Carbon capture and storage – legal and regulatory framework

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Abstract

In 1998, a colleague introduced a paper on greenhouse gas (GHG) reduction with a famous Mark Twain quote: 'Everybody talks about the weather, but nobody does anything about it.' Humour aside, the colleague's point was to highlight the considerable body of work under way to develop technologies to address the climate change impacts of GHG emissions. One option is carbon capture and storage (CCS), a technology that has been in the making for over 50 years. Thousands of scientists, engineers, and policymakers throughout the world are not only talking about CCS, but also diligently pursuing the technical know-how and legal and regulatory frameworks needed to deploy CCS as a climate change solution. CCS has many passionate supporters, some equally passionate detractors, and some who view it as a technology that must be tolerated to bridge the gap to fossil-free energy. This is a progress report on CCS readiness throughout the world with regard to the legal and regulatory framework development that is critical to CCS deployment.

Abbreviations

ACCSDC	Alberta Carbon Capture and Storage Development Council
APEC	Asia Pacific Economic Cooperation
APP	Asian Pacific Partnership
BAT	best available techniques
CCA	UK Climate Change Agreement
CCL	UK Climate Change Levy
CCS	carbon capture and storage
CCT	clean coal technology
CDIAC	Carbon Dioxide Information Analysis Centre for the UN
CDM	Clean Development Mechanism
CERT	UKs Carbon Emissions Reduction Target
CESP	UKs Community Energy Saving Programme
CO_2	carbon dioxide
CO_2 EOR	enhanced oil recovery using CO_2
CO_2-e	carbon dioxide equivalent
COP	Conference of the Parties UNFCCC
CPRS	Carbon Pollution Reduction Scheme
CSLF	Carbon Sequestration Leadership Forum
CTL	coal-to-liquids
EC	European Commission
EEA	Agreement on the European Economic Area
EEPR	European Energy Programme for Recovery
EFTA	European Free Trade Association
EIB	European Investment Bank
EOR	enhanced oil recovery
ERCB	Energy Resources Conservation Board of Alberta
ETS	emissions trading system
EU	European Union
EU-ETS	European Union Emissions Trading Scheme
EUA	European Union Allowances
GCCSI	Global Carbon Capture and Storage Institute
GDP	gross domestic product
GHG	greenhouse gas
GSS Act	Offshore Petroleum Amendment (Greenhouse Gas Storage) Act of 2008
$GtCO_2$	gigatonnes of carbon dioxide
IEA	International Energy Agency
IEA GHG	International Energy Agency Greenhouse Gas (Programme)
IGCC	integrated gasification combined cycle
IMO	International Maritime Organization
IOGCC	Interstate Oil and Gas Compact Commission
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control Directive
JCCS	Japanese CCS Company Ltd
JVETS	Japan Voluntary Emissions Trading Scheme
LCOE	levelised cost of electricity
LNG	liquefied natural gas
MCMPR	Ministerial Council on Mineral and Petroleum Resources of Australia
METI	Ministry of Economy, Trade and Industry (Japan)
MIT	Massachusetts Institute of Technology
MMV	monitoring, measurement and verification

Mt	million tonnes
MWe	megawatt electric
MVA	measurement verification and accounting
NAAQS	National Ambient Air Quality Standard
NACUSS	National Administrator of CO2 Underground Storage Sites
NEDO	New Energy and Industrial Technology Development Organisation
NETL	Department of Energy National Energy Technology Laboratory, USA
NER	new entrant mechanism
NGCC	natural gas combined cycle
NZEC	Near Zero Emission Combustion Initiative (UK-China)
OECD	Organisation for Economic Cooperation and Development
OPEC	Organisation of Petroleum Exporting Countries
PNNL	Department of Energy Pacific Northwest National Laboratory, USA
ppm	parts per million
RCSP	DOE Regional Carbon Sequestration Partnerships, USA
R&D	Research and Development
RD&D	Research, Development and Demonstration
SBSTA	Subsidiary Body for Scientific and Technological Advice of the UNFCCC
SRU	German Advisory Council for the Environment
UBA	German Federal Environmental Agency
UCL	University College London Carbon Capture Legal Programme
UIC	underground injection control
UK	United Kingdom
UK DECC	Department of Energy and Climate Change, UK
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USEIA	US Energy Information Agency
US EPA	US Environmental Protection Agency
US DOE	US Department of Energy
WRI	World Resources Institute
WWF	World Wildlife Fund

Contents

1 Introduction

Carbon dioxide (CO_2) capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere (IPCC, 2005), *see also* Figure 1.

This report focuses on a subset of the technology known as geological CCS where captured CO_2 is compressed into a dense fluid and injected into deep underground formations for permanent storage. Hereinafter, the term CCS will mean the geological storage of CO_2 captured from power plants and industrial facilities. Other CO_2 storage options not considered here include terrestrial sequestration in plants and micro-organisms, ocean storage, and mineralisation processes that store carbon in solid form. Also not considered is the use of air scrubbers to remove CO_2 directly from the atmosphere for permanent storage. Although these options are part of the climate change equation, they differ sufficiently in technology and/or readiness from point source capture and geological storage to be outside the scope of this report. For over 20 years scientists have been investigating CCS as an option to mitigate the effects of GHG emissions on climate change. The roots of CCS go much farther back to when CO_2 was first used for enhanced oil recovery (EOR). During the past decade CCS has gained great momentum with billions of dollars committed worldwide to research, development and demonstration (RD&D) projects in an effort to prove and improve the technology in time for full-scale

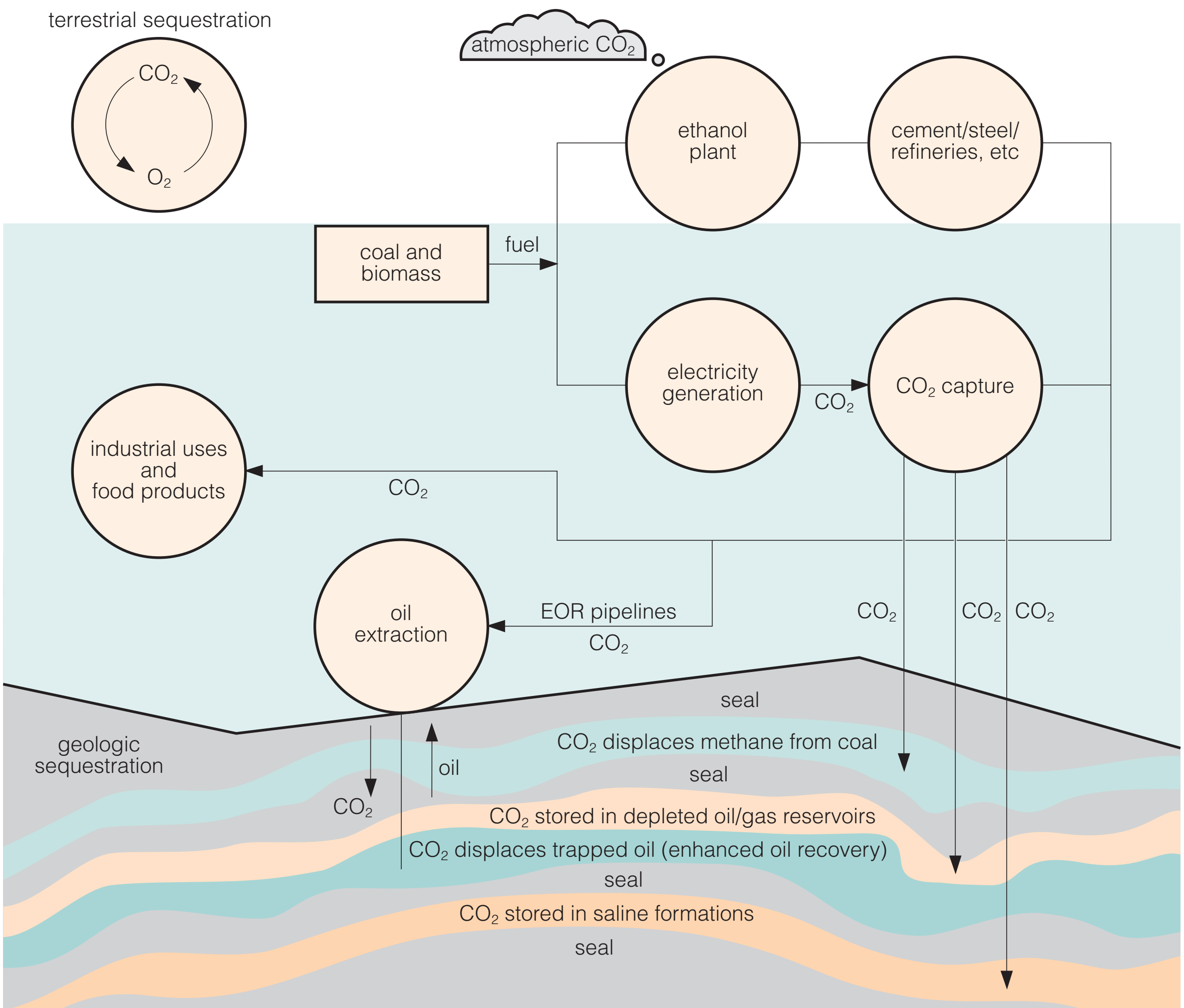

Figure 1 Diagram of CCS (US DOE National Energy Technology Laboratory, NETL)

commercial use. To understand the attention placed on CCS, a brief history of climate change awareness is helpful.

Scientists first recognised the heat trapping properties of CO_2 and other atmospheric gases in the 19th century (Paterson, 1996). In 1908, the Swedish scientist, Arrhenius, made the correlation between industrial activities and climate change noting that an increase in atmospheric carbonic acid might improve climates, particularly in the colder regions of the earth (Arrhenius, 1908; Paterson, 1996). By 1980, scientists and policymakers had gained an appreciation of the potential harmful consequences of human activity on global climate (Paterson, 1996). In 1989, the United Nations (UN) and the World Meteorological Organization established the IPCC to review the science and societal impacts of climate change and recommend response strategies (IPCC, 2010a). The UN Framework Convention on Climate Change (UNFCCC, 1992) came into force in 1994 with the objective to stabilise atmospheric GHG concentrations at a level that will prevent dangerous human interference with the climate system. The Kyoto Protocol (UNFCCC, 1997) followed and came into force in 2005, committing 37 industrialised countries and the European Union (EU) to specified GHG emission reductions. Annex I Parties to the UNFCCC and Kyoto Protocol are industrialised countries and countries in transition. Annex I Parties to the Protocol are subject to binding reductions. Developing country Parties to the Protocol, sometimes called non-Annex I Parties, are not subject to binding reductions. Attempts to negotiate a successor to the Protocol were unsuccessful at the 15th session of the UNFCCC Conference of the Parties (COP 15) held in Copenhagen in December 2009. While disappointing to many for lack of a binding agreement, COP 15 was important in that it produced the Copenhagen Accord wherein the world leaders coalesced around the principle that climate change is one of the greatest challenges of our time requiring urgent action (UNFCCC, 2009). The Accord accepted the scientific view that global temperature rise should be limited to 2°C to prevent the most serious impacts of climate change. To achieve the objective, the Accord states that deep cuts in global GHG emissions are required and the Parties should co-operate in achieving the peaking of global and national emissions as soon as possible. As of 29 July 2010, 137 Nations and the EU expressed their intention to be listed as agreeing to the Accord. Annex I Parties to the UNFCCC committed to implement proposed quantified economy-wide emissions targets for 2020. Non-Annex I Parties would implement nationally appropriate mitigation actions. Statements of quantified economy wide emission targets from Annex I Parties and nationally appropriate mitigation actions of non-Annex I Parties are available at: http://unfccc.int/home/items/5262.php.

Why then CCS? CO_2 is the largest man-made (anthropogenic) contributor to atmospheric GHG levels. Increases in CO_2 concentrations are primarily due to fossil fuel use which is expected to dominate the global energy mix through 2030 and beyond (IPCC, 2007). Therefore, GHG stabilisation must deal with the reality of fossil energy now, and well into the future. Major sources of CO_2 are power plants; industrial facilities such as chemical, cement, and paper plants; refineries; natural gas processing facilities; and, cumulative emissions from the transportation and building sectors. CCS is the only technology that can significantly reduce CO_2 emissions from large point sources. It has the support of many scientific and multinational organisations including the IPCC, the IEA and the G8 countries. However, CCS support is not universal. Some scientists and stakeholders believe CCS may not work as expected or that it is simply an excuse to continue using fossil energy.

Although CO_2 injection has been used for enhanced oil and gas production for decades, permanent geological storage integrated with power plants and industrial facilities is emerging technology. Most experts and CCS sceptics agree that CCS must be successfully demonstrated at commercial scale in various geological formations and geographic regions before the technology is considered ready for wide-scale deployment.

In addition to technological development, a comprehensive legal and regulatory framework is recognised as a necessary antecedent to wide-scale CCS deployment. Framework issues are complex and include access to onshore and offshore storage sites, porespace ownership, pipeline access, liability, long-term stewardship, air permitting, subsurface permitting, and measurement, verification and accounting (MVA). Government support for early projects is also a significant element of framework discussions. Much work has occurred internationally and nationally on this front and, while legal and regulatory frameworks are not one-size-fits-all, common themes are emerging.

Chapter 2 of this report reviews the evolution of CCS and examines various opinions on the value of CCS as part of a climate change mitigation strategy. Chapter 2 also outlines legal and regulatory framework issues at the global and national levels.

Chapter 3 of the report examines framework progress and other CCS related activities in a representative group of countries and the EU.

Chapter 4 identifies next steps that may facilitate CCS development and advance wide-scale deployment.

2 Status

The background science is complete and CCS has progressed to the point where the technology is ready for demonstration in order to address remaining questions about feasibility, reliability, and safety at commercial scale. From a deployment perspective, additional work is needed to reduce cost, establish legal and regulatory frameworks, and satisfy policymakers and the public that CCS is a prudent and cost-effective pathway to GHG reduction.

2.1 The history of CCS development

2.1.1 1950-2000

Long before CCS was considered an option for mitigating climate change, scientists were investigating CO_2 injection into oil-bearing formations for EOR. The first CO_2 EOR patent was granted in 1952 (Whorton and others, 1952). Research continued through the 1960s and the first commercial CO_2 EOR project was initiated in 1972 in Texas (Contek Solutions, nd). The technology has enjoyed widespread use ever since. In the USA alone, approximately 3400 miles of high pressure pipelines transport CO_2 to over 13,000 EOR wells (IEA, 2010; Contek Solutions, nd). The technologies used for CO_2 EOR compression, transport, and injection are virtually identical to technologies that will be used for CCS.

The avoidance of CO_2 emissions through capture from fossil energy plants was first proposed in the 1970s, but significant research in the field did not occur until close to 1990 (Herzog and others, 1997). Some of the earliest work was conducted in Japan, Norway, the United Kingdom (UK), Canada, the Netherlands, and the USA (Herzog and others, 1993). During the 1990s, much of the CCS work involved studies and smaller-scale research projects. One notable exception is the Sleipner Project in Norway. Motivated by a Norwegian tax on offshore CO_2 emissions, Statoil began operation of the world's first commercial scale CCS project in 1996 at the Sleipner natural gas platform in the North Sea.

2.1.2 This millennium

CCS research exploded in the 2000s with active programmes in government agencies, academia, and the private sector. Considerable effort was placed on research to reduce the substantial cost penalty associated with CCS which, using current technology, is estimated to be in the range 60–14 $/t of CO_2 avoided (*see* Figure 2). Other reports have estimated the levelised cost of electricity (LCOE) of integrated gasification combined cycle (IGCC) and natural gas combined cycle (NGCC) plants with CCS to be effectively equal, and the LCOE from a supercritical pulverised coal plant with CCS to be 9% higher than an NGCC plant with CCS (Carter, 2010). Rubin and others (2007) found that the LCOE for IGCC was slightly lower than NGCC for storage in saline aquifers; IGCC substantially lower in LCOE than NGCC in EOR storage applications; and pulverised coal and NGCC effectively equal in EOR storage applications.

Researchers also explored new leak detection methods and geophysical techniques to characterise formations for their capacity to store CO_2 and track CO_2 movement once injected. Countries began the important task of mapping potential geological storage sites and CO_2 emission sources.

When IPCC released its *Special Report on Carbon Capture and Storage* in 2005, they found no major technical or knowledge barriers to the adoption of geological storage of captured CO_2. They also found that technologies for the capture of CO_2 are relatively well understood based on prior experience in hydrogen production and CO_2 separation for natural gas processing. Nevertheless, IPCC

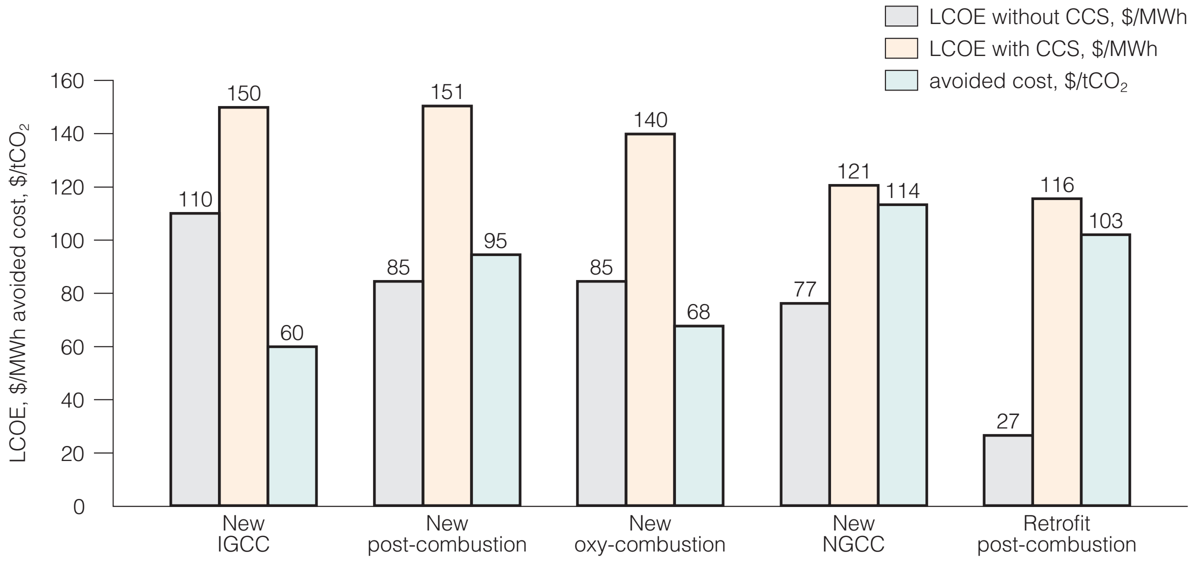

Figure 2 Comparison of CCS cost for different types and configurations of power plants (US, 2010)

identified several key technology gaps where additional work would reduce uncertainty and facilitate decision making about large-scale deployment. Specifically, IPCC saw the need for:

- Knowledge of integration of capture, transport, and storage in full-scale projects.
- Demonstration of CO_2 capture on coal-based and natural gas plants at the several hundred megawatt (or several million tonnes CO_2) scale to establish the reliability and environmental performance of CCS on different types of power systems, to reduce the costs of CCS, and to improve confidence in cost estimates.
- Large-scale implementation in industrial processes, such as the cement and steel industries that have little or no experience with CO_2 capture.
- An improved picture of the proximity of major CO_2 sources to suitable storage sites to evaluate how well large CO_2 emission sources (both current and future) match suitable storage options that can store the volumes required.
- More pilot and demonstration storage projects in a range of geological and economic settings to gain a better understanding of long-term storage, migration, and leakage processes.
- An enhanced ability to monitor and verify the behaviour of geologically stored CO_2.
- Research and Development (R&D) for emerging concepts and enabling technologies for CO_2 capture that have the potential to significantly reduce the costs of capture for new and existing facilities (IPCC, 2005).

Much CCS knowledge has been obtained over the five years since IPCC issued its special report. Information is now available from five commercial-scale capture and storage projects listed in Table 1. Rangely is considered to be CCS because it employs a monitoring, measurement and verification (MMV) plan that satisfactorily assesses long-term storage of CO_2 (IEA, 2010a).

These projects have produced valuable geophysical and operational data. For these projects, CO_2 was separated from natural gas or synthesis gas to make the gas suitable for commercial sale. This process provided a highly pure stream of CO_2 that could be stored at a lower cost penalty than CCS on power plants or other industrial applications. Therefore, while the projects provide valuable data, they are not a good technical or economic analogue for many CCS projects. In addition to the commercial projects, a large volume of research and development, geophysical characterisation, and sub-commercial scale injection testing has been completed worldwide. As of 1 August 2010, the US Department of Energy (US DOE) was tracking 193 CCS projects in 18 countries ranging from small-scale research to fully-integrated demonstration projects in the early stage of development (NETL, 2010).

Table 1 Commercial-scale CCS projects in operation (In Salah, 2010; Statoil, 2009a,b; PTRC, 2010; IEA, 2010)

Name	Location	CO_2 Source	Storage Formation	$MtCO_2/y$	Year injection began
Rangely	Colorado USA	Natural gas processing plant	Oil-bearing EOR	1.0	1986
Sleipner	North Sea Norway	Natural gas processing plant	Offshore subsea saline	1.0	1996
In Salah	Algeria	Natural gas processing plant	Depleted gas reservoir	1.2	2004
Snøhvit	Barent Sea Norway	Onshore liquefied natural gas plant	Offshore subsea saline	0.7	2008
Weyburn-Midale	Saskatchewan Canada	Synthetic natural gas plant	Oil-bearing EOR	1	2000 Weyburn 2005 Midale

Notwithstanding the body of work that occurred over the last decade, a number of the technology gaps and cost concerns identified by IPPC in 2005 remain valid today and are echoed in the IEA *Technology Roadmap: Carbon Capture and Storage* (IEA, 2009) and the *Carbon Sequestration Leadership Forum Technology Roadmap* (CSLF, 2009). An integrated commercial-scale coal or natural gas power plant with CCS has yet to be built. A number of countries have announced plans for such plants; however, full-scale injection from the earliest of these projects is still several years away. Hence, data on integrated operations, reliability, and environmental performance from commercial-scale plants are not yet available. Furthermore, while progress has been made in new technologies to reduce the CCS cost penalty, more research is needed and the technologies must then be demonstrated at scale before they are ready for commercial deployment.

2.1.3 Multi-national initiatives

No history of CCS is complete without mention of multinational initiatives. The first was the IEA Greenhouse Gas R&D (IEA GHG) Programme established in 1991 as an international collaborative effort to evaluate technologies aimed at reducing GHG emissions, facilitate the implementation of potential mitigation options, and disseminate the data and results from studies. IEA GHG members include 19 countries, the European Commission, the Organisation of Petroleum Exporting Countries (OPEC), and 21 multinational industrial sponsors (http://www.ieaghg.org). IEA has been instrumental in CCS development, knowledge sharing, education, and capacity building.

The Carbon Sequestration Leadership Forum (CSLF) followed in 2003 as a Ministerial-level international collaboration focused on the development of improved cost-effective technologies for CCS. CSLF has 23 country members plus the European Commission (EC) representing many of the industrialised nations and emerging economies in the world. The CSLF performs a number of important roles including: development of CCS roadmaps; promoting and facilitating international collaboration and knowledge sharing; supporting capacity building exercises in developing countries; and identifying technical, legal, and regulatory gaps standing in the way of CCS deployment (http://www.cslforum.org/aboutus).

The most recent addition is the Global Carbon Capture and Storage Institute (GCCSI) launched by the Australian Government in 2008 with annual support of A$100 million. GCCSI became a fully-independent organisation in 2009 and has 226 members, including national governments, corporations, research organisations, and non-government bodies. GCCSI is developing a knowledge base of CCS information which it can use to provide expert advice throughout the world to facilitate the development and deployment of safe, economic, and environmentally sustainable CCS technology (http://www.globalccsinstitute.com/institute).

2.2 CCS as a climate change mitigation strategy – the discussion

In the Copenhagen Accord, policymakers agreed that human activity causes an increase in global temperatures and that if left unchecked there will be significant and costly impacts worldwide. Many scientists and policymakers believe CCS must be part of the solution. However, there are opposing opinions from those who believe CCS may not perform as expected or that it is just an excuse to prolong the use of fossil fuels. Viewpoints from the scientific community, policymakers, economists, and environmental groups are examined below. Regardless of individual positions, an overall analysis of the viewpoints suggests that CCS should be aggressively pursued in the near term to prove its readiness in time for full-scale deployment.

2.2.1 Scientist viewpoint

The Copenhagen Accord endorses the view that global temperature rise should be less than 2°C to prevent the worst impacts of climate change (UNFCCC, 2009). To achieve a 2.0–2.4°C target, IPCC concluded that CO_2 emissions should peak no later than 2015 and be reduced by 50–85% from 2000 levels by 2050 (*see* Table 2).

Table 2 IPCC characteristics of post-third assessment report (TAR) stabilisation scenario source (IPCC, 2007)

Category	CO_2 concentration at stabilisation	CO_2-e concentration at stabilisation including GHGs and aerosols	Peaking year for CO_2 emissions	Change in global CO_2 emissions in 2050 (% of 2000 emissions)	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity	Global average sea level rise above pre-industrial at equilibrium from thermal expansion lyly	Number of assessed scenarios
	ppm	ppm	year	%	°C	metres	
I	350–400	445–490	2000-15	–85 to –50	2.0–2.4	0.4–1.4	6
II	400–440	490–535	2000-20	–60 to –30	2.4–2.8	0.5–1.7	18
III	440–485	535–590	2010-30	–30 to +5	2.8–3.2	0.6–1.9	21
IV	485–570	590–710	2020-60	10–60	3.2–4.0	0.6–2.4	118
V	570–660	710–855	2050-80	25–85	4.0–4.9	0.8–2.9	9
VI	660–790	855–1130	2060-90	90–140	4.9–6.1	1.0–3.7	5

Many scientists and scientific organisations believe CCS is essential to meeting these targets. IPCC found that all the stabilisation levels it assessed could be met by current technology or technology expected to be commercialised in the coming decades, but noted that at lower stabilisation levels (such as those required to achieve a 2°C target) more emphasis is placed on the use of low-carbon energy sources including CCS (IPCC, 2007).

In its BLUE Map Scenario, IEA concluded that CCS would need to provide approximately one-fifth of the total emission reductions to achieve a 50% target by 2050 in the most cost effective manner. Without CCS the overall cost will increase by 70% (IEA, 2008; IEA, 2009), *see* Figure 3. IEA proposed 100 full-scale CCS projects by 2020 and 3400 projects by 2050 (IEA, 2009) *see* Figure 4.

Academia also recognises the potential of CCS as reflected in the Massachusetts Institute of Technology (MIT) study *The Future Of Coal* which concluded that CCS 'is the critical enabling technology that would reduce CO_2 emissions significantly while also allowing coal to meet the world's pressing energy needs' (MIT, 2007).

Some scientific organisations are not sure. The German Advisory Council on the Environment cautions against moving too quickly on CCS on the basis that technical, ecological, and cost questions remain to be answered. The Council recommended that the German Government enact a law that permits only the testing and demonstration of CCS; the results of which can be used to inform a later decision on wide-scale deployment (SRU, 2009). Similarly, the Union of Concerned Scientists recognises the potential of CCS to play a major role in reducing CO_2 emissions. However, they believe demonstration projects are needed 'to determine the relative cost-effectiveness of CCS compared to other carbon-reducing strategies and to assess its environmental safety – particularly at the very large scale of deployment needed for CCS to contribute significantly to the fight against global warming' (Freese and others, 2008).

Other scientists are concerned about the impact of even small leaks over the millennia that CO_2 must

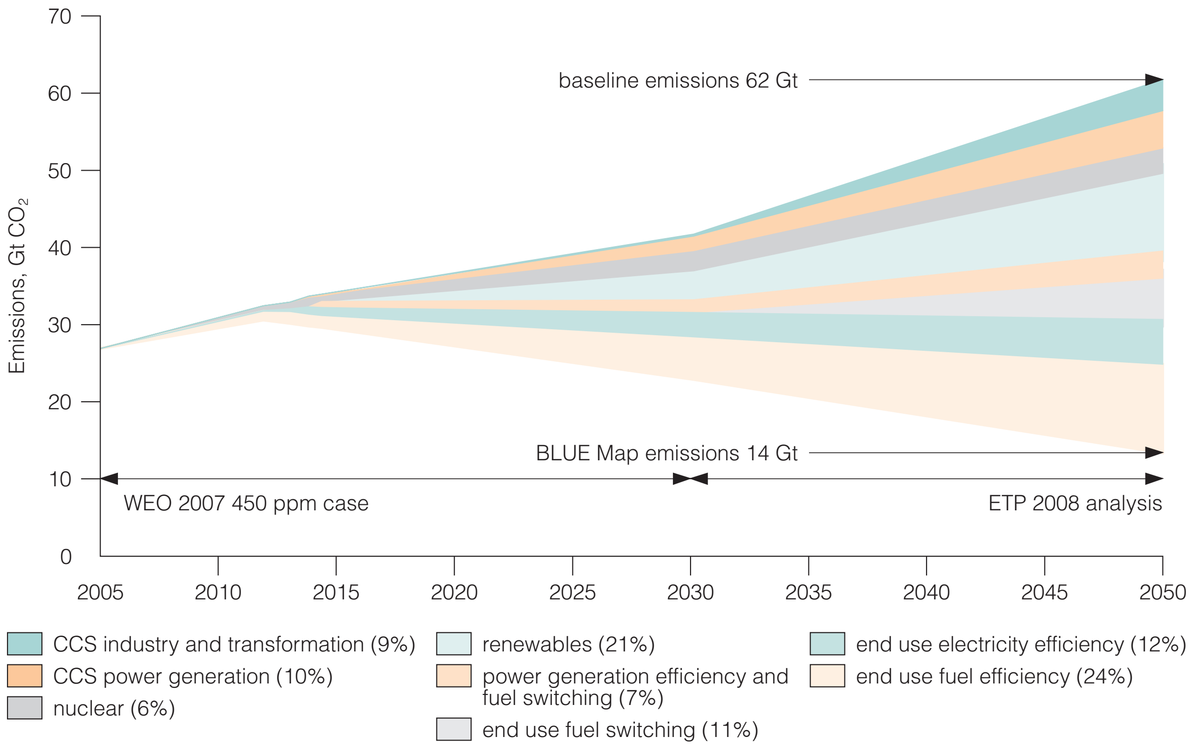

Figure 3 Comparison of the World Energy Outlook 2007 450 PPM Case and the Blue Map Scenario, 2005-50 (IEA, 2008)

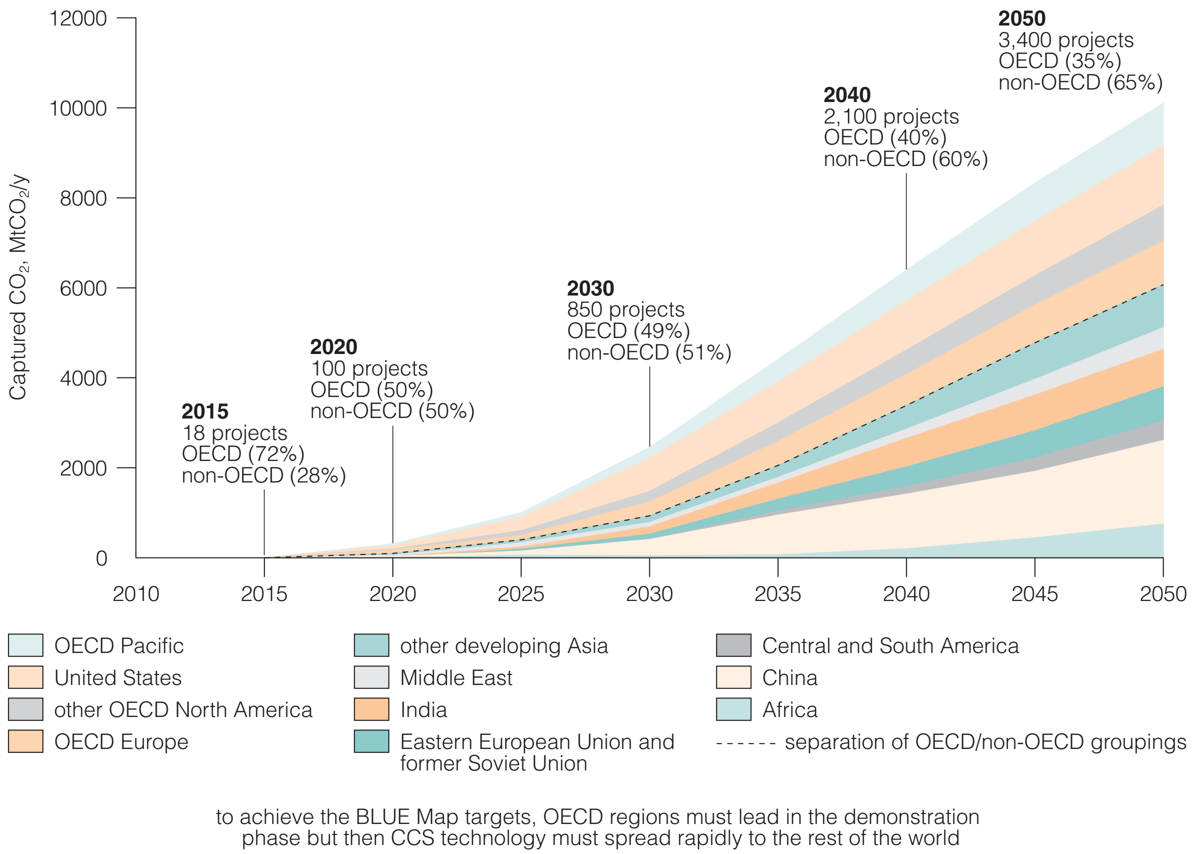

Figure 4 Global deployment of CCS 2010-50 by region, $MtCO_2$ captured per year (IEA, 2008)

be stored. Among them is Professor Shaffer of the Niels Bohr Institute in Denmark who agrees that 'CO_2 sequestration has many potential advantages over other forms of climate geo-engineering and it makes good sense to modify the Earth's radiation balance by putting carbon back in where it came from.' However, he cautions that potential short- and long-term problems with leakage from underground reservoirs should not be underestimated and that CO_2 storage will only be effective if leakage is limited to 1% or less per millennium (ScienceDaily, 2010).

Resolution of CCS science issues is well beyond the scope of this report. The discussion is presented here only to illustrate that CCS, like any emerging technology, comes with risk. The conclusion to be made is that more research and operational data from demonstration projects are needed in the near term to settle technical and cost uncertainties before the critical time period when CCS must be commercially deployed.

2.2.2 Policymaker viewpoint

Over the past three years, the G8 Leaders and Energy Ministers throughout the world have consistently endorsed CCS as a climate change solution, *see* Table 3.

Policymaker support for CCS development is also strong at the national level as evidenced by legal and regulatory efforts to facilitate CCS (discussed in Chapter 3) and by the substantial funds committed to near-term CCS demonstration projects.

Support for CCS development, however, does not uniformly equate to support for immediate CCS deployment. In Germany for example, the draft CCS Act released in 2010 strictly limits CCS activity to testing and demonstration through 2017. In a joint press release, the Economics and Environment

Table 3 Statements of G8 Leaders and Energy Ministers

G8 Statement Hokkaido Toyako July 2008	We will establish an international initiative with the support of the IEA to develop roadmaps for innovative technologies and co-operate upon existing and new partnerships, including carbon capture and storage (CCS) and advanced energy technologies. We strongly support the launching of 20 large-scale CCS demonstration projects globally by 2010, taking into account various national circumstances, with a view to beginning broad deployment of CCS by 2020.
G8 Declaration L'Aguila, Italy July 2009	We are aware that despite effective diversification strategies, fossil fuels will continue to be an essential component of the energy mix in many countries, at least in the medium term. The development and deployment of innovative technologies such as Carbon Capture and Storage (CCS) is therefore expected to contribute substantially to reducing emissions.
Joint Statement G8 Energy Ministers The European Energy Commissioner The Energy Ministers of Brazil, China, Egypt, India, Korea, Mexico, Saudi Arabia, and South Africa Rome, Italy May 2009	We are aware that despite diversification strategies, fossil fuels will continue to be a key component of the energy mix in worldwide, for many decades into the future. Therefore, the development of innovative technologies such as Carbon Capture and Storage (CCS) will contribute to tackle the climate change challenge. We support the launch of large-scale CCS demonstration projects globally and call for the active involvement of the private sector in this endeavour. We support work by the International Energy Agency, Global Carbon Capture and Storage Institute and Carbon Sequestration Leadership Forum (CSLF) to advance this technology.
G8 Muskoka Declaration Muskoka, Canada June 2010	Carbon capture and storage (CCS) can play an important role in transitioning to a low-carbon emitting economy. We welcome the progress already made on our Toyako commitments to launch the 20 large-scale CCS demonstration projects globally by 2010 and to achieve the broad deployment of CCS by 2020, in co-operation with developing countries. Several of us commit to accelerate the CCS demonstration projects and set a goal to achieve their full implementation by 2015.

Ministers acknowledged that CCS is a necessary technology. However, the Ministers stated that CCS technologies will be thoroughly evaluated in 2017 to take into account the remaining open questions and the many concerns of the public (BMU, 2010).

Germany can be contrasted with fellow EU member, the UK where, as of 9 November 2009, any applicant who applies for (or who has sought, but not yet obtained) a permit to construct a new coal-fired power station over 50 MWe, or upgrade an installation to a supercritical coal-fired boiler, must include CCS on at least 300 MWe net of its capacity from the outset. New power stations less than 300 MWe capacity must include CCS on the entire capacity (UK DECC, 2009d).

India is another example where the national government is approaching CCS cautiously. While India has been an active and valuable participant in international CCS co-operation and research, India's National Action Plan on Climate Change released in 2008 viewed CCS as a developmental technology with serious technical and cost questions that remain to be answered (India, 2008).

Although technical and economic questions remain to be addressed before CCS deployment is embraced by all policymakers, there appears to be general consensus that CCS has great potential.

2.2.3 Economist viewpoint

Economists describe climate change as a market failure – a distortion in the price of goods and services through failure of markets to consider the cost of climate change impacts. They advocate for a carbon price to remove the distortion and incentivise deployment of low-carbon technology.

Sir Nicolas Stern, Head of Government Economic Service and Advisor to the UK Government, presented an extensive analysis of the economics of climate change in his 2006 report commonly known as the Stern Report (Stern, 2006). The key finding of the report is that if the world does not act quickly to mitigate climate change impacts, the overall costs and risks of climate change will be equivalent to losing at least 5% and as much as 20% (or more) of global GDP per year. Lord Stern predicted that strong early action could limit economic damage to 1% of GDP each year. Many analysts and nations are concerned about the impact of climate change mitigation on economic growth. Lord Stern believes well designed climate change policy could bring opportunities for growth through new markets for low-carbon energy products, more efficient energy systems, and other societal benefits.

The Stern Report calls for much greater support for R&D on CCS and other low-carbon technologies. It found that the forecast growth in emissions from coal, especially in China and India, means that failure to develop viable CCS technology risks locking in a high emissions trajectory.

The Stern Report is not without critics. Shortly after the report was released, several distinguished economists questioned some of its assumptions – particularly the discount rate used to calculate economic damages. Professor Weitzman at Harvard University noted that the majority economist viewpoint is that deployment of GHG reduction measures should be more gradual than proposed in the Report (Weitzman, 2007). Professor Nordhaus at Yale University similarly took issue with the assumptions and said that questions about how quickly GHG reductions must be deployed remain to be answered (Nordhaus, 2007). If the majority viewpoint as described by Professor Weitzman is correct, then the world may have more time, from a purely economic perspective, to test and perfect CCS before it is needed for wide-scale commercial use. On the other hand, if the Stern Report is correct, there are sound reasons to further accelerate development and deployment of all low-carbon solutions in the near term, including CCS.

2.2.4 Environmentalist viewpoint

One might expect that the environmental community would be solidly and uniformly opposed to CCS on the basis that CCS enables the continued use of fossil fuels. In reality the environmental opinion is more balanced. The different positions of three well known international environmental organisations are discussed below.

The World Wildlife Federation (WWF) is apprehensive about CCS and calls on governments and industry to resolve key issues before deploying the approach. Concerns highlighted by WWF include:

- Permanence of longer than 100,000 years must be assessed and confirmed through independent science.
- Storage of CO_2 must be proven not to interfere with, or have negative direct or indirect impacts on, biodiversity.
- Stakeholder processes should be built into all pilot projects to allow for review, comment, and resolution of concerns.

- There must be internationally-agreed procedures for independent verification and monitoring of storage and related activities before CCS technologies are allowed to count against GHG reduction targets.
- Energy conservation technology and/or renewable energy supply should be considered first.

WWF also believes CCS should not be counted toward Kyoto targets in the first commitment period and developed countries should only receive credit for CCS if they have an absolute CO_2 cap. If these questions are satisfactorily addressed, WWF believes CCS may have a role as a short-term, 'bridging technology' in order to gain time in the switch to carbon-free energy (WWF, nd).

Contrasted with WWF, Greenpeace is firmly opposed to CCS. In its 2008 report, *False Hope, Why Carbon Capture and Storage Won't Save the Climate* Greenpeace maintains (Rochon, 2008):

- CCS cannot deliver in time to avoid dangerous climate change because the earliest possibility for CCS deployment is not expected before 2030 and to avoid the worst impacts of climate change, global GHG emissions have to start falling after 2015.
- CCS wastes energy using 10–40% of the energy produced by a power station.
- Storing carbon underground is risky and unsafe and permanent storage of CO_2 cannot be guaranteed. Even very low leakage rates could undermine any climate mitigation efforts.
- CCS is expensive. It could lead to a doubling of plant costs, and an electricity price increase of 21–91%.
- CCS carries significant liability risks. It poses a threat to health, ecosystems, and the climate.

The Norwegian based Bellona Foundation supports energy efficiency and renewable energy technologies, but does not believe they can be deployed fast enough to obtain sufficient emission reductions. They view CCS as necessary to meet reduction targets. Bellona identifies five main challenges for CCS:

- The technology remains to be tested for full-scale industrial and power plants.
- The costs must be reduced through research and demonstration programmes.
- Standards to ensure safe storage must be developed.
- Laws and regulations facilitating CCS deployment must be enacted.
- The wider public must be informed about the potential of CCS.

Bellona does not consider CCS a commercially-available technology. In Bellona's opinion, the next step is to build many large-scale CCS demonstration plants and use the knowledge and experience gained from the plants to make CCS cheaper, more efficient, and safer (Bellona, 2009).

While there is no consensus among the environmental community, a common theme is concern about the readiness and safety of CCS that can only be answered through more research and demonstration.

2.3 The importance of legal and regulatory frameworks

Legal and regulatory frameworks enable CCS development and deployment on two levels. First, a global climate change agreement is necessary because emissions must be reduced throughout the world for a climate change strategy to be effective. Second, national frameworks are necessary because they implement international agreements and national mandates, and provide regulatory certainty for demonstration and early adopter projects. Both are discussed below and individual country frameworks are examined in more detail in Chapter 3.

2.3.1 Global Climate Change Agreement

The UNFCCC and its subsidiary Kyoto Protocol are the existing global climate change agreements. The UNFCCC established goals while the Protocol set binding emission reduction targets for industrialised nation Parties. Low-carbon technologies (with few exceptions) are more expensive than conventional technologies, making a commercial case for investment in low-carbon technology unsustainable. Therefore, deployment of low-carbon technologies requires an overarching societal mandate. On the global level the objective is climate change abatement. At the national level, objectives may also include energy security, energy diversity, and/or the reduction of fossil energy use because of other environmental impacts.

Without a multinational binding agreement, where everyone shares the burden, many countries will not deploy low-carbon technologies in sufficient quantity to stabilise GHG concentrations. This is evidenced by the statements of quantified economy wide emission targets submitted by Annex I Parties pursuant to the Copenhagen Accord, many of which were conditioned on comparable reductions from the other Parties.

A global agreement is also necessary to assist with deployment of low-carbon technologies in developing countries. The UNFCCC, Kyoto Protocol, and Copenhagen Accord all call for developed countries to provide financial resources and other assistance to developing countries. To that end, the Clean Development Mechanism (CDM) was established under the Protocol to permit developed countries to take credit for emission reduction projects they finance in developing countries. At present, CCS is not considered an eligible technology under the CDM – a topic of considerable debate. The IEA and the CSLF support inclusion as a critical step to CCS deployment in developing countries (IEA, 2010). A number of countries share this belief. Some countries, such as Brazil, firmly oppose inclusion, citing issues such as permanence, safety, and liability plus concerns that CCS credits would flood the CDM and drop credit prices to a level that dismantles the carbon market (SBSTA, 2010a). The UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) continues to assess the matter with a decision deferred until its 33rd session scheduled for November 2010 in Cancun (SBSTA, 2010b).

CCS deployment in developing countries is a problem in need of a solution as illustrated by the predicted increase of CO_2 emission in China, India, and other developing country regions by 2030, *see* Figure 5.

For a global climate change strategy to be effective, these countries must reduce emission in the long term. Since much of the increase will be attributable to large point source facilities, CCS is presently the only option. However, a number of these countries have more critical priorities and, therefore, do not have the financial resources for CCS. This reality is acknowledged in the Copenhagen Accord which states that low-emission technologies are indispensable to sustainable development, but that social and economic development and poverty eradication are the first and overriding priorities of

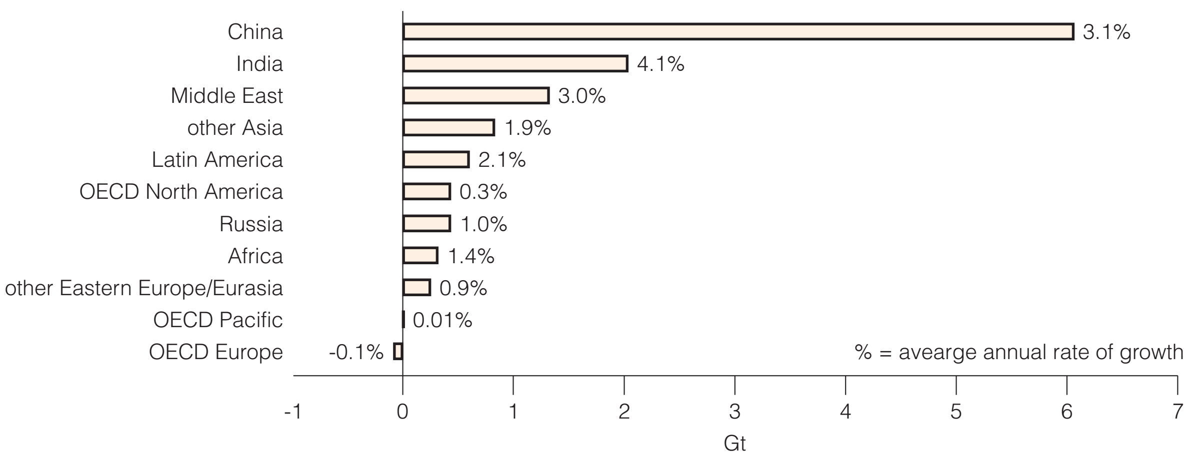

Figure 5 Incremental energy-related CO_2 emissions by country and region, 2006-30 (WEO, 2008)

developing countries (UNFCCC, 2009). Developing countries will need experience with CCS prior to wide-scale deployment. But unless CCS is included in the CDM, or a different financial mechanism is created, the prospects for some developing countries to gain that experience in the near- and mid-term are reduced. Technical and safety concerns may be valid, but CCS research to date has resulted in geophysical understanding and CCS best practices that significantly mitigate risks if properly implemented. Between 2006 and 2008, the World Research Institute (WRI) conducted a stakeholder review of CCS technology. A key finding was that even though additional research is needed in some areas, there is adequate technical understanding to safely conduct large-scale demonstration projects (Forbes and others, 2008). Risks will be further reduced as more information from pilot and demonstration projects becomes available over the next five to ten years.

2.3.2 National legal and regulatory frameworks

Comprehensive and well designed national legal and regulatory frameworks are critical to CCS development and deployment. At the highest level, the framework establishes the national mandate for GHG reduction and translates the mandate into a methodology to meet emission targets. A national framework also establishes the ground rules for CCS projects which are essential for investment decisions by utilities, industry, and financial markets. A CCS project may cost hundreds of millions to billions of dollars. Without regulatory certainty, developers and investors are reluctant to assume the considerable financial risk.

An emerging theme is that frameworks should evolve in parallel with CCS experience and that demonstration projects should not be made to wait for completion of a comprehensive regime. IEA's timeline calls for Organisation for Economic Cooperation and Development (OECD) countries to adapt existing frameworks by 2011 to accommodate demonstration projects and non-OECD countries by 2015. All countries would have comprehensive frameworks in place by 2020 in time for large-scale deployment, *see* Figure 6.

Regulatory flexibility is particularly important for storage facilities. Current uncertainties about site suitability and the long-term fate of CO_2 may cause over or under regulation on early projects in areas such as site characterisation, risk assessment, MVA, financial responsibility, and post-injection monitoring. If the regulations do not adapt to results from pilot and demonstration work, unnecessary costs can be locked into CCS deployment, or in some cases the regulations may be inadequate to protect the public safety.

Feedback mechanisms and dissemination of best practices should be built into CCS planning. IEA calls for best practice guidelines by 2012 with revised guidelines by 2020 following demonstration testing (IEA, 2009). The US DOE plans to issue best practices manuals in six areas by the end of 2010 which will be updated in 2016-17 and then finalised in 2020. The best practice manuals are being prepared in co-operation with the Regional Carbon Sequestration Partnerships (RSCPs). The RSCPs are seven consortia comprised of more than 350 state agencies, universities, and private companies, three Native American organisations, and four Canadian provinces with participation by six CSLF countries (NETL, nd).

Many respected organisations have been engaged in regulatory gap analysis and the development of model CCS frameworks. Among these are IEA, the CSLF, GCCSI, WRI, Bellona Foundation, the US DOE RSCPs, the Interstate Oil and Gas Compact Commission (IOGCC) and governments throughout the world. From these efforts, key barrier issues have been identified as necessary and appropriate for resolution in national CCS frameworks. These are summarised in Table 4.

Barrier issues will be discussed in more detail in Chapter 3 in the context of individual country efforts to develop frameworks.

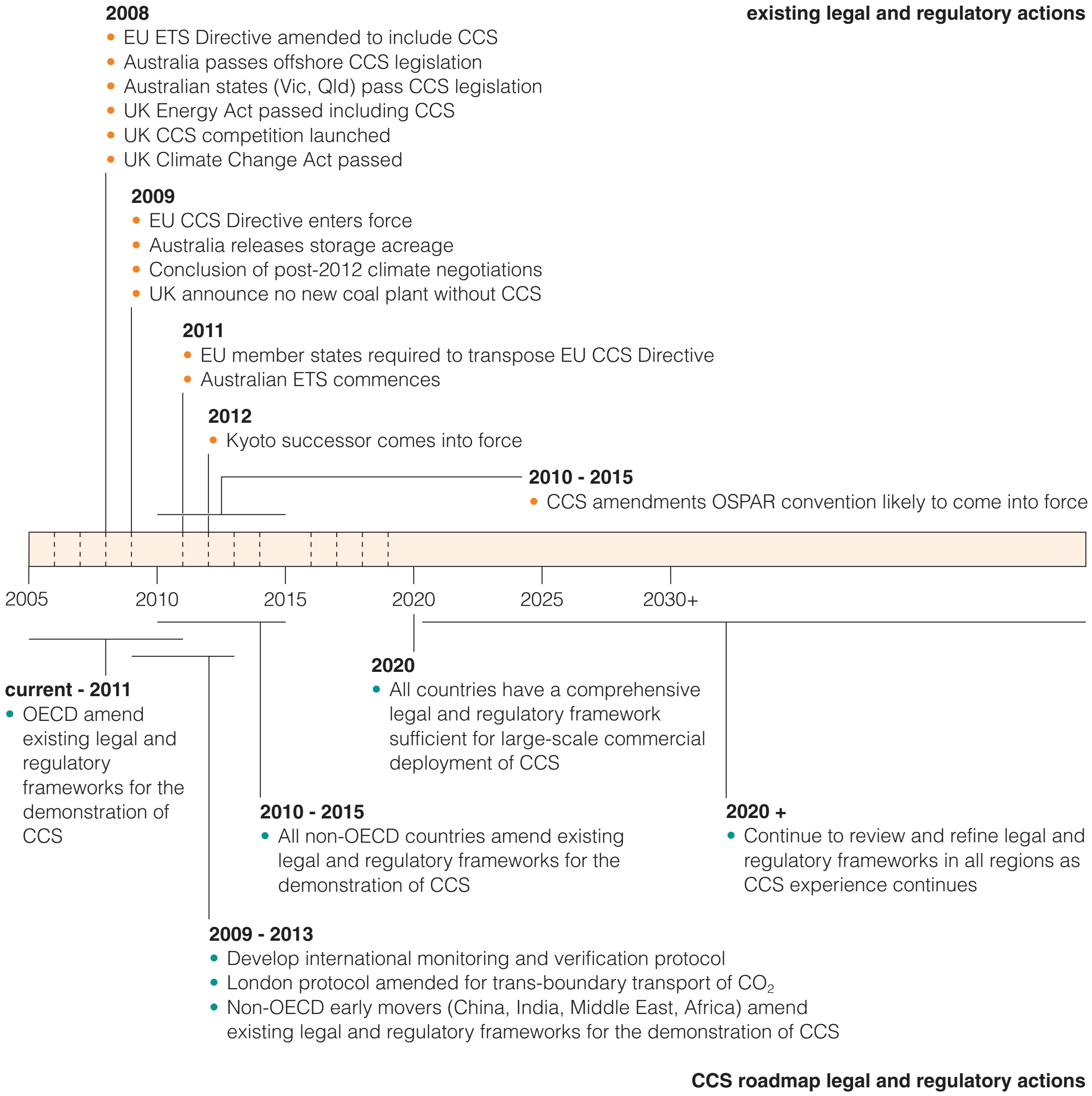

Figure 6 IEA framework timeline (IEA, 2009)

2.4 Summary

It is unlikely that CCS will be deployed without an overarching climate change policy. However, this linkage does not require climate change policy and CCS development to proceed at the same pace. Many countries, states, provinces, and companies are already aggressively pursuing CCS to ready the technology for full-scale deployment once an overarching framework is in place. There are good reasons for this behaviour, including environmental consciousness, protection of national and local economic interests in fossil fuels, and the recognition that it takes many years to develop a technology to the point of commercial comfort.

There are also good reasons for enhanced support for CCS research and demonstration. Questions and doubts remain among scientists, policymakers, the environmental community and the public. Through multiple projects we can obtain a comprehensive understanding of CO_2 behaviour in all types of geological formations, along with valuable lessons that will reduce the risk of mistakes during wide-scale deployment. The knowledge obtained will also inform legal and regulatory frameworks and lead

Table 4 CCS barrier issues and possible framework resolution

Barrier issue	Possible framework resolution
Pore Space Access. CCS projects must have access to geological pore space for CO_2 storage. In some jurisdictions pore space is privately owned or ownership is unclear. In other jurisdictions, pore space is owned by national, provincial, or state government.	• Clarify private ownership rights. • Provide mechanisms to secure access to privately-owned pore space subject to equitable compensation to the owners. • Establish procedures for licensing pore space owned by national, provincial, or state government. • Harmonise the right to store CO_2 with other rights to exploit the subsurface such as oil and gas extraction.
Storage Site Access. CCS Projects must have access to storage sites, which in many cases are not co-located with the emission source. Sites may be privately owned or owned by the national, provincial, or state governments. Storage sites may also be located beneath the sea-floor in national, state, or provincial waters.	• Provide mechanisms to secure access to privately-owned storage sites subject to equitable compensation to owners. • Make government-owned storage sites (onshore and offshore) available to CCS projects.
Pipeline Access. CCS projects must have access to pipelines and pipeline routes to transport CO_2 from source to storage facility. Some jurisdictions have existing rules for CO_2 pipelines or other pipeline rules that may be used or modified.	• Provide mechanisms to obtain pipeline right-of-ways or third party access to pipelines as applicable. • Develop common CCS pipeline networks. • Establish, adopt, or modify CO_2 pipeline transport rules as necessary.
Geological Storage. Some jurisdictions have no rules for geological storage facilities. Others have analogs in CO_2 EOR and natural gas storage. Potential remediation and third party liability costs during the injection and post-injection monitoring phases are not well understood.	• Issue permits for demonstration projects under existing or interim rules where possible, using appropriate measures to ensure operator financial and technical capability, site suitability, safety, and permanence. • Establish rules for permanent storage that address: Site selection; suitability of storage formations; environmental requirements; purity of stream requirements; ownership of injected CO_2; MVA requirements; storage operator financial responsibility/financial security; site closure, certification, and abandonment; harmonisation with hazardous waste rules. Use knowledge from demonstration projects to inform and adjust final rules.
Long-term Liability/Stewardship. CO_2 must be stored indefinitely. However, indefinite responsibility and liability for storage facility operators is neither practical (because companies do not last indefinitely) nor conducive to CCS deployment.	• Assumption of liability and long-term stewardship by government bodies, trusts, or other entity with perpetual existence after completion of post-injection monitoring period.
Financial Support - Demonstration Projects. The lack of clear rules, first-of-a-kind technology risk and cost penalty, and insufficient carbon price are disincentives for investment in demonstration projects. Many demonstration projects under development may fail for lack of adequate financing and access to capital.	• Incentivise demonstration projects through: grants; tax incentives; credit support; liability relief.
Financial Support Deployment Phase. CCS deployment may require financial incentives, particularly in the early stages.	• Incentivise deployment through: Tax incentives. Bonus allowances in trading schemes Feed-in tariffs. CCS inclusion in portfolio standards.
Public Acceptance. Public acceptance is essential to CCS deployment because of concerns about CCS effectiveness and risk associated with transport and underground storage of large quantities of material.	• Transparent processes for approving CCS storage facilities that include public involvement. • Knowledge dissemination. • Public outreach.

to an optimised set of guiding principles for CCS permitting. If CCS will not work as expected, the world needs to know that as well.

There are 19 to 43 near-term demonstration projects anticipated throughout the world (IEA, 2010). However, these projects are far from certain. Even with government support, the projects have a delicate financial balance due to demonstration risk, CCS cost penalty, tight credit markets, and legal and regulatory uncertainty. The world must complete as many of these projects as possible to provide the information needed for deployment.

Finally, CCS cost must come down and that can only happen through new developments and operational experience at commercial scale.

3 National and multinational CCS frameworks

Chapter 3 reviews the status of legal and regulatory frameworks and other CCS related developments in the EU and a representative group of geographically dispersed countries. The nine largest emitters are discussed, along with some smaller emitters who have been active in CCS advancement. Emission rankings are provided only as a point of reference – not as a criticism. Not being mentioned does not equate to an absence of CCS activity. Examples include individual EU countries which are transposing the EU CCS Directive into national law; Indonesia where a comprehensive study of CCS potential has been completed (Indonesia, 2009); and Mexico which is collaborating with the USA and Canada on CCS activity including the production of a North American Carbon Atlas.

As would be expected, CCS readiness is at various stages with developed countries generally farther along than developing countries. No country has a complete legal and regulatory framework in place that addresses all barrier issues to deployment. Some countries are authorising demonstration projects under existing regulatory regimes modified where necessary for CCS.

A number of countries, both developed and developing, remain cautious about wide-scale deployment of CCS. Cost reduction and funding are major factors, along with the need for conclusive evidence that CCS is technically effective at commercial scale.

Some countries have focused attention on storage in offshore lands owned by the state. Offshore storage has been facilitated by a 2007 amendment to the London Protocol authorising storage of CO_2 beneath the seabed. In 2009, the Parties to the Protocol adopted a resolution for a second amendment to permit transboundary export of stored CO_2 subject to agreement by the countries concerned. The 2009 amendment will enter into force after it has been accepted by two-thirds of the Contracting Parties (IMO, 2010; UCL, 2010a). The OSPAR Convention, which is an agreement among 15 governments to protect the marine environment of the North East Atlantic, has also been modified to permit storage of CO_2 beneath the seabed (OSPAR, 2010).

3.1 Australia

3.1.1 Overview

Australia ranks sixteenth in CO_2 emissions at 1.28% of the world total. Rankings represent CO_2 emissions from fossil-fuel burning and cement manufacture (Wikepedia, 2010). The country relies on coal as its primary source of electricity and coal and liquefied natural gas (LNG) as major export products. The ability to continue to exploit coal and natural gas through deployment of CCS is important to Australia's energy security and economy. The country has committed substantial sums to CCS research and demonstration and is actively involved in international activities, including the establishment of the Australian based GCCSI whose fundamental mission is to accelerate the safe, economic, and environmentally sustainable commercial-scale deployment of CCS worldwide.

Australia has not enacted a comprehensive climate change law. An emissions cap and trade programme identified as the *Carbon Pollution Reduction Scheme* (CPRS) failed passage twice in Parliament. Under the CPRS, CO_2 transferred to CCS facilities would not count towards the originating entity's gross emissions (CPRS, 2008). On 27 April 2010, then Prime Minister Rudd announced the delayed implementation of the CPRS until after the end of the first Kyoto commitment period in 2012 and only when there is greater clarity on the action of other major economies including the USA, China, and India. On 27 September 2010, Prime Minister Julia Gillard announced formation of a Climate Change Committee that will explore options for introduction of a carbon price in Australia (Gillard, 2010).

Despite the lack of an overarching climate framework, Australia has made significant progress with legal and regulatory initiatives to facilitate CCS projects. At the national level, a comprehensive legal framework for offshore storage has been enacted. Individual states are also using a combination of existing laws and regulations and new laws to enable CCS activity within their jurisdictions.

3.1.2 Discussion

CCS Framework – Offshore Storage in Commonwealth Waters

The Australian Government passed the Offshore Petroleum Amendment (Greenhouse Gas Storage) Act of 2008 (GSS Act), amending the Offshore Petroleum Act to establish a legislative framework for GHG storage beneath the seabed in waters under Commonwealth jurisdiction. The Offshore Petroleum Act was identified as the most appropriate vehicle to implement a CCS regime due to the co-existence of the petroleum and CCS industries, the need to establish determinable rights between the industries, and the similarities between the industries (Australia Department of Resources Energy and Tourism, 2010a), The GSS Act addresses many of the CCS barrier issues identified in Chapter 2, including access for CCS project developers to government-owned storage sites.

The GSS Act allows the storage of CO_2, one or more prescribed GHGs, or a mixture thereof. Stored substances may be in gaseous or liquid state. Incidental GHG-related substances and detection agents may be included so long as the mixture consists overwhelmingly of CO_2 and/or other prescribed GHGs. The term ‘overwhelmingly’ is not defined in the law. The EU CCS Directive and the London Protocol use the same term ‘overwhelmingly’ to define the gas stream; however, the EU and the Protocol limit storage to CO_2 and incidental and tracer substances.

The Commonwealth periodically releases offshore acreage for storage exploration. Developers must apply for a GHG assessment permit to explore for potential GHG gas storage formations and injection sites. The law allows the responsible Minister to reject or accept applications, choose between competing applicants, and establish permit conditions. Once the Minister declares a formation to be eligible for storage, the developer may apply for an injection licence. If the developer is not in a position to immediately inject, it may apply for a holding lease. The Minister must consider impacts on petroleum interests when approving injection permits. The GSS Act allows for the construction and operation of an offshore GHG pipeline upon issuance of a licence by the federal and state Joint Authority. If regulations are issued that provide for third party access to GHG pipelines, the licensee is required to comply with the regulations. The government has issued implementing regulations for environmental plans and safety requirements; additional regulations and guidelines are expected.

The GSS Act addresses long-term liability by providing for surrender of licences to, and assumption of liability by, the Commonwealth. When injection has ceased, the licensee applies for a site closure certificate from the Minister. If a certificate is issued, the licensee retains liability for at least a 15-year closure assurance period and until the Minister determines that there is no significant risk of adverse impact on the geotechnical integrity of the formation, the environment, and human health and safety. Once the Minister is satisfied, liability is transferred to the Commonwealth and the Commonwealth must indemnify the licence holder for liability accruing after the end of the closure assurance period. The Commonwealth also assumes long-term liability for certain orphan sites.

The GSS Act provides the government authority with considerable discretion to set permit and licence conditions. Therefore, it will be important for the Commonwealth to establish clear policies and guidelines to provide a sufficient degree of regulatory certainty to prospective developers.

Other National CCS Framework Developments

In 2005, Australia’s Ministerial Council on Mineral and Petroleum Resources (MCMPR) issued Regulatory Guiding Principles for CCS to facilitate a nationally consistent approach by federal, state, and territorial bodies (AUS MCMPR, 2005). A theme throughout the principles is reliance on, and adaption of, existing regulations, policies, and protocols where possible. The Guiding Principles align with a number of the key CCS barrier issues. Major points include:

- Assessment and Approval Process: Processes should be consistent with agreed national protocols and guidelines. Existing legislation and regulations relating to CCS should be identified and modified and augmented where necessary.
- Access and Property Rights: Surface and subsurface rights should provide certainty to rights-holders. Rights should be based on established legislative and regulatory arrangements, custom and practice, and accommodate the likely evolution of multiple CCS infrastructure and facilities. Governments should give due consideration to land use planning issues that may arise.
- Transportation Issues: Regulations should be consistent where possible, using agreed national protocols and guidelines.
- Monitoring and Verification (M&V): Regulations should provide for appropriate M&V, enabling the generation of clear, comprehensive, timely, accurate, and publicly accessible information that can be used to effectively manage environmental health, safety, and economic risks. Regulations should provide a framework to establish the quantity, composition, and location of gas captured, transported, injected, and stored; the net abatement of emissions; and, identification and accounting of leakage.
- Liability and Post-Closure: Current regulatory principles and common law should continue to apply to liability for all stages of CCS projects. Governments' overall consideration of post-closure storage must aim to minimise exposure to health, environmental, and financial risks for operators, governments, and future generations.
- Financial Issues: Wherever practical, established legislative, regulatory, and accounting processes should be used in preference to new regulations. Income from capital and operating costs associated with a CCS project should be treated in the same way as for other business ventures for taxation purposes. Regulations should recognise the potential for post-closure liabilities for CCS activities and consider appropriate financial instruments to assist in the management of such risk.

It is noted that the GSS Act is partially at variance with the Guiding Principles in that the Act provides for Commonwealth assumption of long-term liability.

CCS Framework Development – Provincial

Victoria enacted the Greenhouse Gas Geological Sequestration Act (2008) to establish a legislative framework for onshore CCS activity. Under the Act, the State asserted ownership to storage formations and storage cannot occur without a State licence. Title to stored CO_2 transfers to the State after a storage permit is cancelled or surrendered by the licensee. The law is silent on long-term liability for the stored CO_2.

Victoria passed the Offshore Petroleum and Greenhouse Gas Storage Act (2010) allowing for storage in state waters. The Act is similar to the GSS Act with the significant difference that Victoria does not assume long-term storage liability. Upon surrender or cancellation of a licence the Crown becomes the owner of GHG injected into the storage formation.

Queensland's Greenhouse Gas Storage Act (2009) is similar to Victoria's Onshore Act in that the State asserts title to geological storage formations and the stored CO_2 becomes property of the State after surrender of a GHG lease. Exploration permits are made available through a competitive bidding process. The law does not expressly provide for assumption of long-term liability by the State.

In 2003, Western Australia enacted the Barrow Island Act specifically for the Gorgon LNG project which plans to store 3.5 Mt of CO_2 per year. The Act provides for the authorisation of underground CO_2 storage subject to the approval of the cognisant Minister. The legislation did not address long-term liability, but in 2009, the Commonwealth and the Western Australia government agreed to share long-term liability on an 80/20 basis.

South Australia amended its Petroleum and Geothermal Energy Act in 2009 to provide for the geological storage of CO_2 under the same regulatory scheme applicable to petroleum and other regulated substances. Ownership of injected substances remains with the licensee. The Amendment does not address long-term liability after cessation of storage operation

CCS Financial Support

Australia has committed significant funding to CCS research and demonstration. Under its CCS Flagships Programme, the government expects to leverage $2 billion in federal funding with $2 billion each from states and industry to support two to four integrated commercial-scale demonstration projects. The government will only share non-commercial costs which are calculated as the differential between the project as proposed and a project without CCS. Funding is not available for projects or components of projects which, if internally funded or commercially financed, would generate a commercial rate of return. Four projects have been shortlisted, Wandoen and ZeroGen in Queensland, Collie South West Hub in Western Australia, and CarbonNet in Victoria. Operations are expected to begin in 2015 (Australia Department of Resources, Energy and Tourism, 2010b).

3.1.3 Conclusion

Australia federal, state, and territorial governments have created a composite legal and regulatory framework that is immediately useful for early CCS projects and is capable of evolving as needed for wide-scale deployment. By creating a national framework for offshore storage, Australia will provide access to additional large quantities of storage capacity while avoiding many of the land use and property right issues associated with onshore storage.

3.2 Brazil

3.2.1 Overview

Brazil ranks sixteenth in CO_2 emission from combustion sources at 1.26% of the world total, but ranks fourth in total CO_2 emissions, largely attributable to land-use activities (IEA Brazil, 2009). Most of Brazil's electricity comes from hydropower, although power generation from natural gas, coal, and nuclear is expected to increase over the next 20 years (IEA Brazil, 2009; IEA Stats, 2009).

Brazil is a non-Annex I Party to the UNFCCC and therefore not subject to binding GHG reduction targets under the Kyoto Protocol. In 2009, Federal Law No. 12.187/09 was signed, approving Brazil's National Policy on Climate Change and endorsing carbon reduction targets of 36.1–38.9% by 2020 (Sant'Anna and others, 2010). These targets correspond to Brazil's nationally appropriate mitigation actions submitted pursuant to the Copenhagen Accord.

Since most of Brazil's emissions are not from combustion processes, CCS cannot be a primary solution for GHG reduction. This is reflected in Brazil's Copenhagen measures, which are based on land use changes, reduction in deforestation, energy efficiency, and increased use of hydropower, alternate energy, and biofuels. Still, Brazil has maintained a robust research programme on CCS for a number of years and is investigating its application for various industries.

3.2.2 Discussion

A CCS regulatory framework is not yet fully developed in Brazil (GCCSI Brazil, 2009; IEA Brazil, 2009). Regulatory certainty has been identified as a key issue for CCS development. It has been noted that there are discussions within the government concerning compensation for CO_2 emissions from new plants and that CO_2 is factoring into permitting deliberations (IEA Brazil, 2009). On 2 February 2010, the Environment Minister issued a Directive to establish a Climate Change Working Group to advise the Minister on issues related to climate change and assist the Ministry in the development of climate change policies (Beveridge & Diamond PC, 2010).

Petrobrás, Brazil's National Oil and Gas Company, is very interested in CCS. The company is developing petroleum resources in offshore 'pre-salt' formations that contain a high quantity of CO_2 (8–18%) in associated gas. Petrobrás is investigating reinjection for EOR and saline storage. The company has many years of experience in CO_2 EOR and is also conducting saline and enhanced coal bed methane pilot storage projects. (IEA Brazil, 2009; Wertheim, 2010). In 2007, Petrobrás teamed with the Pontifical Catholic University of Brazil to create the Energy and Carbon Storage Research Centre.

Potential geological storage formations in Brazil have been mapped and storage capacity is believed to be very large (2000 Gt) with good matching of the majority of stationary sources with petroleum fields and saline aquifers in the southeastern part of the country (Ketzer and others, 2007).

As mentioned in Chapter 2, Brazil opposes inclusion of CCS in the Kyoto CDM financial mechanism notwithstanding that inclusion might benefit some CCS projects in Brazil. In its views submitted to the SBSTA on 31 May 2010, Brazil supported acceleration of CCS research and the diffusion of CCS technologies. However, Brazil believes CCS is incompatible with the CDM citing issues of leakage, long-term liability, monitoring, permanence and additionality. Brazil is also concerned with potential impacts from a large influx of CCS credits that could drop prices to a level which could dismantle the carbon market and undermine incentives for technologies oriented toward decarbonisation of the economy (SBSTA, 2010a).

3.2.3 Conclusion

Work remains to be done on Brazil CCS framework. While CCS is not the primary focus of Brazil's climate change strategy, CCS research, development and demonstration is actively being pursued by Brazil's petroleum industry and academic institutions. Brazil is technologically prepared and the country's geology is well suited for CCS.

3.3 Canada

3.3.1 Overview

Canada ranks seventh in CO_2 emissions, at 1.9% of the world total. Domestic emissions coupled with large oil and gas exports to the USA gives Canada an economic and environmental interest in the success of CCS. Canada has large oil sand reserves where production results in higher CO_2 emissions than conventional oil production.

Canada is an Annex I Party to the UNFCCC and a Party to Kyoto Protocol; however, the country has struggled to meet its Kyoto targets. Canada announced a proposed framework for controlling industrial GHG emissions in 2008 commonly known as the 'Turning the Corner' document. Targets would be established for existing and new facilities with annual improvements required thereafter. Facilities could meet compliance requirements through a number of mechanisms, including credit trading. Turning the Corner endorsed CCS, noting that Canada's potential for storage could be as much as one-third to one-half of projected GHG emissions by 2050 (Canada, 2008). The framework has not been implemented. Canada's climate change experience is similar to that of the USA in a number of respects. In fact, Canada has largely aligned its position in global negotiations with the

USA citing the close integration of the countries' economies and geographic proximities (Government of Canada, 2010a).

Canada does not have a dedicated national legal or regulatory regime for CCS. However, Canada has a well developed system of laws and regulations addressing mineral and petroleum extraction, CO_2 pipelines, and CO_2 EOR, which the provinces have relied on to authorise CCS projects.

3.3.2 Discussion

Climate Change – Provincial Frameworks

Several provinces have regulated GHG emissions. British Columbia passed a revenue neutral carbon tax on fuels starting at $10 per tonne carbon dioxide equivalent (CO_2-e) and increasing to $30 per tonne by 2012 (Government of British Columbia, 2010). Quebec imposed a smaller carbon tax in 2007 Government of Canada, 2010b). Alberta passed GHG reduction legislation requiring facilities emitting over 100,000 t/y to reduce the intensity of greenhouse emission by 12% (Government of Alberta, 2010). Compliance may be met by in-house reductions, credit trading within the province, or payments of $15 per tonne for emissions over target. Four Canadian provinces (British Columbia, Manitoba, Ontario, and Quebec) have joined with seven US states in the Western Climate Initiative in an effort to establish a regional cap and trade programme. A detailed roadmap was issued in July 2010 (WCI, 2010).

CCS Framework Development – Provincial

The Canadian provinces are using existing regulatory regimes to accommodate CCS demonstration projects. Alberta and Saskatchewan are two examples.

Alberta

Bulletin 2010-22 from the Alberta Energy Resources Conservation Board (ERCB) expresses the Board's clear intent to regulate CCS activities under existing procedures (ERCB, 2010).

> The Energy Resources Conservation Board (ERCB) has been regulating the disposal, storage, and injection of fluids to underground geologic formations in Alberta for many years and with respect to carbon dioxide (CO_2) for more than 20 years. The ERCB has processes in place to provide for the effective regulation of these activities, including the more than 50 schemes involving CO_2 currently operating in Alberta.
>
> This bulletin is to inform readers that the ERCB intends to use these existing processes when processing applications for the development and operation of carbon capture and storage (CCS) projects in Alberta

The Bulletin outlines the laws, regulations, directives, and standards applicable to the various stages of the storage chain which taken together provide a basic framework for licensing, MVA, and site closure. The Bulletin acknowledges that CO_2 regulation is an evolutionary process and that updates may be issued as more CCS knowledge is gained.

Alberta's regulatory regime addresses some, but not all CCS barrier issues. The Bulletin notes that the applicant must obtain disposal rights in the underground formation which in Alberta may be held by a private owner or the Crown. Section 57 of the Alberta Mines and Mineral Act provides that the owner or owners of petroleum and natural gas rights also own storage rights with respect to every formation within that land, and that the owner of mineral rights who has created a cavern by extraction of minerals, also owns storage rights in the cavern. Therefore, access to storage locations and pore space may be a problem for some projects. The Bulletin also references existing directives for liability requirements. Under current practice for oil and gas operations, the licensee is liable during injection and after abandonment. Working interest owners may be required to perform abandonment duties if the licensee does not have financial capacity. If no one is available to perform those functions, an orphan fund covers the cost of abandonment and reclamation, but not tortious liability or liability for environmental harm (Bankes, 2010).

An earlier report by the Alberta Carbon Capture and Storage Development Council (ACCSDC) was generally approving of Alberta's regulatory preparedness; however, the report identified a number of gaps in the existing framework and recommended legislation and other actions including:

- Clarification that disposal rights extend to permanent disposal of CO_2.
- Clarification of the Crown's disposal rights in saline formation; development of a mechanism to provide for granting of those rights; delineation of the circumstance where disposal rights supersede other rights in the same formation.
- Publication of guidelines on how industry may acquire storage rights which includes an open and transparent process for obtaining rights.
- Development of a long-term management framework (ten years post decommissioning monitoring recommended for early projects).
- Development of a framework for long-term liability and stewardship.

On 1 November 2010, the Carbon Capture and Storage Statutes Amendment Act, 2010, was introduced in Alberta. If enacted, the Bill will clarify ownership of pore space by declaring that 'pore space is vested in and is the property of the Crown in right of Alberta' regardless of any prior grant from the Crown of land, mines or minerals. The Bill provides that the declaration is not an expropriation of rights and that no person has a right of action to claim damages or compensation as a result of its enactment. The Bill does not affect title to land belonging to the Crown in right of Canada. The cognisant minister may enter into agreements for the use of pore space for CO_2 storage. Upon issuance of a closure certificate by the minister, the Crown becomes the owner of, and assumes liability for, the captured CO_2. After liability transfer, the Bill provides that the Crown shall indemnify a lessee against liability for damages in an action in tort if the liability is attributable to an act or omission of the lessee in the lessee's exercise of rights under the agreement, and any other conditions specified in the regulations are met. The Bill would also establish a post-closure stewardship fund, financed by payment from CCS operators, for ongoing monitoring costs and remediation.

Saskatchewan

Considerable knowledge has been gained from one of the longest running CO_2 storage projects located at the Weyburn and Midale oil fields in Saskatchewan. Production began in the 1950s, and in 1998 plans were announced for large-scale EOR using CO_2 captured from a coal gasification plant in North Dakota. An international initiative spearheaded by IEA was established to study geological storage at the site (PTRC, 2010). Like Alberta, the provincial oil and gas regulatory regime was the main source of governing authority for storage operations. In March 2010, the project released a comprehensive report analysing the framework governing injection and storage. The main observations and conclusions from the report include:

- The provincial regulatory system provides comprehensive controls to ensure productive and safe operation.
- The controls reflect lengthy experience both in Saskatchewan and North America with measures in the oil and gas industry to protect the environment, the public, and workers.
- The provincial system is also capable of regulating safe and effective CO_2 storage and of adapting to emerging issues that may arise.
- The current regulatory framework is flexible enough to accommodate the needs of potential crediting systems, once details are known.

The report also notes that provincial regulators have used the existing legislative framework to ensure effective regulation of CO_2 injection at the sites (Zukowsky, 2010).

Other CCS activities

Canada and the USA collaborated in producing the Carbon Sequestration Atlas of the USA and

Table 5 Major CCS projects in Canada with government support (websites: SaskPower Boundary Dam; Transalta Project Pioneer, Quest Project Fact Sheet; Enhance Energy; Swan Hills Synfuels; Government of Alberta)

Project	Project description	Contribution
SaskPower Boundary Dam	Capture: Coal retrofit Storage: EOR Quantity: 1 Mt	Federal: $280 million
Transalta Project Pioneer Keephills	Capture: Coal retrofit Storage: EOR Quantity: 1 Mt	Federal: $343 million Alberta: $431 million
Quest Project Shell, Chevron, Marathon	Capture: Oil sands upgrader Storage: Saline formation Quantity: 1+ Mt	Federal: $120 million Alberta: $745 million
Swan Hills Project Swan Hills Synfuels	Capture: In situ coal gasification Storage: EOR Quantity: 1.3 Mt	Alberta: $285 million
Alberta Carbon Trunk Line Enhance Energy Inc	40,000 t/d CO_2 pipeline distribution system.	Federal: $63 million Alberta: $495 million

Canada, mapping geological sinks and emission sources (NETL, 2008a). This will help inform decisions about access to storage sites and pipeline needs. The collaboration has recently expanded to include Mexico, with the goal to develop a comprehensive North American Atlas.

The Canadian and provincial governments have committed approximately $3 billion in support for CCS demonstrations. Table 5 identifies some of the largest projects.

3.3.3 Conclusion

Canada has made considerable progress in advancing CCS. By taking advantage of the economic overlay of CCS and petroleum production, and by adaptation of existing provincial regulatory frameworks, Canada has facilitated key demonstration projects. Some barrier issues still need to be addressed, such as access to storage space, long-term liability, and long-term stewardship. Furthermore, it is not clear how regulatory responsibilities will be allocated between the national government and the provinces as climate change and CCS framework development progresses at the federal level.

3.4 China

3.4.1 Overview

China ranks first in CO_2 emission at 22.3 % of the world total. China's emissions nearly tripled between 1990 and 2007 and despite government initiatives to reduce energy intensity, absolute emissions are expected to almost double again by 2030. Much of the increase is attributable to new coal-based power generation (IEA Stats, 2009). Coal dominates the energy sector in China accounting for 70% of primary energy consumption and approximately 75% of power generation (USEIA, 2010a).

China issued its *National Climate Change Programme* in 2007 setting out a portfolio of legal, regulatory, institutional, and energy-related measures aimed at reducing energy consumption per unit of GDP by 20% by 2010. Energy conservation, renewable energy, nuclear energy, and hydropower are elements of the programme, but China also intends to develop advanced technologies for clean and efficient use of coal, including combustion and gasification based power systems, coal liquefaction, and CCS (China, 2007).

China is a developing country Party to the Kyoto Protocol and, therefore, not subject to binding emission reduction targets. Like India, China's nationally appropriate mitigation actions submitted pursuant to the Copenhagen Accord are based on a reduction in emission intensity rather than a gross reduction in emissions. China offered to lower emissions by 40–45% per unit of GDP by 2020 compared to 2005 levels and increase the share of non-fossil fuels in primary energy consumption to approximately 15% by 2020. China also offered to increase forest coverage by 40 million hectares and forest stock volume by 1.3 billion m^3 by 2020 from 2005 levels. These targets are expected to slow China's emissions growth rate, but not result in an absolute reduction of emissions. The country's rapid economic development and associated energy demand makes absolute reductions unlikely in the near term (Seligsohn and Levin, 2010).

Clearly, there is great opportunity for CCS in China. This fact has attracted considerable attention from the world community. For its part, China is actively engaged in international CCS co-operation and domestic CCS research, development and demonstration (RD&D).

3.4.2 Discussion

Legal and regulatory framework

China does not have national legislation mandating GHG reduction. Recent reports indicate that China is considering initiating pilot carbon trading programmes in some cities and regions beginning in 2011 (Reuters, 2010a; Carbon Positive, 2010).

China also does not have a dedicated legal and regulatory framework for CCS. Independent studies by the China-UK Near Zero Emissions Coal Initiative (NZEC), GCCSI, and WRI identified various Chinese laws that would be applicable to CCS projects and analogues in other laws that could be adapted for CCS (Odeh and Haydock, nd; Seligsohn and others, 2009; GCCSI China; 2009). Significant regulatory gaps were identified in the area of geological storage, including issues related to exploration and licensing; property rights; site selection criteria; CO_2 stream purity and classification (industrial product, waste, hazardous waste); risk assessment; measurement, monitoring, verification; post-closure stewardship; and long-term liability. China-UK NZEC was launched in 2007 as an outgrowth of NZEC agreement between the EU and China. The two countries established a team from government, industry, and academia to conduct a three phase programme with the aim to (1) build CCS capacity in China, (2) develop storage and capture options, and (3) construct a demonstration plant by 2015 (NZEC, 2010a) GCCSI noted that the absence of policy or legislation would not likely be a major hindrance to the discovery and development of storage facilities due to Government's role in such projects (GCCSI China, 2009). Tsinghua University and WRI, with support from the US Department of State and the Asian Pacific Partnership (APP), are developing guidelines for safe and effective CCS that can be used by China to address some of these concerns (WRI, 2009).

Other CCS activities

The Pacific Northwest National Laboratory (PNNL) and the Institute of Rock and Soil Mechanics in China completed a study of regional opportunities for CO_2 storage (Dahowski and others, 2009). The study found that China has a total estimated onshore and offshore storage capacity of 3068 $GtCO_2$ – on a par with the USA. Furthermore, many of China's major emission sources are located in close proximity to at least one candidate storage formation. The report concludes that 'Most of the large CO_2 emissions sources in China should be able to transport and geologically store their CO_2 for decades – and potentially a century or more – at costs of 2 and 8 $/tCO_2$.' The estimated cost includes pipeline transport, site characterisation, injection, MMV, plus production and CO_2 recycling costs for EOR or enhanced coalbed methane recovery, but excludes CO_2 capture and compression cost (Dahowski and others, 2009). Additional work is needed to fully assess China's storage capacity, but the apparent large storage volume and matching of sources and sinks are favourable conditions for CCS in China.

China's *Outline of the National Programme for Medium- and Long-term Science and Technology Development* issued by the State Council in 2006, established guidelines and objectives for China's science and technology development through 2020. CCS and near zero fossil energy were identified as key research areas. (NZEC, nd). Consistent with the Programme, China has a full portfolio of CCS and near-zero emissions related RD&D including (NZEC, nd):

- Fundamental research on syngas production through coal gasification and pyrolysis.
- Fundamental research on the high efficiency transfer of natural gas and syngas.
- A study of high efficiency heat transfer in gas turbines.
- Development of absorption and adsorption based capture technologies.
- Study of CO_2 EOR and geological storage.
- CO_2 injection/sequestration in deep coal seams for coal bed methane exploitation
- Pilot CO_2 EOR programme in Jilin oilfield.
- GreenGen IGCC CCS demonstration project.
- Post-combustion CO_2 capture demonstration project.

China's international collaborators include the EU, UK, USA, Canada, Japan, Australia, and Norway. In addition to bilateral collaboration, China is a member of the CSLF, GCCSI, and the APP.

3.4.3 Conclusion

China's CCS efforts are primarily oriented toward technology advancement, testing, and demonstration. China has not yet focused its attention on development of a comprehensive legal and regulatory framework; however, international organisations are working with China on framework issues.

Deployment of CCS in China over the next 10–20 years will likely depend on the outcome of multinational climate change negotiations. China, like India, firmly believes in the principle of 'common but differentiated responsibilities and respective capabilities' embodied in the UNFCCC. Prior to COP 15, China's legislature approved a resolution endorsing carbon reduction as a new source of economic growth. However, the resolution also calls upon developed countries to 'take the lead in quantifying their reduction of emissions' and 'support developing countries with funds and technology transfers' (China Department of Climate Change, 2009). Once financial issues are resolved, China should have the geological, technological, and regulatory capacity to successfully deploy CCS.

3.5 EU

3.5.1 Overview

The EU has established itself as a leader in climate policy. It also has member states that rely heavily on fossil energy and will for decades to come. Therefore, the EU appreciates the importance of CCS to its climate change strategy.

In 2003, EU Directive 2003/87/EC (ETS Directive) created the world's first cap and trade system to

Table 6 EU Climate Change and Energy Package Legislation (Europa, 2010)

Directive 2009/28/EC (Renewable Energy Directive)	Establishing binding national targets for renewable energy for each member state.
Decision No 406/2009/EC (Effort Sharing Decision)	Establishing an effort sharing agreement where each member state agrees to a national emission limitation target for 2020 (based on relative wealth) for emissions from sectors not covered by the ETS Directive.
Directive 2009/29/EC (Amending the ETS Directive)	Revising and strengthening the ETS Directive and establishing a reserve of 300 million European Union Allowances (EUA) to support CCS and renewable energy demonstration projects.
Directive 2009/31/EC (CCS Directive)	Establishing a legal framework to promote the development and safe use of CCS.

control GHG emissions from electric utilities and other energy-intensive industries. (A Directive is a legislative instrument in the EU.) Five years later the European Parliament and Council agreed to a comprehensive Climate Change Package built around three targets for 2020.
1 Reducing GHG emissions by at least 20% of 1990 levels (30% conditioned on other major emitting countries in the developed and developing worlds committing to do their fair share).
2 Increasing use of renewable energy to 20% of total energy production.
3 Reducing energy consumption by 20% by improving energy efficiency.

The package has four main legislative components listed in Table 6.

The amended ETS Directive, the new CCS Directive, and amendments to several other existing directives, form the backbone of a comprehensive legal and regulatory framework for CCS in the EU.

3.5.2 Discussion

ETS Directive
The ETS Directive provides the overarching mandate within the EU to reduce GHG emissions from large emission sources. Its stated purpose is to promote reduction of GHG emissions in a cost-effective and economically efficient manner. This is accomplished through a cap and trade mechanism (the European Union Emissions Trading Scheme or EU-ETS) whereby member states are subject to a national cap on emissions which is translated into emission limits for covered installations within the state. Installations must surrender allowances at the end of the compliance period equivalent to their emissions. The member state is responsible for monitoring, verification, and compliance. Allowances are transferrable within the European Market and installations may satisfy a portion of their compliance requirement by the purchase of offset credits available through the CDM and JI financial mechanisms of the Kyoto Protocol. The ETS Directive was amended in 2004 to link the EU-ETS with the Kyoto Protocol Joint Implementation and CDM financial mechanisms. The percentage of off-set credits that may be purchased varies by member state.The Directive establishes a penalty of €100 for each tCO_2-e emitted by an installation for which the operator has not surrendered allowances.

The EU-ETS is divided into three phases. The first phase ran from 2005 to 2007; the second runs from 2008 to 2012; and, the third thereafter. During the first and second phases, the Directive required allocation of at least 95% of allowances free of charge. During the second phase, at least 90% must be allocated free of charge. Originally, the Directive covered CO_2 emissions from electricity generation and several energy intensive industries. Coverage has been expanded to include additional industries and additional GHGs. The revised Directive permits member states to exclude installations that emit less than 25,000 t/y if the state imposes measures (such as taxation) to achieve an equivalent contribution to emissions reduction. The EU-ETS scheme covers approximately half of the EU's CO_2 emissions (EC, 2008).

The first trading period was a learning experience for the EU. The large number of free allowances coupled with over allocation to some member states reduced the incentive effect expected to be obtained with the trading system (EC, 2008; Jeffery, 2010). To achieve the EU's 20% reduction goal by 2020 and improve the stability of the EU ETS, the revised ETS Directive seeks to remedy the early problems by establishing an EU-wide cap on total emissions, reducing the cap by 1.74% annually, setting additional restriction on the use of off-set credits, and phasing out free allocations starting in 2013. Free allowances generally will not be provided to electricity generators after 2013. However, Article 10c defines an optional transitional period where member states who meet certain economic and energy criteria may allocate 70% of their allowances free of charge, gradually decreasing to no free allowances by 2020. Member states are required to fully transpose the revised Directive into their national laws by 31 December 2012.

ETS Directive and CCS

The revised ETS Directive contains several provisions directly applicable to CCS.

- Article 10 encourages Member States to use at least 50% of auction revenue for environmental initiatives, including support for CCS from solid fossil fuel power stations and industrial sectors.
- Article 10a makes available up to 300 million allowances in the new entrants' reserve until 31 December 2015, for commercial CCS projects and innovative renewable energy demonstration projects (*discussed below*).
- Article 10a prohibits free allocation of allowances for CO_2 capture, pipeline transport, and storage.
- Article 12 now expressly excludes any obligation to surrender allowances where emissions are verified as permanently stored in accordance with the CCS Directive. Prior to the amendment, member states could have sought approval from the EC for CCS activities under Article 24 of the Directive.
- GHG capture, transport and storage are added as covered industries under Annex I of the Directive.

ETS Directive – New Entrant Reserve (NER) Mechanism

The revised ETS Directive creates a large, off-budget, funding resource for CCS by setting aside a new entrant reserve (NER) of 300 million allowances to be monetised and made available for CCS and innovative renewable energy demonstration projects. The applicable rules are set forth in an EC Decision (EC, 2010) and summarised below. The summary does not address rules applicable exclusively to renewable projects.

- Two rounds of competitive applications are planned targeting support for eight CCS projects in four categories (pre-combustion power, post combustion power generation, oxy-combustion, and industrial applications) along with 34 renewable projects. The competitions will be managed by the European Investment Bank (EIB) on behalf of the EC.
- Qualification criteria include:
  - Projects must be located in the territories of the Member States, their exclusive economic zones, and their continental shelf.
  - Power projects must be at least 250 MW. Industrial projects must store 500 kt/y.
  - The capture rate must be at least 85% from the flue gas stream to which capture is applied.
  - Projects must include capture, transport and storage and must implement heat integration for the capture component.
  - Projects must contain an independent research block related to safety of storage sites and improvement of monitoring technologies.
  - First round projects must demonstrate a reasonable expectation of entry into operation by 31 December 2015 on the basis of adoption of the award decision by 31 December 2011.
- No project may receive the equivalent value of more than 45 million allowances (15% of the

reserve). Awards are limited to 50% of relevant costs defined as those investment costs which are borne by the project due to the application of CCS net of the net present value of the best estimate of operating benefits and costs arising due to the application of CCS during the first ten years of operation. Award values are reduced by the amount of any financing received from European Energy Programme for Recovery (EEPR).

- Member States collect funding applications within their territory and review the applications for compliance with project eligibility criteria prior to submission to the EIB for financial and technical evaluation. Projects are ranked and selected based on cost (borne by the public) per unit of performance (total amount of CO_2 stored in the first ten years of operation). The selection decision is retained at the EU level. Awards are conditional upon receipt of permits, approval of any State aid being granted, and final investment decisions by all sponsors. Conditions must be satisfied within 24 months of adoption of the award decision; 36 months for projects storing in saline aquifers.
- Allowances will be sold by the EIB prior to distribution of funds to Member States for disbursement to projects. Disbursements occur annually on the basis of the amount of CO_2 stored, reported, monitored, and verified. Where Member States guarantee that excess funding will be returned, a State may disburse part or all of the funding for a project prior to its entry into operation.
- Knowledge-sharing will be required by project operators, consortium members, suppliers and subcontractors who receive substantial benefit from the public support in development of their product or service. Information must be made available regarding technical set-up and performance, cost-level, project management, environmental impact, health and safety, and CCS storage site performance.

How many projects can be supported under the NER mechanism remains to be seen as the number is a function of total funding available and the requested amounts. Based on data from the European Climate Exchange, during July 2010, allowances were trading at less than €15. Accordingly, at today's prices, 300 million allowances would create a reserve of approximately €4.5 billion. Improvements to the EU ETS as a result of the revised ETS Directive should result in higher trading prices in the coming years. In 2008 McKinsey and Company estimated the cost of a CCS demonstration project to be 60–90 €/tCO_2 abated (Nauclér and others, 2008). Using McKinsey's estimates, for a modestly-sized power plant sequestering 2 Mt/y, the additional cost of CCS for a ten-year period is €1.2–1.8 billion. Assuming as McKinsey does that the median selling price of allowances will be €35 through 2030, that leaves CCS demonstration project with a deficit of roughly €500 million to €1.1 billion over the first ten years.

Since projects are ranked based on cost/unit of performance, theoretically a few large projects could absorb a substantial portion of the reserve capped only by the 15% limit on individual projects. Furthermore, the first round requirement to commence operations by 31 December 2015, will likely limit applicants to projects that are already in planning. Knowledge sharing requirements could discourage participation by some vendors unless member state implementation provides vendors the clear right to protect exploitable technology.

CCS Directive

The stated purpose of the CCS Directive is to establish a legal framework for the environmentally safe geological storage of CO_2 to contribute to the fight against climate change. The Directive: (1) creates a new EU-wide set of rules expressly for geological storage; (2) makes conforming amendments to existing directives that will regulate aspects of the CCS chain; and (3) excludes CCS from the coverage of several directives in order to avoid legislative conflicts. Member states retain the right to determine what storage sites will be authorised within their territory and the right not to allow any storage within their territory. The CCS Directive must be transposed by the member states into national law by 25 June 2011. Key requirements include:

1 A geological formation may only be selected for storage if there is not significant risk of leakage, and no significant environmental or health risk. Annex I contains a detailed three-step process for

determining site suitability that includes: (1) data collection, (2) three-dimensional modelling, and (3) characterisation of the storage dynamic behaviour, sensitivity characterisation, and risk assessment.

2 Permits are required for exploration and storage. Procedures for granting permits must be based on objective, non-discriminatory and published criteria. Holders of exploration permits are provided priority for storage permits. Member states are responsible for ensuring that no conflicting uses of the storage complex are permitted during the tenure of the permit.

3 Permit applicants must prove their financial responsibility and technical competence to conduct the project. Financial security must be in place prior to injection sufficient to meet all financial obligations during injection, closure, and post-closure periods. Financial security shall be adjusted periodically to account for changes in assessed risk and estimated cost of obligations.

4 CO_2 streams must consist overwhelmingly of CO_2. No waste or other matter may be added for the purpose of disposal. The stream may contain incidental substances from the capture and injection process, including tracer materials for monitoring and verification.

5 The operator is responsible for monitoring, reporting, and corrective measures. The member state is responsible for ensuring that the operator complies with its responsibilities, including the performance of routine and non-routine inspections. In accordance with the ETS Directive, allowances must be surrendered for leaked CO_2.

6 After injection ceases, the storage site shall be closed if permit conditions have been met or otherwise upon authorisation by the competent authority at the request of the operator. The operator remains responsible for monitoring and corrective action after closure until responsibility is transferred to the competent authority. A storage site may also be closed by decision of the competent authority after withdrawal of a storage permit. In such case, the authority is responsible for monitoring and corrective action, but may recover the costs from the operator or by drawing on the financial security.

7 The post closure monitoring period shall be at least 20 years unless the competent authority is convinced that the applicable criterion for transfer of responsibility has been met before the end of the period. Upon evidence that the CO_2 will be completely and permanently stored and the site has been sealed and injection facilities removed – all obligations for monitoring and corrective action, including the surrender of allowances in the event of leakage, shall be transferred to the competent authority. The operator is required to make a financial contribution to the competent authority of at least the anticipated cost of monitoring for 30 years.

8 Member states are required to take measures to ensure that potential users are able to access CO_2 transport networks and storage sites in a transparent and non-discriminatory manner. This includes an obligation on the part of transport network operators and storage site operators to enhance capacity when a potential customer is willing to pay for the changes and there is not a negative impact on the environmental security of the transport or storage activity.

An analysis conducted by the University College London Carbon Capture Legal Programme (UCL) suggests that transfer of responsibility to the competent authority will not relieve the operator from all potential claims. UCL found that claims brought under civil or common law for bodily injury, property damage, and other losses recognised by the courts would not be relieved unless the member state affords such protection in the transposition of the Directive. Similarly, member state statutory laws on environmental damage may impose liability unless the state grants protection. EU environmental laws not addressed in the Directive may be applicable and the Directive does not provide relief for contract claims brought by other parties (UCL, 2010b).

The CCS Directive contains a short grace period for storage sites operating on 25 June 2009, or authorised on or before 25 June 2009, and used within a year thereof. Member states must ensure that such sites are in compliance by 25 June 2012. Rules concerning site selection, exploration permits, site characterisation, and EC review are excluded.

Third party access to pipelines and storage facilities may be a disincentive for some potential operators due to planning difficulties and potential liability concerns. The open-ended nature of financial security requirements – which may be changed during the course of operations – may also be a disincentive.

Changes to other Directives

The CCS Directive amended the Integrated Pollution Prevention and Control (IPPC) Directive (2008/1/EC) to expressly include CO_2 capture in the list of covered activities. IPPC permitting requires the use of best available techniques (BAT) defined as:

> . . . the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole (IPPC Directive Article 2(12)).

The meaning of BAT in the context of CCS demonstration projects is not clear. Reference manuals from 2007 considered fuel efficiency measures to be BAT for CO_2 reduction and stated that CO_2 capture could not be considered BAT for large combustion plants (Zakkour, 2007). In view of the changes to the IPPC directive, it is uncertain whether BAT will require greater CO_2 control than planned by the demonstration project developer. Confusion over BAT may delay demonstration projects or result in project cancellation if BAT is broadly construed.

The Large Combustion Plant Directive (2001/80/EC) was amended to require operators of plants with output of 300 MW or more, permitted after CCS Directive comes into force, to assess whether: (1) suitable storage sites are available, (2) transport facilities are technically and economically feasible, and (3) it is technically and economically feasible to retrofit for CO_2 capture. If the conditions are met, the competent authority shall ensure that suitable space on the installation site for the equipment necessary to capture and compress CO_2 is set aside. The competent authority shall determine whether the conditions are met on the basis of the assessment referred to in paragraph 1 and other available information, particularly concerning the protection of the environment and human health.

The Environmental Impact Assessment Directive (85/337/EEC) was amended to include CO_2 pipelines, storage sites, and capture facilities within its coverage.

The Environmental Liability Directive (2004/35/EC) was amended to include the operation of geological storage sites within its coverage.

To avoid conflicts with other Directives, the CCS Directive also amended:

- The Waste Directive (2006/12/EC) to exclude CO_2 air emissions and CO_2 storage from its coverage.
- The Shipment of Waste Regulation (EC No 1013/2006) to exclude the transport of CO_2 for CCS from its coverage.
- The Water Directive (2000/60/EC) to expressly provide for injection of CO_2 into geological formations which for natural reasons are permanently unsuitable for other purposes.

EU CCS financial support

In addition to funding provided under the NER mechanism, the EU has supported, and continues to support, CCS research under its Framework Programme for Research and Technological Development. Furthermore, the EU recently announced the selection of six demonstration projects under the EEPR with a combined support of €1 billion, *see* Table 7.

3.5.3 Conclusion

The EU is ahead of most countries in climate policy and CCS legal and regulatory framework

Table 7 EEPR selected projects (Europa, 2009)

Project	Sponsor/country	€million
Jänschwalde: Demonstration of the oxyfuel and the post-combustion technology on an existing power plant site. Two storage and transport options are analysed.	Vattenfall (Germany)	180
Porto-Tolle: Installation of CCS technology on a new 660 MW coal power plant. The capture part will treat flue gases corresponding to 250 MW electrical output. Storage in an offshore saline aquifer nearby.	Enel Ingegneria e Innovazione S.p.A. (Italy)	100
Rotterdam: Demonstration of the full chain of CCS on a capacity of 250 MW equivalent using post-combustion technology. Storage of CO_2 in a depleted offshore gas field near the plant. The project is part of the Rotterdam Climate initiative that aims at developing a CO_2 transport and storage infrastructure for the region.	Maasvlakte J.V. / E.ON Benelux and Electrabel (Netherlands)	180
Belchatów: Demonstration of the entire CCS chain on flue gases corresponding to 250 MW electrical output in a new supercritical unit of largest lignite-fired plant in Europe. Three different saline aquifer storage sites will be explored nearby.	PGE EBSA (Poland)	180
Compostilla: Demonstration of the full CCS chain using oxyfuel and fluidised bed technology on a 30 MW pilot plant which is to be upscaled by December 2015 to a demonstration plant of more than 320 MW. Storage in a saline aquifer nearby.	ENDESA Generacion S.A. (Spain)	180
Hatfield: Demonstration of CCS on a new, 900 MW IGCC power plant. Storage in an offshore gas field nearby. The project is part of the Yorkshire Forward initiative that aims at developing a CO_2 transport and storage infrastructure for the region.	Powerfuel Power Ltd (UK)	180

development. While the EU-ETS encountered some early problems, these were understandable and provide valuable lessons for countries contemplating a cap and trade system. The EU is taking corrective measures to remedy the problems which should lead to a more stable and reliable allowance market that can provide meaningful incentives for low-carbon technologies such as CCS.

The CCS Directive, together with the amended ETS Directive and other amended Directives, constitutes a complete CCS legal and regulatory framework. Many details remain to be resolved through additional EU guidance and member state implementation. However, the composite framework addresses the key barrier issues for CCS including pipeline and storage site access, siting and storage requirements, long-term stewardship, long-term liability, and financial support mechanisms to help demonstration projects bridge the CCS economic gap.

3.6 Germany

3.6.1 Overview

Germany ranks sixth in CO_2 emissions at 2.69% of the world total. Unlike many countries that view fossil fuels as a primary source of electricity for years to come, Germany may most embody the concept that fossil energy is a bridge to no-carbon power. A recent study by the Federal Environment Agency (UBA) indicates that Germany could supply all of its electricity needs from renewable sources by 2050 (UBA, 2010).

Germany's approach to CCS regulation is best described as cautious. Unlike some of its European neighbours who have fully embraced CCS, Germany is taking gradual steps to CCS deployment.

3.6.2 Discussion

Germany has no regulatory framework designed specifically for CCS. CCS activities could be subject to regulation under various laws including those applicable to emission control, pipelines, mining, and federal and state waters (German Energy Blog, 2010). As an EU member state, Germany must transpose the CCS Directive into German law and future CCS activities in Germany will be subject to the Directive requirements.

A CCS Bill introduced in 2009 failed to pass due to widespread opposition including a negative opinion from the German Advisory Council for the Environment (SRU) which cautioned against a premature commitment to CCS based on its belief that CCS could not currently be regulated in a satisfactory way. SRU noted that many CCS issues are unresolved, including questions related to storage capacity, ecological risks, interference with future use of geological resources, and fundamentally whether it is appropriate to store CO_2 underground in Germany. The Advisory Council recommended a research law that only permits testing of CCS technology (SRU, 2009).

Heeding the public concerns, the Government introduced a new CCS Bill in July 2010 which contains a number of limitations on CCS activity. The revised Act permits only CCS testing and demonstration activities through 2017 at which time CCS will be thoroughly evaluated. Other features of the draft Act set out in a joint press release from the Environment and Economic Ministries are:
- Storage facilities may only be licensed if the application for the licence is filed by the end of 2015, and the annual storage volume per facility does not exceed 3 $MtCO_2$/y, and the overall volume nationwide does not exceed 8 $MtCO_2$/y.
- In all demonstration storage facilities, precautionary measures must be taken against negative impacts on human beings and the environment according to the state of the art in science and technology.
- Funds will be set aside for aftercare (post-closure) from the first tonne stored.
- Other potential uses for underground sites, for example, for geothermal energy production or energy storage, are given even greater consideration.
- If land must be accessed or used for exploration, better protection of the rights of land owners is ensured.
- In line with constitutional provisions, municipalities affected are to receive financial compensation.

A final decision on the Bill is expected by the end of the year (BMU, 2010). If passed, the Bill will establish a regulatory framework for large-scale CCS demonstration projects such as Vattenfall's 250 MWe oxy-combustion project at Jänschwalde. The potential for strong public opposition nevertheless remains. Furthermore, the temporal and quantity limitations in the Bill will discourage CCS investment beyond 2015 until such time as Germany makes a decision to fully deploy CCS.

3.6.3 Conclusion

The legal and regulatory landscape for CCS in Germany will likely remain unsettled through at least 2017. If, at that point, sufficient information is available from research and demonstration projects to instill scientific and public confidence, Germany will go forward with a permanent CCS regime.

3.7 India

3.7.1 Overview

India ranks third in CO_2 emissions at 5.5% of the world total. However, India's CO_2 emissions per capita is comparatively small – about one-fourth the world average (IEA Stats, 2009). Approximately 80% of India's electricity comes from fossil fuel and IEA estimates that India's CO_2 emission will double between 2007 and 2030 (IEA Stats, 2009: IEA WEO, 2008).

India released its first National Action Plan on Climate Change in 2008 (India, 2008). Recognising that climate change is a global matter, India aims to 'establish an effective, co-operative and equitable global approach based on the principle of common but differentiated responsibilities and respective capabilities, enshrined in the UNFCCC.' Citing Mahatma Gandhi: 'The earth has enough resources to meet people's needs, but will never have enough to satisfy people's greed.' the Plan promotes sustainable development and notes India's determination not to exceed the per capita GHG emissions of developed countries. Like China, India's nationally appropriate measures submitted as a developing country pursuant to the Copenhagen Accord are framed in terms of emission intensity reduction as a function of GDP rather than as a gross reduction of CO_2 emissions. The Plan defines an approach to climate change based on eight National Missions. CCS is mentioned once under the discussion of the Mission on Strategic Knowledge for Climate Change (India, 2008).

> There are three ways of lowering the emissions from coal based plants: increasing efficiency of existing power plants; using clean coal technologies (relative emissions are circa 78% of conventional coal-thermal), and switching to fuels other than coal, where possible. These measures are complementary and not mutually exclusive. Another option that has been suggested is carbon capture and sequestration (CCS). However, feasible technologies for this have not yet been developed and there are serious questions about the cost as well permanence of the CO_2 storage repositories.

Despite this less than enthusiastic endorsement of CCS, there is still substantial CCS activity under way in India.

3.7.2 Discussion

India's guarded policy statements about CCS should not be mistaken for a lack of CCS interest. India is active in international CCS co-operation, including memberships in IEA GHG, GCCSI, the CSLF, and the APP. India's National Geophysical Research Institute is a participant in the US Big Sky RCSP. Furthermore, India conducts a substantial amount of CCS research in its own right. All of these activities are aimed at determining how CCS can be part of India's climate change strategy. Three main challenges face CCS deployment in India: (1) lack of a legal and regulatory framework, (2) suitable geological storage capacity, and (3) cost. Each is discussed briefly below.

India does not have a CCS regulatory regime. In its Country Study of India, GCCSI found that the lack of regulation is 'the single largest impediment to investment of CCS project in India' and suggested that India consider amending existing regulations or enacting dedicated legislation (GCCSI India, 2009). Pending India's acceptance of CCS as a solution, it is not likely that the country will develop a comprehensive stand-alone CCS regime, and when it does, India will have to deal with the same regulatory issues currently being addressed by other countries. Until then, India may be able to adapt its current regulatory scheme to accommodate pilot and demonstration projects that can help India make choices about CCS.

Geological storage capacity is a concern for India. A 2008 study conducted by the British Geological

Survey for the IEA GHG found considerable potential for storage in deep saline aquifers, but also found that many large emission sources were located long distances from potentially favourable storage sites (IEA GHG, 2008). Transport distance equates to additional cost which is already a barrier for CCS deployment in India. To that end, the National Thermal Power Company Ltd and the National Geophysical Research Institute in India are collaborating with PNNL to study the feasibility of CO_2 storage in the basalt formations of the Deccan Volcanic Province in central India. The formations could theoretically store 300 $GtCO_2$ – equivalent to 250 years of CO_2 at India's current production rate (Sonde, nd). Storage in basalt formations requires additional investigation, but if proven successful, it expands the viable geological options for India and other parts of the world (NETL, 2008b).

India's economic growth in recent years has been impressive. Nevertheless, India still suffers from high poverty levels and a large population without access to essential services such as electricity, clean drinking water, affordable health care, etc (Government of India, Eleventh Five-Year Plan, 2007-12). Solving these problems are among India's highest priorities, leaving little room in the National budget for investment in CCS. The Eleventh Five-Year Plan calls for additional research and development on CCS. India's Climate Change Plan takes note of the UNFCCC dual principles that: (1) social and economic development and poverty eradication are the first and overriding priority of developing countries; and (2) developed countries are to transfer financial resources and technology to developing countries for purposes of mitigation and adaptation (India, 2008). Accordingly, without an international financial mechanism that includes CCS, the prospects for deployment of CCS in India are not high – at least in the near term.

3.7.3 Conclusion

India is still in the exploratory phase of CCS and it may be some time before the country has a comprehensive CCS legal and regulatory framework. However, India is taking appropriate steps to understand how CCS could be part of its climate change strategy.

The rate at which India and other developing countries are adding new coal-based electricity reinforces the need for research investment to lower CCS cost. These plants will all be CCS retrofit applications which cost substantially more than CCS on a new plant.

3.8 Japan

3.8.1 Overview

Japan ranks fifth in CO_2 emission at 4.28 % of the world total. The country is highly industrialised, trailing only the USA and China in total electricity generation and oil consumption. Approximately 60% of Japan's electricity comes from conventional thermal sources. Nearly all of Japan's oil, gas, and coal supply is imported, which is a concern for the country (USEIA, 2010b). The objective of the New National Energy Strategy, introduced in 2006, is to promote energy security and sustainable development coupled with a commitment to assist Asia and the world in addressing energy problems (Koyamo, 2006).

Japan does not have a mandatory GHG reduction framework. To meet its Kyoto Protocol obligation, the country has largely relied on voluntary industrial reductions, increased energy efficiency, a renewable portfolio standard, and the purchase of international emissions credits (Yamaguchi, 2007). Recent reports indicate that the country intends to turn to additional domestic reductions to avoid a shortfall rather than the purchase of additional foreign credits (Daily Yomiuri, 2010).

When it comes to CCS, Japan is proactive domestically and throughout the world. Japan's Action Plan for Low Carbon Growth states (Japan, 2008):

> CCS technology has the potential for massive emissions reductions in thermal power generation, which accounts for roughly 30% of Japan's emissions, and in the steelmaking process, which accounts for roughly 10%. Japan will promote the development of this technology with the target of the cost of capture and storage in the order of 2000 yen per ton by around 2015, falling to 1000 yen or so in the 2020s. At the same time, Japan will commence verification tests on a large scale at an early stage from 2009 onward, with the aim of implementation by 2020. Regarding application, Japan will work to resolve issues such as enhancing environmental impact assessments and monitoring, putting legislation in place, and ensuring public approval.

Japan views CCS as not only an environmental solution but also as a market opportunity (METI, 2010). To that end, Japan has committed resources to CCS technology development, pilot-scale testing and eventual demonstration. Much of Japan's CCS research is sponsored by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organisation (NEDO).

3.8.2 Discussion

Climate Change Framework

Japan has operated a Voluntary Emissions Trading Scheme (JVETS) since 2005. JVETS was initiated by the Ministry of Environment to allow Japan to gain experience with emissions trading and to support GHG reduction by Japanese businesses. It has familiar elements of a mandatory emission trading system (ETS) including monitoring, reporting, and verification; a registry for emissions trading; and, an emissions management system (MOEJ, 2009).

National legislation was introduced in 2010 to institute a mandatory cap and trade system and possible carbon tax but the Bill failed to pass in the Upper House of Parliament prior to the end of the legislative session (Business Green, 2010; Bloomberg, 2010). The draft law also provided for expansion of nuclear energy, feed-in-tariffs for renewable energy and a possible carbon tax. Japan's Copenhagen Accord target is a 25% reduction in emissions from 1990 levels. Mandatory cap and trade with a 25% reduction target, worries some Japanese business out of concern for damage to the economy from competition with countries not subject to hard caps. Similar concerns have plagued cap and trade legislation in other developed countries.

Although national legislation has yet to be passed, Japan does have a first of a kind cap and trade system at the prefectural level. After a six-year voluntary ETS, the Tokyo Metropolis – the fifteenth largest economy in the world – enacted a mandatory ETS in 2008 that is scheduled to start in 2010 (Tokyo, 2010). The ETS covers 1400 universities, hospitals, businesses, and factories targeting an overall 25% GHG reduction by 2020 from 2000 level. Installations that miss their individual target in the first compliance period must reduce emissions by 1.3 times the shortfall in the second period. If targets are missed in the second period, the government will buy allowances and assess the cost against the emitter. Purchase of offset credits is limited to: (1) emission reductions from small and medium-sized installations, (2) renewable energy credits, and (3) emission reductions outside of Tokyo limited to one-third of a company's obligations (Allianz, 2010).

CCS Legal and Regulatory Framework

Japan does not have a dedicated CCS legal and regulatory framework for onshore storage. Offshore storage is regulated under Japan's Law Relating to the Prevention of Marine Pollution and Maritime Disaster of 1970 as modified to comply with the 2006 CO_2 storage amendments to the London Convention. Pursuant to the Law, a developer must submit an application for a storage permit from the

Environment Minister that includes:
(1) A CO_2 disposal implementation plan addressing: the disposal period, CO_2 quantity and characteristics, disposal location and method, measures to prevent and contain damage to the marine environment, a monitoring plan, and a post-injection closure procedure.
(2) A sub-seabed disposal assessment addressing potential impacts to the marine environment in the event of a leak.

Criteria for application approval include: compliance with standards; a finding that there is no other appropriate means of disposal; a finding that the applicant has sufficient financial and technical capability; no prior seismic activity; ease of monitoring; and ease of implementation of pollution prevention measures. Permits are issued for five years and may be renewed thereafter (GCCSI Japan, 2009). Safe operations guidelines for CCS demonstration projects have been issued by METI's Carbon Capture and Storage Study Group (METI, 2009).

Other CCS activities

Japan is active in international CCS co-operation, including memberships in the IEA-GHG, CSLF, GCCSI, and the APP. The Japanese Bank for International Cooperation, the international arm of the Government-owned Japanese Finance Corporation, has taken on the role of advising and supporting Japanese industries in development of overseas business associated with CCS (JBIC, 2009).

Japanese CCS Co Ltd (JCCS), incorporated in 2008, is a consortium of utilities, industrial concerns, petroleum companies, engineering firms, and trading companies, organised for the purpose of advancing CCS in Japan. Its mission includes (JCCS, 2008):
- supporting the government's demonstration and deployment goals;
- integrating private sector opinions on laws, regulations, and standards for CCS;
- co-operating with foreign organisations for CCS deployment outside of Japan;
- conducting CCS knowledge transfer with foreign organisations.

With support from NEDO and METI, JCCS activities have included a feasibility study on offshore storage, an offshore pipeline route survey and 3-D seismic storage site survey, and an investigatory well at a candidate demonstration site (JCCS, 2010).

Other Japanese research includes development of lower cost CO_2 capture systems, pilot-scale storage testing, a feasibility study of CCS for natural gas plants, and investigation of CO_2 injection for coal bed methane recovery and storage (Yamagata, nd).

3.8.3 Conclusion

Japan is facing the same problem as other countries who are trying to balance concerns over economic impact with a national policy mandate for GHG reduction. Even without a compulsory control scheme, Japan is likely to continue on a path of emissions reductions through its voluntary programmes.

Japan has some additional work to do towards a complete CCS legal and regulatory framework. The offshore framework has the necessary elements to provide for proper evaluation and safe operation of storage facilities which will facilitate Japan's demonstration objectives. But it does not appear to address some key barrier issues to CCS deployment such as long-term liability and stewardship.

Japan is clearly taking steps to position itself as a world provider of CCS technology and it may be that a significant portion of Japan's CCS related emission reductions come from overseas projects rather than domestic activities.

3.9 Norway

3.9.1 Overview

Norway ranks sixty-fifth in CO_2 emission at 0.15% of the world total. Although a small contributor to world emissions, Norway has been at the forefront of GHG reduction efforts driven by a strong sense of environmental responsibility coupled with an economy that depends heavily on fossil fuel. In 2009, oil and gas exports and pipeline transport services accounted for 22% of Norway's GDP, and 27% of government revenues (USEIA, 2010c). Norway's electricity comes primarily from hydropower and therefore power generation is currently not a major source of GHG emissions. A significant portion of Norway's emissions are attributable to its petroleum industry.

Norway hopes to be carbon-neutral by 2030 and development of CCS technology is a key part of the country's strategy to meet this objective. For a thorough discussion of the factors that led to Norway's endorsement of CCS, *see* Technology as Political Glue: CCS in Norway (Tjernshaugen and Langhelle, 2010).

3.9.2 Discussion

Norway's legal and regulatory landscape is influenced by its relationship to the EU. Norway is not an EU member state, but is a member of the European Free Trade Association (EFTA) having entered into the Agreement on the European Economic Area (EEA) which permits Norway to participate in the EU Internal Market. Relevant EU legislation is integrated into annexes and protocols to the EEA Agreement and subsequently transposed into Norwegian law (EFTA, 2007).

Climate Change Framework

In 1991, Norway introduced one of the world's first, and highest, taxes on CO_2 applicable to fuels and emissions from the petroleum industry on the continental shelf. The tax was a catalyst for the Sleipner Project in the 1990s, but as a GHG reduction tool it has received mixed reviews. A 2002 report from Statistics Norway found that the tax contributed to a reduction in onshore emissions of only 1.5% and total emissions of 2.3%. This small effect was attributed to 'extensive tax exemptions and relatively inelastic demand in the sectors in which the tax was actually implemented' (Bruvoll and Larsen, 2010). Similarly, IEA found that while the tax was pioneering, its effectiveness was limited by the number of exemptions for large emitters (IEA Norway, 2005).

Norway's Greenhouse Gas Emission Trading Act (2004), created a trading scheme that is similar to the EU-ETS. It covered CO_2 emissions from combustion installations greater than 20 MW and certain industrial operations, but excluded installations subject to Norway's CO_2 tax and installations subject to special emission reduction agreements with the Government. The ETS was merged into the EU-ETS in 2008. Adjustments were made to Norway's CO_2 tax to avoid a double burden on industries exempt under the Norway ETS but covered by the EU-ETS (IEA, 2010a,b).

CCS Legal and Regulatory Framework

Norway's CCS activities are primarily focused on the continental shelf which is also the location of Norway's oil and gas production. Norway has a well-developed legal and regulatory framework for petroleum activities that has been adapted for CCS. Pursuant to the Petroleum Activities Act, the state maintains ownership and the right to exploit petroleum resources on the continental shelf. Exploration and production licences are granted by the state. When formations on the shelf are used for CO_2 storage not related to petroleum activities, the storage is covered by the Act for the Continental Shelf rather than the Petroleum Act (Solomon and others, 2007).

As an EFTA Country, Norway is in the process of transposing the EU CCS Directive into Norwegian law. From a substantive standpoint, it can be presumed that Norway's CCS legal and regulatory framework will follow the CCS Directive requirements. Procedurally, it appears that Norway will continue to regulate CCS related to petroleum activities under the Petroleum Activities Act harmonised with the CCS Directive, and regulate all CCS activities under general legislation (Grøndalen and Bjørnebye, 2010; *see also* Simonsen, 2008).

Other CCS activities

Norway has an active CCS portfolio. The country is involved in international co-operation through memberships in IEA GHG, CSLF, and GCCSI. The Sleipner Project in the North Sea has been collecting large-scale storage data for 15 years and its younger sibling, the Snøhvit project, began injection in 2008. In 2009, Norway pledged €140 million as part of its contribution to the EEA Financial Mechanisms for projects in EU countries (Stoltenberg, 2009).

A unique aspect of Norway's CCS programme is Gassnova SF, a state-owned enterprise formed in 2008 to manage Norway's investment in CCS projects. Unlike many countries where state-supported CCS activities are conducted by private companies, Gassnova contracts with companies to build the CCS projects on behalf of the Norwegian Government (Element Energy, 2010).

Norway's Kårstø and Mongstad Projects are worth noting. Kårstø is expected to capture 1.2 $MtCO_2$/y from a natural gas power plant. Mongstad is expected to capture up to 1.3 $MtCO_2$/y from a combined heat and power plant. Both projects involve pipeline transport for offshore storage. As conceived, State funding would cover 100% of the CCS investment cost and CCS operating cost for ten years. Like some other large-scale projects around the globe, these projects have encountered setbacks linked to technical and economic issues. In Kårstø's case, the Government explains that construction of the CCS facility has been postponed due to irregular operation of the gas-fired power plant. At Mongstad, the Government delayed its investment decision by two years to evaluate progress, risk, costs, and technology development (Norwegian Ministry of Petroleum and Energy 2010a,b). A CO_2 Technology Centre planned as a first phase at Mongstad is still moving forward. These projects illustrate the fragile nature of early projects – even with strong support from a government like Norway.

3.9.3 Conclusion

The world has learned valuable lessons from Norway as a result of its groundbreaking CCS activities. Once transposition of the EU CCS Directive is complete, Norway will have a CCS legal and regulatory framework that aligns with EU requirements and, therefore, addresses the key barrier issues to CCS. Like the EU, the fine details remain to be developed. Norway has also demonstrated a willingness to provide substantial financial support for CCS which should facilitate early projects.

3.10 Poland

3.10.1 Overview

Poland ranks twenty-first in CO_2 emission at 1.08% of the world total. Over 90% of Poland's electricity generation is coal-based and the country exports a significant amount of coal (Europa, 2007). Fossil fuel will dominate Poland's energy mix for the foreseeable future, making CCS important to Poland's energy security and economic interest. However, Poland is concerned with CCS cost and has reservations about its effectiveness until proven at full scale. The Energy Policy of Poland Until 2030 includes CCS as a priority, but the policy also recognises the importance of energy diversification (Poland, 2009) .

Poland has a long history of CCS research. In 2001, Poland partnered with an international consortium to perform one of the first field tests of CO_2 storage in coal seams. The project is known as RECOPOL (Reduction of CO_2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland). Poland's research leadership continues today with plans for at least two large-scale CCS demonstrations by 2015.

3.10.2 Discussion

Legal and Regulatory Framework

Poland is a member of the EU and therefore the EU-ETS provides the overarching mandate for GHG reduction in Poland. The EU CCS Directive will provide the legal framework for geological storage projects once transposed into Polish law.

Transposition of the CCS Directive is expected to require amendments to Poland's energy, mining, business, environmental, and public information laws (Poland Ministry of Environment, 2010). The Ministry of Environment initiated public consultation in late 2009 and posted guidelines on the Ministry's website outlining the new legal requirements. As required, the proposed Polish transposition follows the requirements of the CCS Directive with several implementing features specific to Poland:

- Prospecting, exploration, and operation of the underground storage sites for CO_2 will be subject to concessioning provisions. Concessions will be granted by the Minister of the Environment. Fees collected for CO_2 storage will be distributed 60% to the municipality in the storage area and 40% to the National Fund for Environmental Protection and Water Management.
- Underground storage of CO_2 will be subject to inspections by the Minister of the Environment and the President of the State Mining Authority. These authorities will also be responsible for resolving inspection findings (for example, ordering elimination of any infringements found or taking specific actions, including cessation of the operation or closure of the mining plant).
- A special entity (the National Administrator of CO_2 Underground Storage Sites (NACUSS) will be appointed for administering obligations of closed storage sites. NACUSS will be financed by concession fees and closure payments deposited into the National Fund.

The website also contains a notable statement from the Under-Secretary of State and Chief National Geologist applauding the CCS Directive, but at the same time observing that its implementation might delay Poland's demonstration activities:

> We could have overtaken the lead in the field of making assessment of the opportunities to deep underground storage of carbon dioxide, while the two demonstration projects in Bechatów and Kędzierzyn will approximate us to such opportunities. The Community resources could make us capable to become one of the first countries testing such technology. But first of all, we must implement the EU legal provisions in order to get to know how and where to locate such CCS projects, and how they are to be monitored. This is a chance to upgrade this technology with simultaneous securing human and environmental safety.

Since the CCS Directive contains only a short grace period and no grandfathering provision, other EU CCS demonstrations may likewise be delayed pending implementation of the Directive.

Other Polish CCS Activity

The Fifth National Communication to the UNFCCC outlines several additional CCS related activities planned for Poland (Poland, 2010):

- use of the proceeds from auctions of CO_2 emission allowances to support measures aimed at reducing GHG emission including construction of CCS installations and performance of CCS research studies;

- introduction of carbon capture ready standards for new power plants;
- continuance of the 2009 programme to identify strata and structures for safe geological storage of CO_2;
- identification of opportunities for application of CCS to petroleum and natural gas extraction operations;
- intensifying research and development on new technologies which allow using captured CO_2 as a raw material for industry;
- continued active participation in the EC's demonstration project initiative.

In addition to the Belchatów project funded in part by the EEPR, the Kędzierzyn Project is a planned polygeneration facility that will gasify coal and biomass to produce electricity, steam, and methanol while sequestering 2.5 $MtCO_2/y$ in a geological formation. The project is significant from a GHG reduction standpoint in that cogasification of coal and biomass combined with CCS can result in a net reduction of atmospheric CO_2 due to the uptake of CO_2 in the biomass. Start-up is planned for 2015 (Kędzierzyn Brochure, 2010).

3.10.3 Conclusion

Once the CCS Directive is fully transposed into Polish Law, Poland will have a complete legal and regulatory framework for CCS.

Poland is taking the necessary steps to ready itself for CCS deployment. Affordability, geological storage capacity, reliability, and public acceptance are key questions that will determine the extent to which CCS is actually used in Poland. The demonstration programme will answer some of the questions; however, affordability will largely depend on CCS cost-reduction and/or the future strength of the carbon market.

3.11 Republic of Korea

3.11.1 Overview

Korea ranks ninth in CO_2 emissions at 1.72% of the world total. The country has limited domestic fossil fuel resources and, therefore, must rely heavily on imports to meet energy demand. The majority of Korea's electricity comes from coal and natural gas (USEIA, 2010d). Korea is heavily industrialised with manufacturing consuming 55% of Korea's energy compared to 26% in the USA and 39% in Japan (Park, 2009).

Korea is a developing country party to the Kyoto Protocol and, therefore, not subject to binding emission reduction targets. Nevertheless, Korea's long-term National Strategy for Green Growth and Five-Year Plan for Green Growth (released in 2008 and 2009 respectively) are based on increased use of renewable and nuclear energy, energy efficiency improvements, and less dependence on fossil fuels (Jee, 2008). This migration away from fossil fuels not only helps Korea's GHG situation, but also buffers it from the market fluctuations of foreign energy supplies.

Despite the trend toward no-carbon technology, fossil fuels will remain in Korea's energy picture for many years and CCS will be part of Korea's climate change strategy if suitable geological storage formations can be found. Korea also sees great potential for CCS as a growth industry and is taking steps to ready the country for competition in the global market.

3.11.2 Discussion

Korea does not have a dedicated CCS legal and regulatory framework; however, GCCSI reported in 2009 that development of policies and legislation was under consideration (GCCSI Korea, 2009).

Korea has been active in international CCS co-operation, including membership in the IEA GHG, CSLF, GCCSI, and APP. The country also has a robust CCS RD&D programme with an expected public and private investment of 2.3 trillion won (US$1.9 billion) by 2019 (Reuters, 2010b).

Korea considers CCS as a green industry and has targeted it for support as a next generation economic growth engine. Other targeted growth engine industries are: (1) Near-term – photovoltaics, light emitting diodes, wind power, and electricity IT, (2) Next-generation – hydrogen fuel cells, gas to liquids, coal-to-liquids, integrated gasification combined cycle power generation, and energy storage (Cho, 2009) However, the country also recognises the need for urgent technological advancement (Park, 2009). Korea's plan for green growth is to close the technology gap with the developed countries and establish markets and export opportunities for the industries (Cho, 2009).

In April 2010, Korea's Framework Act on Low Carbon Growth and accompanying Enforcement Decree came into effect directing the government to establish a national climate strategy coupled with green growth. The legislation mandates emission reporting by controlled entities and authorises the government to establish a cap and trade system. In its analysis of the legislation, the United Nations Environment Programme (UNEP) noted that the operational structure, method of allocation of emission permits, sectoral coverage and other details are reserved for implementing laws (UNEP, 2010). Matters identified by the framework legislation as necessary for green growth include procurement of financial resources, taxation, financing, training of human resources, education, and public relations activities.

The Green Growth Framework is noteworthy law in that it links Korea's climate change strategy so closely with entrepreneurial growth. In his comments on the Framework, Korean President Lee Myung-bak identified three pillars of green growth and entrepreneurship:

> First, there needs to be strong political will and leadership to make the transition to a new paradigm.
>
> Second, the public needs to embrace the new paradigm and discard old habits of thinking and acting . . . From a policy standpoint, this requires measures to raise awareness of green growth and provide proper incentives and disincentives – such as carbon pricing and taxation — to help the public make the right decisions.
>
> Last but not least, there needs to be technological revolution to support the first two requirements. Breakthroughs in technology are what will enable the path to green growth and allow the public to truly transform its lifestyle.

The President also said Korea can play a catalysing role by adopting what he called a 'me first' approach. He noted that 'Too often in the past, the need to mobilise global action to combat climate change has been stymied by a reluctance of nations to act until others act first' (Global Asia, 2010).

The Green Growth strategy should facilitate use of CCS within Korea by establishing a pricing mechanism for carbon. It should also help with future deployment of CCS by virtue of Korea's efforts to support and advance the technology for commercialisation in worldwide markets.

It is not yet clear how useful CCS can be within Korea. A 2006 analysis by the PNNL found that there was little onshore storage potential and that offshore potential in saline formations was also not large (approximately 0.4 GtCO_2) (Dooley, 2006). The Asia Pacific Economic Cooperation (APEC) reached a similar conclusion in 2007 (APEC, 2007). The Korean Institute of Geoscience and Mineral Resources is conducting a carbon storage programme to assess the potential for geological storage in Korea and to screen sites for pilot-scale testing (KIGAM, 2009). Korea is also studying CO_2 carrier and ocean storage systems for carbon sequestration which could align with Korea's shipbuilding industry (KAIST OSE, 2010).

Korea is conducting extensive research to reduce the cost of CO_2 capture, which Korea sees as a key to CCS commercialisation. Technologies being investigated include: wet scrubbing by absorbent; CO_2 capture by dry sorbent; chemical looping combustion; membranes; oxyfuel combustion; and pressure swing adsorption (Yi, 2007).

3.11.3 Conclusion

Korea has a climate change law and strategy in place that lays the groundwork for GHG reduction coupled with development of green technologies including CCS. Implementing legislation and regulations will take additional time to develop. Actual use of CCS in Korea will depend upon geological storage capacity. Regardless, Korea plans to be a world supplier of CCS and is taking action to position itself for that role – which will ultimately help CCS deployment.

3.12 Russian Federation

3.12.1 Overview

The Russian Federation ranks fourth in CO_2 emissions at 5.24% of the world total. Russia estimates that it possesses one-third of the world natural gas reserves, one-tenth of oil reserves, and one-fifth of coal reserves (Russia, 2003). Natural gas supplies over half of Russia's domestic energy needs with coal and oil between 15–20% each (USEIA, 2010e). Russia is also a major exporter of natural gas, oil, and coal and expects to increase production of all three resources significantly by 2020, *see* Table 8.

Table 8 Projected increase in Russian fossil fuel production (Russia, 2003)

Oil production	324 Mt in 2000 450–520 Mt in 2020
Gas production	584 billion m^3 in 2000 680–730 billion m^3 in 2020
Coal production	258 Mt in 2000 375–430 Mt in 2020

Russia's Climate Change Doctrine, signed by the President in December 2009, does not mention CCS. However, it does state that the Russian Federation will encourage research and development in GHG sink technologies and other environmentally acceptable technologies. It also lists as a priority the creation of legal frameworks and mechanisms of state regulation aimed at the reduction of man-made impact on the global climate system (Russia, 2009).

3.12.2 Discussion

There is little evidence of CCS legal and regulatory activity in Russia. A 2010 report from the independent G8 Research Group, which tracks compliance with G8 declarations, stated that Russia has not taken steps to accelerate the design of policies, regulatory frameworks, and incentive schemes towards the development and deployment of CCS technology (Davidson and others, 2010). At the 2009 G8 Summit in L'Aquila, Italy, the G8 declaration included a commitment to 'accelerate the design of policies, regulatory frameworks and incentive schemes focused on the development and deployment of CCS technology.' The G8 Research Group monitors country compliance with these declarations. France, Germany, Italy, and the USA also did not receive a favourable review from the G8 Research Group.

Russia is engaged in CCS research and is a member of the GCCSI and CSLF. In a 2005 report to the CSLF, the Russian representative noted that Russia had initiated several CCS research projects including: capture from IGCC plants; chemical looping research; and collaborations under projects funded by the EU's Sixth Framework Programme (Mazurenko 2005).

In 2009, a team led by the International Bureau for Environmental Studies in collaboration with the Siberian Branch of the Russian Academy of Sciences completed a study of the feasibility of CO_2 storage in the Russian permafrost and its compatibility with the oil industry in the region. The study found that CO_2 storage through EOR could occur near emission sources and that the permafrost could serve as a secondary caprock, trapping the CO_2 as a gas hydrate if the primary caprock fails (IBES, nd).

3.12.3 Conclusion

Russia's interest in CCS research is encouraging. In view of Russia's economic dependence on fossil fuels, Russia will eventually have to take steps to deploy CCS including the development of a legal and regulatory framework. Otherwise, Russia may have difficulty exporting its fossil resources and meeting international commitments. There may be early opportunities in Russia for the economic use of CCS for EOR, particularly in the production regions of western Russia.

3.13 South Africa

3.13.1 Overview

South Africa ranks thirteenth in CO_2 emissions at 1.48% of the world total. Coal accounts for most of South Africa's electricity generation and, together with gas, approximately 35% of liquid fuel requirements (Surridge, nd). Like many developing countries, South Africa's electricity demands are exceeding supply. Eskom, the country's primary electric generator, plans to add 17,000 MWe by 2017 and double its total capacity to 80,000 MWe by 2026. Coal and natural gas account for a significant portion of the expansion (Eskom, 2010).

In its Copenhagen Accord submission, South Africa expressed its intention to take nationally appropriate measures to reduce business as usual emission by 34% by 2020 and 42% by 2025, which are among the most aggressive targets offered by developing countries. The measures are subject to the provision of financial resources, the transfer of technology, and capacity building support from developed countries in accordance with Article 4.7 of the Convention.

A 2007 government report on potential mitigation scenarios in South Africa identifies CCS as a large part of the solution for both coal-to-liquids (CTL) and coal-based electricity. The report cautions that CCS development needs to address economic, geological, environmental, and regulatory challenges and uncertainties (LMTS, 2007).

Framework development in South Africa is in the early stages. However, the country has taken a number of steps over the past ten years to advance CCS.

3.13.2 Discussion

South Africa has no statutory framework to control GHG emissions. The Department of Environmental Affairs plans to conduct consultation on a climate change mitigation and adaptation strategy during 2010 with the hope of finalising a policy by year's end. Similarly, South Africa has not yet developed a dedicated CCS framework.

South Africa is a member of the IEA GHG, the CSLF, and GCCSI. In 2009, South Africa launched the National Centre for Carbon Capture and Storage as part of the South African National Energy Research Institute. The Centre's mission includes technology and regulatory development and public outreach (Sonjica, 2009).

South Africa has an unofficial CCS roadmap that takes it from determination of CCS potential, which occurred in 2004, through industrial use in 2025. The first injection testing is targeted for 2015 with a fully integrated demonstration plant operational by 2020 (Gilder, 2010).

A 2004 report to the Department of Energy and Minerals found that 61% of South Africa's CO_2 emissions (249 Mt) were potentially sequestrable (Engelbrecht, 2004). Of those, 30 Mt originates from synthetic fuel plants which have been suggested as good candidates for a demonstration project since the CO_2 is already separated in the conversion process, thereby eliminating the need and associated cost for a capture system (Surridge, nd).

In 2008, South Africa initiated a comprehensive exercise to map onshore and offshore geological storage basins resulting in a Carbon Capture and Storage Atlas expected to be released in 2010. Access to storage sites is a key barrier issue to CCS deployment and South Africa's mapping exercise is an important step.

As South Africa develops its CCS legal and regulatory framework, it will have to consider under what authority storage sites will be made available to CCS developers particularly in cases where there is not clarity of private ownership rights. One model used by South Africa in the past is the Mineral and Petroleum Development Act (2002) which was enacted with the stated purpose to make provision for equitable access to, and sustainable development of, the nation's mineral and petroleum resources. The Act vested ownership of mineral rights in the state and production became subject to a state licensing regime. The Act includes provisions to allow existing owners to obtain a licence under the new regime.

3.13.3 Conclusion

South Africa has work remaining to develop a comprehensive CCS legal and regulatory framework. However, the country has taken steps in the right direction. Like many countries, South Africa has existing laws and regulations at the national, provincial, and municipal level that could be adapted for CCS projects (Gilder, 2010).

South Africa's major challenge will be to balance economic growth, energy security, and societal needs with climate change policy – complicated all the more by South Africa's overwhelming reliance on fossil energy. As reflected in South Africa's Copenhagen Accord submission, deployment of CCS and other low-carbon technologies may depend on financial and technical support from the developed countries.

3.14 UK

3.14.1 Overview

The UK ranks eighth in CO_2 emissions at 1.84% of the world total. Over 75% of the UK's energy consumption is fossil based. Within the past 20 years electricity generation from natural gas has increased from a negligible amount in 1990 to 45% of the UK total in 2009, while coal went from the primary source to a 28% share. The UK has major oil and gas operations on the continental shelf; however, production from both has been declining in recent years (UK DECC, 2010a).

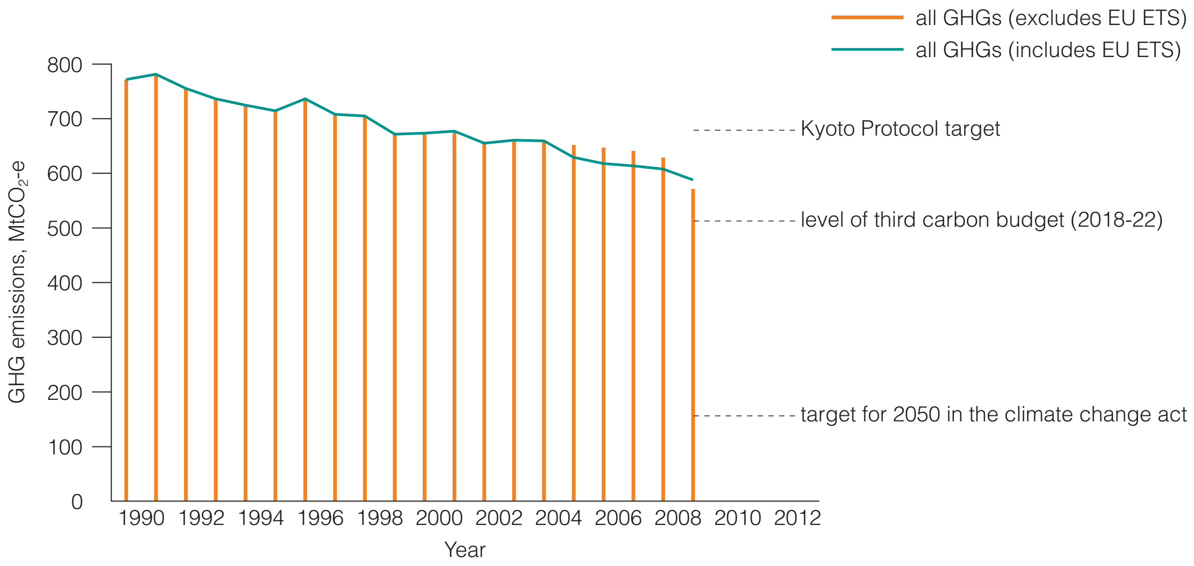

Figure 7 UK GHG emissions progress toward targets (UK DECC, 2010b)

The UK is a leader in climate policy. Going beyond its international commitments, the UK passed a Climate Change Act that established a legal framework designed to achieve an 80% reduction in GHGs by 2050, thereby aligning with the IPCC recommendations. Indications are that the UK is beating its targets under both the Kyoto Protocol and the Climate Change Act, *see* Figure 7.

The UK is also a strong proponent of CCS – well on its way to a comprehensive regulatory framework for offshore CCS activities. Furthermore, the UK has enacted legislation that will provide a stable source of financial support for CCS demonstration projects.

3.14.2 Discussion

Climate Change Framework

The UK has a multifaceted legal and regulatory strategy for GHG reduction across all energy sectors. As an EU Member State, the UK is subject to the EU ETS Directive and the EU Effort Sharing Decision, however, the UK's GHG reduction efforts did not start or stop with these instruments. Several initiatives are outlined below. The UK energy strategy includes reduction of GHGs from the transportation and other sectors not discussed here (UK DECC, 2010d).

The UK introduced the Climate Change Levy (CCL) in 2001 as a tax on the use of certain fuels in the non-domestic sector. Recognising the potential impact on certain industries, the Climate Change Agreement (CCA) Scheme was also introduced in 2001 allowing energy intensive businesses to receive an 80% discount on the levy if they enter into a CCA with the government. The CCA scheme covers 54 sectors with approximately 10,000 facilities, grouped into 5000 target units. Targets are set at the sector level based on negotiations between the Government and sector associations. The associations distribute the target among the target units within their sectors (UK DECC, 2009a).

The Climate Change Act (2008) established a national obligation to reduce GHG emissions by 34% by 2020 and 80% by 2050 against a 1990 baseline. The Act creates a carbon budgeting system which caps emissions over five-year periods. To promote domestic reductions, the Act imposes a limit on the purchase of international credits. The Act also created the Committee on Climate Change as an independent expert body to advise the Government on carbon budgets and on where cost-effective savings can be made (UK DECC, 2010e).

The Carbon Emissions Reduction Target (CERT) and Community Energy Saving Programme (CESP) are similar schemes aimed at increasing efficiency and reducing carbon emission from UK households. Running from 2008 to 2011, CERT requires electricity and gas suppliers with 50,000 or more customers to undertake measures to reduce customer CO_2 emissions. The suppliers determine the best way to meet targets which may include insulation, energy efficient lighting and appliances, micro-generation technologies, and behavioural measures (UK DECC, 2009b). Similar to CERT, CESP runs from 2009 to 2011 and targets low income households in Great Britain. CESP requires all licensed gas and electricity suppliers with at least 50,000 domestic customers, and all licensed electricity generators that have generated on average 10 TWh/y or more in a specified three-year period, to meet a carbon reduction obligation (UK DECC, 2010f).

The CRC Energy Efficiency Scheme, started in 2010, is an enhanced trading-based system aimed at improving energy efficiency and cutting emissions in large public and private sector organisations not otherwise covered by climate change agreements or the EU-ETS. Participants must purchase allowances equal to their annual emissions. During the introductory phase, the government plans to sell allowances at a fixed price of 12 £/tCO_2. After the introductory phase participants may buy or sell allowances on the secondary market. As an additional incentive for energy reduction, money raised from government sale or auction of allowances is recycled back to participants based on a performance oriented scoring formula (CRC, 2010).

CCS Legal and Regulatory Framework

The UK initiated its CCS framework development before the EU CCS Directive was finalised. As such, the UK believes its existing legislative instruments are sufficient for transposition of the CCS Directive. A comprehensive study conducted on behalf of the North Sea Basin Task Force on North Sea CO_2 transport and storage found that 'around 50% of European CO_2 storage potential is located under the North Sea' and that 'the geographical clustering of sources and/or sinks give opportunities to develop efficient transport and storage networks' (Element Energy, 2010).

Much of the UK's attention is focused on offshore storage beneath the North Sea. The Energy Act 2008 set the stage for such storage by asserting the right of the Crown under the UN Convention on the Law of the Sea to exploit areas within the 200 nautical mile exclusive economic zone for gas storage and importation – including storage of CO_2. In 2009, the Government initiated consultation on its proposed offshore licensing regime which is based substantially on the UK's petroleum licensing rules. The Government's response to the consultation was released in August 2010. The proposed regime contemplates a two-tiered regulatory process where non-intrusive exploration may occur under a general non-site specific licence issued by DECC, but once a site has been identified for further detailed exploration the developer will require a carbon storage licence from DECC and a property lease from The Crown Estate (UK DECC, 2009c,d), *see* Table 9.

An operating permit will also be required from the Environment Agency to operate and export power to the grid (UK DECC, 2009d).

The consultation documents incorporate most requirements of the EU CCS Directive. Issues reserved for further consideration include the level of priority afforded to pre-existing hydro-carbon production operators for redevelopment of formations for CO_2 storage; and, arrangements for the termination of the licence and the transfer of responsibility to the State (UK DECC, 2010g).

Relating to capture, the UK has established rules for coal-fired power stations that go beyond the capture ready requirement of the revised EU's Large Combustion Plant Directive. From 9 November 2009, any applicant who applies for (or who has sought but not yet obtained) consent to construct a new coal-fired power station over 50 MWe must include CCS on at least 300 MWe net of its capacity from the outset. The same rule applies to applicants for consent to upgrade existing power stations to allow for the installation of supercritical coal-fired boilers. If a new coal-fired plant is less than 300 MWe capacity, it must include CCS on its entire capacity (UK DECC, 2009d).

Table 9 Pipeline and storage consents UK (UK DECC, 2009d)

Consent	Description	Issuing body	Time required
Storage permit (Energy Act 2008)	Allows storage of CO_2 in manner set out in permit	DECC	~ 2 years, depending on length of time required for exploration
Storage lease (Energy Act 2008)	Grants property rights to storage area	Crown Estates	None
Onshore CO_2 pipelines (1962 Pipeline Act: subsequently 2008 Planning Act for >10 miles)	Transport of CO_2 to container or to low level water line for connection to offshore pipeline to storage area	DECC (over 10 miles) LPA (under 10 miles)	6 months – 2 years
Offshore CO_2 pipelines (Pipeline Works Authorisation (PWA) under 1996 Petroleum Act and consent under 1949 Coast Protection Act)	Offsore transport of CO_2 to storage area	DECC or Scottish Executive	6 months
Hazardous Substances Consent	To handle substances deemed hazardous by HSE	The Hazardous Substances Authority (HSA)	variable

In June 2010, the Committee on Climate Change advised the government that it should consider extending proposed emissions performance standard to new gas plants added after 2020, which would have the effect of requiring new gas plants to be fitted with CCS. The committee noted that there is very little international effort currently under way to develop CCS for gas plants (UK Committee on Climate Change, 2010).

The Energy Act 2010, established a new incentive programme for CCS that is expected to generate £9.5 billion to support up to four commercial-scale demonstration projects. A levy is assessed against electricity suppliers and then distributed to CCS projects via a competitive process. The collection of the levy and the disbursal of funds will be administrated by Ofgem (Office for Gas and Electricity Markets), with project selection carried out by government (House of Commons, 2009; UK DECC, 2009e).

Other CCS related activities

Although not specifically targeted to CCS, there have been planning developments in the UK that may assist CCS projects. Recognising the potential for project delay or failure due to multi-layered permitting schemes, the Planning Act 2008 established a new Infrastructure and Planning Commission (IPC) to facilitate the approval of large-scale projects such as power plants and pipelines. The Act consolidated review and approval authority in independent commissioners who would examine projects in accordance with government policy as set out in National Policy Statements. The objective was to simplify the permitting process, maintain public involvement, promote better planning for sustainable development, and reduce the time for project approval to less than a year. Having existed for less than two years, a decision was made in June 2010, to abolish the IPC, and replace it with a Major Infrastructure Planning Unit in the Planning Inspectorate. Ministers will make decisions on applications within the same statutory timeframe established for the IPC (UK Communities and Local Government, 2010). Many countries have multi-layered permitting and approval processes similar to the UK. It will be worthwhile to follow the UK's progress to see if the country has success with their new system.

3.14.3 Conclusion

The UK has in place an aggressive national strategy to control GHG emissions. The UK is also well along in the development of a comprehensive legal and regulatory framework for offshore CO_2 storage activities and has established a secure funding mechanism to bridge the financial gap that is vital to demonstration project success. Details of the framework remain to be finalised and the UK must decide to what extent onshore storage will be an option.

3.15 USA

3.15.1 Overview

The USA ranks second in CO_2 emissions at 19.91% of the world total. Petroleum is the largest source of energy-related CO_2, followed by coal and then natural gas. Electric power generation is the largest sector contributor to CO_2 emissions (USEIA, 2009). The majority of electric power generation is fossil based with coal and natural gas providing 46% and 21% of the supply respectively (USEIA, 2010f). The USA is actively promoting energy efficiency, nuclear power and renewable energy; however, fossil fuels are expected to remain a large part of the mix for many years. Accordingly, the USA views coal power as the primary near term target for CCS application. Industrial applications are also being considered (US, 2010).

US climate change policy is unsettled. Legislation has been introduced but not passed by Congress. Nevertheless, the US Environmental Protection Agency (US EPA) is regulating GHGs under its existing Clean Air Act authority based on the US EPA Administrator's December 2009 determination that atmospheric GHG concentrations may reasonably be anticipated to endanger the public health and to endanger the public welfare (the 'Endangerment Finding'). The US EPA's Endangerment Finding is an outgrowth of the US Supreme Court's decision in Massachusetts v. EPA, 549 U.S. 497 (2007), which required the EPA to reassess its discretion to regulate GHGs under the Clean Air Act. (US EPA, 2009). Multiple lawsuits have been filed by states, industry groups and others challenging the US EPA's determination. The Administrative Procedure Act permits parties impacted by federal agency regulatory action to challenge the action in court. Agencies are provided considerable discretion and the court may only set aside an action if it is arbitrary and capricious, an abuse of discretion, or otherwise not in accordance with law.

In 2008, the US EPA proposed nationwide regulations for CO_2 storage facilities. The US EPA lacks statutory authority to address barrier issues such as pore-space ownership, storage site access, pipeline access, and long term liability. Several states enacted their own CCS regimes that deal with some of these issues. The state frameworks were largely based on a model developed by the IOGCC with support from the US DOE. The state frameworks must be harmonised with the US EPA's final storage regulations. In states without CCS legislation, many barrier issues remain.

The USA is a leader in CCS technology advancement. Research, analysis, geological characterisation and pilot-scale testing done under the auspices of the US DOE's Fossil Energy Program is highly regarded throughout the world. DOE's Carbon Sequestration Reference Shelf, located at http://www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html, contains a library of current CCS knowledge that is freely available to the public. The USA is supporting ten commercial-scale demonstration projects that are expected to begin operations by 2016.

3.15.2 Discussion

Climate change framework

Attempts at climate legislation in the USA have been unsuccessful. Comprehensive bills introduced in the House and the Senate in 2009 would have established a cap and trade regime for covered entities, economy-wide emission reduction targets, performance standards for new coal plants, and CCS bonus allowances (GovTrack.us, 2009a,b). Neither bill received sufficient support to pass both houses. A compromise bill was proposed in the Senate in 2010 but withdrawn from the legislative agenda in August. Other legislation was proposed to establish federal renewable or clean energy portfolio standards but not a cap and trade regime (GovTrack.us, 2009b, 2010).

Some states have taken their own climate change measures individually or in combination with other states and Canadian provinces. Worthy of note is California – the twelfth largest emitter of carbon in the world. The California Global Warming Solutions Act of 2006 set a goal to reduce emissions to 1990 levels by 2020 and reduce emissions by 80% by 2050. GHG reporting requirements began in 2009 for the largest emission sources and mandatory caps begin in 2012 for covered entities. Reductions will be achieved through regulatory actions, incentives, voluntary measures, and market mechanisms such as cap and trade (Schwarzenegger, 2006; California Air Resources Board, 2010). A measure (Proposition 23) included in the November 2, 2010 California ballot proposed to suspend the Global Warming Solutions Act until California's unemployment rate drops to 5.5% or less for four consecutive quarters. The measure failed to pass (California Secretary of State, 2010).

In the absence of new climate change legislation, the US EPA is regulating stationary GHG sources under the existing Clean Air Act. The Agency elected to phase the regulation starting with larger emission sources (US EPA, 2010a). Beginning in July 2011, new construction projects that emit GHGs in excess of 100,000 t/y CO_2-e, and facilities that are modified such that GHG emissions increase by at least 75,000 t/y, will be subject to the ‘Prevention of Significant Deterioration (PSD)’ permitting programme and ‘Title V’ operating permit programme. From January 2011 through June 2011, only facilities that trigger permitting requirements for other controlled pollutants and increase GHG levels by 75,000 t/y will be subject to PSD BACT requirements for GHGs. Similarly, only sources subject to Title V permitting for other pollutants would be subject to Title V permitting for GHGs (US EPA, 2010b). PSD permits require the use of Best Available Control Technology (BACT) similar to BAT under the EU’s Integrated Pollution Control Directive. BACT is determined by an analysis of the maximum degree of control that can be achieved taking into account energy, environmental, and economic impacts (US EPA, 2010c). Recognising that BACT application to CCS projects is not clear-cut, the US EPA empanelled a group of experts to make recommendations. Permitting guidance was issued by the US EPA on 10 November, 2010 (US EPA, 2010d).

In addition to the pending litigation challenging the Endangerment Finding, questions have been raised by members of Congress, industry, and the US EPA itself (under the prior Administration), as to whether GHG regulation under the Clean Air Act is the best approach (US EPA, 2008a). Several attempts have been made in Congress to block or limit the US EPA’s actions. Accordingly, the future of GHG regulation in the USA is uncertain.

Underground storage framework

The US EPA’s Underground Injection Control (UIC) Program under the Safe Water Drinking Act defines regulatory requirements for five classes of injection wells:

- Industrial & Municipal Waste Disposal Wells (Class I);
- Oil and Gas Related Wells (Class II);
- Mining Wells (Class III);
- Shallow Hazardous and Radioactive Injection Wells (Class IV);
- Shallow Non-Hazardous Injection Wells (Class V).

CO_2 EOR projects historically have been granted permits under Class II. Pilot-scale CO_2 storage projects have been permitted as experimental wells under Class V. In 2008, the US EPA determined that the existing regulations were not developed with CCS in mind and issued for comment proposed regulations for a new UIC well class (Class VI) expressly for geological storage (US EPA, 2008b). The draft regulations cover siting, public participation, construction, operation, post-injection monitoring and closure of a storage facility. The Agency expects to continue permitting CO_2 EOR wells under Class II unless the wells are specifically intended for the purpose of geological storage. Final regulations are planned to be released by the end of 2010. The Agency is also planning to issue regulations in 2011 concerning the applicability of hazardous waste law to CO_2 storage (US, 2010).

Under the current US approach, the US EPA lacks statutory authority to address many CCS barrier issues such as pore space ownership, site access, pipeline access, long-term liability, and long-term stewardship. Several states have enacted their own laws to address barrier issues. Examples include North Dakota, Montana, and Louisiana where the law provides for transfer of liability to the State after a post-injection monitoring period. Louisiana law also sets limits on the amount of compensatory damages for non-economic loss that can be recovered from storage facility and pipeline owners and operators, and CO_2 generators. Illinois law authorises the state to indemnify the FutureGen Industrial Alliance for liability accruing from operation of the storage facility by the Alliance.

Access to storage sites is a key barrier issue in the USA since onshore subsurface rights are generally owned by private parties and many property documents do not define whether pore space belongs to the surface estate or the mineral estate. Thus it is difficult for a CCS developer to acquire CO_2 storage rights because the developer does not know who owns the pore space. Wyoming, North Dakota, and Montana resolved the issue by presuming title to pore space belongs to the surface owner. North Dakota law also creates a mechanism to ‘amalgamate’ property interests if the storage facility operator cannot obtain the consent of all of the pore space owners. Louisiana law creates a process whereby private entities may exercise eminent domain authority to acquire rights necessary to develop storage facilities and CO_2 pipelines. Texas law authorises the State to develop state-owned offshore storage facilities which the State may then make available on a fee basis to private parties.

Legislation has also been introduced at the federal level to address various barrier issues. The Carbon Sequestration and Deployment Act of 2010 would provide indemnification from liability for ten first-mover projects and establish a permanent trust to cover long-term liability for later CCS projects. An earlier Senate Bill, the American Clean Energy Leadership Act of 2009 (S.1462) likewise would authorise indemnity for up to ten demonstration projects. The Carbon Stewardship Trust Fund Act of 2009 would establish a trust for long-term liability. Senate Bill 1856 would clarify the federal government’s interest in pore-space beneath federal land.

CCS financial support

At the federal level, CCS R&D is funded through the US DOE’s annual Fossil Energy appropriations. CCS demonstration projects may be supported under any of four financial mechanisms: (1) direct funding under financial assistance agreements, (2) loan guarantees, (3) investment tax credits, and (4) sequestration tax credits. The first three categories are awarded through separate competitions; however, a single project may be eligible to compete under each programme. The tax credits have been interpreted to be mutually exclusive. The ability to access multiple financial support mechanisms is a benefit for US CCS projects since a single mechanism is often not sufficient to bridge the CCS financial gap. However, the independence of the mechanisms presents a problem for developers because the financial viability of a project may depend upon their success in winning two or three separate competitions, each with its own criteria. This concern was recognised by the Interagency Task Force on CCS empanelled by the President. The recently released Task Force Report calls for increased co-ordination of incentives among the federal agencies:

> Increased Federal coordination would enhance the government’s ability to assist these projects by providing more effective incentives and/or addressing barriers. DOE, in coordination with EPA, Treasury, and USDA, should track the use and efficacy of Federal

> financial support for CCS projects. Increased coordination will enhance the government's ability to tailor Federal funding and assistance to each project's market context, improve the clarity of eligibility criteria for projects to receive Federal support, allocate resources efficiently, and enable the Administration to more effectively consult with Congress and the States on the efficacy of existing incentives (US, 2010).

In 2009, the US DOE received $3.4 billion for CCS under the American Recovery and Reinvestment Act (Recovery Act), which when added to annual appropriations, permitted the Agency to provide direct financial support for a total of ten large-scale power and industrial CCS demonstration projects (US, 2010), *see* Table 10.

The US DOE has also selected six projects for Phase II development of technologies to convert captured CO_2 from industrial sources into useful products such as fuels, plastics, cement, and fertilisers (US DOE, 2010).

The CCS funding provided under the Recovery Act was a one-time event. Bills have been introduced in Congress to provide a future source of financial support for CCS projects through an assessment on fossil based electricity similar to the levy under the UK's Energy Act 2010.

Table 10 Planned US DOE CCS demonstration projects (US, 2010)

Performer	Location	Capture technology	Capture rate, t/y	Target formation	Start date
Pre-combustion capture					
Summit Texas Clean Energy	Odessa, TX	Selexol™	2,700,000	EOR	2014
Southern Company	Kemper County, MS	Selexol™	1,800,000	EOR	2014
Hydrogen Energy California	Kern County, CA	Rectisol®	1,800,000	EOR/Saline	2016
Post-combustion capture					
Basin Electric	Beulah, ND	Amine	450,000–1,360,000	EOR/Saline	2014
NRG Enegy	Thompson, TX	Amine	400,000	EOR	2015
American Electric Power	New Haven, WV	Chilled ammonia	1,500,000	Saline	2015
Oxy-combustion					
Future Gen	Meredosia and Mattoon, IL	Oxy-combstion	1,000,000	Saline	2015
Industrial					
Leucadia Energy Lake Charles	Lake Charles, LA	Rectisol®	4,000,000	EOR	2014
Air Products	Port Arthur, TX	Amine	900,000	EOR	2013
Archer Daniels Midland	Decatur, IL	Amine	900,000	Saline	2014

Other CCS activities

The US DOE has mapped geological storage potential and emission sources in the USA. The results are found in the Carbon Sequestration Atlas of the USA and Canada (NETL, 2008a). The US DOE has also completed a two-phase study to model potential CO_2 pipeline networks (Grant, 2009). The IOGCC and the Southern States Energy Board, with financial support from the US DOE, established a CO_2 Pipeline Transportation Task Force in 2009 to conduct a comprehensive review of the existing legal and regulatory regime governing CO_2 transport in the USA and assess potential business and regulatory models for a national pipeline network to accommodate wide-scale CCS deployment.

A bill introduced in Congress would appoint the US DOE as the lead agency for the purpose of co-ordinating federal authorisations and environmental reviews for CCS projects with the objective to complete all permits and reviews within one year after the submission of a complete application (GovTrack, 2009c). Regulatory congestion is a significant problem for major projects in the USA. Like the UK's recently announced Major Infrastructure Planning Unit, this initiative would be an attempt to streamline the process.

3.15.3 Conclusion

Technologically and geologically, the USA is well positioned for CCS deployment. The USA is also making a significant contribution to the world goal of 20 near-term demonstration projects. There are major gaps in the US legal and regulatory framework that can only be closed through legislation. Until that occurs, barrier issues and regulatory uncertainty will be an impediment to deployment. Some barrier issues such as surface and subsurface rights, pipeline access, and monitoring requirements may not be impediments for early projects intending to use CO_2 for EOR where rights are established and obligations understood.

4 Next steps

CCS has great potential, but questions remain to be answered. Much has been accomplished in the past decade to move CCS toward commercial use. However, much more work needs to be done over the next ten years to ready CCS for wide-scale deployment. This includes a global agreement on climate change, support for CCS in developing countries, finalisation of national legal and regulatory frameworks that address key barrier issues to CCS deployment, and additional research, development and demonstration to prove to policymakers and the public that CCS is a technically and economically viable climate change solution.

During the coming decade, seven steps will help pave the way for CCS deployment.

Maintain the momentum

It would be remiss not to recognise the efforts of all the multinational organisations, countries, state and provincial governments, non-governmental organisations, companies, and research institutions that have put so much effort into CCS. These efforts must continue. CCS capacity building in developing countries is especially important since these countries will be the major source of new GHG emissions over the next 30 years.

Pay attention to the demonstration projects

Demonstration projects are fragile. Financial viability is often the problem more so than technical risk. National support regimes for CCS demonstrations vary, but there is a common theme that governments should only contribute a portion of the incremental cost of CCS. There is a risk that such support may be insufficient to bridge the CCS economic gap and therefore attract commercial investment for the balance of the project. Many projects are also very early in development and total project costs have not yet been accurately defined. If government support is capped from the time of project selection, cost overruns may also cause project failure. Some large CCS projects have already faltered for financial reasons. Although not predictive of CCS outcomes, the US Clean Coal Technology (CCT) Program of the 1980s and 1990s may be a useful analogue. The US DOE selected a total of 57 demonstration projects under the programme. Of those 57 projects, 24 did not finish. For a significant number of the projects, the US DOE cost share at the time of selection was at or near 50% of the total project cost – rather than the incremental cost of the demonstration technology. The intent is not to criticise the US DOE – the CCT programme was very successful. The point is that demonstration project failure rate may be high even with seemingly large amounts of government support. In the absence of a carbon price that nears the actual cost of CCS implementation, additional government incentives may be required to help bridge the CCS economic gap.

Adapt existing regulatory regimes

It is important to heed IEA's advice and adapt existing permitting regimes for demonstration projects rather than make the projects wait for a final regulatory framework. Framework uncertainty equates to investor risk which may cause project delay or failure.

Streamline permitting and approval

Initiatives to streamline permitting and review processes, as is occurring in the UK and proposed in the USA, could significantly contribute to CCS meeting its deployment schedule. Delays in permitting and approvals increase project cost and investor risk and may cause a project to fail. Streamlined processes must retain high standards for quality, safety, and public involvement.

Support CCS research and development

Considerable attention is currently focused on demonstration projects. These projects are necessary to establish the safety and effectiveness of CCS and convince policymakers and the public that CCS is a viable solution. Experience and best practices gained from the projects will help optimise CCS design and lower the risk of operational upsets during deployment – both of which should reduce CCS cost. The demonstrations will also provide a knowledge base of information that can be used by regulators to finalise CCS frameworks.

Nevertheless, the urge to declare success based on demonstration projects should be avoided. Cost-reduction through research innovation is the best hope for wide-scale deployment, particularly for more expensive retrofit applications and particularly in the less affluent countries. Research budgets should be enhanced over the next ten years with the aim to accelerate development of cost-reduction technologies before CCS is needed for deployment.

Plan the pipelines

The current approach to demonstration projects is largely one plant, one pipeline unless the CO_2 will be transported in already-established EOR pipelines. This will suffice in the short term, but for wide-scale deployment, large-scale pipeline networks must be available, particularly in countries such as the USA, China, India, and EU countries where CO_2 will be captured from many point sources and transported over significant distances for storage. Timing, size, ownership, access rights, property rights, and regulation of the pipeline networks are complicated issues that must be resolved in parallel with CCS deployment plans. The problem is illustrated in a recent analysis of the US CO_2 pipeline system (Nordhaus and Pitlick, 2009):

> The ability to transport massive volumes of carbon dioxide (CO_2) via pipeline will be crucial to using large-scale carbon capture and sequestration (CCS) projects as a means of reducing greenhouse gas (GHG) emissions in the USA. The small existing CO_2 pipeline infrastructure may eventually have to be expanded to be comparable in size to the country‘s natural gas pipeline system. To build out a national CO_2 pipeline system, the USA will need to create a workable regulatory framework. Today, CO_2 pipeline developers have no access to federal siting or federal eminent domain authority for construction of such pipelines; rather, they must deal with a patchwork of individual state laws and regulations. The shape of any applicable economic regulation, including rules on rate and access regulation, will also need to be resolved and addressed before project sponsors will build pipelines to support CCS.

Other countries with less CO_2 pipeline experience than the USA, will face similar challenges. Hence, it is important in the near term that attention be devoted to pipeline planning and regulatory development so that infrastructure can be in place when it is needed for deployment.

Develop knowledge sharing regimes that balance the need for dissemination and technology transfer with the innovation potential from exploitable technology

Knowledge sharing is clearly important to CCS success and considerable sharing is already taking place throughout the world. Collaboration can reduce duplication of efforts. Dissemination of lessons learned and best practices can avoid errors on other projects. Transfer of technology to developing countries can accelerate CCS demonstration and deployment. And publication of results can help CCS gain acceptance among policymakers and the public. However, a knowledge sharing regime must balance the need to disseminate with the reality that most CCS innovation will come from the private sector which expects to benefit from its technology developments. Overly burdensome knowledge sharing requirements attached to government support may discourage private sector investment and thereby be counterproductive to CCS advancement. Regimes should be designed to allow technology developers to protect background intellectual property and exploit foreground innovations but also require broad dissemination of non-exploitable research results.

5 References

CCSDC (2010) *Accelerating Carbon Capture and Storage Implementation in Alberta, Final Report, March 2009*, Alberta Carbon Capture and Storage Development Council, Edmonton, Alberta. Available at: http://www.energy.alberta.ca/Org/pdfs/CCS_Implementation.pdf

Allianz (2010) *Big in Japan: Cap-and-Trade*, Allianz Knowledge. Available at: http://knowledge.allianz.com/climate/business/?586/japan-cap-trade-carbon-market-interview-miyazawa

APEC (2007) *CO_2 Storage Prospectivity of Selected Sedimentary Basins in the Region of China and South East Asia*, Asian Pacific Economic Cooperation. Summary available at: http://www.co2crc.com.au/dls/pubs/regional/apec/Summaries_APEC_05_0007.pdf

Arrhenius S (1908) *Worlds in the Making, The Evolution of the Universe*, Translated by H. Borns, Harper and Brothers, New York and London

AUS MCMPR (2005) *Carbon dioxide capture and geological storage: Australian regulatory guiding principles* Ministerial Council on Mineral and Petroleum Resources, Australia

Australia Department of Resources Energy and Tourism (2010a) http://www.ret.gov.au/resources/carbon_dioxide_capture_and_geological_storage/Pages/ccs_legislation.aspx

Australia Department of Resources, Energy and Tourism (2010b) http://www.ret.gov.au/energy/Documents/Clean%20Energy%20Program/CCS%20Flagships%20Factsheet%20August%202010.pdf

Bankes N (2010) *Mutatis Mutandis – The ERCB Speaks on the Subject of Carbon Capture and Storage*, University of Calgary, Faculty of Law Blog on Developments in Alberta Law, June 29, 2010. Available at: http://ablawg.ca/2010/07/27/mutatis-mutandis-the-ercb-speaks-in-latin-on-the-subject-of-carbon-capture-and-storage/

Bellona (2009) *Bellona CCS Position*, Bellona Foundation, Oslo, Norway. Available at: http://www.bellona.org/ccs/Artikler/bellona_ccs_position

Beveridge & Diamond PC (2010) Brazil Highlights - Latin American Region Environmental Quarterly, http://www.bdlaw.com/news-859.html (Apr 2010)

Bloomberg (2010) Japan's Cabinet Endorses Cap-and-Trade Climate Bill (Update2), 12 March 2010, http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aJfS6SkG1KDc

BMU (2010) *Brüderle and Röttgen: CCS Act an Important Step for a Future Technology*, Press Release No 109/10, July 14, 2010, Federal Economics Minister, Federal Environment Minister, Germany

Bruvoll A, Larsen B M (2002) *Greenhouse gas emissions – do carbon taxes work?* Statistics Norway

Business Green (2010) Japan Pledges to Pass Delayed Climate Bill this Year, 17June 2010, http://www.businessgreen.com/bg/news/1807530/japan-pledges-pass-delayed-climate

California Air Resources Board (2010) http://www.arb.ca.gov/cc/ab32/ab32.htm

California Secretary of State (2010) http://www.sos.ca.gov/elections/ballot-measures/qualified-ballot-measures.htm

Canada (2008) *Turning the* Corner, *Regulatory Framework for Greenhouse Gas Emissions*, Canada

Carter L D (2010), *Prospecting for Power: The cost of meeting increases in electricity demand*, United States Carbon Sequestration Council. Available at: http://www.uscsc.org/Files/Admin/Educational_Papers/7.%20CO2%20Reduction%20Costs%203May_10.pdf

Carbon Positive (2010) China to proceed slowly on cap and trade, http://www.carbonpositive.net/viewarticle.aspx?articleID=2080 (Aug 2010)

China (2007) *National Climate Change Program*, National Development Reform Commission, China, English translation available at: http://www.china.org.cn/english/environment/213624.htm#14

China Department of Climate Change (2009) National Development and Reform Commission, 28 August 2009, http://cdm.ccchina.gov.cn/english/NewsInfo.asp?NewsId=3826

Cho C (2009) *Green Growth and Green Industry Development in Korea, Scope and Policy Directions from Korea Perspective*, Korea Instituted for Industrial Economics and Trade (KIET) Industrial Economic Review, May/June 2009, Volume 14, No. 3. Available at:

http://220.72.21.21/pub/docu/kr/AA/04/AA042009OAA/AA04-2009-OAA-001.PDF
Contek Solutions (nd) *Summary of Carbon Dioxide Enhanced Oil Recovery (CO2EOR) Injection Well Technology, Supporting Information Provided by James P. Meyer PhD*, Prepared for the American Petroleum Institute. Available at: http://www.gwpc.org/e-library/documents/co2/API%20CO2%20Report.pdf
CPRS (2008) *Carbon Pollution Reduction Scheme, Australia's Low Pollution Future White Paper*, Commonwealth of Australia. Available at: http://www.climatechange.gov.au/publications/cprs/white-paper/cprs-whitepaper.aspx
CRC (2010) *The CRC Energy Efficiency Scheme User Guide 6 April 2010 Update*. UK Environment Agency, Northern Ireland Environment Agency, Scottish Environment Protection Agency. Available at: http://www.decc.gov.uk/assets/decc/what%20we%20do/a%20low%20carbon%20uk/crc/1_20100406154137_e_@@_21934crcpdfawv9.pdf
CSLF (2009) *Carbon Sequestration Leadership Forum Technology Roadmap*. Carbon Sequestration Leadership Forum. Available at:
http://www.cslforum.org/publications/documents/CSLF_Techology_Roadmap.pdf
Dahowski R, Li X, Davidson C, Wei N, Dooley J (2009) *Regional Opportunities for Carbon Capture and Storage in the Peoples Republic of China*, Prepared for the US Department of Energy under Contract DE-AC05-76RL01830, Pacific Northwest National Laboratory. Available at:
http://energyenvironment.pnl.gov/pdf/roccs_china_pnnl_19091.pdf
Daily Yomiuri (2010) Govt to stop buying intl CO_2 credits / Eyes domestic trades to offset shortfall. 9 July 2010, http://www.yomiuri.co.jp/dy/business/T100708004779.htm
Davidson A, Logarajah S, Plett S, Fitzgerald E, Demneri N, Rakhmangulov M, Guebert J (2010) *2009 L'Aquila G8 Summit Interim Compliance Report*, Munk School of Global Affairs at Trinity College in the University of Toronto, Canada. Available at:
http://www.g8.utoronto.ca/evaluations/2009compliance-interim/
Dooley J (2006) *A Brief Analysis of Geologic CO_2 Storage Potential in South Korea*, Report PNNL-15895, Prepared for the US Department of Energy under Contract DE-AC05-76RL01830, Pacific Northwest National Laboratory. Available at:
http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15895.pdf
Engelbrecht A, Goldin A, Hietkamp S, Scholes B (2004) *The Potential for Sequestration of Carbon Dioxide in South Africa*, Contract Report 86DD / HT339 submitted to the Department of Minerals and Energy, South Africa, prepared by CSIR, Pretoria, South Africa
EC (2010) *Commission Decision 3.11.2010 laying down criteria and measures for the financing of commercial demonstration projects that aim at the environmentally safe capture and geological storage of CO_2 as well as demonstration projects of innovative renewable energy technologies under the scheme for greenhouse gas emission allowance trading within the Community established by Directive 2003/87/EC of the European Parliament and of the Council*, Decision C(2010) 7499 final, Commission of the European Union, Brussels
EC (2008) *Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions, 20 20 by 2020 Europe's climate change opportunity*, COM(2008) 30 final, 23.1.2008, Commission of the European Union, Brussels
EFTA (2007) Fact Sheet of the European Free Trade Association,
http://www.efta.int/publications/fact-sheets/eea.aspx (Nov 2007
Element Energy (2010) *One North Sea, A Study Into North Sea Cross-border CO2 Transport and Storage*, Final Main Report For: The Norwegian Ministry of Petroleum and Energy and The UK Foreign and Commonwealth Office, Element Energy Ltd, United Kingdom. Available at:
http://www.npd.no/Global/Engelsk/3%20-%20Publications/Reports/OneNorthSea/OneNortSea_Final.pdf
ERCB (2010) *ERCB Processes Related to Carbon Capture and Storage (CCS) Projects*, Energy Resources Conservation Board, Alberta, Canada. Available at:
http://www.ercb.ca/docs/documents/bulletins/bulletin-2010-22.pdf
Eskom (2010) New Build Programme, http://www.eskom.co.za/live/content.php?Item_ID=5981
Europa (2007) Poland Energy Mix FactSheet,
http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_pl_en.pdf

Europa (2009) Europa Press Release, 9 December 2009
http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/09/543
Europa (2010) European Commission Environment Website, The EU climate and energy package,
http://ec.europa.eu/clima/policies/brief/eu/package_en.htm
Japan (2008) *Action Plan for Achieving a Low-Carbon Society*, Government of Japan. Available at:
http://www.kantei.go.jp/foreign/policy/ondanka/final080729.pdf
Forbes S, Verma P, Curry T, Friedmann J, Wade S (2008) *CCS Guidelines Guidelines for Carbon Dioxide Capture, Transport, and Storage*, World Resources Institute, Washington, DC
Freese B, Clemmer S, Nogee A (2008) *Coal Power in a Warming World, A Sensible Transition to Cleaner Energy Options*, Union of Concerned Scientists, Cambridge, Mass, USA
GCCSI Brazil (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage Report 3: Country Studies – Brazil*, Global CCS Institute, Canberra, Australia
GCCSI China (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage Report 3: Country Studies – China*, Global CCS Institute, Canberra, Australia
GCCSI India (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage Report 3: Country Studies- India*, Global CCS Institute, Canberra, Australia
GCCSI Japan (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage Report 3: Country Studies - Japan*, Global CCS Institute, Canberra Australia
GCCSI Korea (2009) *Strategic Analysis of the Global Status of Carbon Capture and Storage Report 3: Country Studies - South Korea*, Global CCS Institute, Canberra, Australia.
German Energy Blog (2010) OverviewGerman Carbon Capture and Storage (CCS) Law, 5 July 2010, http://www.germanenergyblog.de/?page_id=3061
Gilder A (2010) *Carbon Capture and Storage, the South African Status Quo*, Presentation, International Energy Agency CCS Regulators Network Meeting 21 January 2010
Gillard (2010) Prime Minister Press Release, September 27, 2010, http://www.pm.gov.au/press-office/prime-minister-establishes-climate-change-committee
Global Asia (2010) Shifting Paradigms:The Road to Global Green Growth. President Lee Myung-bak, Republic of Korea, http://www.globalasia.org/V4N4_Winter_2010/Lee_Myung_Bak.html
Government of Alberta (2010) News Release, Alberta industries comply with pivotal climate change legislation, http://alberta.ca/home/NewsFrame.cfm?ReleaseID=/acn/200804/23421A13065B8-02F7-B8BB-28C7FACB086E54EE.html
Government of British Columbia (2010) Backgrounder B.C.'s Revenue-neutral Carbon Tax,
http://www.bcbudget.gov.bc.ca/2008/backgrounders/backgrounder_carbon_tax.htm
Government of Canada (2010a) Canada's Action on Climate Change Fact Sheet,
http://www.climatechange.gc.ca/default.asp?lang=En&n=D43918F1-1
Government of Canada (2010b)
http://www.climatechange.gc.ca/default.asp?lang=En&n=3DA45D49-1
GovTrack (2009a) American Clean Energy and Security Act (H.R. 2454),
http://www.govtrack.us/congress/bill.xpd?bill=h111-2454
GovTrack (2009b) Clean Energy Jobs and American Power Act (S.1733)
http://www.govtrack.us/congress/bill.xpd?bill=s111-1733
GovTrack (2009c) The Carbon Capture and Sequestration Deployment Act of 2010,
http://www.govtrack.us/congress/bill.xpd?bill=h111-1689
GovTrack (2010) Practical Energy and Climate Plan Act of 2010.
http://www.govtrack.us/congress/bill.xpd?bill=s111-3464
Grant T (2009) NETL CO2Pipeline Study –Phase II. Presentation March 3-4 SECARB Meeting, US Department of Energy, National Energy Technology Laboratory. Available at:
http://www.secarbon.org/value/nonpublic/Grant.pdf
Grøndalen T, Bjørnebye H (2010) *European Energy Review 2010 Norway*, Herbert Smith LLP
Herzog H E, Drake J, Tester, Rosenthal R (1993) *A Research Needs Assessment for the Capture, Utilization, and Disposal of Carbon Dioxide from Fossil Fuel-Fired Power Plants*, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, DOE/ER-30194, US Department of Energy, Washington, DC

Herzog H, Drake E, Adams E (1997) *CO_2 Capture, Reuse, and Storage Technologies For Mitigating Global Climate Change A White Paper,* Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, Final Report, DOE Order No. DE-AF22-96PC01257
House of Commons (2009) Research Paper 09/88, 3 December 2009, Energy Bill, Bill 7 of 2009-10. House of Commons Library, United Kingdom. Available at: http://www.parliament.uk/documents/commons/lib/research/rp2009/rp09-088.pdf
IBES (nd) *Assessment of the Feasibility of CO_2 Storage in the Russian Permafrost*, INTAS 06-100025-9220, International Bureau for Environmental Studies, Brussels, Belgium. Available at: http://www.ibes.be/permafrost/index.htm
IEA (2010a) Addressing Climate Change, Policies and Measures, Norway, http://www.iea.org/textbase/pm/?mode=cc&id=3548&action=detail
IEA (2010b) Addressing Climate Change, Policies and Measures, Norway Domestic Emissions Trading Scheme 2005-2007, http://www.iea.org/textbase/pm/?mode=cc&action=detail&id=2143
IEA Brazil (2009) *IEA CCS Roadmap Brazil CCS Roundtable Summary*, OECS/IEA, Paris, France. Available at: http://www.iea.org/subjectqueries/ccs/Brazil_Summary.pdf
IEA GHG (2008) *A Regional Assessment of the Potential for CO_2 Storage in the Indian Subcontinent*. Report 2008/2, May 2008, IEA GHG, Cheltenham, United Kingdom
IEA (2008) *Energy Technology Perspectives 2008*, OECD/IEA, Paris, France
IEA (2009) *Technology Roadmap: Carbon Capture and Storage*, OECD/IEA, Paris, France
IEA (2010) *Carbon Capture and Storage, Progress and Next Steps: IEA/CSLF Report to the Muskoka 2010 G8 Summit*, OECD/IEA, Paris
IEA Norway (2005) *Energy Policies of IEA Countries, Norway 2005*, OECD/IEA Paris, France
IEA Stats (2009) *IEA Statistics, CO2 Emissions From Fuel Combustion, Highlights 2009 Edition*, OECD/IEA, Paris, France. Available at: http://www.iea.org/co2highlights/co2highlights.pdf
IEA WEO (2008) *IEA World Energy Outlook 2008*, OECD/IEA Paris, France
India (2008) *National Action Plan on Climate Change June 2008*, Prime Minister's Council on Climate Change, India
Indonesia (2009) *Understanding Carbon Capture and Storage Potential in Indonesia*, A *Report by the Indonesia CCS Study Working Group* Indonesia and the United Kingdom
In Salah (2010) *About the In Salah Project*, British Petroleum, Statoil, Sonatrach. Available at: http://www.insalahco2.com/index.php?option=com_content&view=article&id=44&Itemid=122&lang =en
IMO (2010) International Maritime Organization http://www.imo.org/Conventions/contents.asp?topic_id=258&doc_id=681#2006
IPCC (2005) *IPCC Special Report on Carbon Dioxide Capture and Storage*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B.,O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp
IPCC (2007) *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*,[Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp
IPCC (2010a) http://www.ipcc.ch/organization/organization.htm
Eskom (2010) New Build Programme, http://www.eskom.co.za/live/content.php?Item_ID=5981
Japan (2008) *Action Plan for Achieving a Low-Carbon Society*, Government of Japan. Available at: http://www.kantei.go.jp/foreign/policy/ondanka/final080729.pdf
JBIC (2009) http://www.jbic.go.jp/en/about/news/2009/1106-01/
JCCS (2008) *Japanese CCS Projects*, Presentation by Masanori Abe General Manager Technology and Planning Dept. Japan CCS Co Ltd. Available at: http://www.cslforum.org/publications/documents/Washington2010/AbeJapaneseCCSProjects2ndFinancingRoundtableWashington0410.pdf
JCCS (2010) http://www.japanccs.com/en_japanccs/business/business.html
Jee M (2008) *The First Basic Plan of National Energy (2008~2030) of Korea's MB Government*, Displaybank. Available at: http://www.displaybank.com/eng/info/show.php?c_id=3539
Jeffery M (2010) *Carbon Capture and Storage: Wishful Thinking or a Meaningful Part of the Climate Change Solution*, Pace Environmental Law Review Vol 27, Issue 2, University of Western Sydney School of Law, Sydney, Australia

KAIST OSE (2010) http://ocean.kaist.ac.kr/index.php/Research_Area
Kędzierzyn Brochure (2010) The World's First Zero-Emission Power & Chemical Complex, http://www.zak.com.pl/upload/pliki/418ae172338bad4e4f45c4ac690de415.pdf
Ketzer J, Villwock J, Caporale G, da Rocha L, Rockett G, Braum H, Giraffa L (2007) *Presentation: Opportunities for CO2 Capture and Geological Storage in Brazil: The CARBMAP Project*, Pontifical Catholic University of Rio Grande do Sul, CO_2 Storage Research Center. Available at: http://www.netl.doe.gov/publications/proceedings/07/carbon-seq/data/papers/wed_025.pdf
KIGAM (2009) *Update of CO_2 Geological Storage Program in Korea*, Presentation March 31. 2009, Korean Institute of Geoscience and Mineral Resources. Available at: http://www.asiapacificpartnership.org/pdf/CFE/meeting_seoul/workshop_presentations/13_Update_on_Korean_Carbon_Geological_Storage.pdf
Koyamo K (2006) *Japan's New National Energy Strategy*, Presentation August 6, 2006, Institute of Energy Economics, Japan. Available at: http://eneken.ieej.or.jp/data/en/data/pdf/350.pdf
LMTS (2007) *Scenario Building Team 2007. Long Term Mitigation Scenarios: Technical Summary,* October 2007, Department of Environment Affairs and Tourism, Pretoria, South Africa
Mazurenko S (2005) *Russian CO_2 Storage and Capture Summary*, CSLF Meeting Berlin, Germany
MIT (2007) *The Future of Coal Options for a Carbon-Constrained World*, Massachusetts Institute of Technology, Cambridge, Massachusetts
METI (2009) *For safe operation of a CCS demonstration project*, Report of the Carbon Capture and Storage Study Group, Industrial Science and Technology Policy and Environment Bureau Ministry of Economy, Trade and Industry, Japan. Available at: http://www.meti.go.jp/english/press/data/pdf/090807_02PDF.pdf
METI (2010) *Formulation of New Innovative Energy Technology*, Press Release, June 18, 2010, Ministry of Economy Trade and Industry, Japan. Available at: http://www.meti.go.jp/english/press/data/20100618_03.html
MOEJ (2009) *Japan's Voluntary Emissions Trading Scheme (JVETS)*, Presentation, Ministry of Environment, Japan. Available at: http://www.env.go.jp/en/earth/ets/jvets090319.pdf
Nauclér T, Campbell W, Ruijs J (2008) *Carbon Capture & Storage, Assessing the Economics*, McKinsey & Company.
NETL (2008a) *Carbon Sequestration Atlas of the United States and Canada, Second Edition*, US Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. Available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf
NETL (2008b) *Project Facts, CO_2 Sequestration in Basalt Formations*. US Department of Energy, National Energy Technology Laboratory. Available at: http://www.netl.doe.gov/publications/factsheets/project/Proj277.pdf
NETL (2010) *NETL Carbon Capture and Storage Data Base*, US Department of Energy, National Energy Technology Laboratory. Available at: http://www.netl.doe.gov/technologies/carbon_seq/database/index.html
NETL (nd) *Carbon Sequestration, Regional Carbon Sequestration Partnerships*, U.S. Department of Energy, National Energy Technology Laboratory. Available at: http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html
Nordhaus W (2007) *The Stern Review on the Economics of Climate Change*, Yale University, New Haven, Connecticut. Available at: http://nordhaus.econ.yale.edu/stern_050307.pdf
Nordhaus R, Pitlick E (2009) *Carbon Dioxide Pipeline Regulation*, Energy Law Journal Volume 30: 1 April 2009
Norwegian Ministry of Petroleum and Energy (2010a) Carbon capture and storage at Kårstø, Updated May 2010, http://www.regjeringen.no/en/dep/oed/Subject/carbon-capture-and-storage/carbon-capture-and-storage-at-karsto.html?id=573777
Norwegian Ministry of Petroleum and Energy (2010b) Large scale carbon capture and storage at Mongstad, Updated June 2010. http://www.regjeringen.no/en/dep/oed/Subject/carbon-capture-and-storage/large-scale-carbon-dioxide-capture-and-s.html?id=604621
NZEC (2010a) http://www.nzec.info/en/what-is-nzec/
NZEC (nd) *NZEC: CCS Activities in China*. Near Zero Emissions Coal Initiative. http://www.nzec.info/en/assets/Reports/CCS-Activities-in-China.pdf

Odeh N, Haydock H, (nd) NZEC*: International CCS Policies and Regulations, WP5.1a/WP5.4 Report*, AEA, Oxford, UK
OSPAR (2010) Commission Website,
http://www.ospar.org/content/content.asp?menu=00120000000043_000000_000000
Park H-J (2009) *Korea Goes For Low Carbon Green Growth*, Presentation, Ministry Knowledge Economy, Korea. Available at: http://www.adb.org/documents/events/2009/Climate-Change-Energy-Workshop/KOR.pdf
Paterson, M (1996) *Global Warming and Global Politics*, Routledge, New York, NY
Poland (2009) *Energy Policy of Poland until 2030 adopted by the Council of Ministers on 10 November 2009*, Ministry of Economy, Warsaw, Poland
Poland (2010) *Fifth National Communication Under the United Nations Framework Convention on Climate Change*, Republic of Poland. Available at: http://unfccc.int/resource/docs/natc/pol_nc5.pdf
Poland Ministry of Environment (2010) Underground Carbon Storage and Sequestration in Poland – What Will it Look Like?, http://www.mos.gov.pl/artykul/123_10309.html?j=en
PTRC (2010) Website, *Weyburn-Midale CO_2 Project*, Petroleum Technology Research Centre Available at: http://www.ptrc.ca/weyburn_overview.php
Rochon E, Bjureby E, Johnston P, Oakley R, Santillo D, Schulz N, von Goerne G (2008) *Why Carbon Capture and Storage Won't Save the Climate*, Greenpeace International, Amsterdam, Netherlands
Reuters (2010a) ANALYSIS-China eyes local carbon trade, CDM priority for now, ?? Aug 2010, https://customers.reuters.com/community/commodities/newsletters/carbon/newsletter%20PDFs/CarbonMarketWeekly20100817.pdf
Reuters (2010b) S.Korea to invest $2 bln in carbon capture to 2019, 12 July 2010, http://uk.reuters.com/article/2010/07/12/carbon-korea-idUKTOE66B06520100712
Rubin, E, Chen C, Rao A (2007) *Cost and performance of fossil fuel power plants with CO_2 capture and storage*, Energy Policy, doi:10.1016/j.enpol.2007.03.009 , Elsevier
Russia (2009) *Climate Doctrine of Russia Unofficial Translation*, President, Russian Federation. Available at: http://archive.kremlin.ru/eng/text/docs/2009/12/223509.shtml
Russia (2003) *Summary of the Energy Strategy of Russia for the Period of Up to* 2020, Ministry of Energy, Russian Federation. Available at:
http://ec.europa.eu/energy/russia/events/doc/2003_strategy_2020_en.pdf
Sant'Anna, L, Spitzeck M, Advogados J (2010) *Environment- Brazil*, Latin Lawyer, Law Business Research Ltd, London, United Kingdom**.** Available at:
http://www.latinlawyer.com/reference/article/40585/brazil/
SBSTA (2010a) *Views related to carbon dioxide capture and storage in geological formations as a possible mitigation technology , Brazil* Submitted May 31, 2010 to the Subsidiary Body For Scientific And Technological Advice, UNFCCC
SBSTA (2010b) *Report of the Subsidiary Body for Scientific and Technological Advice on its thirty-second session, held in Bonn from 31 May to 10 June 2010* , FCCC/SBSTA/2010/6, UNFCCC
ScienceDaily (2010) Carbon Sequestration: Boon or Burden?
http://www.sciencedaily.com/releases/2010/06/100627155110.htm (28 June 28 2010)
Schwarzenegger (2006) Press Release, Governor's Office, 27 September 2006, Gov. Schwarzenegger Signs Landmark Legislation to Reduce Greenhouse Gas Emissions,
http://www.gov38.ca.gov/index.php?/press-release/4111/
Seligsohn D, Levin K (2010) *ChinaFAQ, China's Carbon Intensity Goal: A Guide for the Perplexed*, World Resources Institute, Washington DC**.** Available at: http://www.chinafaqs.org/library/chinafaqs-chinas-carbon-intensity-goal-guide-perplexed
Seligsohn D, Liu Y, Forbes S, Dongjie Z, West L (2009) *WRI Issue Brief, CCS in China: Toward an Environmental, Health, and Safety Regulatory Framework*, World Resources Institute, Washington DC
Simonsen (2008) *A Dawn for New Regulations on CCS*, Simonsen Advokatfirma, Oslo, Norway. Available at:
http://www.simonsenlaw.no/A+DAWN+FOR+NEW+REGULATIONS+ON+CCS.9UFRrK4Z.ips
Solomon S, Kristiansen B, Stangeland A, Torp T, Kårstad O (2007) *A Proposal of Regulatory Framework for Carbon Dioxide Storage in Geological Formations*, Bellona Foundation, Oslo,

Norway. Available at: http://www.bellona.org/files/fil_CCS_Framework_paper_ccs.pdf
Sonde R (nd) *Presentation: Demonstration of capture, injection and geological Sequestration (storage) in Flood Basalt Formation of India*. National Thermal Power Corporation Ltd, India. Available at: http://www.cslforum.org/publications/documents/Basalt_Formation.pdf
Sonjica (2009) South African Government Information, Speech by the Minister of Minerals and Energy B P Sonjica during the signing ceremony of the charter for the South African Centre for Carbon Capture and Storage Centre, 27 March 2009,
http://www.info.gov.za/speeches/2009/09032711451001.htm
SRU (2009) *Avoiding a Premature Commitment: The Need for a Debate About the Future Before Setting the Course for CO_2 Storage*, German Advisory Counsel for the Environment Press Release, May 5, 2009
Statoil (2009a) *Sliepner Updated 2009-09-23*, Statoil. Available at: http://www.statoil.com/en/TechnologyInnovation/NewEnergy/Co2Management/Pages/SleipnerVest.aspx
Statoil (2009b) *Snøhvit, Updated 2009-09-23*, Statoil. Available at:
http://www.statoil.com/en/TechnologyInnovation/NewEnergy/Co2Management/Pages/Snohvit.aspx
Stern N (2006) *Stern Review on the Economics of Climate Change*, Available in hard copy from Cambridge University Press, Cambridge, UK, or on-line at
http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/sternreview_index.htm
Stoltenberg (2009) Office of the Prime Minister Press Release, 27 May 2009, €140 million for carbon capture and storage in the EU, http://www.regjeringen.no/en/dep/smk/pressesenter/pressemeldinger/2009/over-en-milliard-kroner-til-karbonfangst.html?id=563640
Surridge A (nd) *Carbon Capture and Storage South African Activities and Plans*, South African National Energy Research Institute, South Africa
Tjernshaugen, A, Langhelle, O (2010) *Technology as political glue: CCS in Norway*, Paper presented at the annual meeting of the ISA's 50th ANNUAL CONVENTION "EXPLORING THE PAST, ANTICIPATING THE FUTURE", New York Marriott Marquis, NEW YORK CITY, NY, USA, Feb 15, 2009 (Not Available). 2010-06-06
http://www.allacademic.com/meta/p310375_index.html
Tokyo (2010) *Tokyo Cap-and-Trade Program (Tokyo-ETS)*, Tokyo Metropolitan Government, Japan. Available at: http://www.norway.or.jp/Global/SiteFolders/webtok/PDF/Tokyou_Cap-and-Trade_Program_Tokyo-ETS.pdf
UBA (2010) Press Release No. 39/2010, 7 July 2010, Energy goal for 2050: 100% renewable electricity supply, http://www.umweltbundesamt.de/uba-info-presse-e/2010/pdf/pe10-039_energy_goal_for_2050_100_percent_renewable_electricity_supply.pdf
UCL (2010a) *Offshore Carbon Capture and Storage International Marine Legislation*, Carbon Capture Legal Program, University College London.
UCL (2010b) *Environmental Liabilities The EU Directive on the Geological Storage of Carbon Dioxide ('CCS Directive') Overview: the basic structure of the liability regime in the EU CCS Directive*, Carbon Capture Legal Programme, University College London
UK Committee on Climate Change (2010) Press Release 18 June 2010, Committee advises Government on approach to fossil fuel generation, http://www.theccc.org.uk/news/press-releases/610--committee-advises-government-on-approach-to-fossil-fuel-generation
UK Communities and Local Government (2010) Major infrastructure stays on fast-track as planning quango closes, 29 June 2010, http://www.communities.gov.uk/news/corporate/1626220
UK DECC (2009a) *Impact Assessment of Proposed Reforms to the Structure of Climate Change Agreements*, Department of Energy and Climate Change, United Kingdom. Available at:
http://www.decc.gov.uk/assets/decc/Consultations/ccaFormContent2nd/1_20100111151847_e_@@_ccaia.pdf
UK DECC (2009b) *Impact Assessment of the Electricity and Gas (Carbon Emissions Reduction) (Amendment) Order 2009*, Department of Energy and Climate Change, United Kingdom. Available at: http://www.decc.gov.uk/assets/decc/Consultations/carbon%20emissions%20reduction%20target/1_20090630122512_e_@@_CERTImpactAssessment.pdf
UK DECC (2009c) *A consultation on the Proposed Offshore Carbon Dioxide Storage Licensing Regime*, Department of Energy and Climate Change, United Kingdom. Available at:

http://www.decc.gov.uk/assets/decc/Consultations/carbondioxidestorage%20licensing/1_20090925094606_e_@@_offshoreco2storagelicensingconsultation.pdf
UK DECC (2009d) *Draft Supplementary Guidance for Section 36 Electricity Act 1989 Consent Applicants for Coal Fired Power Plants – A Consultation*. Department of Energy and Climate Change, United Kingcom. Available at: http://www.decc.gov.uk/assets/decc/Consultations/guidancecoalpowerstations/1_20091113101059_e_@@_condocsuppguidancecoal.pdf
UK DECC (2009e) Energy Bill Factsheets, Carbon Capture and Storage, Available at: http://www.decc.gov.uk/assets/decc/legislation/energybill/1_20091215163644_e_@@_ccsfactsheet.pdf
UK DECC (2010a) *UK Energy in Brief 2010*, Department of Energy and Climate Change, United Kingdom. Available at: http://www.decc.gov.uk/assets/decc/Statistics/publications/brief/190-uk-energy-in-brief-2010.pdf
UK DECC (2010b) *UK Greenhouse Gas Emissions, Performance Against Emissions Reduction Targets, 2009 Provisional Figures*, Department of Energy and Climate Change, United Kingdom. Available at: http://www.decc.gov.uk/assets/decc/Statistics/climate_change/332-1990-2009-provisional-progress-data.pdf
UK DECC (2010c) *Government Response to the Consultation on the Proposed Offshore Carbon Dioxide Storage Licensing Regime*, Department of Energy and Climate Change, United Kingdom. Available at: http://www.decc.gov.uk/assets/decc/Consultations/carbondioxidestorage%20licensing/422-govt-response-offshore-co2-storage.pdf
UK DECC (2010d) The UK Low Carbon Transition Plan. Available at: http://www.decc.gov.uk/assets/decc/white%20papers/uk%20low%20carbon%20transition%20plan%20wp09/1_20090724153238_e_@@_lowcarbontransitionplan.pdf
UK DECC (2010e) Climate Change Act 2008. Available at: http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx
UK DECC (2010f) Community Energy Savings Programme (CESP). Available at: http://www.decc.gov.uk/en/content/cms/what_we_do/consumers/saving_energy/cesp/cesp.aspx
UK DECC 2010g) Press Release 27 August 2010, Undersea CO_2 storage licensing plans published, http://www.decc.gov.uk/en/content/cms/news/pn10_97/pn10_97.aspx
UNEP (2010) *Overview of the Republic of Korea's National Strategy for Green Growth*, United Nations Environment Programme. Available at: http://www.unep.org/PDF/PressReleases/201004_UNEP_NATIONAL_STRATEGY.pdf
UNFCCC (1992) *United Nations Framework Convention on Climate Change*, UNFCCC Available at: http://unfccc.int/essential_background/convention/items/2627.php
UNFCCC (1997) *Kyoto Protocol*, UNFCCC. Available at: http://unfccc.int/kyoto_protocol/items/2830.php
UNFCCC (2009) *Decision 2.CP.15 Copenhagen Accord*. Available at: http://unfccc.int/home/items/5262.php
US (2010) *Report of the Interagency Task Force on Carbon Capture and Storage, August 2010*, US Government
US DOE (2010) Fossil Energy Techline, Secretary Chu Announces Six Projects to Convert Captured CO_2 Emissions from Industrial Sources into Useful Products, 22 July 2010, http://fossil.energy.gov/news/techlines/2010/10027-DOE_Announces_Six_Projects_to_Conv.htm
USEIA (2009) Emissions of Greenhouse Gases Report December 8, 2009, http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/0573(2008).pdf
USEIA (2010a) Country Analysis Briefs China, http://www.eia.doe.gov/cabs/China/pdf.pdf (Nov 2010)
USEIA (2010b) Country Analysis Briefs Japan, http://www.eia.doe.gov/cabs/Japan/pdf.pdf (Sep 20100
USEIA (2010c) Country Analysis Briefs Norway, http://www.eia.doe.gov/emeu/cabs/Norway/pdf.pdf (Aug 2010)
USEIA (2010d) Country Analysis Briefs South Korea, http://www.eia.doe.gov/emeu/cabs/South_Korea/pdf.pdf (Oct 2010)
USEIA (2010e) Country Analysis Briefs Russia, http://www.eia.doe.gov/emeu/cabs/Russia/pdf.pdf (Nov 2010

USEIA (2010f) Electric Power Monthly, August 2010, http://www.eia.gov/ftproot/electricity/epm/02261008.pdf

US EPA (2008a) Advanced Notice of Proposed Rulemaking, Regulation Greenhouse Gas Emissions under the CAA, Federal Register, 30 July 2008, Vol 73, No. 147, pp 44353-44520

US EPA (2008b) Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells; Proposed Rule, Federal Register, 25 July 2008, Vol 73, No. 144, pp 43491-43541

US EPA (2009) Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act; Final Rule, Federal Register Vol 74, 15 December 2009, No. 29, pp 66495-66546

US EPA (2010a) Final Tailoring Rule, http://www.epa.gov/nsr/documents/20100413final.pdf

US EPA (2010b) Fact Sheet, Final Rule: Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule, http://www.epa.gov/NSR/documents/20100413fs.pdf

US EPA (2010c) New Source Review, Prevention of Significant Deterioration (PSD) Basic Information, http://www.epa.gov/nsr/psd.html

US EPA (2010d) New Source Review, Clean Air Act Permitting for Greenhouse Gases, http://www.epa.gov/nsr/ghgpermitting.html

WCI (2010) *Design for the WCI Regional Program*, Western Climate Initiative. Available at: http://westernclimateinitiative.org/component/remository/func-startdown/282/

Weitzman M (2007) *A Review of The Stern Review of the Economics of Climate Change*, Journal of Economic Literature 45(3): 703–724

Whorton L P, Brownscombe E R, Dyes A B (1952) *Method for Producing Oil by Means of Carbon Dioxide*, US Patent 2,623,596 (1952)

Wertheim H, (2010) *Petrobras Tests New Technologies for CO2 Capture Storage*, Offshore Magazine February 1, 2010, Pennwell. Available at: http://www.offshore-mag.com/index/article-display/6340897993/articles/offshore/volume-70/issue-2/special-report_carbon/petrobras-tests_new.html

Wikepedia (2010) based on data collected by Carbon Dioxide Information Analysis Center (CDIAC) for the UN. Available at: http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions

WRI (2009) Ensuring Safe Carbon Capture and Storage in China, http://www.wri.org/stories/2009/03/ensuring-safe-carbon-capture-and-storage-china (March 2009)

WWF (nd) *WWF POSITION PAPER Carbon Capture And Storage From Fossil Fuels*, World Wildlife Federation. Available at: http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/carbon_capture_storage/

Yamagata H (nd) *Carbon Capture and Storage Activities in Japan*, Ministry of Economy, Trade and Industry, Japan. Available at: http://www.cslforum.org/publications/documents/Japan_CCS.pdf

Yamaguchi M (2007) *Japan's Implementation Plan of the Kyoto Protocol Target and a Proposal for the Future International Framework*, Presentation ICCF AP6 panel discussion at National Press Club, Washington D.C. February 13, 2007. Available at: http://m-yamaguchi.jp/english_page/ICCF_AP6_Revised.pdf

Yi C (2007) *Current CCS R&D Activities in Korea*, Presentation, November 19th, 2007 CCS Workshop Tokyo, Korea Institute of Energy Research. Available at: http://www.rite.or.jp/Japanese/labo/choryu/ccsws/ccsws2007tokyo/p03_Chang-Keun_Yi.pdf

Zakkour P (2007) *Technical support for an enabling policy framework for carbon dioxide capture and geological storage Task 2: Discussion paper Choices for regulating CO_2 capture and storage in the EU*, ERM, Amsterdam, London, Katawice. Available at: http://ec.europa.eu/environment/climat/ccs/pdf/policy_options_paper.pdf

Zukowsky R (2010) *The Regulatory Framework Governing Injection and Storage of Carbon Dioxide at the Cenovus Weyburn and Apache Midale Enhanced Oil Recovery Operations in Saskatchewan*, Available at: http://www.ccs101.ca/regulatory_framework_governing_injection_and_storage_of_carbon_dioxide_at_the_Cenovus_weyburn_and_apache_midale_enhanced_oil_recovery_operations_in_saskatchewan