potential future development of CCS including suitable legislation.

The topics were decided during the first and second STRACO$_2$ expert meetings, and include industry and competition policy, intellectual property rights (IPR) and research policy, and impact assessment (IA) policies. Applicability for China regarding these issues is also assessed.

The two overarching research questions are:

- What are the critical factors highlighted in EU policy documents regarding CCS regulation and policies in order for CCS to be compatible with the European industrial policy aims of maintaining international competitiveness and securing jobs in the EU?
- What are the challenges in assessing CCS' strategic role in a portfolio of mitigation options and its potential contribution to sustainable development?

4.1.1 Method

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[61] Council of the EU, 2006; EC, 2005.

This chapter is foremost a literature study, where the writings of the directive proposal on CCS and its impact assessment have been compared to EU, MS, and international policy examples as well as scientific literature on the subject. The views of different stakeholders regarding CCS policy and regulation are assessed through a literature study and a questionnaire. The focus has been on identifying gaps where either more research or political action is needed, or new/improved assessment tools are justified, or political and societal discussions warranted.

4.2 CCS as Industrial Policy

4.2.1 CCS regulation as industrial policy

The aim to stimulate the timely introduction of CCS is often seen as an important part of climate change policy. There is an urgent need to promote the research, development, demonstration and deployment of technology (RDD&D) as well as stimulate technology transfer to regions like India and China where fossil fuel consumption grows most rapidly. CCS regulation development is also an issue of industrial policy as it may be important in keeping European industry competitive in a global economic environment, which in the future will likely be dominated by an emissions restrictions framework.

The following section will examine CCS regulation from the perspective of industrial policy providing insights into, and recommendations on, how CCS regulation and policies can help facilitate reaching the aims of European industrial policy, the first of which is international competitiveness for European industry to secure jobs in the EU.

The EU has a long tradition of supporting growth of new industries through its industrial and competition policies. Industrial policy is understood as policy aimed at fostering development of industries within a political realm, in this case the EU.[62] It is horizontal and aims to secure framework conditions favourable to industrial competitiveness. Successful introduction of CCS in Europe can help keep European industry competitive by lowering production costs caused by emissions in the future, preserving European industry’s leading role in climate change technology, and thereby opening new markets for European industry. Countries like India and China are expected to become the most expansive future markets for CCS. It is of strategic importance for EU industry to get a share of such markets.

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[62] see Federico & Foreman-Peck, 1999.

Industrial policy goes beyond codified regulation and financial incentivisation. It can influence industrial development through competition policy, research policy, information policy and societal policy. Unlike incentivisation, which encourages individual stakeholders in industry and finance to invest in CCS, industry policy is the governance process that coordinates branches of governance, research, industry, competition, trade, etc., with an aim to fulfil industrial targets.[63]

While scientific literature on industrial policy is abundant, literature that includes climate change issues is not. CCS was until recently seen as a climate change or environmental issue, so academic research on its development in the EU is limited. This section thereby first must identify the body of CCS regulation as part of industrial policy, looking at the change towards a climate change and environment-oriented framework that EU industrial policy took after 2004. It will then look at existing regulations on CCS and how they interact with industrial policy, namely the CCS Directive in the EU. This will be followed by a review of the different policy instruments namely competition policy, research policy and other relevant policy areas.[64]

This section, section 2, relies mostly on EU industrial policy documents and the STRACO$_2$ questionnaires. It also draws on research done in other areas of industrial and competition policy. The gap analysis at the end of this chapter draws primarily from literature, and results in recommendations on policy and regulation aiming to facilitate industrial policy goals in CCS.

4.2.1.1 EU industrial policy and climate change

The general basis of EU industrial policy dates from the October 1990 communication “Industrial policy in an open and competitive environment: guidelines for a community approach.”[65] It aims to provide framework conditions for entrepreneurs and business to take initiative, exploit their ideas and build on opportunities. Openness of the markets and competitiveness of industry are viewed as key to market survival and three factors of industrial competitiveness are most relevant: knowledge, innovation and entrepreneurship.

The Lisbon agenda detailed the aims of European industrial policy as making the Union “the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the

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[63] For a more detailed discussion of incentivisation see WP5.

[64] Incentivisation, while identified above as an important industrial policy issue has been discussed separately in WP5 and is therefore not a focus of WP6.

[65] EC, 1990.

environment by 2010."[66] These aims were further developed in the following policy making process, climaxing in the 2004 Kok report.[67]

4.2.1.2 Instruments and Institutions of industrial policy in general

The legal basis and definition for industrial policy can be found in the European treaty system as described by the European Parliament: “While the ECSC (European coal and steel community) Treaty and the Euratom Treaty may be regarded as having established policy for two key industrial sectors, the EC Treaty, which covers all sectors of the economy, does not make any reference to an industrial policy. However, the treaties contain many provisions, on which a common industrial policy can be based. An industrial policy may be construed as the overall application to industry or certain sectors, of all the general treaty provisions with a view to accelerating the process of resource allocation among and within the various sectors. The Maastricht Treaty modified the EC Treaty [Article 157 (130)] in order to provide a legal basis for a common industrial policy. It enables the Commission to propose measures to improve the competitiveness of European industry. However, the Commission must have the Council's unanimous support to conduct industrial policy operations.”[68]

The Commission therefore has the right, and duty, to promote the development of new industry that it sees as instrumental in reaching the overall goals of EC industrial policy, as long as it has Member State approval through the Council. However, most industrial policy is carried out by the Member States themselves. The EC thereby has a coordinating role between different industrial policies of Member States. The Directorate General for Economy and Trade is leading industrial policy with help from DG Research, DG Competition and DG Environment among others on the European level. In Member States, industrial policy is mostly executed by the ministries of economy or industry, with support from agencies responsible for finance, research, infrastructure and increasingly environmental protection.

4.2.1.3 Climate change as a framework for industrial policy

With climate change now widely accepted as a framework for all forms of policy, industrial policy aims must be adjusted. For new low carbon technologies, this means foremost two specific aims: to keep the EU as a development and production base for high-end technologies, so as to gain the first mover advantage and not only dominate European, but also export markets and; to improve energy security for the European industry under the constraint of emission reductions, which will increasingly be implemented in European industry.

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[66] see EU, 2008.
[67] Kok, 2004.
[68] EU, 2009.

This changing industry environment was targeted by the Commission's release of its energy and climate change package in January 2008, of which the CCS draft directive was a part. The Commission repeatedly pledged to help European industries in facing the pressures of climate change.

To keep the move to climate change mitigation from becoming a competitive disadvantage, the EC wants to encourage climate change policies in partner nations, like China, Russia, India and the US, through trade policy to create a "global approach to climate change" that will create opportunities for innovative green products from the EU. EU industrial policy will also continue to focus on cutting administrative burdens for enterprises, improving the EU intellectual property framework to encourage research and innovation, and promoting clusters and "lead markets" to enhance co-operation between business, research and consumers.[69]

4.2.2 Instruments and issues of EU industrial policy in the field of CCS

With a technology like CCS, which demands a concerted approach by Member States and EU-institutions, the legal and policy environment that these institutions create plays a major role in deploying the technology successfully. In this regard, incentivisation plays a major role but so do direct state intervention, mandatory rules, research policy, resources policy and trade issues. In recent years, industry leaders and politicians alike have voiced fears about the EU's manufacturing base moving out of Europe to benefit from cheaper labour and lower social costs in countries such as China and India.

To counter this threat the EU tries to get the "first mover" advantage and the corresponding export benefits from these markets, since scenarios show that from 2020 onwards CCS may rapidly be deployed in developing countries with large coal reserves. Co-operation with developing countries plays a major role in facilitating market access in emerging economies, for European stakeholders who are willing to invest in costly RD&D.

For CCS, competition is currently confined to RD&D, and nations and corporations strive to become the first to build a full scale plant. The European flagship project is an important step for the EU to prove the availability of European CCS technology to the global market.

The Commission, as the main guardian of European competition policy, must also ensure that CCS technology does not develop into a monopoly for one industry consortium, but it remains

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[69] Euractiv, 2007.

available at market prices and it facilitates the early introduction, which also extends to the accessibility, of relevant resources like pipeline transport and pore space for the storage of CO_2.

An analysis of European and Member State industrial policy follows, with insights into international examples and references to scientific literature. While industrial policy may consist of a range of measures and instruments, the focus in this section is on direct intervention, research and innovation, competition and export markets.

4.2.2.1 Political and regulatory framework

The importance of CCS for the EU's industry is stressed in the climate action and renewable energy package decided in December 2008. It is stated that, although the different components of CCS exist and have been tested both in large scale and in some instances in pilot scale, it is now crucial to build and test integrated systems. It is thought that research and development will bring down cost and development of a suitable regulatory framework and will help guarantee that CCS is implemented in an environmentally friendly way: "... technological costs need to be reduced and more and better scientific knowledge has to be gathered. It is therefore important that EU efforts on CCS demonstration within an integrated policy framework start as soon as possible, including in particular a legal framework for the environmentally safe application of CO_2 storage, incentives, notably for further research and development, efforts by means of demonstration projects as well as public awareness measures."[70]

With the CCS Directive in place as of April 2009, there is hope that this directive will lead to the deployment of CCS in a way that does not compromise health, safety or environment. However, the parliament recognises that further legal decisions are needed to push CCS towards commercialisation. The following is one of parliament's amendments: "Besides a legislative framework or storage sites, incentives for further development of the technology, support for the installation of demonstration plants, as well as a legal framework created by the Member States for ensuring transport, should be put in place as quickly as possible in order to successfully advance the use of CCS technologies."[71]

4.2.2.2 Research policy

While direct intervention and subsidies may be important to get CCS up and running, research is required to make CCS a viable technology that does not require financial support.

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[70] EU, 2009.

[71] European Parliament, 2008.

Research policy is a cornerstone of EU policy. It is seen as vital to ensure Europe's competitiveness in a global economy as well as sustainable development, as highlighted in a memo on EU's research Framework Programme 7 (FP7). The European Strategic Energy Technology Plan (SET-plan) calls for dedicated policy to ensure sustainable, secure and competitive energy. The specific aim is to: "accelerate the development and deployment of cost-effective low carbon technologies". The EU has a large research budget under DG Research, among others, to finance CCS research projects including: technology-based projects like ENCAP that focuses on developing efficient capture technologies; international co-operation projects like the Carbon Sequestration Leadership Forum and CO_2 Capture Project and; networking projects like CO_2 GeoNet European Network of Excellence and Zero Emission Platform (ZEP).

The Member States themselves can organise research into CCS to promote their industry policy as exemplified by UK projects, one example being the NZEC project (the UK-China Zero Emission Coal project). $STRACO_2$ and the COACH project also relate to China. This interest in China is related to its increasing coal use, but also its potential business and export opportunities.

On top of the technologies that are close to being commercial, there is research into the chemical looping technology in ENCAP as well as membranes. One thing that seems to be missing in Europe, however, is coordinated research into technologies that may be required in order to reach really low concentrations of atmospheric CO_2. These include CO_2 capture from air and Bio-energy with carbon storage (BECS). This could be strategically unwise considering: i) the increasingly alarming reports on climate change that support goals to achieve very low concentrations of GHGs in the atmosphere, as well as ii) an increasing number of stakeholders lining up to support such goals. Also, more support for BECS and air-capture could increase public acceptance of CCS, as CCS would no longer be seen as just a solution for sustaining coal use but as a way of restoring the GHG concentrations in the atmosphere to pre-industrial levels.

There is a gap in the understanding of the pros and cons of a winner-picking strategy. Winner-picking has proven to be successful in some instances and less successful in other. In light of the urgency of climate change and the limited budgets for RDD&D, this issue is critical. Some kind of winner-picking may be required for CCS, even if limited to avoiding picking loser technologies.

Another critique of European research policy is the often used assumption that the cost of CCS will decrease with cumulative investment and research in line with some predestined learning curve. Economic models often use these learning curves, adopted from experiences with other technologies, when trying to predict how CCS will penetrate the market. Correlation between lower costs and cumulative deployment is not certain, which has been shown by MacKerron by reference to the nuclear power industry in the 70s and 80s. [72] Since there is no guarantee or control over whether costs will decrease, we propose that more technical goals as well as qualitative objectives and goals are set for European research on CSS.

4.2.2.3 Competition policy

Competition policy is the cornerstone of the EC's role in European industry policy, due to the belief that only a fair and open market can guarantee enough supply and demand at reasonable prices. Therefore the EC tries to minimise the danger of market domination by single companies. With a capital intensive new technology like CCS, the EC has to take care that it will be available for everybody interested, to facilitate early deployment of CCS. This concern over competition is handled by the inclusion of Article 20 in the CCS Directive proposal that deals with open access to CO_2 transport networks and storage sites.

Vedder has distinguished two phases in the development of CCS.[73] Currently, as CCS is not a competing carbon abatement option and requires subsidisation it is therefore subject to the provisions on state aid. Vedder identifies several ways to justify such aid by among other things referring to the Coal Sector Regulation in the EU and security supply. In a second phase, when the costs of CCS will have dropped and the price of carbon is higher, CCS may be able to compete without subsidisation. In such a case, Vedder foresees that the CCS market will be characterised by vertical integration and that future competition law decisions could have to do with "access to and market power in the market for carbon storage".

One cornerstone of the creation of a common and competitive market in the EU is liberalisation of European Energy markets. The justification for opening up the electricity market to competition was that it should result in "increased consumers' choices, reduced the barriers to entry, and thereby encourage innovation and lessen prices."[74] The impacts of liberalisation of the electricity sector on CCS are yet to be analysed, but could be sizable. The discussion is more focussed on how this will impact the technology still in its early stage of R&D.

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[72] MacKerron,1992.
[73] Vedder, 2008.
[74] Defeuilley, 2008.

4.2.2.4 Export markets policy

The high costs of CCS development and rapid expansion of energy production in developing countries like China and India make access to these key markets for European industry key in order to stay competitive, as stressed by the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP). At present, competition and co-operation over CCS involves mainly EU, Canada, USA, Australia and Japan, but China is a potential huge market. Technology diffusion to China is important in order to reach climate change objectives, and CCS is considered a necessity because of the dominance of coal. While China is not the only promising market for European CCS technology, it is one of the most promising markets. This chapter focuses on CCS technology co-operation between the EU and China as the overall focus of the STRACO$_2$ project.

In addition, the EU tries to support the access to foreign markets for its industrial players through international research consortia. For example Alstom, BP and SINTEF are members of the EU COACH project. On the MS level, Doosan Babcock, Shell and BP are part of the UK-NZEC project.

4.2.3 Intellectual Property Rights (IPR)

CCS involves many different component technologies that are at different commercial and technological levels of maturity. Each component technology requires specific policy actions. In general, technologies differ in maturity as they progress down an initial learning and cost curve; they have different carbon mitigation potential and require different policy responses in developing and developed countries. To stimulate investment in appropriate technologies at the right moment and place, countries need to consider the full technology life cycle and create a portfolio of technologies to be developed in parallel.[75] The technology lifecycle and learning curve illustrates the importance of technology policy supporting different stages of a technology's evolution, and is discussed in the full report.

International co-operation has an important role to play as a catalyst for technology progress in the demonstration phase. In particular, delivery of critical CCS facilities by 2020 lies far beyond the financial and technical capacity of individual countries or businesses, and requires large-scale co-operation on the demonstration phase. A major shift in national strategic innovation

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[75] WBCSD, 2008. The WBCSD publication, *Power to Change: A business contribution to a low-carbon electricity future*, describes all electricity generation technologies, together with the key challenges and policy recommendations (WBCSD, 2009).

priorities is needed to make international collaboration on research and development (R&D) activities work at the scale and pace needed. New forms of public-private partnerships must be defined where governments, R&D institutions, supplier industries and potential technology users work together to organise, fund, screen, develop and demonstrate selected technologies.

Throughout the technology life cycle, the strength of IPR regimes is an essential policy tool for inducing private companies to address climate challenges. IPR regimes in tandem with other regulations will affect a company's expectations on future earnings from a new technology and can encourage further investments in R&D.

4.2.3.1 Intellectual property rights

Intellectual property law aims at safeguarding creators and other producers of intellectual goods and services by granting them certain time-limited rights to control the use made of those productions.[76] A variety of mechanisms can protect intellectual property, both registered rights, such as patents, trademarks and designs, or unregistered rights like trade secrets. With CCS, IPR refers mainly to patents and trade secrets.[77]

A patent is a right granted for any device, substance, method or process that is new or novel, inventive or non-obvious and useful. A patent is legally enforceable and gives the owner exclusive rights to practice their inventions for a limited period of time (generally limited to 20 years). Patents provide both incentive and resources to invest in the development of new technologies and are registered and granted in each country.[78]

Companies with large research and development (R&D) resources want to protect their competitive advantage when they introduce products to the marketplace specifically because many of those inventions do not succeed. Protecting IPR is essential to preserving the ongoing ability to innovate through costly research and development.

A trade secret has a broader scope and could be anything that has not been publicly revealed, or is not known in the industry, and gives the owner a competitive advantage. Trade secrets include processes, methods, techniques or formulae that a business may use to produce a product. Therefore a trade secret is both a type of IPR and a strategy for protecting IPR. The protection of a trade secret does not involve formal registration and relies on the capacity of

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[76] WTO, 2008.

[77] IEA, 2007b.

[78] There are international mechanisms available to assist protection in multiple countries. For example, the Paris Convention, the Patent Cooperation Treaty, regional patent agreements such as the European Patent Convention, the Eurasian Patent Convention, and the African Regional Industrial Property Organisation, and bilateral agreements such as Free Trade Agreements and technical agreements between countries and companies (IEA, 2007).

the owner to keep the information a trade secret. The protection remains as long as the information is secret and has economic value.

4.2.3.2 IPR in the intergovernmental discussion on climate change

IPR issues are sometimes controversial, especially between developed and developing countries when it comes to international negotiations on climate change.[79] Addressing climate change will require new technologies. Developing and disseminating these technologies will require policy frameworks to encourage research and ensure that an intellectual property system is in place. Some governments are concerned that IPR will be a barrier to diffusion of technology to developing nations. However, the more serious issue may turn out to be governments trying to ensure subsidies benefit their own national industries.[80]

Patent data is the only indicator available today that provides a comprehensive view of innovation and technology diffusion on a global scale, although it also presents some drawbacks. Many technologies are mature and non IP protected solutions are generally available for a wide range of sectors. Patents are not the only tool to protect inventions and successful technology transfers also involve the transfer of know-how that is not patentable.

Within the UNFCCC discussions, technology transfer presents two related, but different challenges. For most developed countries the challenge is to ensure that technology is protected and creates commercial advantage. In emergent economies technology is needed to reduce the impact of growth on climate change and avoid being locked in to high-carbon energy infrastructure. IPR is not mentioned by developing countries as a barrier to the diffusion of environmentally sound technologies[81] and is not expressly included in the UNFCCC or Kyoto Protocol provisions on transfer of technology. However, it has been raised in the discussions of the Expert Group on Technology Transfer, for example, as both an element of, and a potential obstacle to, an “enabling environment” for transfer of technology.

Although no comprehensive study has been conducted on the potential impact of the cost of IPR in the different climate related technologies, including CCS, initial research found that the impacts of patents on access to solar, wind and biofuel technologies in developing countries might not be significant.[82] In the case of biofuel it is not IPR that restrict technology diffusion,

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[79] Countries have submitted their proposals around technology transfer. These can be viewed at unfccc.int/resource/docs/2008/awglca4/eng/16r01.pdf.

[80] Barton, 2008a.

[81] UNFCCC, 2007. Developing countries submissions on technology transfer to the UNFCCC in 2007 did not refer to IPR as a barrier.

[82] ICTSD, 2008.

but tariff and other trade restrictions linked to international ethanol and sugar markets.[83] In photovoltaic, the large number of firms in the sector means that the benefits of the basic (silicon-slice) technology are likely to be available to developing countries through licenses on reasonable terms.[84] Furthermore, royalties for wind turbines are in the order of 1% of the sale price of the wind turbine.[85] The entry of developing country companies into markets for producing new high-tech goods might be difficult, but not impossible. For example, in the photovoltaic and wind turbine sectors, companies from developing countries have recently bought firms from the developed world, another form of technology transfer.[86]

The fact that the majority of patents for clean technologies in developing countries are only found in 3 or 4 countries suggests that patents are not a significant barrier to technology diffusion in developing countries.[87]

4.2.3.3 Current status of CCS technologies

CCS is a multi-stage process divided into distinct capture, transport and storage stages, which involve a range of different technologies, each with its own IPR issues, maturity stages and commercial interests. Potential breakthrough technologies are mainly in the capture stage; transport technologies are mature and commercial, while technologies in the storage phase are in general, close to, or in the commercial stage.

4.2.3.4 Capture technologies

The CO_2 capture stage is highly capital-intensive and will usually involve large-scale plants. Capture technology IPR is largely owned by business and can range from materials such as catalysts to processes and process integration. In the case of process integration, patent law may be more difficult to apply. There is a relatively small number of capture technologies and hence ownership is relatively limited. These technologies are detailed in the full report.

When it comes to commercialisation of those technologies, companies might have a commercial concern that IPR would not be recognised in certain developing countries. Increasing exposure of capture technologies to IPR risks makes it unclear whether the owner of the IPR will be willing to license them, especially in the absence of a stringent regulatory framework.[88] Capacity building is necessary to establish trust in their IPR systems.[89]

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[83] Barton, 2007.
[84] Barton, 2007.
[85] Barton, 2008b.
[86] Barton, 2008a.
[87] Copenhagen Economics, 2009.
[88] IEA, 2007.

Transportation and injection technologies

Although there may be technological advances in the future that merit IPR - e.g., composite plastic pipeline materials, monitoring technologies, etc. - significant intellectual property issues are less likely because technologies will be available from a large number of suppliers.

Storage Technologies

Some storage technologies may be considered to be at an early commercial stage. It is anticipated that IPR for these technologies will be less significant. However, IPR might exist in some technologies, such as CO_2 corrosion resistant cement for injection wells or measuring, and monitoring and verification systems and protocols during injection and post-injection stages.[90]

4.2.3.5 CCS and IPR

In the case of CCS technologies, the limited number of annual patented inventions compared to other technologies does not provide enough information to assess IPR issues. In 2005, around 60 CCS inventions sought legal protection, while renewables had an annual average of nearly 2,000. It is also striking that CCS has the largest abatement potential and it is the category with the least patented innovations. These figures are due in part to the amount of technologies involved in CCS and the lack of an international patent code including them all. These figures probably underestimate the rate of innovation, because many inventions designed to isolate, transport, monitor, inject, store gases, etc. are likely to have potential applications to CO_2.

4.2.3.6 Intellectual property rights in joint collaborative research

Whenever a collaborative R&D project is developed between governments, companies and research organisations, a contract is signed to establish how IPR should be shared and protected. This applies to CCS projects currently in operation or in development as shown in Table 21.

Table 21- IPR regimes for CCS projects

CCS project	**IPR regime**

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[89] Countries like China are making "huge progress towards making intellectual property a mainstay of its economy" and the government is "working hard" to address some of its problems (Harvey, 2008).

[90] A network of research and technology organisations is getting closer to piecing together a system that would fast-track nature's own greenhouse gas recycling process in large volumes.
Scientists are working towards creating a system that would convert carbon dioxide diverted from industrial facilities into valuable products using plants – micro-algae (Innoventures Canada (I-CAN)).

Weyburn, the U.S.-Canada	No specific IPR issues, although the project developers signed confidentiality agreements to assist in protecting IP and jointly agreed to own IPR resulting from the project
CO_2SINK, Germany	No IPR issues
In Salah, Algeria	No IPR issues
Gorgon project, Australia	No IPR issues yet, but will manage them on a case-by-case basis
RECOPOL project, Poland	The IPR issues arising out of the project will lie with the consortium, project partners and the European Commission - that funded the project.
Sleipner project, Norway	IPR has been addressed through a consortium agreement between the project partners that grants them broad, worldwide and irrevocable rights to use project results

4.3 Impact Assessment Policies and CCS

If CCS is implemented on a large scale in the EU it cannot be only because of its contribution to the competitiveness of EU industry or job creation, but has to contribute also to the EU's overarching goal and policy of a sustainable development in general.

The EU aims to develop new and better CCS policies by integrating sustainable development into policy-making at all levels. A key component of that approach is stated in the "Review of the EU Sustainable Development Strategy – Renewed Strategy," to ensure that: "all major policy decisions are based on proposals that have undergone high quality impact assessments, assessing in a balanced way the social, environmental and economic dimensions of sustainable development and taking into account the external dimension of sustainable development and the cost of inaction."[91] As the EU has proposed a regulatory framework to safely implement, commercialise and subsidise this new technology and has also set up a Technology Platform on Zero Emission Fossil Fuel Power Plants, Impact Assessments have been a critical foundation. EU Impact Assessments that have already been performed and are related to CCS will be the focus of the review and analysis work done in this section. A complementary brief analysis of Member State initiatives and international assessments is also performed.

Several types of impact assessment come into play in different stages of developing technology like CCS. The European Impact Assessment (IA) system aims to ensure "better regulation". The

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[91] Council of the EU, 2005.

impact assessment accompanying the CCS Directive results from that system. The basic principles of environmental impact assessments are outlined in the full report. The Strategic Environmental Assessment (SEA) methodology is a useful tool that, like the IA, is performed early in the decision making process, on a strategic level. It is intended for policies, plans and programmes. The Environmental Impact Assessment (EIA) assesses the environmental impact of a planned activity. It is a project specific assessment and applies to many CCS installations.

This section includes only impact assessments of policies, plans and programmes.

4.3.1 The European Impact Assessment system

The impact assessment (IA) system aims specifically to ensure “evidence-based policy making inside the Commission through an integrated and balanced assessment of problems and alternative courses of action.” It aims to assess “potential impacts of new legislation or policy proposals in economic (including competitiveness), social and environmental fields”, and is the primary tool for the EC to ensure that existing and new regulation is consistent with its sustainable development strategy.

The analysis is focussed on the impact assessment of the CCS Directive proposal, specifically following up some central comments given by the IA board in October 2007. The board stressed that uncertainties attached to forecasts must be clarified. The interaction with policies on renewable energy sources, impacts on fuel consumption mix, and demand for CCS technology outside the EU need to be explained. Furthermore, a forecast for future global market demand for CCS should be added, especially in China and India. The uncertainties of impacts must be described: deployment, technology performance, costs and carbon prices.[92]

4.3.1.1 EU impact assessment system applied to CCS

At least three consecutive impact assessments have pointed at the EU’s need for new low carbon technologies and in particular CCS:

Table 22- Impact Assessments for CCS in the EU

Impact Assessment	Content
Sustainable Power Generation from Fossil Fuels: Aiming for Near-Zero Emissions from Coal	Aims to keep coal competitive and spread sustainable coal in the shortest possible time. It is expected that the total cost of CCS may be lowered to €20/tCO_2 in the medium term, and references are made to the PRIMES model. The reduction of CO_2 is assumed to be around 90% from the CCS coal-fired plants. The positive

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[92] EU IA board, 2007.

after 2020 (EC, 2007c)	externalities of CCS are discussed, such as reduced SO_2 and NO_x emissions. Three policy options are evaluated. Option 0) No change, 1) Removal of barriers to sustainable coal technologies and 2) Incentives for demonstration and penetration of sustainable coal technologies. Option 2 is recommended because the ETS price for CO_2 emissions may be too low. Further impact assessments are needed to explore pro-active options to improve market-based incentives and pro-active measures.
A European Strategic Energy Technology Plan (SET-plan) (EC, 2007d)	The SET-plan focuses on energy technology innovation and a set of large scale initiatives to accelerate the development of key energy technologies. The SET-plan pursues: "(i) transformation of the governance of the energy research and innovation system through the engagement and the commitment of all stakeholders in a coherent programme; (ii) strategic planning that orientates the research and innovation efforts towards technologies and measures with the greatest potential to deliver the European energy policy targets; (iii) a more effective implementation, execution and management of all activities across the whole innovation process; and (iv) a cost-effective and results-oriented allocation and increase of means." Four policy options are analysed. The preferred option is the establishment of a strategic coordination as it combines the best features for leadership, implementation and resources. The aim is to reach an integrated and more centralised innovation process at the European level that is more attractive than today's.
Supporting Early Demonstration of Sustainable Power Generation from Fossil Fuels (EC, 2008d)	This IA focuses mainly on options for achieving coordinated and timely demonstration of CCS technologies in Europe which will in particular require: demonstration plants by 2015, and the stimulated involvement of European industry and preparations for wider deployment of CCS after 2020. An evaluation recommends "combining EU coordination and stimulation of strong MS and other stakeholder commitments as the preferred option, with a strong suggestion to also issue EU Guidelines for harmonising the national funding schemes." The main policy objective is to stimulate the construction of demonstration plants by 2015. The related main issue is the high current costs of CCS. Additional costs of CCS are not sufficiently compensated. The aim is to reach costs in the range between €25-30/tCO_2 by 2020. CCS policies need to provide coordination of the demonstration plants, improve public awareness and bring access to public financial support. Three policy options were analysed and the option focusing on establishing a mechanism combining EU coordination and strong MS and other stakeholder commitments was chosen.

The first and main point to discuss is the overall conclusion that "the impact assessment takes the need for widespread CCS deployment in the EU from 2020 as established."[93] Even if that claim is based on political decisions and conclusions drawn by the Council, it leads to a strict scope where alternative courses of action, which are important in impact assessments, do not

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[93] EC, 2008d.

include non-CCS futures. Before having tested CCS on a full scale, or having assessed public attitudes of CCS in the EU, this could be unwise.

Energy security is treated in a simplistic way. Coal is reported to be abundant and reserve data is quoted without critical analysis: “reserves of hard coal are equivalent to close to 200 years of production at present rates; those of lignite should last for around 130 years”.[94] However, energy security is not clearly defined, which is necessary as it has many dimensions.

The IAs also consequently avoid trade-offs and negative externalities by reducing the environmental issues to only include CO_2, SO_x and NO_x. Life cycle effects on GHG emissions are not included either.

Another issue relates to economic modelling. There seems to be little use of sensitivity analysis, which is useful when modelling outcome depends to a high degree on e.g. future fossil fuel prices.[95]

The last issue brought up here is the stakeholder consultation process, which is a basic principle and practice of an impact assessment that often decides the quality of the outcome. Even though the impact assessment of the CCS Directive proposal included stakeholder consultation it does not represent the more sceptical NGOs. Even though invitations were sent out for the stakeholder meeting in May 2007, no real effort went into getting a wide representation of stakeholders. An illustrative example of that issue comes from the Australian regulatory development process and is described in the full report.[96]

4.3.2 Strategic environmental assessment for CCS plans and programmes

An SEA may work as a supporting tool that incorporates environmental issues and trade-offs into strategic decision making in a structured way. Its functions include: to raise awareness about environmental issues in the process; to identify important environmental impacts in the studied systems; to choose between different alternatives and; to control whether or not critical thresholds are met, e.g. when it comes to air quality standards.[97]

In the EU the SEA is now viewed as a very important tool for securing sustainable development. Unlike the EU impact assessment system for policies, however, it is not yet clear if/how the SEA Directive could be applied for plans and programmes related to CCS.

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[94] EC, 2007c.

[95] see e.g. Capros et al., 2007; EC, 2008b.

[96] MCMPR, 2007; CANA, 2004.

[97] Johansson et al., 2004.

Several factors make it hard to apply the SEA Directive for CCS activities. These are screening, i.e. if there is an obligation for a programme or plan to conduct an SEA, and scoping, i.e. where to draw the boundaries, which aspects to include and how to manage the level of detail.

Problematic issues with SEAs include that there have been few good and appropriate techniques and very little experience in conducting them. Other problems are that policies, plans and programmes evolve incrementally; there is no clear time when SEAs should be performed. Also SEAs are sometimes required for programmes and plans only, so overall policies could still not be environmentally friendly. There is uncertainty over whether SEAs should include social and economic issues. As policy making is a political process, impact assessments are weighed against other interests of the policy makers.

4.3.3 General impact assessment challenges

In previous sections the motives for and the current frameworks for conducting Impact Assessments have been presented. The conclusion, amongst others, is the need for Impact Assessments to make good strategic choices in mitigation techniques is not as evident. Also, there is no clear definition of what is meant by energy security. Nonetheless, diversity is often considered a good security of supply, meeting the energy and climate change challenges. However, there are many hurdles to overcome. In the following sections, some problematic issues in conducting impact assessments are reviewed.

4.3.3.1 Fossil fuel resources and energy security

The executive summary of the IA states that CCS is needed to: “reconcile the need for urgent action to tackle climate change with the need to ensure security of energy supply”.[98] In the near future it is easy to understand how coal may contribute to security of supply, but in the long run when taking CCS and other GHG strategy, it is not the only one. Effective functioning of energy markets could offer the best contribution to energy security. However, as domestic supplies of coal in the EU diminish and international competition for energy increases, shortages and conflicts may arise. In that perspective, and if CCS leads to increasing dependence on the international coal market, its contribution to energy security is questionable.

Even though the CCS Directive proposal refers to findings of the Communication and impact assessment on sustainable power generation from fossil fuels,[99] which concludes that zero-

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[98] EC, 2008b.
[99] EC, 2007c.

emission power generation from coal is highly warranted in order to secure the twin benefit of secure supplies and environmentally sustainable energy, the authors of this report claim that it is still an open question. Considering recent scientific findings on the coal resources issue, decision makers need to be aware of, and plan for, a future with more scarce resources, in which coal prices may be higher and more volatile than currently expected. Accurate and comprehensive estimates of coal reserves, globally and in the EU, are essential for the development and planning of the future energy system and CCS. This is discussed further in the full report, with reference to relevant studies, like ACCSEPT.[100]

4.3.3.2 Timely transition to a renewable energy system

CCS is a transitional technology and will eventually be phased out as fossil fuels become scarce and perhaps as other renewable alternatives become more competitive. Until then, CCS will have to be deployed, and for CCS proponents that time is hopefully long enough to pay off the investments made. Most people in the CCS “thought collective” dismiss this by saying that we have to use all technologies at the same time. However, others note that we cannot afford to wait for future CCS. The concern about CCS being too futuristic and hindering renewable energies cannot be neglected, as it has reached top-level decision making. However, it is missing in large parts of European politics and impact assessments conducted by the Commission. The parliament has suggested amendments to the CCS Directive proposal in order to lift this concern as they stress that CCS is one of the instruments aiming to reduce CO_2 emissions “but not the only one.”[101]

While research into renewable energy alternatives is one way of securing long-term energy supplies when coal supplies dwindle, performance standards are discussed in Europe as a way of preventing new unabated coal-fired power stations being constructed.

Since CCS is not commercially available yet, and no CCS obligations are in place the issue of capture readiness is important, especially from the perspective of timely transition and risks of lock-in. There is a risk that power plants without abatement systems will never be abated, and that the EU and especially China will be stranded with high emission power plants for a long period of time. The importance of these issues is mirrored in the strong support for the objectives on capture readiness (CR) in the EU internet consultation: before 2020, all new fossil-

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[100] ACCSEPT, 2007a.

[101] European Parliament, 2008

fuel power plants should be "capture-ready" and; all these "capture-ready" plants should be retrofitted soon after 2020.

Another critical issue that for CCS is the urgency of the climate change challenges. The question is how evolution of climate change could affect the development of, and attitudes towards, CCS? Such a trend would not be good for CCS, since the technology is often connected to the burning of coal. The lifecycle emissions of coal fired power plants with CCS are substantial, and it is only possible today to decrease greenhouse gas emissions by around 80% from many CCS processes. The question is whether or not that would be accepted in a society aiming to stabilise atmospheric concentrations of CO_2 at 350 or below, and especially when considering that the commercialisation of such processes are still in the distant future? On the other hand, research shows that reaching e.g. 350 ppm could become very expensive without using CCS at all.[102] However, by using CCS in combination with biomass conversion processes, biomass energy with CO_2 capture and storage (BECS), it would be possible to remove CO_2 from the atmosphere while producing CO_2 neutral energy carriers, and such solutions could decrease the total mitigation costs significantly.

If society becomes ready to take on tougher climate challenges in the future it must be ready to pursue options such as BECS and perhaps also air capture technologies that are more suitable for low CO_2 concentration targets than coal fired options.

4.3.3.3 Economical performance of CCS in a portfolio of mitigation options

The difficulty in assessing the economy of CCS lies in the technology’s complexity and immaturity as well as the volatility in prices of commodities and fuels. Some costs depend on external factors that cannot be affected by learning, while some aspects of the costs are internal and are bound to decrease as CCS approaches commercialisation and maturity. Even though CCS is bound to slide down the learning curve in several respects, those trends may be counteracted by external factors that increase costs such as increasing fuel prices.

In order to assess the implications of CCS deployment in Europe the energy system was modelled using the PRIMES model,[103] which helped construct several scenarios to show how CCS and the energy system might develop depending on different assumptions and policies up until the year 2030. The costs were calculated for each scenario.The scenarios are divided into four options: 0. No enabling policy for CCS at EU level, including no inclusion of CCS in the EU

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[102] Azar et al., 2006.

[103] Capros, 2007.

ETS; 1. Enable CCS under the EU ETS; 2. In addition to enabling under the ETS, impose an obligation to apply CCS from 2020 onwards and assess the impact on the potential positive externalities not captured by the carbon market; 3.In addition to enabling under the ETS, apply a subsidy so as to internalise the positive externalities not captured by the market.[104]

The conclusion of the Commission after having examinedt the results of this economic modelling was to go with the inclusion of CCS under the EU ETS, without any further subsidies. According to de Coninck et al. this stance of the commission reveals their high trust in EU ETS being able to deliver the strong incentives needed in order to stimulate the introduction of CCS.[105] According to Lockwood it is questionable if European politicians will stick to the stringent CO_2 emissions cap needed.[106] Further economic modelling is discussed in the full report.

One positive thing about the Capros study is that one scenario, option 0, is a CCS-free scenario. Other studies often decided beforehand that a future without CCS is impossible.[107] The problem with a narrow range of scenario options is that scenarios can be self-fulfilling. It is, however, evident that in order to fairly evaluate the no-CCS option, option 0, it is of utmost importance to also include negative externalities of CCS in other scenarios.

Another critical aspect that characterises many economic models is that they incorporate cost models where the cost estimates of different technological options are done in a simplistic way ignores the risk profiles of the different energy alternatives. “Levelised cost” is a common approach used by today’s engineers. In the full report, tools are described that could come to be very useful in the future to hedge against an uncertain future with increasingly scarce fossil fuels and volatile market conditions.

The level of uncertainty regarding CCS costs is high and needs to be acknowledged in order to have informed and sound discussions, investments and policy making. Hamilton et al. mention that at the moment CCS is still prohibitively expensive and that it is unlikely that CCS will be commercially available for years to come.[108]

The estimated cost of CCS (capture and storage) in 2030 in the USA is \$62/t CO_2. Under the Lieberman-Warner Bill the highest carbon price in 2030 is \$61, thus leaving a \$1 gap. The

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[104] EC, 2008b.
[105] de Coninck et al., 2008.
[106] Lockwood, 2008.
[107] Clarke et al., 2007.
[108] Hamilton et al., 2008

authors conclude that a break-even situation for CCS by 2030 is too late if the goal is to build the necessary 800GW providing new coal power stations with CCS worldwide by 2054, which corresponds to a wedge or about 1/7 of the total mitigation effort as proposed by Pacala & Socolow.[109] A more aggressive R&D and demonstration programme for reducing costs and a more strict carbon regulation are suggested as necessities in order to enable CCS as an effective technology for climate change mitigation.[110]

The economy of future full scale plants remains highly uncertain, as is the cost for preparing for retrofit of CCS, especially since there is an on-going debate on what "capture ready" comprises.

4.3.4 Externalities, life-cycle effects and environmental trade-offs

According to the CCS impact assessment there are several commercial barriers to the deployment of CCS, for example, the added capital and operating costs compared to conventional power plants. To overcome these barriers it identifies five positive externalities (on top of CCS being included in the ETS which would internalise the climate benefit of CCS) that if internalised would help speed-up the deployment of CCS. The five externalities are:

- Positive impacts from developing the technology on the costs and its efficiency (learning-by-doing effects based on adoption) are not captured by the market (positive externalities).
- Potential positive externalities relating to security of supply would not be captured by the market.
- Positive externalities relating to export potential would not be captured by the market.
- Potential positive impacts on achievement of global climate objectives from deployment in the EU would not be internalised.
- Any positive reductions in traditional air pollutants from deployment of CCS are not internalised.[111]

Only positive externalities are mentioned. It is obvious that the competitiveness and economy of CCS will benefit from internalising positive externalities. However, CCS is also associated with many negative impacts, e.g. from the increased coal extraction, environmental trade-offs due to toxic chemical use, fresh water use. The IA named some negative externalities but not in the same context as the positive, and none are proposed to be internalised or evaluated using

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[109] Socolow, 2004.
[110] Hamilton et al, 2008.
[111] EC, 2008b.

economic modelling. A reason for not including environmental trade-offs could be that it is hard to quantify such effects, but this reasoning applies to many aspects that were included.

One ongoing debate in the scientific community is that CCS may require greater use of water for cooling purposes, which will worsen the situation for areas already under water stress.[112] ACCSEPT study mentions the alternative use of pore space, which could become relevant if renewable energy sources become abundant and pore space is needed to store energy in the form of compressed air. Another use of pore space is for storage of natural gas. In such cases CCS would face competition.[113] Another interesting topic that deserves attention is the environmental impacts of different solvents for CO_2 capture. When considering all solvent properties that are important when determining the feasibility of a certain system (chemical equilibrium, kinetics, degradation, corrosion, solubility in water, toxicity and cost), there may be a trade-off between the technical performance of a solvent and the environmental performance. Due to environmental uncertainty on this issue, several researchers have proposed the inclusion of life cycle assessments in the EIA or inclusion of LCA when assessing CCS.[114] Other negative effects that are not often taken into consideration are CCS' potential negative effects on eutrophication, acidification and ozone layer depletion.

The IA system in the EU is fairly new and in 2007 the European Council invited the Commission to identify further improvements of the system by means of an external evaluation. During the evaluation some Commission members were concerned that "a number of IAs are carried out to justify a preferred option determined independently of the impact assessment."[115]

4.4 China Applicability

4.4.1 Identification of Key Cross-Cutting Issues in China

Since awareness and knowledge of CCS in China is at an early stage, crosscutting issues related to CCS have not yet been systematically considered. Thus, China can learn from European and international experiences and take the key crosscutting issues into consideration when implementing CCS on a large scale. However, crosscutting issues of CCS are strongly related to regional policy context, socio-economic conditions, perspectives of stakeholders and other specific factors. Thus, identification of crosscutting issues should be based on local context.

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[112] see e.g. ACCSEPT, 2007a.
[113] ACCSEPT, 2007a.
[114] Manuilova et al., 2008; Koornneef et al., 2008b; Odeh & Cockerill, 2008.
[115] EC, 2008c.

To date, Huaneng Power Plant's post-combustion capture pilot project, started in 2008, is the only demonstration project on carbon capture applied to a power plant in China, with few results available. However, the Chinese oil and gas industry has accumulated extensive knowledge regarding enhanced oil recovery applications.[116] China ranks first in the world in terms of the proportion of oilfields using enhanced oil recovery (EOR). CO_2 injection was in use in Daqing oilfield between 1990 and 1995 and has been used in Subei.[117] The priorities of current and pending CCS projects in China include EOR and enhanced coal bed methane recovery projects. Activities focus on CO_2 storage and less on carbon capture and transportation technology, and an entire industrial chain including carbon capture, transportation, storage and post-storage has not yet been established.

In the Chinese context, cross-cutting issues that are widely discussed and may have significant implications for the future CCS deployment are identified as: awareness of CCS regulatory issues in China; energy production and CCS and; impact assessments regarding coal resources and the trade-offs between CCS and renewables/energy efficiency; and IPR and technology transfer.

4.4.2 Awareness of CCS regulatory issues

CCS technology development in terms of reducing energy efficiency loss and cost is widely understood as the core issue of CCS development by both Chinese and international scientists. Scientists and industries in China have already carried out extensive research on addressing the engineering and technical issues of CCS and proposed various technical options to optimise the energy system and CO_2 capture. Integrated Gasification Combined Cycle (IGCC), poly-generation in the power sector, and gas recovery in chemical production are examples of innovative technologies that can reduce energy loss.

However, opinions on regulatory issues differ among key stakeholders in China. One of the mainstream views is that it is still too early for comprehensive CCS regulation in China at this time, and China should focus on the technology development of CCS.[118] Conversely, other scientists, especially those working in the field, argue that CCS regulatory issues should go hand in hand with technology research from an early stage.[119] There are no clear regulations for current pilot projects (mainly EOR and ECBM) to comply with. The pilot projects are therefore

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[116] IEA, 2007a.
[117] IEA, 2007a.
[118] IGEC conference notes, 2008.
[119] Li, 2008.

viewed as meaningful for both technology development and regulation improvement.[120] International regulatory experiences are also useful. However, the timing of official regulation requires further assessment as sustainable economic development is still the top priority for the Chinese Government. Climate change related topics are therefore discussed under issues of development. Although the uncertainties in CCS regulation in China are high, the future co-operation on research methodologies, regulatory framework, and common interest issues is still promising.

4.4.3 Energy Supply and CCS

The demand for energy in China continues to grow, with a projected annual average rate of 6.6% up until 2010.[121] The drastic growth on the demand side has put stress on the energy supply and highlighted the issue of energy security.[122] The response to this has focused on diversifying the geographic sources of imported oil and physical supply routes and sourcing domestic new energy sources and energy conservation. Current energy loss associated with CCS technology equates to an approximate 10% energy efficiency penalty, which is one of the main concerns in developing CCS in China. Therefore, enhanced oil recovery and enhanced coal bed methane recovery as the offset to the energy loss are viewed as the most promising storage options for CCS development in the short term in China.

The volume of oil to be produced from the proven reserves in China is estimated to be 29 billion barrels, with most reserves located onshore. Most oil fields are mature, having been in production since the 1960s and 1970s and injection of CO_2 has been proven to increase the oil production at most of these oil fields.[123] Compared to water injection, CO_2 streams can have higher performance in terms of oil extraction rate, and avoid water scarcity issues.

Coal is the backbone of Chinese energy supply and is likely to remain as such up until 2030.[124] Around 50% of the coal resources in China is between 1000-2000m depth.[125] The utilisation of coal-bed methane is a new resource for the domestic energy supply. Injecting CO_2 to coal seams not only to enhance coalbed methane recovery, but also stores CO_2, with significant

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[120] Li, 2008.
[121] IEA, 2007a.
[122] IEA, 2007a.
[123] IEA, 2007a.
[124] IEA, 2007a.
[125] Ye *et al.*, 2005.

storage potential estimated in China.[126] The current increased energy production can offset the energy lost in applying CCS technology.

The high priority and possibility of CCS development in the future is led by enhanced oil recovery and enhanced coal bed methane projects in China. The earliest deployment of CCS can be expected to be driven by the additional energy production, and to be carried out among key oil and coal industries. Consequently, when oil production is the major focus, the CO_2 storage rate, as well as safety and liability issues may be underestimated. Regulatory issues will require particular attention to safety, liability and site qualification aspects.

4.4.4 Impact assessment

There is currently no policy in China to correspond with the EU's decision-making process. However, some of the respective issues that will have significant impact under Chinese socio-economic context also need to be analysed. Two particularly important issues for China are the impact on fuel consumption mix, especially the interaction of coal resources and CCS development; and the interaction with renewable energy and energy efficiency policies.

4.4.5 Coal resources and CCS in China

The estimation of coal resource and energy mix in China is particularly essential for strategic planning of CCS since coal is China's main energy source. Coal reserves are currently estimated with 115 billion tonnes capacity, and a reserve-to-production ratio of around 50 years at the current production scenario.[127] Coal production in China has drastically increased since the start of the decade driven by high demand, reaching 1,800 metric tonnes of coal equivalent (Mtce) in 2006.[128] Under the Business as Usual Scenario, coal production is projected to increase further to 2,248 Mtce in 2010, 2,604 Mtce in 2015 and 3,334 Mtce in 2030.[129] The production growth rate since 2000 has increased drastically compared to historical data. The projection shows that the growth rate is likely to remain high. Therefore the reserve-to-production ratio is going to be less than previously estimated.

CCS technology is now at the R&D stage in China. The technology development, operations and impacts from CCS are all considered on a long-term timeline. Although other industrial sectors based on fossil fuels, such as oil and natural gas, are also potential users of CCS technology, coal

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[126] Ye *et al.*, 2005.
[127] IEA, 2007a.
[128] IEA, 2007a: 336.
[129] IEA, 2007a.

is inherently more carbon-intensive than other sources and coal-based industries are viewed as the most promising for CCS adoption. The estimation of coal resource and the reserve-to-production ratio will significantly influence the expectation, planning and deployment scale of CCS in China, and should be taken into account at an early stage.

4.4.6 Matching Source-Sink

Another issue directly linking to the CCS strategy both in Europe and in China is to match the CO_2 sources and sinks. The data of both CO_2 emission sources and sinks are inadequate in China, particularly for the geological data of aquifers. Although the data of CCS storage sites are mostly site-specific, the establishment of a general database and a scientific estimation of overall capacity can facilitate the decision-making of CCS planning and development.

Furthermore, as a centralised country, China is facing less trans-boundary issues due to administrative arrangement. On the other hand, China, as an extremely large country with various geological zones, the transport of CO_2 is one of the central issues in source-sink matching. Transportation networks should be integrated into the estimation of source and sink. The key parameters for the source-sink relationship include transport distance and capacity, coordinating the timing of planning, approval and construction of power stations, pipelines and CO_2 sinks.[130] Due to the fact that most power plants are located in Eastern China where the population density is high, the potential environmental impacts or risks can be higher, and require particular attention when designing source-sink systems.

4.4.7 CCS vs. Renewables and Energy Efficiency

The future of CCS potential is not only influenced by the cost of CCS technology, but also by the cost of other competing climate change mitigation options such as renewable technologies and energy efficiency improvement.[131] Two main concerns of the potential impacts of CCS on renewable technologies include: that CCS may hinder development of renewable energy due to rebound effects from continuously using fossil fuels on a large scale, or that CCS can be a bridging technology for transition to renewable energies as a complementary option to mitigate climate change.

In China's *National Strategy and Actions towards Climate Change Mitigation and Adaptation*, the policy priority has been to facilitate the development of renewable energies and nuclear power, and energy efficiency improvement. In 2005, the energy supply from renewable sources

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[130] Wuppertal Institute, 2008.
[131] IEA, 2004.

was 8% of the total energy supply in China.[132] Although with the specific targets for different types of renewables by 2020, the share of renewable energy in total energy consumption in China is increasing. The solutions to climate change should be a comprehensive package of all options, including CCS. Deployment of renewable technologies and CCS is largely determined by costs, which can be reduced through technology learning. And cost reduction from 'learning-by-doing' depends on future investments and learning rates. Relevance of technology 'learning by doing' can be much higher for certain renewable energy technologies than for CO_2 capture technologies. Therefore, the future use of CCS might decline and allow a gradual transition to renewables in the long term.[133]

Currently in China, renewable energy and energy efficiency are key priorities. In order for CCS to be a realistic option, support for CCS is required from additional sources, rather than competing with investment for renewables and energy efficiency.

4.4.8 Intellectual Property Rights and Technology Transfer

Since energy consumption and GHG emission are increasing drastically in developing countries, including China, the potential demand of climate change mitigation strategies and technology could be shifted more to developing countries. During this process, IPR can be both a barrier and driver. In order to strengthen IPR as a driving force for industries in Europe to invest in developing countries and increase global competitiveness, the IPR system in developing countries will be a core issue for CCS deployment at the international level. At the same time, along with the growing international co-operation in R&D, it is important for Europe to maintain the cutting-edge competitiveness of knowledge and innovation.

With regards to CO_2 storage, the prominent IPR is patents and trade secrets and, to a lesser extent, trademarks. An effective IP management strategy involves managing risk, liability and benefits associated with the IP.[134] The complexity level of IPR depends not only on the complexity level of the technology itself, but also the integration of the technology with the existing local context, such as expertise, operational skills and knowledge. Thus, the complexity level of IPR for CCS is considered to be high, which results from the uncertainty of CCS technology itself, the existing energy system of the recipient country, and the availability of geological pore space. Currently, IPR law exists in China and the enforcement is being enhanced

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[132] Li et al., 2006.

[133] IEA, 2004

[134] IEA, 2007b.

both in terms of the quality and quantity.[135] However, due to the imbalance between intensified demand and the lack of expertise and institutional capacity, especially in less developed regions in China, the IPR management is now at a turning point in China. Increased R&D input from Chinese government has led to more demand on IPR and the government is facilitating the development of IPR management; on the other hand, the drastically increased demand also puts pressure for faster improvements of domestic IPR management.[136]

The technology transferred must be able to be adapted to the local conditions of the recipient country, particularly in terms of the level of skill required, and the expertise of developing countries should not be underestimated.[137] For a developing technology like CCS, it is important to access the existing level of technology and expertise in the recipient country when technology transfer is carried out. The application of post-combustion technology increases the degree of complexity for power plants and other industrial facilitation. In China, it would be necessary to test whether the system can be reliably controlled by the local engineers and whether the low flexibility of such a system can be reconciled with the existing energy infrastructure. Partially or completely new technologies such as IGCC and oxy-fuel may require even higher standards of knowledge and training than post-combustion technologies.

4.4.9 Stakeholder consultation and public acceptance

Public acceptance is a crucial issue for CCS and new low-carbon technologies. This is recognised in policy making and regulation where stakeholder consultation is required for deployment of CCS facilities and introduction of CCS policies, plans and programmes, at least in the EU. Such regulation helps involve the public and other stakeholders in all levels of decision making.

Public acceptance has become an important research area within CCS, perhaps because coal-fired power production with CCS is often one of the least desired options in surveys, together with nuclear power. Industry has a huge incentive to turn this situation around. The main purpose of most public acceptance research is to gain knowledge regarding lay person’s perceptions of CCS, which factors shape the perceptions and in some cases how to influence them; mainly towards more positive attitudes. The majority of acceptance studies have been conducted in the USA, Japan, Great Britain and the Netherlands. A few studies have also looked

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[135] Harvey & Morgan, 2007.
[136] Harvey & Morgan, 2007.
[137] IEA, 2007b.

at Canada, Australia, France, Italy and Sweden. In the ACCSEPT study the lack of knowledge about public perception in the EU-27 is highlighted.[138]

The studies may be divided into three main categories depending on methodology and aim: quantitative surveys, qualitative interviews and mass media studies. Some studies combine categories. A general finding is that the public's knowledge about CCS is very low compared to different mitigation technologies. In general CCS is still one of the least desired technologies or mitigation options.

Mass media, which was investigated in the UK, the Netherlands, Italy and Australia, has been more positive towards CCS in recent years, which may affect public perceptions. Many acceptance studies conclude that awareness of climate change risks, the relatively low costs of CCS and the recognition of CCS as a climate mitigation technology raises the level of CCS acceptance.

Daamen et al. emphasised the need for more qualitative methodologies when investigating attitudes, such as focus group interviews and putting more effort into the information giving, to avoid what they refer to as "pseudo opinions."[139] Another problem is the NIMBY phenomenon, which raises the need for social site characterisation. Reiner emphasises the need to bridge the "communications gap", including the lack of educational materials, methods of communication and credible messengers.[140]

Table 23- Acceptance Studies for Further Reading

Quantitative	**Qualitative**	**Mass media framing**
Ha-Duong et al. (2008)	Ashworth et al. (2008)	Bradbury & Dooley (2004)
de Best-Waldhober et al. (2008)	Shigetomi et al. (2008)	Mander & Gough (2006)
Johnsson et al. (2008)	Shackley et al. (2005)	van Alphen et al. (2007)

4.5 Conclusions

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[138] ACCSEPT, 2007.
[139] Daamen et al., 2006.
[140] Reiner, 2008.

A number of gaps and needs for cross-cutting issues of CCS have been highlighted in this section. These gaps and the recommendations made to fill them are presented in this conclusion.

4.5.1 Conclusions on EU industrial policies

The EU is not alone in its ambition to become the number one provider of low-carbon technologies in the world. The same ambition is found in Japan and the United States. Strong competition is expected and it is far from certain that the EU will become the prime exporter. However, CCS may be good for EU climate policy alone, without any export revenues, and possible future exports to China and India could be seen as a co-benefit.

The anticipated recipient countries of European CCS technology, in particular India and China, have as of yet little incentives to implement CCS. Priority one is economic growth, and when it comes to energy issues, energy efficiency is given priority over emissions reductions. The demand and strategic importance of CCS in China and India are linked to, among other things, the supply of cheap and abundant coal and environmental trade-offs.

Recommendation 1 :

Comprehensive assessments of CCS

Assessments of CCS that include factors such as coal supply and environmental trade-offs, under different future scenarios, in the recipient countries are also needed. Debates on possible inclusion of CCS in the CDM have shown that many stakeholders think CCS should be tested and developed in industrialised countries before it is deployed in developing countries.

Recommendation 2:

Focus on more technical goals and qualitative aspects

Many research projects focus on reducing costs of CCS, although many factors of the costs are external. Thus, learning may be counteracted by developing the markets for fuels and commodities. It is beneficial to focus on more technical goals, such as efficiency improvements, and qualitative aspects that have to do with reducing environmental risks and trade-offs.

Recommendation 3:

Conduct more research into BECS and air-capture

BECS and air-capture are given little priority in research, which could be strategically unwise.

Recommendation 3:

Examine financial support to unbiased research

Although this study does not quantify the amount of money that funds unbiased research, i.e. research on CCS without financial ties to industry, we propose that this issue is further examined. Unbiased and transparent research could not only enhance the quality of research but also positively affect public attitudes towards the technology.

4.5.2 Conclusions on IPR

Recommendation 1:

Implement IPR in the area of CCS

Intellectual property rights are essential to promote and protect innovation in new technologies that address climate change. IPR is a tool to hedge some of the risks of investing in R&D activities and prevents free riders from reaping the benefits of a particular innovation. In the case of CCS, it plays a crucial role because the technology is at an early stage of development and there is an urgent need for scale-up and demonstration of projects. Technology cost reductions and the recognition of IPR in key markets will enable rapid deployment.

The largest area of IPR relating to CCS appears in the technology for capturing CO_2. Research into emerging capture technologies suggests that there is likely to be a competitive market, because competition for CO_2 capturing technologies will develop and result in more efficient technologies in the market.

4.5.3 Conclusions on impact assessment policies

The European Impact Assessment system is a good framework that aims to stimulate better policy making, however, there are many gaps as has been shown in the review of the CCS related assessments. Additionally, the SEA framework may become a very useful tool when assessing strategic issues regarding CCS plans and programmes. It complements the Impact Assessment system that deals with overarching policies. Practical experience is very limited and the few examples show that a SEA is difficult to conduct.

One gap that has been identified on a general level is that basic assumptions are often made that should not be assumptions but rather subjects of close scrutiny. The European council has decided that there is a need for CCS after 2020, partly because of energy security reasons, which has led to Impact Assessments in EU using this as an established fact, when it is merely an assumption. However, new scientific findings and political discontinuities have shown that there may be strong arguments for opening up this "black box" and take a closer look at how the EU defines security of supply, and also how coal reserves are measured.

Recommendation 1:

Widen the scope of research of CCS issues

To provide a complete picture of CCS that can be used in decision making, everything from coal extraction, fresh water consumption, eutrophication and ecotoxicity have to be taken into account, which is not in line with current practice. Also, assessing all GHG emissions from a LCA perspective is better than assessing CO_2 *only, and it creates a better ground for comparing CCS with alternative mitigation options.*

Recommendation 2:

Include a thorough sensitivity analysis when constructing scenarios

Scientifically, it is hard to deal with the uncertain future, which has been shown in studies, in trying to estimate future costs of CCS. During 2007-2008 prices on commodities and fuels rose dramatically and rendered already developed scenarios outdated. Although prices returned to previous levels in late 2008, this illustrates the importance of including a thorough sensitivity analysis when constructing scenarios. The scenarios constructed for the impact assessment accompanying the CCS Directive proposal exemplify this risk.

Recommendation 3:

Introduce analytical methodologies for energy diversity and security

Economic models and estimations of CCS costs that are currently used in impact assessments often neglect risk. This gap could be overcome by introducing analytical methodologies for energy diversity and security that are currently confined to the financial sector.

Recommendation 4:

Choose impact assessment tools and methods wisely

The choice of impact assessment tools is paramount for the entire assessment. This is a critical gap that reflects the difficulties and immaturity of the SEA and Impact Assessment frameworks. The authors recommend several methods for use in assessments, which could render a range of final results.

Recommendation 5:

Capture Readiness

There is a concern, not least among parliamentarians, that CCS diverts resources from these renewables that are possible solutions in the long run. There seems to be no strategy that can bridge this gap between Parliament's ambition and the lack of evaluation methods.

In order to avoid a lock-in situation where stranded assets may be the outcome, capture readiness is often proposed. It includes, among other things, assessment of technical and economical feasibility as well as the anticipated costs of avoided CO_2. A gap in such an assessment is the lack of assessment of local demographics as well as public outreach and consultation activities to see if public acceptance is probable.

Recommendation 6:

Public Acceptance

Consultation and public participation is a basic principle of environmental impact assessments. This should not only be seen as an issue to create acceptance for CCS, but should foremost be seen as a valuable tool to bring forward viable and successful low-carbon alternatives.

Chapter 5

STRACO$_2$ Work Package 7
The International Dimension

Final Report

Project Leader

ZHANG JIU TIAN

ACCA 21

5 International Dimension

5.1 Introduction

This is a synthesis of Work Package 7 (WP7) of the STRACO$_2$ project, which sets out the international dimension of policy and regulatory issues of CCS with the involvement of Chinese stakeholders. This section reviews current energy and climate change policy in China in the context of CCS development, including a questionnaire distributed to relevant stakeholders for needs assessment, and gap identification. Changes in China's future energy mix, trends of energy demand, and current energy and climate change policies in China are summarised to give an overview of China's future energy development.

China has a high energy demand and its energy supply including coal, oil and electricity is stretched. At the same time, the oil sufficiency rate will be lower, and per capita power supply is quite low. Coal will remain the pillar energy source (taking up to 60% of the total) in the foreseeable future. China faces many energy supply problems: uncertain oil security, low energy efficiency, heavy pollution and pressure to achieve sustainable development.

As a means of reducing CO$_2$ emissions, CCS technology represents a safe and reliable technical reserve. However, as a relatively new carbon emission reduction technology, CCS still encounters many obstacles both technically and institutionally. There is an urgent need to clarify the legal status, technical specifications and evaluation of emission reduction benefits of CCS, both nationally and internationally. This will speed up the development of CCS technologies and their recognition and popularity in China.

5.2 Review of Energy and Climate Change Policies

Currently China does not have specific policies related to CCS. In this section the promulgation of China's energy and climate change policy is reviewed. These policies are closely related to the future development of CCS in China.

5.2.1 General energy plan

This section presents a table to update readers on China's *11th Five-Year Plan for energy development,* so as to provide a broad view of China's future energy development, changes to the future energy mix, and the trends of China's energy demand. The *11th Five-Year Plan of* *energy industries* will also be analysed, including coal industry, power industry and renewable energy.

Table 24- General Energy Plan in China

Plan	Content
The 11th Five Year Plan for Energy Development ***(April 2007)***	Provides for national energy development strategy, energy development goals, development layout, future direction of reforms with energy conservation and environment protection as priorities, plus an overall action plan for energy development in China. States that overall energy demand should be constrained and the share of new energy and renewable energy increased. Adds that by 2010, China's total prime energy consumption should be within 2.7 billion tons of standard coal equivalent (btce), with an annual growth rate of 4%. The proportion of nuclear power, hydropower and other renewable energies should be 0.9%, 6.8% and 0.4% respectively. The goal for total output of prime energy is 2.446 btce, with an annual growth rate of 3.5%. The proportion of nuclear power, hydropower and other renewable energies should be 1.0%, 7.5% and 0.5% respectively. Presents five major energy projects including nuclear power and renewable energy development, shown in the full report. Defines energy conservation requirements. Highlighted areas are important industries, transportation, construction and commercial and civil energy use. States that by 2010, energy consumption per 10,000 Yuan GDP should be reduced from 1.22 tce in 2005 to 0.98 tce. Sets goals to hit a 4.4% annual energy conservation rate, with a cut in SO2 emission of 8.4 million tons and a decrease of 360 million tons of CO_2 emission.
The 11th Five Year Plan for the Coal Industry	Will accelerate the building of a major coal base and facilitate the development of large coal companies and groups. Calls for orderly exploitation of coal. By 2010, the total output of major coal bases will reach 2.24 billion tons. Several state-controlled large coal companies and groups should be built to be responsible for trans-provincial coal supply. In so doing, the state can better control coal resources, regulate the coal market, secure coal supply and deliver healthy, stable and coordinated development of the coal industry. States that obsolete production practices should be abandoned, and supply and demand of coal industry be balanced so as to encourage greater productivity. During the *11th five year plan* period, one important task of the coal industry is "to restructure the industry, shut down small coal mines which are wasting resources and lacking safe production procedures, and regulate the total output of coal." Governments should work with the market to cultivate and develop major coal groups, achieve economic growth and close down, integrate, remold and restructure small coal mines over three years.
The 11th Five Year Plan for Power	Places equal emphasis on the development of medium and large projects and the closing of small coal-fired power units. States that 165 million kilowatts power of generating capacity

Plan	Content
Industry	will be created even though small coal-fired condensate units with a total of 15 million kilowatts capacity will be shut down. The generating capacity of medium and large projects being built amounts to 150 million kilowatts (annual average at 30 million kilowatts), including 45.127 million kilowatts of hydropower, 87.38 million kilowatts of coal-fired power, 4 million kilowatts of nuclear power, and 13.64 million kilowatts of natural gas generated power. New energies will generate 1 million kilowatts. At the same time, the closing threshold for coal-fired power units is increased to an average of 80,000 kilowatts. Coal consumption per kWh should be lowered to 370 grams of standard coal. Puts forward guidance for better development of coal-generated power and new energy-generated power. As to the better development of coal-generated power, within the coverage of the grid, newly-built coal fired power units should have a generating capacity of 600,000 kWh. The construction of supercritical power units and ultra-supercritical power units should be encouraged. In terms of using new energy to generate power, we recommended to harness both hydropower and wind power, and build large wind turbine farms with 100,000 kWh to 200,000 kWh generating capacity. Will increase the demand for new efficient power-generating equipment. “To conserve energy and cut emissions” requires an internal shake-up of the power industry, thus making it possible for further growth of the manufacturing of electricity-generating facilities. China should increase the supply of relevant equipment, especially supercritical power units and ultra-supercritical power units, large gas-powered units and large nuclear-powered units. To do so, China should hold open bids, import overseas equipments and technologies, learn their technology and apply them as soon as possible. Will boost the development of the power industry and related equipment manufacturing industry. State policy has a direct bearing on the power industry, particularly price control, and it also affects coal industry and the relevant equipment manufacturing industry. As for the highly efficient companies and electrical equipment manufacturers, state policy can help them to increase their competitiveness and gain a bigger market share.
The 11th Five Year Plan on Renewable Energy	Small hydropower developments will grow rapidly during the period of the plan. The guidance on power development, a special chapter, states that by the end of 2002, the installed capacity of small hydroelectric plants (with the installed capacity less than 50MW) should have an annual installed capacity of 2000 MW during the *11th five year plan* and the total newly installed capacity will reach 23,000,000 KW. The medium- and long-term plan for renewable energy, which was unveiled in September 2007, indicates that in areas with greater water resources, small hydroelectric power development should be increased. By 2010, the nationwide installed capacity of small hydroelectric plants will be 50,000,000 KW; By 2020, the nationwide installed capacity of small hydroelectric plants will be 75,000,000 KW.

5.2.2 Climate change policy

This section introduces the White Paper *Response to Climate Change: China's Policies and Actions* (2008) and *China's National Climate Change Program* (2007) as well as other energy-saving policies that have already been in place to provide readers a general picture of China's basic stance on climate change and current energy-saving actions.

5.2.2.1 Guidance, principles and goals

China's economic and social development faces important strategic opportunities. China will carry out such basic national policies as energy conservation and environmental protection, encourage the circular economy, and protect the biological environment. China will shoulder responsibilities identified in the *Climate Change Protocol*, restrain greenhouse gas emissions, and increase its adaptability to climate change.

China plans to carry out a scientific approach to development, build a socialist harmonious society, and stick to the national policies of conserving energy and protecting the environment. The goal is to control greenhouse gas emissions, increase sustainable development, ensuring economic development is at the core, with energy conservation, improving energy structure and protecting the biological environment as its priorities. China will rely on scientific and technological development to boost its capacity to tackle climate change so as to make new contributions to safeguarding the global climate.

In terms of overall objectives of China's fight against climate change: policies and measures to cut greenhouse gas emissions will make a difference; China's ability to adapt to climate change will grow steadily; climate change research should be improved and make new headway; public awareness on tackling climate change should grow dramatically; and relevant systems and mechanisms in fighting climate change should be improved.

5.2.2.2 Major areas of China's fight against climate change

China will cut greenhouse gas emissions in the following major areas: energy production and transformation; increasing energy efficiency and energy saving; industrial production process; agriculture; forestry; urban solid waste disposal. Major areas for China to adapt to climate change include: agriculture; forestry and other biological systems; water resources; coastline and coastal areas.

5.2.2.3 Scientific research and technological development

In order to tackle climate change, China has already worked on scientific research and technological development in the major areas of its fight against climate change. The priority should be a wide range of climate change accurate observation technologies, increasing energy efficiency and developing clean technology, emissions control and reusing technologies of greenhouse gases such as CO_2 and methane in major industries as well as carbon sequestration technologies and projects. While increasing scientific and technological input, China will also give more financial support to research related to climate change and encourage enterprises to do the same. China should also make full use of bilateral and multilateral funds provided by foreign governments and international organisations to carry out scientific research and technological development in the field of climate change.

5.2.2.4 Requirement for international co-operation

-*Technology transfer and co-operation needs*

These mainly include: (1) Technology for climate change observation and monitoring, (2) Greenhouse gas (GHG) emissions mitigation technology, (3) Climate change adaptation technology.

-*Capability building needs*

These mainly include: (1) Human resource development (2) Climate change adaptation (3) Technology transfer and co-operation (4) Enhancing public awareness (5) IT building (6) State information disclosure and compilation.

5.2.2.5 Policy on energy conservation

China promulgated and implemented over 20 regulations on energy conservation from 1980-2006. Major regulations include energy conservation regulations, energy conservation product design regulations, energy planning and protection measures concerning energy conservation.

China’s energy conservation policy mainly focuses on energy usage management at an early stage. The *Mineral Resource Law*, passed in 1986, played an important role in using energy resources rationally and reducing environmental pollution. A number of energy conservation policies based on energy conservation experiences followed from 1985 to 1987. The *Energy Conservation Law of People’s Republic of China* enacted in 1997 provided that energy conservation will play a long-term strategic role in China’s economic development. The law shows that energy conservation management is an important approach to enhancing energy efficiency and “technology improvement is the driving force of energy conservation.” It stresses the importance of the environment, which guarantees sustainable development. It will accelerate technological growth of enterprises, transform the mode of economic growth, and encourage social and economic sustainable development in China.

China attaches significant importance to energy conservation technologies and combines energy conservation and environmental protection. The idea for developing major energy areas stated in the *National Mid-long term Scientific and Technological Development Outline* includes "stick to the principle of putting energy conservation first, reducing energy consumption; make breakthroughs in key technologies of energy conservation in the major energy consuming sector; develop construction energy conservation technologies; and enhance one-time energy efficiency and terminal energy efficiency." *The Eleventh Five-year Plan for Energy Development* issued in April 2007 also has a full chapter dedicated to energy conservation and environmental protection. The Plan points out that, while implementing direct energy conservation and environmental protection measures, efforts shall be made to develop a circular economy, accelerate the development of high-tech industries, increase the service industry's proportion in national economy, improve indirect energy conservation and environment protection contribution through optimising the economic structure.

Energy conservation policies and regulations of the Chinese government are likely to become stricter and more complete. Because the energy conservation and emission reduction goal of 2006 was not realised, the NDRC adopted eight measures including "increasing restructuring efforts, improving technologies, strengthening energy conservation and consumption reduction management, promoting development of the recycling economy, reinforcing pollution control, completing legislation and standards, optimising relevant policies, and emphasising education of energy conservation" in 2007 to bolster energy conservation and emission reduction efforts.

5.2.3 Energy policies

This section introduces key policies and regulations concerning coal, electrical power and other regular energy industries.

5.2.3.1 Policies on the coal industry

Due to the nature of China's resources, coal was, is and will be the major basic energy resource in China for a long time. Coal plays a very important role in China's energy supply and energy security. Coal Industry Policies would change the business environment of China's coal industry enormously. They also have significant impacts on the coal industry's supply and demand balance, structure and profit prospect during the 11th five-year plan period. These policies are outlined in the full report and will guide the coal industry to develop according to the following plans:

-*Complete a system for paid mining rights and realise asset management on mining rights, which lead to the increase of mining cost of some new coal projects.* This was called for by *Some Opinions of the State Council on Promoting the Sound Development of the Coal Industry*. In 2006, the Ministry of Land and Resources said that China would charge state-owned enterprises for their mining rights acquired freely in the past according to the principle of paid use, and pilot projects will be carried out in the coal industry.

-*Separate social functions from coal enterprises, remove their burdens and improve coal industry's profitability in the future.* Local government shall separate the social functions from the coal enterprise in accordance with related policies of the state, clear all funds and charges which need to be cancelled, and remove the burden of coal enterprises.

-*Impose sustainable development fees which will increase the operation costs of the coal industry.* On 19 April 2007, the State Council approved at its executive meeting a pilot in Shanxi Province on the coal industry's sustainable development. The policies drawn from the pilot covered three fees: firstly, the energy basis construction fee will be changed into a Shanxi coal sustainable development fee, to the value of approximately 25 yuan/ton; secondly, a guarantee will be charged to the coal enterprise to recover the environment in mining areas, to the value of about 10 yuan/ton and; thirdly, a production line change development fee will be charged, to the value of about 5 yuan/ton.

-*Energy conservation and emission reduction policies will reduce coal consumption per unit production.* However, the relationship between supply and demand in the coal industry will remain unchanged. At present, China's economy is still in the mid and late stages of industrialisation; in fact, energy consumption is high. Therefore, energy conservation and emission reduction policies will not have huge impact on the relationship between coal supply and demand.

-*China supports the development of the coal-based chemical industry, and attempts to standardise investment projects and improve operation.* In 2006, the NDRC proclaimed that it would improve planning in this industry and set size caps for new projects. It would focus on the new investment projects and industrial regulation. Goals would be set and responsibility would be clarified so as to standardise investment and improve the operation of this industry.

5.2.3.2 Policies for the power industry

Policies targeting the power industry include industrial policies, price policies and taxation policies. The impact of industrial and price policies is direct while the impact of taxation policies is indirect.

-*Industrial Policies - to promote scientific development, improve energy conservation and emission reduction and advance industrial upgrading.* The goals of China's industrial policies are to develop high-tech industries, improve energy conservation and emission reduction and advance industrial upgrading. Restrictions are imposed on the electricity consumption of key energy-using industries, and on the start of new power projects. On 12 March, 2006, the State Council issued the *Announcement Concerning the Restructuring of Industries with Excess Capacity.* One month later, the NDRC, together with 8 government agencies, issued the *Announcement Concerning the Acceleration of Restructuring of the Power Industry for its Healthy Development.*[141] Thus began a new round of official power restructuring.

-*Price Policy – (1) to link coal and electricity prices and improve the differentiated price system.* Since 2004, the constraints on resources for China's economic development have become ever tighter. Coal and electricity were in short supply and the price structure was not rational. In July 2004, the NDRC issued *Opinions on Linking Coal and Electricity Price*, which states that: prompt and accurate understanding of coal prices are key to linking electricity and coal prices. Price authorities at all levels should strengthen the monitoring of the prices of coal for power generation, especially the coal prices of local state coal mines and township coal mines. The NDRC will, together with price authorities at provincial levels and power and coal companies, implement a mechanism to link coal and electricity prices. The NDRC requires that price authorities at all levels should strengthen the price monitoring of coal for power generation. (2) *Differentiated power price policies:* On 17 September, 2007, the General Office of the State Council issued the *Announcement Concerning the Improvement of Differentiated Power Price.* This announcement also provided the catalog and standards for some energy-intensive industries. It requires that all provinces and municipalities establish a working team headed by a provincial official so as to develop plans and monitor implementation. It also constrains the development of energy-intensive industries and encourages energy usage units to control cost.

-*Taxation policies - to adjust the export tax rebate rate for energy-intensive products to limit their export. (1) Eliminate the export rebate for some energy-intensive products.* In December 2005, NDRC, Ministry of Finance, Ministry of Commerce, Ministry of Land and Resources, General Administration of Customs, and the State Administration of Taxation and State

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[141] Document 66.

Environmental Protection Agency jointly issued the Announcement Concerning the Export of Energy-intensive, High Polluting Resources Products. (*2) Export tariffs have been raised on some energy intensive products.* The Ministry of Finance announced on 21 May 2007 that in order to strike a trade balance, China would adjust export and import tariffs on some products since 1 June 2007 so as to limit the export of energy intensive, pollutant-emitting and resource products, and increase the import of energy and resource products as well as key parts and components.

5.2.3.3 Renewable energy policies

In May 1997, the former State Development Planning Commission issued the Provisional Rules of the Management of New Energy Construction Projects; In February 1999, it joined efforts with the Ministry of Science and Technology in issuing the *Note on Increasing Support for Renewable Energy Law;* On 1 January 2006, The People's Republic of China Renewable Energy Law issued on 28 February 2005 came into force, creating incentives for developing renewable energy.

-Policies for small hydropower projects: intensified support with more incentives. Governments at different levels have been active in designing incentives to encourage investment in small hydropower stations. The central government has identified the following policy programs: The *National Program of Replacing Fuel with Hydropower for Ecological Protection, Middle and Long Term Program of Renewable Energy Development; the Eleventh Five Year Plan for Electric Power Industry; National Hydropower and Rural Electrification during the Eleventh Five Year Plan and 2020, Regulations on Supervision and Management of Power Grid Enterprises' Full Purchase of Electricity Generated by Renewable Sources issued by the State Electricity Regulatory Commission* on 2 August 2007 stipulated that power grid enterprises should purchase electricity generated by renewable sources in total. The price policy ensures the yield of small hydropower stations.

-Policies for wind power: improve the policy environment for its development. (1) Fiscal policies: The fiscal incentives for the wind power industry include subsidies and treasury bond money, and the former involves central government and local government subsidies. Subsidies for renewable energy from the central government aim at funding R&D, investment loans, projects and on-grid power. *(2) Taxation policies:* The State Council decided to abolish import tariffs and VAT on a category of equipment for state-encouraged projects with domestic or foreign investment since 1 January 1998. Some renewable energy equipment falls into this category, such as wind turbines and photovoltaic cells. For foreign invested renewable energy projects

that transfer technologies or are covered by the encouraging category in the *Catalogue for the Guidance of Foreign Investment Industries (2004)*, if equipment is imported within their total investment for internal use, import tariffs and VAT should not be levied. Relevant technologies, components and spare parts imported with the above mentioned equipment and listed in the contract should also be exempted from import tariff and VAT. *(3) Other policies and regulations***:** Since 1997, the Chinese government has launched a range of programs to develop wind power, such as the *Riding Wind Program, Double Engineering*, treasury bond-financed projects, wind power concession and industrialisation programs. The *National Key Technologies R&D Program* and the *National High-Tech Research and Development Plan* has identified projects to develop and produce wind turbines by Chinese companies. Arrangements have been made for the R&D on 750kW stall-regulated wind turbines during the Tenth Five Year Plan period. In addition, China has made a tentative attempt at offering incentives for the wind power industry, so clear and specific measures have been put in place.

-*Policies for biomass (straw) power generation industry—more government support and fund input.* In recent years, the government has attached great importance to the development and utilisation of biomass energy and promulgated a flurry of supporting laws and regulations, including the *Renewable Energy Law, Mid and Long-Term Program of Renewable Energy, Agricultural Biomass Energy Development Plan (2007-2015), Guiding Catalogue for Renewable Energy Industry, Relevant Regulations on Renewable Energy Generation, The Trial Measures for Administration of Renewable Energy Power Generation Pricing and Expense Sharing, Interim Measures on Special Fund Management for Development of Renewable Energy and Implementation Opinions of Fiscal and Taxation policies supporting the Development of Bio-energy and Bio Chemical Industry.* The government has also set state or industry-wise standards for 20-plus projects involving agricultural biomass, and comprehensive utilisation of straw and fuel ethanol.

5.2.4 Evolution of China's energy management

This section is devoted to the evolution of China's reform of its energy management system. By following the track of reform of China's investment and finance system and energy management system, the reform and development of the energy investment and finance system can be broken down into 4 periods:

1-Government-dominant mechanisms from 1949 to 1978. China was a highly centralised planned economy in this period. The state was its biggest investor, providing supplies needed by enterprises, determining investment activities and allocating fiscal budget.

2-Exploring period of energy system reform from 1979-1988. During this period, the management of enterprises and the administration of government began to decouple. The three ministries of oil, power and coal were replaced by the Ministry of Energy, three big companies in petrol and chemical industry and three big companies in coal industry.

*3-Market-oriented system began to take shape from 1989-1996***.** In 1994, China Development Bank was established. In 1995, the State Council authorised the state to be the unified investor and capital management representative, consolidating the role of state as the main investor. In 1996, an investment project accountability system, a legal person accountability system and an investment project capital system were implemented. All the above developments have helped the energy enterprises become a investor, making decisions, investing and taking investment responsibilities and risks. *(a) Energy enterprises carried out the business model of dependent accounting and self management.* PetroChina Company Limited started to study ways to enter the market and realise self operation and dependent accounting. *(b) The state made policy-guided investment in energy industry while enterprises took investment risks.* In April 1994, the original six specialised national investment companies were reshuffled to be China Development Bank. According to the regulations, the proportion of policy-oriented loans for construction projects in energy industry issued by China Development Bank for coal, oil and power was 94%, 53% and 44% respectively.

4-The framework of energy system featuring market economy took primary shape from 1997-2005. During this phase, reform of China's investment system deepened and the macro-administration system on energy experienced remarkable changes. As the reform deepened and the economy became more market-based, China ushered in a new phase in reforming the investment system, which was especially marked by the promulgation and enforcement of the *Decision of the State Council on reforming the Investment System* in 2004. Meanwhile, as the transformation of the corporate system in China's energy industry gathered momentum, the jurisdiction between the government and business on investment and financing was detailed. *(a) The shareholding system reform of energy enterprises reached an essential stage, with a more specified relationship between government and business on investment and financing.* The promulgation of the *Decision of the State Council on Reforming the Investment System* in 2004 exerted great influence on the state-owned enterprises in the energy industry. With the vicissitude of the government authorities and system in China's energy industry, the transformation of the corporate system in this area also increased, with the government-to-business, business-to-business investment and financing relationship, governmental administration of business and business internal management in investment and financing becoming clearer, more science-based and more appropriate. Since 1998, the China National Petroleum Corp.(CNPC), China Petroleum Chemical Corp.(CPCC) and China National Offshore Oil Corp.(CNOOC) have been reformed into group corporations with integration from upstream to downstream, devoid of the government functions as the original State Petroleum Corp. *(b) The administrative duties of the energy industry have been gradually distributed to a variety of specialised authorities.* The comprehensive energy authority was dissolved in the process of reform, leaving its administrative duties of the energy industry distributed to a variety of specialised authorities. In 2008, the National Energy Administration was launched under NDRC. It inherited the duties of the original National Energy Leading Group and assumed the functions of State Commission of Science, Technology and Industry for National Defence in administrating nuclear power. This served as a prologue to a unified administration and comprehensive plan for the development of the energy industry in China, laying a solid foundation for the upcoming establishment of the Ministry of Energy.

5.3 Stakeholder needs assessment

5.3.1 Questionnaire overview

In order to gain further insights into the outlooks of various institutions in China on CCS and its development, in May 2008, the Administrative Center for China's Agenda 21 (ACCA21) designed and conducted a questionnaire-based survey, aiming to identify the future direction of CCS development in China, and preparing for CO_2 emission reduction technology reserves.

The questions covered the following issues:

- The role of CCS in greenhouse gas control and climate change mitigation
- Obstacles in the commercial utilisation of CCS
- Insufficient understanding of CCS technology
- The potential contribution of CCS in climate change mitigation
- Outlook of CCS technology
- Perspective modes of transportation

- Perspective modes of sequestration
- CO_2 capture methods worthwhile for promotion for coal-fired units
- CO_2 capture methods worthwhile for promotion For gas-fired units
- Applicable CO_2 capture means for coal-fired units
- Applicable CO_2 capture means for gas-fired units
- Main technical barriers in transportation
- Major obstacles in sequestration locations
- The potential of sequestration locations in China
- Comparison of geological sequestration and oceanic sequestration
- Problems to be addressed in oceanic sequestration
- Main technical barriers in geological sequestration
- Problems to be addressed in geological sequestration
- CCS pilot projects and financial investors at their early stage of implementation
- Financial measures to ensure the long-term viability of CCS projects
- Questions need to be addressed in CCS-related regulations

5.3.2 Main outputs of questionnaire analysis

The following conclusions were obtained from the questionnaire. (1) CCS-related costs should first be reduced and a series of interest incentives be adopted; (2) At present, there is still a lack of understanding of geological sequestration capacity and effectiveness as well as the length of time of CO_2 sequestration; (3) The major contribution of CCS technology to the mitigation of climate change lies in its transfer and dissemination potential; (4) Carbon capture technologies in accordance with the prospects from good to bad are in sequence, post-combustion capture, pre-combustion capture and oxygen-enriched combustion; (5) In accordance with the prospects from good to bad, the modes of transportation are in sequence, pipeline, ship and truck; (6) In accordance with the prospects from good to bad, the modes of sequestration are in a sequence of oil and gas fields at late exploitation stage, non-exploitable coal layer, deep brine layer and oceanic sequestration; (7) For coal-fired units, the applicable CO_2 capture method is chemical absorption-based post-combustion capture technology; (8) For gas-fired units, the applicable CO_2 capture method is physical absorption-based pre-combustion capture technology; (9) At present, the main obstacles in transportation technology are pipeline corrosion, leakage detection and route selection; (10) Currently, the main barriers in terms of sequestration locations are geological features and monitoring plans; (11) In terms of sequestration mode, geological sequestration is better than oceanic sequestration; (12) The primary problem to be addressed in oceanic sequestration is ecological and environmental risks; (13) The obstacles in geological sequestration are in the following sequence: monitoring and inspection, the geographical distribution of the sequestration locations, and sequestration technologies and mechanisms; (14) The development of geological sequestration should first address the technical issues, followed by funding challenges; (15) The developed countries and their governments should provide finance to CCS pilot projects and first-stage project implementation; (16) In the long run, the governments and the developed countries should be the main investors for CCS technology; (17) The emission trading mechanism is able to ensure the long-term financial viability of CCS projects; (18) The issues to be addressed in CCS-related laws and regulations, in accordance with their levels of importance are safety, responsibility, incentives and site selection.

-Integrating the research of the policy selection and the technological innovations may provide a comprehensive solution for China. Carbon sequestration is a complex problem, which is not only concerned with policy issues, but also highly related to technical evolution. The research of the technical level can provide concrete support to improve feasibility of the policy research. Accordingly, the major task of the technical group is to identify the role of CCS technology in the Greenhouse Gas Control Strategy of China, and at the same time, to recommend the optional CCS technical routes suitable for China. Accordingly, this work had been divided into three parts, including (a) the introduction of representative options for Greenhouse Gas control; (b) the techno-economic evaluation of representative CO_2 capture technologies for energy systems and their adaptability to the specific conditions of China; (c) introduce the new CCS technologies and recommend the optional CO_2 sequestration technical routes suitable for China.

-*The introduction of representative options for Greenhouse Gas control.* In this part, the major approaches for greenhouse gas control, including the efficiency increment, adjustment of the energy mix, and CO_2 capture & storage, had been introduced generally. The basic principle and the characteristics of each approach have been described, and their potential for CO_2 reduction has been investigated. In some scenarios, the possible reduction contribution from each approach has been evaluated. In the scenarios with an assumed reduction target (to keep the CO_2 emission of 2050 lower than 2020), the results shows that with the contribution from efficiency, improvements can be higher than 30% of total reductions. Meanwhile, the reduction caused by adjustment of the energy mix may account for another 30%, in which the wind energy may play an important role in the last 40 years. Finally, to meet the reduction targets, CCS will be adopted, which will contribute to 40% of total reductions. In summary, as a major energy consumer and CO_2 producer in the world, China may have to rely on CCS technology if the emission reductions target is to be met.

-*The techno-economic evaluation of representative CO_2 capture technologies for energy systems and their adaptability to the specific conditions of China.* The energy and economic penalty caused by CO_2 capture accounts for nearly 80% of total cost for carbon capture and storage. Therefore CO_2 capture is the focus of this section. Until recently, three types of approaches for integrating CO_2 capture into energy systems have been investigated: post-combustion capture, pre-combustion capture and oxy-fuel combustion. Post-combustion capture is generally regarded as a more feasible approach because it can be adapted to existing power plants. However, because the exhaust gas is diluted by nitrogen, the concentration of CO_2 in the exhaust gas is rather low, which causes considerable energy consumption in the CO_2 separation process. Consequently, around 8.0 to 13.0 percentage points in efficiency will be lost due to the energy penalty for CO_2 capture in power plants adopting the post-combustion scheme. To increase the CO_2 concentration before separation, another important scheme, pre-combustion CO_2 capture, recovers the CO_2 before it is diluted by the air. In order to accomplish this, extra processes such as shift reactions should be employed. Consequently, the energy penalty for pre-combustion capture is mainly composed of three parts, including the energy consumption caused by the shift reaction, the energy consumption caused by CO_2 separation processes, and the reduction of power output caused by the decrease of the heating value of fuel gas. Most studies indicated that the thermal efficiency of a system adopting pre-combustion capture will be decreased by 7.0 to 10.0 percentage points.

To summarise the techno-economic characteristics of each capture technology, a table illustrating the results of several general cases including the ultra-super critical power plants with post-combustion capture, IGCC power plants with pre-combustion capture and coal liquification with CO_2 capture is provided in the full report. The economic cost for CO_2 capture may be reduced after being transferred and localised in China. For example, the cost will be around US $ 53 per ton of captured CO_2 for ultra-super critical power plant. After technical transfer and localisation of the key technology in China, the cost will be reduced to around US $ 35 per ton of captured CO_2 due to lower cost for instrument manufacture and salary for manpower.

However, the energy penalty (around 7%-15% decrease in efficiency for most existing CCS technologies, including post-combustion capture, pre-combustion capture and oxyfuel combustion) is still the main challenge. The unique energy conditions in China, including its heavily reliance on coal, the low energy utilisation efficiency and the rapid growth of energy consumption, make this problem much more complicated: Considering the enormous CO_2 emission from coal, to meet the goal of reducing billions of CO_2 emission per year, billions of additional tce energy consumption has to be paid as the penalty if the existing CCS technologies is adopted. Meanwhile, several hundred billion USD will be paid for implementation of CCS technologies, including the profit of CDM being taken into account. It is evident that China could not afford the sharp increment of energy consumption and economic cost due to existing CCS technologies, which will be extremely challenging to sustainable development in China. In conclusion, the exploration of new CCS technologies, which can make a breakthrough to solve the conflict between energy saving and CO_2 capture, will be indispensable for China.

-Introduce new CCS technologies and recommend the optional CO_2 sequestration technical routes suitable for China. How to improve the energy utilisation in chemical processes and power systems is one of the key problems for sustainable development of the energy and environment. The traditional concept for pollutant emission control is confined to the method of “polluting first and controlling after”, which is named as “the chain mode”. In this mode, the energy utilisation and pollutant control are almost independent of one another, which is actually the fundamental reason for the high energy penalty for CO_2 recovery. In contrast to the traditional chain mode, this work emphasises integration between the cascade utilisation of fuel chemical energy (which has the greatest potential for efficiency increment) and CO_2 separation. In this “integrated mode”, the CO_2 will be captured in the upstream processes of chemical energy utilisation, instead of in the downstream. Accordingly, the polygeneration system can realise the low or even “zero” energy penalty in two ways: the first is by reducing energy consumption for CO_2 capture through reducing the CO_2 generation irreversibility (for example, increasing the concentration of COX) in the chemical energy utilisation processes or

alternative fuel production processes, and the second is by offsetting the effect of CO_2 capture through renovation of system integration, which can promote the efficiency of energy utilisation.

Consequently, several innovative CO_2 capture technologies have been recommended. A novel coal-based polygeneration system, which integrates power generation, alternative fuel (methanol) production and CO_2 capture, was recommended. In the individual chemical production process, complete conversion is generally the major goal, which can be achieved with the aid of composition adjustment in fresh gas preparation or a recycle scheme in a synthesis unit. This is at the cost of a sharp increase in energy consumption along with an increment of the conversion ratio. With primary energy savings as high as 12-15% in comparison to the individual energy system (IGCC system with pre-combustion capture), this new system is superior also to the polygeneration system adopting the *Once Through Methanol synthesis scheme* (originated by Air Products and Chemicals Inc. under support of DOE, whose primary energy saving ranges from 4-8%). The more important point is located at the approach integrating CO_2 capture: In the new system, the CO_2 is captured from the unreacted gas after synthesis reaction, instead of the syngas generated by the gasifier in the case of IGCC with pre-combustion capture. For an IGCC system adopting the pre-combustion capture scheme, the highest CO_2 concentration that could be achieved before separation is just 30~35%. In contrast, in the new system, CO_2 concentration before separation can be as high as 50-52%, which is due to the internal phenomena of COX (CO and CO_2) intended transfer and concentration in the polygeneration system. As a result of this advantage, the new system can significantly reduce energy consumption for CO_2 capture compared to conventional systems adopting pre-combustion or post-combustion CO_2 capture. In the conventional coal-based IGCC systems, the thermal efficiency is around 42-44% for a case without CO_2 capture and around 34-36% for a case with CO_2 capture. However, the new system can achieve the equivalent thermal efficiency of as high as 47% with recovering 70-75% of CO_2, thereby providing a significant improvement for CO_2 capture. Moreover, the cost for CO_2/ton recovery will be lower than 10 USD, which is obviously competitive to the existing CCS technologies.

Corresponding to the characteristics of China (“abundant coal, few petroleum and natural gas,” “concentrated energy resource bases, dispersed energy-use terminals,” and “the developing western areas and the developed eastern area”), a new technical route of the Energy Network, which is composed of the energy source, transportation chain, and terminal user, is recommended. The Energy Network is suggested as one promising solution for sustainable development in China: First, at the upstream of the energy resource bases, adopting the innovative energy systems based on cascade utilisation such as the polygeneration system proposed in this research, coal is converted into alternative fuels (like methanol, DME or Hydrogen) and electricity. Then CO_2 is recovered simultaneously, which can achieve concentrated storage of CO_2 on site. Second, the transportation of clean energy consumes less energy than primary coal. Finally, at the downstream, clean liquid fuels can be substituted for gasoline as transportation fuels or can be utilised to generate electricity in advanced energy systems. This can abate the dependence on oil imports, increase energy utilisation efficiency, and avoid emissions of pollutants in population-dense areas especially for CO_2 mitigation in China.

5.4 Techno-economical evaluation of CCS technologies

5.4.1 Introduction

This section was prepared by the Institute of Engineering Thermophysics, Chinese Academy of Sciences, herein IET. The major task of IET is to identify the role of CCS technology in the *Greenhouse Gas Control Strategy of China*, and to recommend optional CCS technologies to suit China. This is presented in three parts: introduction of representative options for Greenhouse Gas control; techno-economic evaluation of representative CO_2 capture technologies for energy systems and; recommendation of optional technical routes for CCS development suitable for China.

A new scenario, in which resource exploitation, energy transportation and utilisation, and CO_2 capture and storage can be integrated, is proposed. Preliminary results illustrate its attractive performance, which can save about 30% energy consumption and reduce CO_2 emission by 70%.

5.4.2 Options and Approaches for Greenhouse Gas Control

5.4.2.1 Technological options for greenhouse gas control

At present, the options for reducing net CO_2 emission to the atmosphere include:

-*Changing energy structure, switching to low-carbon fuels*, e.g. natural gas instead of coal, increasing the use of renewable energy or nuclear energy, which emits little or no net CO_2;

-*Technological solutions for reducing energy consumption by increasing energy conversion and utilisation efficiency, or capturing and storing CO_2 with sequestration technologies*;

-*Sequestering CO_2 by enhancing biological absorption capacity in forests and soils*.

5.4.2.2 Adjustment of energy structure, utilising low or no-carbon fuels

Known as zero-emission energy resources, nuclear energy and most renewable energy do not emit any CO_2 in their conversion and utilisation processes. The application of bio-energy, whose carbon element comes from the atmosphere during the growth of plants, will not increase net CO_2 concentration in the air. So bio-energy can also be considered as a kind of clean energy resource. Furthermore, if CO_2 produced in bio-energy utilisation processes can be captured and stored, net removal of CO_2 from the atmosphere can be achieved. The overall effect is referred to as 'negative net emission', an innovative concept that has attracted wide attention in policy making rather than in technical improvement in European countries.

However, energy structure adjustment is restricted by many objective factors, including resource structure, technical level and energy safety.

Promoting energy utilisation efficiency as well as exploiting techniques of CO_2 separation, storage and utilisation- Besides adjusting the energy structure in China, another important pathway to controlling greenhouse gases is to improve energy utilisation efficiency as well as to exploit CO_2 technologies of separation, storage and utilisation. Increased utilisation efficiency will mean less fossil fuels are consumed, finally leading to mitigation of CO_2 emission.

Storage and utilisation of CO_2 provides a terminal for excessive CO_2. The CCS process is to separate CO_2 from the flue gas in a combustion system and to compress it under high pressure, then to transport it to the site for storage. A considerable amount of CO_2 needs to be captured and stored in order to alleviate global warming. As CO_2 should be used and stored in its purest forms, separating CO_2 from other gases should be the first step of CCS technologies.

About 56% of CO_2 emission from fossil fuel combustion (which accounts for 83% of total CO_2 emissions), comes from power plants, steel industries and chemical production processes, and about 32% and 12% from transportation and daily life, respectively.

5.4.2.3 International attitudes and options for greenhouse gas control

The UN Climate Treaty aimed to stabilise the concentrations of greenhouse gases in the atmosphere at a level that will not have a damaging effect on the environment. Improving energy utilisation efficiency and pursuing advanced technologies to utilise clean energy, are at the core of the treaty, which has also becomes one of the main themes of energy research in the 21st century.[142] In 1997, the Climate Treaty was extended to include the Kyoto Protocol, which contains agreements about reducing greenhouse gases emissions.[143]

To improve energy utilisation and greatly reduce CO_2 emission, the Vision 21 program was proposed by the U.S. DOE. Its basic aim is to generate hydrogen from coal, and sequestrate CO_2 simultaneously. Power generation efficiency of coal-based and natural gas-based power plants with quasi-zero emissions are expected to reach 60% and 75% by 2050, respectively. The greenhouse gas control strategy proposed by the European Community aims at accelerated development of new technologies for energy utilisation, a decrease of dependence on oil, and reduction of environmental pollution. To achieve these goals it focuses mainly on the increased utilisation of biomass and other renewable energy. The Syngas Park concept (Shell Corporation) has higher expectations than Vision 21: coal-based syngas can be used for power generation and cooking, as well as to produce clean liquid fuels such as methanol and DME. Nuclear energy will play a momentous role in greenhouse gas control in Japan. Japan's "New Sunshine Project" researches energy release methods, such as High-Temperature Air Combustion (saving 30% energy and reducing 50% NO_X emission), thermal cycle with O_2/CO_2 combustion, and WE-NET project (composed of hydrogen production, transportation, storage and utilisation). The technical routes for greenhouse gas control are proposed based on each country's special conditions.

5.4.2.4 Greenhouse gas control problems in China

Although only developed countries in Annex I of the Kyoto Protocol must implement the reduction commitment, increasing emissions caused by economic development have led to rising pressure imposed on developing countries. As the second largest CO_2 emission producer, China has high CH_4 and N_2O emissions. 823 million tons of CO_2 emissions were added by China during the period of 1990-2001, which accounted for 27% of the total world growth. Increased CO_2 emission from China than in U.S. will result in China becoming the largest GHG producer in the world. However, due to old equipment, underdeveloped techniques and high energy consumption intensity, CO_2 emissions per unit of GDP in China are higher than the average global level.

A suitable technical route for greenhouse gas control should be proposed in China as soon as possible during the processes of industrialisation, urbanisation and modernisation in China, in

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[142] UNFCCC, 1992; Rio de Janeiro.
[143] UNFCCC, 1997; Kyoto.

order to offer scientific foundation and theoretical support for policy making, and contribute to abating global climate change.

5.4.3 Scientific problems in CO_2 recovery

CO_2 capture technology could be applied to power generation and other industrial processes due to their stable sources and high CO_2 emission. It typically involves separation from a gas stream, techniques for which include cryogenic, chemical absorption, physical adsorption, and membrane methods. When CO_2 concentration is low, some impurities, e.g. SO_2, NO_X and ashes, should be removed before chemical absorption due to their negative effects. Adsorption is only applicable to small-scale systems because of the adsorbent's limited capacity. Membrane methods are not ideal for large scale separation due to their selectivity, high cost and work conditions at a low temperature and high pressure. However, a considerable energy penalty has to be paid in all technologies. A great deal of saturated steam is needed for absorbent regeneration. Pressure and temperature losses in the separation process are fatal defects of adsorption technology. As membrane separation proceeds at a low temperature, separating CO_2 from high temperature flue gas causes a large amount of thermal loss. Although technically there is a low barrier to separating CO_2, because CO_2 is very stable, its separation requires a great deal of energy and costly nitrogen which is used to dilute the CO_2. Although CO_2 separation may be technically viable, it is unsustainable in terms of energy and the economic impacts.

The focus should be on finding a compromise between energy utilisation and environmental protection to solve CCS issues, namely to improve energy utilisation efficiency and recover CO_2 simultaneously under direction of the principle of combined energy cascade utilisation and coupling energy with an environment-friendly energy system.

5.4.4 Innovative CCS technologies for the next generation

Chemical energy of fuels is turned into physical energy which is then converted into work within the maximum Carnot cycle efficiency in traditional thermal cycles. So far, most investigations of thermodynamics are concerned with the cascade utilisation of physical energy and complication of thermal cycles, following the principles of temperature match and cascade utilisation. Nevertheless, a neglected issue is that the greatest energy destruction of the thermal cycle system is in the combustion process, namely the process of converting chemical energy into physical energy. Hence, research on efficient conversion/utilisation of chemical energy, which adheres to the principle of chemical energy cascade utilisation, has become a leading topic in the thermodynamics field. CO_2 is conventionally separated from flue gas, which illustrates that the combustion process is the source of CO_2 production. Separating diluted CO_2 after combustion will decrease system efficiency by 10 percent because of the high energy penalty for separation. In recent years many researchers have decreased energy consumption of CO_2 separation via system integration. The O_2/CO_2 cycle is one of the systems which can lower energy consumption of CO_2 separation to zero, but it diverts energy consumption to oxygen separation work, which still decreases the system's network by approximately 10 percent. These above studies suggest that existing technologies of CO_2 separation do not fulfil the harmonious development between energy utilisation and environmental protection.

In fact, the CO_2 separation process is also mutual conversion of physical and chemical energy, which indicates that the conversion/utilisation of chemical energy is closely associated with CO_2 separation. For instance, can the difference in energy-level in the chemical energy release process be used to separate CO_2? Or can the energy penalty of separation be reduced by concentrating CO_2 during chemical energy conversion? Here novel integrated energy systems with CO_2 recovery based on the principle of cascade utilisation of chemical energy are proposed.

5.4.4.1 Integration of combustion and CO_2 recovery

A suggestion was chemical-looping combustion (CLC) thermal cycle, combining chemical energy release with CO_2 recovery, which can highly utilise chemical energy of fuels and pay no energy penalty for simultaneous CO_2 recovery. CLC achieves integration of chemical energy release from fuel and CO_2 recovery. CLC also achieves a leap in system efficiency. The process is detailed in the full report. The investigation shows that efficiency of the energy-environmental power system with natural gas-based or syngas-based CLC, is at least 10 percentage points higher than that of gas-steam combined cycle with CO_2 recovery. The CLC system can address problems connected to energy utilisation and environmental protection.

5.4.4.2 The polygeneration system for production of clean energy and power with CO_2 recovery

Clean coal technology has been the main direction of the thermal power industry in the world in recent years. And coal-fired combined power generation system are the most prospective clean coal technology, which has attracted worldwide attention in the energy power field. The integrated gasification and combined cycle system (IGCC) and pressure-fluidised bed and coal-fired combined cycle system (PFBCC and its second generation) have demonstrated great advantages and potential, but some problems still exist, including that they are complicated and costly, and neither system has been able to mitigate CO_2 for the moment.

IET have proposed a partial-gasification IGCC system that integrates internal and external coal-fired combined-cycle systems in a novel power-generating system to achieve the integration of the thermal process and CO_2 recovery. This novel system, a combination of internal and external coal-fired systems, has better economic performance than an IGCC system for a number of reasons. Through coarse calculation, the total cost of this system is 20% lower than that of semi-closed Brayton IGCC system. More details can be found in the full report.

Among clean-coal technologies, in addition to producing electric power by utilising coal directly, productions of alternative liquid fuels through coal gasification or natural gas are also connected. The polygeneration system based on this concept, which can generate electricity, chemical products, and clean synthetic fuels simultaneously, combines flexible conversion of components in the chemical process with a high energy utilisation level of the power system, therefore, it will make a breakthrough in energy utilisation with CO_2 recovery, and will become a major technical route of energy utilisation in the future. The integrated system of clean energy generation with CO_2 recovery, a kind of polygeneration system, is an attractive way of using fossil fuels to provide clean, affordable energy, especially including potential for CO_2 emission control at low energy consumption.

As demonstrated in the full report, CO_2 emissions per unit of electricity output can be reduced by 8.7 percentage points in a new system compared with the IGCC system without CO_2 recovery, whose thermal efficiency is about 43.9%. Based on the equivalent CO_2 recovery ratio, the thermal efficiency of the new system is 47.3%, superior to the IGCC system adopting conventional pre-combustion CO_2 capture (around 35%). Compared to a single product IGCC system, thermal efficiency of this polygeneration system with CO_2 recovery increases 3.4 percentage points, which indicates its potential to recover CO_2 at a low cost.

Because the polygeneration system with CO_2 recovery can recover partial CO_2 under the equivalent energy consumption in the chemical process and thermal efficiency of a single product system, it can be considered as one of the main technical routes of energy systems with CO_2 mitigation. Opening out the interrelationship of component conversion, energy conversion/utilisation and CO_2 recovery, discovering a new separation point, and recovering CO_2 at low or void energy consumption on the basis of decreasing the ideal work for CO_2 separation, will become the core of the principle of integrated energy conversion/utilisation and CO_2 recovery in the future.

5.4.4.3 Integration of cryogenic energy utilisation and CO_2 recovery

At present, the energy utilisation manner of fossil fuels commonly is direct combustion with air, which brings problems of CO_2 recovery as well as pollution by NO_X, SO_X and particulate matters. The CO_2 concentration in flue gas is diluted by N2 to no more than 10%, and the liquefaction and compression processes of the separated CO_2 need a lot of energy, both of which are the main reasons for the high energy penalty for CO_2 recovery. Different from the usual two-step (separation and compression) CO_2 recovery process, the new system can separate and liquefy CO_2 simultaneously through the integration of cryogenic energy in an air separation unit (ASU) and CO_2 recovery unit. In this way, a large amount of compression work and energy consumption for CO_2 recovery can be greatly reduced.

The IGCC system has merits of not only high efficiency, low pollution, and water-saving, but also pre-combustion decarbonisation. The CO_2 concentration of up to 20%-40% after the shift reaction reduces energy consumption and the cost of CO_2 recovery. Therefore, the approaches of recovering CO_2 from the IGCC system are mostly traditional chemical and physical methods. Research indicates that traditional absorption approaches decrease energy efficiency by 6%-17% due to their high energy consumption. Through system innovation, a combination of air separation processes and CO_2 sequestration, it is possible to realise CO_2 separation and recovery simultaneously to reduce energy penalty for CO_2 separation.

When the product is liquid CO_2, energy consumption of CO_2 recovery in the IGCC system with integration of ASU and CO_2 recovery (0.626 MJ/kg CO_2) is 38.6% lower than that of MEA absorption process (1.02 MJ/kg CO_2). The IGCC system with integration of ASU and CO_2 recovery can generate extra oxygen, which can be used to organise the H_2/O_2 combined cycle. More virtues of the new system integration are explained in the full report.

5.4.5 Environment-friendly energy technology route in the urbanisation of China

On account of coal's great proportion in the energy structure, China needs its own energy-environmental technical route, differing from developed countries whose main energy sources include natural gas and biomass energy. As mainstreams of current clean-coal technology, the IGCC system and supercritical system always receive widespread attention, but their inherent obstacle to CO_2 control, the high energy penalty for CO_2 separation, will prevent them from achieving sustainable goals of energy utilisation compatible with environmental protection.

China's geographical distribution in terms of energy resources and the development gap between eastern and western areas, a lagging economy but rich resources in western areas and a developed economy yet scarcity of resources in eastern areas, determine that energy industry in China can be divided into two parts, energy resource bases upstream and energy-use terminals downstream. Energy demand is not urgent in western areas, while in eastern areas it is rising sharply due to rapid economic development.

The traditional energy utilisation concept is that primary energy in western regions is transported by vehicles or through pipes to eastern regions, and large-scale coal-fired power plants adopting general techniques are built in eastern cities, which causes several problems:

(1) Simple export of primary energy in low added value cannot drive the economy and even causes pollution and breaks the local eco-balance. If resources become exhausted in western regions, economic development will slow down.

(2) There is an extremely high energy penalty for transporting primary energy with low energy density, containing a mass of non-combustible components and pollutants, from west to east.

(3) Traditional energy-use technologies (e.g. coal-fired power plants and coal-fired heating boilers) with low efficiency, will bring pollutants from less populated to more densely populated areas, resulting in adverse environmental protection.

Due to the problems above, traditional concepts cannot achieve the requirement of sustainable development. In seeking to solve the energy-environmental problems, a novel technical route should be carefully considered in the energy industry in the context of China’s urbanisation.

Considering the energy structure, resource distribution and economic status of China, we propose a new national energy network concept, whose material concept and essential traits are outlined below. It changes the conventional energy utilisation concept of transporting primary energy to energy-use terminals, then producing electricity by general techniques. It draws a technical route of exploiting different energy utilisation technologies on the basis of distinct characters in different sections of energy industry, then combining them on the national energy utilisation level. As an example, the polygeneration system, combining chemical processes with a power system, can be used in energy resource bases in the national energy network upstream. Its technical predominance is shown below:

(1) Greatly simplify the technical process and system structure, by taking steps to increase energy utilisation efficiency (saving energy by 20%) by cancelling the syngas reforming process or recycle structure of unreacted gas, in order to reduce equipment investment (a 15~30% decrease) and operation costs (a 20~30% decrease).

(2) Based on the course flexibility of the polygeneration system, its capacity ratio between electricity and chemical products can be adjusted depending on market demands. When electricity is in great demand (or in peak load hours) or the market price of methanol is low, polygeneration can produce a lower amount of methanol or use methanol as fuel to meet the demand for electricity. On the contrary, when electricity is in lower demand (or in light load hours) or methanol sells at a high price, polygeneration can produce a greater amount of methanol. This process has flexible market adaptability, and good partial load property.

(3) As products of clean coal technologies, coal-based methanol can substitute gasoline and DME can replace diesel oil, both of which have prospective markets in China. Questions about toxicity, low heat value, and corrosion of methanol as fuel are now answered. At present, the annual yield of methanol is about 6 million tons in China. With the rising global oil price, alternative fuels such as methanol and DME will have a strong market drive in China. The demand of methanol will increase to tens of millions of tons, which will mainly be used in transportation as alternative fuels, while the rest will be used as chemical sources.

(4) Coal-based methanol production costs less than natural gas-based methanol production. In China, the majority of methanol comes from coal gasification and the minority comes from coke-oven gas. Compared to the high initial investment and long payback period of a coal-based single product system, polygeneration not only can decrease the cost and specific investment of coal gasification, but also can reduce the production cost of F-T liquid fuels and DME. With the low price of raw materials, high added value of liquid fuels and electric power products, and flexible market adaptability, construction of the polygeneration system in China’s coal-abundant region enables power generation and liquid fuel production from coal gasification to be more competitive on the market, in order to fully exploit resources and develop the local economy.

Besides the traits identified above, the more significant advantage of polygeneration is efficient energy conversion/utilisation with simultaneous CO_2 recovery. CO_2 removal from fuel gas will increase the ratio of hydrogen and carbon in chemical processes, and will avoid the dilution of the combustion process to CO_2, which can reduce the energy penalty for CO_2 separation greatly. An attractive feature is that advanced polygeneration can concentrate carbon with no energy penalty by producing liquid fuels, which can further reduce energy consumption of CO_2 separation. Compared to the IGCC system without CO_2 recovery, the thermal efficiency of the IGCC system with pre-combustion separation drops almost 10 percent for CO_2 recovery, while that of the polygeneration system with CO_2 recovery rises 3 percent, which overcomes the unaffordable energy penalty for CO_2 recovery in energy systems, and shows prospects of polygeneration as a sustainable energy technique. Application of the polygeneration system in energy resource bases is realistic. Firstly, CO_2 can be liquefied and stored in mines or oil fields nearby at a low cost, which can address the CO_2 storage problem. Secondly, the conversion of resource output in low added value, to clean energy output in high added value, can fully promote the economy of energy resource bases and bring a new pattern of healthy and sustainable development in the western regions of China. Therefore, the chemical-power polygeneration system is particularly applicable for resource-rich and economically developing areas, and is the crucial part of the technical routine of the national energy network.

The flexible national energy network has several distinct characteristics. First, in the multi-output of energy resource bases upstream, adopting energy synergic cascade utilisation technologies such as polygeneration and clean synthetic-fueled multi-utilisation systems, coal is converted into clean fuels and electricity, and CO_2 is recovered simultaneously, which can achieve an increase of resources on site and concentrated disposal of pollutants. Secondly, transportation of clean energy consumes less energy than that of coal. Finally, in the multiple usage of products downstream, adopting energy synergic cascade utilisation technologies, clean liquid fuels can substitute gasoline as transportation fuels or be used to generate electricity in advanced energy systems, which can abate dependence on oil imports, increase energy utilisation efficiency and avoid emissions in densely populated areas.

Superior to current advanced power technologies, such as a supercritical power plant, the technical route of the national energy network can save energy by 30-40% and mitigate CO_2 emission by 40-60%, as well as reduce other pollutant (particulate matters, NO_X, SO_X etc.) emissions dramatically. A rough estimation shows that a 30-50% greenhouse gas mitigation would be possible in the next 100 years with the spread of the technical route of national energy networks.

In conclusion, the national energy network appears to be the best solution for China when considering the country’s resources and development. China’s energy make-up is dominated by coal, with scarce oil and natural gas. As for resource distribution, there is a high concentration of energy resource bases with few dispersed energy-usage terminals. These factors combined with the development gap between the eastern and western regions, mean that a national energy network offers a suitable route to sustainable development in China through a technically developed, environmentally-sound energy supply which would promote urbanisation.

5.5 Conclusion: Gap Analysis and Recommendations

As a relatively new carbon emission reduction technology, CCS still faces many challenges and obstacles both technically and institutionally. Technically, to introduce CCS technology into the energy systems, it is necessary to redesign and transform related infrastructure of energy systems (such as transportation pipelines, hydrogen production equipment, etc.) which need institutional support. However, institutionally, the CCS related legal framework and policy system are still in their initial stages of development. With a coal-dominant energy mix, the needs for coal in China's power system will remain high. Coal burning emits a high level of greenhouse gases, which means that CCS technology has great development potential in China. However, for CCS projects' industrialisation, there are still many problems such as technical uncertainties, environmental risks, financial support, and social and legal recognition.

5.5.1 Socio-economic factors restricting CCS development in China

CCS is still a new emissions reduction technology in China. It is helpful to assess its socio-economic impacts because, as a measure to mitigate climate change, it is gradually receiving more attention from academic and business communities. However, development of this technology will be subject to many environmental, economic and social impacts.

As an acidic property with potential for causing suffocation, CO_2 and its capture and storage will affect human health and safety, and will bring risks to nature and the environment. These risks are mainly related to potential CO_2 leakage from engineering systems (such as the capture and transport pipelines) or geological storage sites. China has relatively poor weather conditions. The majority of the country has a continental monsoon climate. The seasonal temperature variation in most areas of China is high. Precipitation is unevenly distributed. China is frequently attacked by meteorological disasters. China also has a fragile ecological environment. A complete and effective environmental monitoring system does not yet exist, nor does it have a reasonable and workable system of monitoring indicators for air pollution and geological leakage detection. Due to this fragile ecological environment and frequent weather disasters, CCS in China poses higher risks than in the US and Western Europe, and also has a higher requirement for selection of CCS sequestration sites.

Insufficient public awareness will prevent widespread promotion of CCS in China. As the world's most populous country, China is still at a low level of urbanisation. The proportion of urbanisation in 2007 was only 44.9%; because of the enormous population size, low levels of urbanisation and high population mobility, it is difficult for the government to increase public awareness of emissions reduction, especially in underdeveloped regions.

CCS with high economic assessment costs would increase the economic impact of energy. China's current economic development level is still relatively low. The income gap is comparatively large between China's urban and rural residents. China's low levels of technological development and independent innovation have made it an urgent task to develop the economy and improve people's living standards. Energy is a necessity of life, and the public is very sensitive to energy price changes. From the latest assessment results, adoption of CCS technology will greatly increase the cost of energy, thus reducing residential expenditure in other aspects, and bringing losses to social welfare.

CCS is likely to encounter market obstacles in China. Market barriers are unavoidable and involve several uncertainties including risk-related organisations and departments, technology and market conditions. The cost-effectiveness of an investment for a factory running for 20 years will be determined by how long its capital investment will be recovered. All these factors in market-oriented operation should be considered comprehensively for better co-operation and risk sharing.

5.5.2 Analysis of energy and climate change policies

If CCS technology is to be widely promoted in China, it must be technically mature and financially competitive, especially when compared with renewable energy. We must see that, at present, unlike other emission reduction technologies, there are insufficient or even no policies or regulations providing definite support to CCS. Financing is a major obstacle for the large-scale development of CCS technology in China. In a developing country like China, although many experts and scholars want to include it in the financing framework of CDM, it is difficult to do so in the short run, before some basic methodological issues, such as the definition of project boundaries, are clear.

China lacks operational preferential policies for CCS technology. Preferential policies play a very important role in promoting technology. These policies are very effective and have greatly protected and promoted the development of renewable energy in China. Since 2001, nuclear power and renewable energy power generation have accelerated their development, and this is inseparable from the promotion of related policies. Therefore, the future rapid development of CCS technology in China will be highly dependent on the support of preferential policies.

China is short of CCS-related legislation. Legislation on a particular energy technology can fundamentally protect its future development. However, as one kind of emerging and new technology, the technology level of CCS must further develop before it is possible to obtain more policy support.

As has been shown, in China so far there are very few regulations and standards for liability and safety of CCS. There are two possible approaches to designing and implementing such legislation in China. The first option would be to define regulations through a contract arrangement during the license and permitting phase of demonstration (similar to the approach in the UK) drawing from the lessons learned from demonstration projects for future regulation to deal with commercial deployment. The second option would be to define a specific CCS regulation (which would be similar to the EU CCS directive) before fully implementing demonstration projects. This is further discussed in the full report.

5.5.3 Major Legal Issues

There is likely to be multiple-management in the jurisdiction of CO_2 sequestration in China in the future. CO_2 capture and sequestration will involve multi-faceted legal relationships locally, regionally, nationally and internationally, and its jurisdiction involves many departments including energy, environment and natural resources. In China, the State Energy Bureau, Ministry of Environment, and Ministry of Land and Resources will all have jurisdiction of CCS projects. As China still lacks policies and regulations on CCS, the early implementation of CCS projects is extremely likely to be multi-managed, which will result in project approval being more difficult and taking longer, with more stages in examination and approval.

It is difficult to define the ownership and accountability of CO_2 sequestration projects. These include the potential impacts on land use rights, existing provisions in trade and property laws on ownership, and acquisition rights which might conflict with existing legal provisions. It might also occur that because there are different investment and management entities (state-owned, private or foreign), the ownership jurisdictions of CO_2 sequestration would be different.

There is no unified technical standard and norm on CCS. Before the industrialisation of CCS in China, it is necessary to establish a series of standards to guide CCS implementation and monitoring, and to ensure the feasibility, safety and efficacy during and after the implementation of projects. Through national, sector or industrial legislation, CCS-related technical standards and norms will be made and this is an important prerequisite for faster and more secure implementation of CCS projects. The final acceptance of the general public of CCS also depends on the authority of technical standards and the security of environmental norms.

China lacks incentivisation schemes for CO_2-related sequestration**.** Although China has proposed to develop low-carbon technologies and a low-carbon economy, a set of related incentives has not yet been designed. CO_2 sequestration is of great significance for climate change mitigation. Financial and tax preferential policies will be important for supporting the development of CCS. All countries should incorporate policy items in favour of CO_2 sequestration in their existing tax and financial systems for renewable energy and low carbon technology investment.

China needs to establish a mechanism for public participation in order to increase public recognition of CCS. Many international organisations and national policy-makers agree that public recognition of CCS is a great challenge for CCS expansion. It is hoped that future availability of more data would help to improve public awareness of the risks and benefits.

Support to Regulatory Activities for Carbon Capture and Storage

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