Policy Brief

Regulation of Carbon Capture and Storage

international risk governance council

Introduction

The International Risk Governance Council (IRGC) is an independent foundation based in Switzerland whose purpose is to help the understanding and management of emerging, global systemic risks. It does so by identifying and drawing on the best scientific knowledge and, by combining it with the understanding of experts in the public and private sectors, developing fact-based risk governance recommendations for policy makers.

The establishment of IRGC was the direct result of widespread concern within the public sector, the corporate world, academia, the media and society at large that the complexity and interdependence of an increasingly large number of such risks was making the development and implementation of adequate risk governance strategies ever more difficult.

A particular concern of IRGC is that important opportunities from new technologies are not lost due to inadequate risk governance. When technologies have the capacity to alleviate major global concerns, a failure to adopt them has potentially catastrophic consequences.

In 2006, IRGC decided to address the risk governance of carbon capture and storage (CCS). In November 2007, the Intergovernmental Panel on Climate Change (IPCC) stated that the total emissions of anthropogenic greenhouse gases (carbon dioxide [CO_2], methane and nitrous oxide) due to human activities increased by 70% between 1970 and 2004 and that global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution [IPCC, 2007]. CCS is therefore an emerging technology that offers potentially enormous benefits for reducing greenhouse gas emissions. It also presents significant technical, financial, legal and other challenges to government, industry and society at large.

This policy brief concentrates on a key institutional barrier: the deficit of regulatory frameworks for capture and storage of CO_2. It builds upon IRGC commissioned papers and a workshop involving eleven international teams (listed in the Appendix) which was held in Washington DC in March 2007[1] and from comments and presentations made during a conference held in November 2007 at the Swiss Re Centre for Global Dialogue, Rüschlikon, Switzerland.

IRGC's work has been led by Professor Granger Morgan, Lord Chair Professor of Engineering and Public Policy, Carnegie Mellon University, who is also the Chairman of IRGC's Scientific and Technical Council, and by Assistant Professor Elizabeth J. Wilson of the Humphrey Institute of Public Affairs, University of Minnesota. Professor Wilson and Melisa F. Pollak are the authors of this policy brief. The project has been supported by E.ON Energie AG, the Allianz Technology Center on behalf of the Dresdner Bank Foundation, Resources for the Future (RFF) and the Swiss Reinsurance Company (Swiss Re).

[1] Papers are posted on the IRGC website (www.irgc.org), see http://www.irgc.org/Expert-contributions-and-workshop.html. A full list of contributing authors is provided in the Appendix of this policy brief.

Contents

1 Purpose and intended audience

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"To continue to extract and combust the world's rich endowment of oil, coal, peat, and natural gas at current or increasing rates, and so release more of the stored carbon into the atmosphere is no longer environmentally sustainable, unless carbon dioxide capture and storage (CCS) technologies currently being developed can be widely deployed."

IPCC 4th Assessment Report, 2007

The raison d'etre for carbon capture and storage (or sequestration) (CCS)[2] is to enable continued use of fossil fuels in a carbon emission constrained world. Benefits include economic competitiveness, energy security and a non-disruptive transition to low-carbon energy systems. The technology is conceptually simple: carbon dioxide (CO_2) is captured from electric power plants or industrial sources, transported to the injection site, and injected deep underground for storage. CCS is at a very early stage of deployment, with only four commercial-scale operations worldwide[3] , but it has the potential to play an important role in the portfolio of climate change mitigation technologies, supplementing the carbon emission reductions to be achieved by energy efficiency, conservation, and renewables. It is estimated that CCS could be used to achieve between 15% and 55% of the carbon emission reductions necessary to avoid dangerous levels of climate change [IPCC, 2005], and that achieving emission reduction goals will be less costly with CCS than without it [MIT, 2007]. To achieve this potential would require large-scale, worldwide deployment of CCS in the electric utility industry, capturing and storing billions of tonnes of CO_2 per year.

Large-scale CCS deployment will require the creation of a regime to manage risks and supporting policies to facilitate technology investment. Within this framework, regulatory, legal, and public perception considerations emerge as crucial factors that could either accelerate or inhibit CCS deployment. Policy makers worldwide need to work towards a system of regulation and risk governance for CCS that is globally consistent, nationally coordinated, and which adequately manages local risks. This policy brief examines regulatory issues post-capture, particularly the transport and geological storage of CO_2. It identifies key areas where relevant stakeholders should collaborate internationally and proposes a model for development of national deployment and regulation, which incorporates jurisdictional specificities.

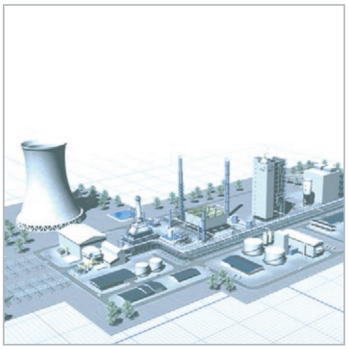
[2] **A note on terminology**: CCS is a new technology, and issues of terminology are still in flux. Some practitioners use the phrase *Carbon Capture and Sequestration* while others prefer *Carbon Capture and Storage*. The EU, the IPCC, and the UNFCCC have adopted *Carbon Capture and Storage*, and that is the convention used in this report.

[3] Sleipner in the North Sea, run by StatoilHydro; In Salah in Algeria run by BP, Sonatrach and StatoilHydro; Weyburn in Canada, operated by EnCana; and Snøhvit in the Barents Sea, operated by StatoilHydro. A comprehensive list of commercial and pilot CCS projects is maintained by the International Energy Agency (IEA) (http://co2captureandstorage.info/co2db.php).

This policy brief is targeted at policymakers engaged in the planning, deployment and risk oversight of CCS. This document first describes the life-cycle of CCS, identifies stakeholders, and outlines potential risks. It then considers the larger context for CCS regulation, as risks are not the only drivers for governance. Finally it examines the current status of CCS regulation and discusses a path toward comprehensive CCS governance. This path would both adapt current regulation to get urgently-needed early commercial-scale projects up and running, and then build on the knowledge base they generate to create comprehensive risk-based CCS governance suitable to wide-scale commercial CCS deployment.

Large-scale CCS deployment will require a regime to manage risks and supporting policies to facilitate technology investment

In Salah Gas. Courtesy of BP



General layout of the RWE Power IGCC CCS demonstration plant

Characterisation and management of geological and technical uncertainty requires methodologies and technologies tailored to the particular circumstances and risks of each site

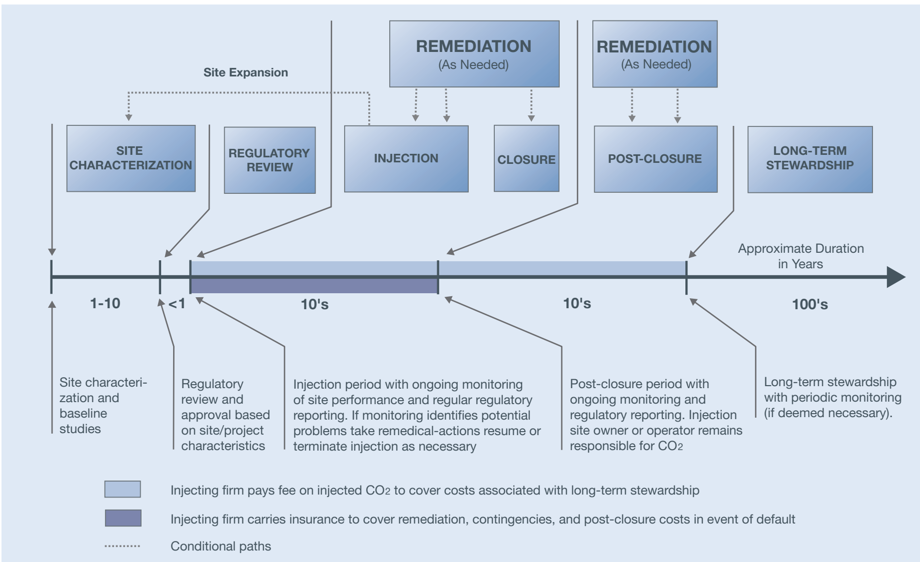
2.1. CCS project life-cycle

For practical implementation, CCS will need to be regulated as an industrial process, with regulations geared to each project stage: capture, transportation, site selection and permitting, site operations, site closure, and long-term stewardship. While all the elements of this industrial process exist, they are not yet developed to scale nor are they integrated. The structure of the future CCS industry could take a number of possible forms in terms of the relationships between CO_2 producers, CO_2 pipeline operators, and geological storage site operators. This policy brief does not cover regulatory issues related to capture but it is worth noting that, while the long-term potential for CCS lies in capturing CO_2 at fossil-fired electric power plants, significant short-term potential lies in other industrial processes that already generate a concentrated CO_2 stream, such as natural gas, ammonia, or hydrogen production. Regulation of transport and geological storage must be designed to manage CO_2 from both electric utilities and from these other industries.

As each CCS project site will be unique, the characterisation and management of geological and technical uncertainty – shades of grey as opposed to black and white – requires methodologies and technologies tailored to the particular circumstances and risks of each site. The life-cycle stages of a CCS project are illustrated in Figure 1.

Figure 1: **Life-cycle stages of a CCS project**

This model assumes that: commercial firms will operate CCS sites; those firms will continue to be responsible for some period of time post-closure; and, ownership will pass to a government entity at some point.



[Illustration from Rubin et al., 2007]

Site characterisation: careful site selection is the single most important way to manage short- and long-term risks of CCS. Establishment of generalised CCS siting guidelines that can be customised to local geology is an important first regulatory step that can be immediately undertaken. Such efforts are underway in Australia, the US, Canada, and throughout the EU. The site characterisation phase will extend into site development. Installation of injection wells and monitoring systems will add detailed understanding of site geological features.

Careful site selection is the single most important way to manage short- and long-term risks of CCS

Site operations: regulation of site operations will centre on pipeline transport, injection, and monitoring. Most CCS projects will require pipeline transport from source to sink. Regulatory requirements regarding injection will shape the industry by specifying parameters such as injection well design, allowed injection quantities, reservoir pressure limits, purity of CO_2 stream, and financial responsibility standards. Current regulations cover some of these, but modifications are needed to adequately manage the risks of injecting large volumes of buoyant CO_2. Additionally, monitoring must verify that sites are performing as expected. Establishment of general monitoring and verification (M&V) requirements will be useful to both industry and regulators but, given the heterogeneity of both capture systems and geology, each site's M&V regime will need to be site-specific and adaptive over time. Extensive baseline measurements before injection will be essential. Technical requirements will not be the only driver for M&V regulations, as the monitoring of results is also important for public acceptance.

Closure/post-closure: closure requirements, established as part of the permitting process, will guide operations, decommissioning, M&V, and regulatory oversight throughout the project, because all parties will be motivated to have the site successfully meet closure requirements at the end of operations. After injection ceases, the CCS site operator should retain responsibility for a specified post-closure period to establish stability of storage. The duration of this post-closure liability period is debatable, however: durations of several years to several decades are possible and may vary across jurisdictions and across projects.

Long-term stewardship: CCS requires CO_2 to remain sequestered underground for hundreds to thousands of years. Public assumption of long-term responsibility will probably be required at some point after site closure, conditional upon proof that CO_2 storage is behaving predictably, as nations are the only entities that can make credible commitments over such long storage time periods. If this model is implemented, regulations will need to specify the temporal and technical requirements to qualify for ownership transfer. See Section 5.4 for more discussion on long-term liability and responsibility.

2.2. Balancing the needs of all actors through project cycle

A comprehensive CCS regulatory framework must balance competing needs and interests of local, national and international publics, CO_2 generators, CO_2 pipeline operators, geological storage site developers, financial and insurance institutions supporting the project, government agencies setting safety and environmental requirements, and national and international agencies managing climate regimes.

Protection of human health and the environment is the primary objective of local and national regulators

The public: public priorities will vary by context. The global public's interest in CCS is to avoid dangerous climate change. National and state level publics will be concerned with economic competitiveness, including the cost of electricity, and with cost and effectiveness of regulatory agencies. The local public will focus on health, safety and environmental concerns, as well as property rights and property value issues, especially for on-shore sites. Off-shore sites, depending on the country, may attract less public interest; however, environmental issues will remain a public concern.

CO_2 generators: CO_2 generators will need secure repositories for CO_2 coupled to a reliable pipeline system linking sources to sinks. Clear definition of CO_2 ownership transference through the industrial process from capture to injection to storage will be important, as will a stable climate policy regime (with clear targets, and additional financial certainty – e.g. a known floor to the long-term carbon price) to make CCS economically viable.

CO_2 pipeline operators: CO_2 pipeline operators need a profitable business model to justify investment in this vital infrastructure (see Box 1).

Geological storage site developers: project developers need CCS to be legal *and* profitable. They must satisfy the rules established by the four key bodies that will govern CCS: government agencies setting safety and environmental regulations; national or international agencies administering climate regimes; insurance institutions participating in liability coverage; and, financial institutions supporting the project.

Local and national regulators: protection of human health and the environment is the primary objective of local and national regulators. They will also strive to minimise the cost of regulation to both the public and industry, and equitably balance the risks of CCS between public and private actors.

Climate regime administrators: a climate regime will need to accurately measure CO_2 emissions avoided. Development of harmonised greenhouse gas (GHG) accounting procedures, as well as a minimum standard for international CCS site operating procedures (site selection, injection, and monitoring) will be necessary to enable international carbon trading and ensure that the value of emissions allowances is not eroded by leakage from CCS sites.[4]

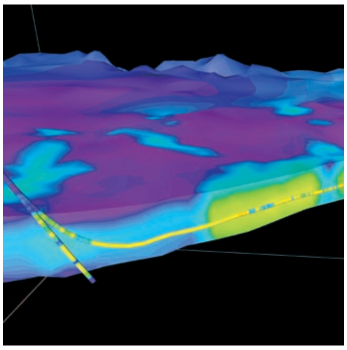
[4] While 'leakage' is used within the UN Clean Development Mechanism framework to specify emissions outside of the project boundaries, here we use it to signify CO_2 leaking from the storage reservoir to the surface.

Insurance companies: the ability of insurers and reinsurers to assess risk will depend on which activities they are asked to cover and the limits on liability (if any) provided under national, state, or provincial law. This analysis will depend on available data and site experience.

Financial underwriting companies: CCS projects will not be possible without financing. Financial institutions will require that CCS be profitable. This calls for incentive structures to render CCS economically viable and special incentives to encourage "first of a kind" projects. It will probably also entail long-term contracts with CO_2 generators, and mechanisms to ensure continued viability of CCS plants. Finally, no investment can occur before legal operation is assured. On-shore and off-shore regulation and guidance must explicitly address CO_2 and associated substances to remove legal uncertainty, must clarify ownership rights and responsibility of injected CO_2, and, in some jurisdictions, must clarify ownership of subsurface pore space and ownership of mineral rights affected by CO_2 storage.

BOX 1: Pipeline infrastructure development

Large-scale CCS deployment cannot proceed until extensive pipeline infrastructure is in place. Large volumes of CO_2 – a 1,000 MW coal-fired power plant produces 5 to 8 million tonnes of CO_2 annually – will need to be transported from source to sink. Linkages are complex, and the business model for pipeline operators includes significant risk, as their operations are subject to uncertainties beyond their control at both ends of the pipe. This risk puts upward pressure on pipeline costs, as do recent steel price increases. Transport infrastructure investment requires regional and site-specific knowledge of geological storage prospects, as well as knowledge of current and future CO_2 source locations, volumes, and characteristics. Pipeline transport of CO_2 is successfully regulated for enhanced oil recovery in the US, but with a framework that does not necessarily translate to the industrial organisation of CCS. Regulation of risks related to pipeline transport is straightforward, but more complicated regulatory decisions will relate to funding, siting and construction of pipeline networks off-shore, on-shore, and through urban zones, natural monopoly concerns, and issues of eminent domain. Different regulatory models for CO_2 pipeline ownership, a privately owned, common carrier approach or a public utility approach could stimulate different levels of investment, potentially influencing the ultimate organisational structure of the CCS industry.



Subsurface seismic image of an injection well, In Salah Gas. Courtesy of BP

2.3. Potential CCS risks and liabilities

Regulations should be adaptive to incorporate emerging information about CCS risks

The risks of CCS are both global – climate related risk – and local – risks dominated by safety concerns, as illustrated in Figure 2. These risks can be grouped into four general categories: human health risks; environmental risks; property risks; and, financial risks. The role for regulation varies with the type of risk, although to some extent government plays a role in each category. Liability for CCS typically differentiates between operational liability and post-injection liability. Operational liability includes health, safety and environmental risks related to CO_2 capture, transport and injection [de Figueiredo et al., 2007]. Post-injection liability includes health, safety, environmental, and climate risks caused by CO_2 that migrates from the intended storage reservoir to another subsurface unit or back to the atmosphere.

Figure 2: **Risks of geological storage of CO_2**

Risks of geological storage

Local

- Effects on humans or ecosystems of CO_2 in the atmosphere or shallow subsurface
- Effects of dissolved CO_2 on groundwater
- Quantity base effects such as induced seismicity, displacement of brines, or damages to hydrocarbon resources

Global

- Release of CO_2 to the atmosphere

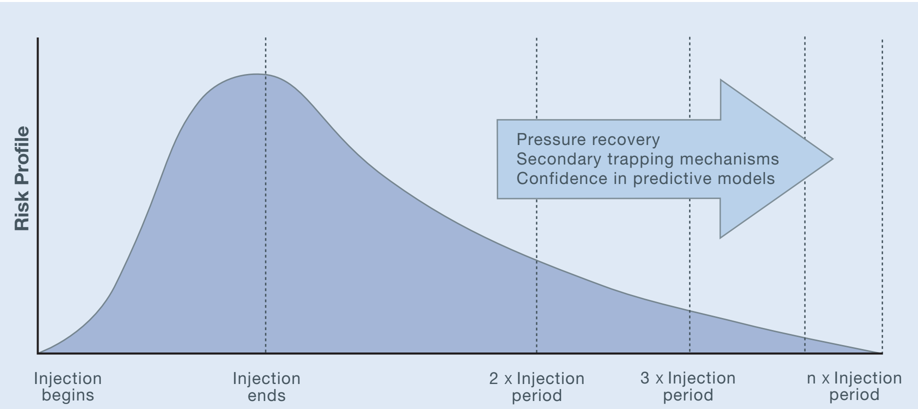
[Illustration adapted from Wilson et al., 2003]

Human health risks include potential impacts to employees or the general public from either sudden, high-volume CO_2 releases, or from chronic low-volume CO_2 seepage. Environmental risks include impacts on surface or near-surface ecosystems, seawater or groundwater. Property risks include property damage (including to mineral or water rights), diminution of value (for properties in the vicinity of CCS sites) and business interruption (for CCS operator or for neighbouring properties if remediation is required). Finally, financial risk entails potential for return on investment, contractual liabilities in the carbon market due to CO_2 leakage, and credit risk related to obligations for long-term operations and maintenance at CCS sites. Our understanding of the risks of CCS will improve with experience. It is important that regulations be adaptive to incorporate emerging information about CCS risks. All the potential risks of CCS must be viewed in the context of the global risks of climate change.

The risk profile of CCS sites will change over time and will be different across different sites and operations, as injection begins and engineered systems are tested, as reservoir pressure builds and the CO_2 plume expands, and as natural processes gradually immobilise CO_2. It is likely that storage becomes more secure over time, as CO_2 becomes immobilised by capillary trapping, dissolution and mineral trapping [IPCC, 2005]. This characteristic of CCS distinguishes it from other waste disposal technologies.

Figure 3: **Hypothetical CCS site leakage risk profile**

The risk profile for CCS will vary with each project and could take very different shapes. The plot here illustrates the increasing operational risk from greater reservoir pressures and increasing spread of CO_2 as a project becomes more mature and the decreasing post-closure risk as reservoir pressures diminish and natural attenuation mechanisms immobilise CO_2.



[Illustration source: Benson, 2007]

A hypothetical risk profile is shown in Figure 3, qualitatively illustrating leakage risk from the beginning of injection operations until hundreds of years after site closure. In this scenario, the risk of leakage gradually builds as reservoir pressure increases and the plume expands, peaking at site closure and gradually falling. Knowledge of site performance will help determine leakage risk profiles, and hopefully focus regulatory effort where risk is greatest.

Risk profiles vary for different stakeholders and managing local risks (environmental, human health, and property rights issues) is fundamentally different from global risk management. Health and safety risks to the local population neighbouring a CCS site would be highest in the case of sudden leakage from a well or a fault (this type of leakage is relatively easy to detect), but financial risk to investors may be highest from slow, long-term leakage liability (more difficult to detect) under a regime where emissions permits need to be purchased. Furthermore, risk profiles are not set in stone, as they can be managed through engineered interventions.

Storage becomes more secure over time, as CO_2 becomes immobilised by capillary trapping, dissolution and mineral trapping

III Drivers for CCS regulation

The objectives of CCS are clear: CCS must be able to safely sequester large amounts of carbon dioxide (billions of tonnes) for a long time (hundreds to thousands of years). In order to abate atmospheric CO_2, CCS should maximise CO_2 emissions avoided. To achieve these objectives, CCS regulation must:

- Establish a framework encouraging responsible operation and investment;
- Balance stability and predictability with flexibility and adaptability to new scientific information; and
- Provide ease of implementation for both regulators and industry.

CCS regulation must manage the risks and liabilities of CCS, distinguishing between risks that should be assumed by the operator, those that can be mitigated through regulation, and those that can be transferred. However, risk and liability are not the only drivers for CCS regulations. Issues related to competition, climate regime commitments, tax policy, financial responsibility, property rights and international treaties will also shape the CCS regulatory framework[5]. For some risks, the most stringent rules may not come from government at all, but instead from the private sector, such as the insurance industry. If financial responsibility is required through regulatory means, then the insurance industry may become another very important stakeholder and support additional risk governance for CCS projects. Stakeholder dynamics and drivers for CCS deployment will vary by jurisdiction, as highlighted (for the EU, US and Australia) in Table 1. Box 2 presents a case study on how factors such as existing energy infrastructure, natural endowments, and legal and political institutions play out in Germany and China.

[5] For additional information on drivers for CCS regulation see the IRGC workshop report which can be downloaded from http://www.irgc.org/Expert-contributions-and-workshop.html

Table 1: **Issues driving CCS deployment in the EU, US and Australia**

	EU	US	Australia
Climate Policy	Signatories to Kyoto with existing climate policy and established trading scheme. Must establish how CCS fits into CO_2 trading and accounting system.	Not a signatory to Kyoto, no coordinated federal policy. Several bills are pending in Congress. Currently, state level initiatives dominate.	Ratified Kyoto in December 2007.
Energy infrastructure	Coal dependence heavier in Germany and several new Member States, anti-nuclear power sentiment in many northern EU countries[6].	Heavy coal dependence in Midwest and mountain states. Large coal reserves and many new coal plants (without capture) currently proposed. Several coal to liquids projects under discussion.	Steady demand growth coupled with strong dependence on coal for electricity generation. Economic dependence on coal exports and technology exports.
Classification of CO_2	Will be defined as either 'waste' or 'special category' under the EU Landfill, Waste and Water Directives.	Underground injection regulatory stringency is based upon the origin and disposal site, not classification of CO_2[7].	Australian regulators have been active at ensuring CO_2 classification will not block CCS.
Location of projects	Off-shore locations are important. No significant on-shore underground injection experience. The Utsira formation under the North Sea is estimated to have the capacity to store all of Europe's emissions for centuries. Coordination with international treaties necessary for CCS deployment.	Significant on-shore geological storage capacity. Target reservoirs often contain high densities of abandoned wells. Potential ecological and human health risk must be actively managed given the import of on-shore injection.	Australia has both on-shore and off-shore targets sites for CCS. However many are far from population centres, changing the potential human health and safety risks.
Subsurface property rights	Mineral rights and pore space ownership controlled by central government, making the legal framework for pore space acquisition more straightforward.	On private lands, mineral rights and surface/pore space ownership may be held by different parties, with the surface estate holder owning the pore space once hydrocarbons have been removed. On public lands, lessees of mineral rights may have an interest.	Mineral rights and pore space owned by the central government.

[6] Germany has decided to phase out its nuclear power.

[7] The exception is Resource, Conservation and Recovery Act (RCRA) Subtitle C listed wastes, see 42 U.S.C. 6901. CO_2 is not a listed waste.

BOX 2: Case studies on drivers for CCS deployment

Germany

Germany's aggressive greenhouse gas reductions commitments are a challenge for the electric power sector, which is heavily dependent upon coal. CCS is an attractive technology for reducing CO_2 emissions due to the political difficulty of constructing new nuclear facilities and the need for energy security. The 2005-6 Russian-Ukrainian natural gas crisis highlighted potential energy security vulnerabilities and many planned natural gas power plants were re-assigned as coal-fired power plants. As Germany possesses potential CO_2 storage sites both on-shore and off-shore [ZEP, 2006] and some pilot-site characterisation has begun [Förster, 2006], CCS has emerged as a technology that would enable the continued use of inexpensive fossil fuels while allowing for substantial greenhouse gas emissions reductions within the electric and other industrial sectors. Furthermore, deployment of CCS could reduce the cost of achieving greenhouse gas reduction commitments for all end use sectors [Martinsen et al., 2007]. Add to this Germany's role as a global technology innovator, core involvement in CCS research and active commitments of several German firms, Germany is emerging as one of the best equipped countries to deploy CCS. However, Germany does not have a significant history of underground injection; securing long-term access for on-shore sites is a consideration, and cost and lifespan of off-shore operations is another. Harmonisation of EU Waste, Water, and Landfill Directives for CCS compatibility is underway, as is an examination of the German regulatory framework.

China

Rapid economic growth, growing demand for energy and electricity, and plentiful coal reserves highlight the potential importance of CCS in China. Eighty per cent of Chinese electricity comes from coal and plans to build over 500 new coal-fired power plants are active. Climate change has now attracted the attention of the Chinese government: the State Council issued China's National Climate Change Program in June 2007, setting a goal of reducing greenhouse gas emissions 20% by 2020 [Liu, 2007]. Barriers to deployment of CCS projects include the current focus on rapid economic growth, the presence of relatively few good geological storage targets and limited regulatory experience with underground injection (though a few pilot projects are underway), however CCS R&D is now ongoing. PetroChina is operating a CO_2 enhanced oil recovery project, and Chinese national science and technology programmes are beginning to fund CCS R&D projects [Liu, 2007]. Technology partnerships with industrialised countries, such as the current Australia/China two-year collaboration on geological capacity assessment, and the China-EU-UK collaboration to generate a road map for CCS in China and carry out a CCS demonstration project, could help to better deploy the first CCS projects in China.

IV Current status of CCS regulation

Regulatory frameworks for CCS will probably build upon existing laws and be governed by existing institutions, but existing regulatory systems are not yet suited to addressing some of the special issues that arise in CCS, such as the need for thorough site characterisation, careful monitoring and long-term stewardship. The current status of CCS regulation varies significantly across the world.

Existing regulatory systems are not yet suited to addressing some of the special issues that arise in CCS

Australia

- The Australian government has proposed a framework of regulatory guiding principles for CCS and proposed several options for future regulation. They recommended that additional amendments to government regulations could decrease uncertainty for CCS deployment [MCMPR, 2005].

EU

- Europe is considering the integration of CCS into the European Union Emission Trading Scheme (EU-ETS). Inclusion of CCS in the EU-ETS would require modification to existing regulations (see Table 2 below). For off-shore storage, these are underway in the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) Annex I. For on-shore storage the European Commission's Environment Directorate General is drafting the necessary modifications needed to the EU Water, Environmental Impact Assessment (EIA), Landfill and Waste Directives, as well as a new, freestanding legal framework to cover geological storage of CO_2. Individual Member States may exceed the EU minimum standards. The UK will be first to bring forward domestic legislation during 2007-08.

US

- The US has a well-developed regulatory framework that governs underground injection, but is primarily focused upon protecting underground sources of drinking water. Additional siting considerations, long-term care frameworks, and integration into a not-yet-defined climate-policy regime remain ambiguous. The US Environmental Protection Agency announced on October 9th 2007 that it is developing rules for CCS.

Globally

- The UNFCCC Clean Development Mechanism (CDM) – The UNFCCC is debating whether to include CCS as CDM project activities, with the intention of taking a decision by the end of 2008. Work is underway to adapt CDM procedures and modalities to the features of CCS projects. CCS presents unique long-term liability and accounting challenges that go beyond the nature of other CDM methodologies.

- G8 leaders pledged to accelerate the development and commercialisation of CCS technology at the Gleneagles summit in 2005. The International Energy Agency (IEA) is coordinating G8 efforts to identify near-term opportunities for CCS, and to develop policy recommendations to present to the G8 leaders at their 2008 summit in Japan.

Krechba CPF Amine Regeneration Tower, In Salah Gas. Courtesy of BP

4.1. Existing regulations can be modified to govern early deployment

Before finalising a regulatory framework there is, first, the need to learn from real-world experience and so not create regulations that lock in inappropriate features or ignore key issues. A number of full-scale CCS projects can proceed worldwide under modifications to existing regulations, with specially negotiated solutions to long-term liability issues (such as the EU offering an opt-in clause for individual early projects to benefit from the second phase of the EU-ETS or the indemnification offered by Illinois and Texas to the FutureGen project in the US). Proposals to plug the gaps in the EU regulatory framework have been suggested [Zakkour, 2007].

Significant recent modifications to enable CCS under existing regulations include an amendment to the London Protocol Annex to permit storage of CO_2 beneath the seabed, and the US Environment Protection Agency's (EPA) decision to use an experimental well category (Class V) to permit CCS pilot projects. Table 2 presents a partial list of current efforts to modify existing regulations, including work to develop CCS site selection guidelines, monitoring protocols, and GHG accounting procedures.

Table 2: CCS regulatory initiatives

Type of initiative	Location	Description
Site selection guidelines, monitoring and verification protocols	EU	Modifications to the Convention of Environmental Impact Assessment (EIA) Directive, the Integrated Pollution Prevention and Control (IPPC) Directive, the Seveso II Directive, the Environmental Liability Directive and the Landfill Directive are being considered to include CCS in the EU-ETS. Freestanding regulations for geological storage of CO_2 are being drafted.
	UK	Cross government task force on CCS; licensing, monitoring and verification guidelines expected in late 2007.
	North Sea	North Sea Basin CCS task force (UK, Norway) pipelines, trans-national grid, value chain model.
	US	Environmental Protection Agency Underground Injection Control Program is developing regulations aimed at ensuring consistency in permitting commercial-scale geological sequestration projects, scheduled for release in the summer of 2008.
	IEA GHG	Best practices database. (http://www.co2captureandstorage.info/BPIntro.php)
	UNFCCC CDM	Consultations underway on inclusion of CCS in the CDM. Possible approaches to CCS methodology are under discussion [IEA, 2007].
GHG accounting	International	IPCC 2006 Guidelines for National GHG inventories includes CO_2 transport, injection and geological storage [IPCC, 2006].
Incentives	EU	It will be possible to opt-in CCS in EU-ETS from 2008 onwards. Target of 10-12 full-scale demonstrations in 2015 (mechanism under discussion). A mandate on CCS in all fossil-fuel-based power production is considered for 2020.
	Netherlands	Investment subsidies for a number of CCS demonstrations.
	Norway	CO_2 tax led to CCS projects at Sleipner and Snøhvit.
	UK	Tender for CCS demonstrations with investment subsidies. Announced 9 October 2007.
General	International	Carbon Sequestration Leadership Forum - working on institutional, regulatory, and legal constraints and issues (www.cslforum.org).
	Australia	Carbon Dioxide Capture and Geological Storage Australian Regulatory Guiding Principles [MCMPR, 2005].
	EU	Zero Emissions Platform, Working group on policy, markets and regulation [ZEP, 2007].
	US	Department of Energy (DOE) Regional Carbon Sequestration Partnerships, FutureGen Draft Environmental Impact Statement (http://www.netl.doe.gov/technologies/coalpower/futuregen/EIS/).

4.2. Key unknowns

Vital information needed to create general governance capable of managing wide-scale commercial deployment of CCS is not yet available. Table 3 summarises key unknowns[8]. These unanswered questions act as barriers to comprehensive regulation in a variety of ways. For example:

Unanswered questions act as barriers to comprehensive regulation

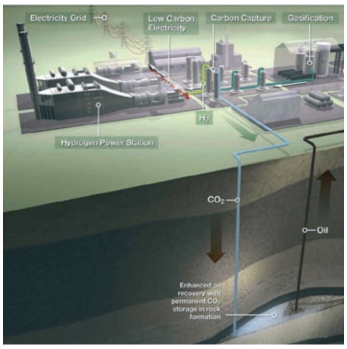
- health and safety regulators need a solid understanding of geological performance in a variety of geological settings and reservoir types in order to design monitoring and remediation requirements;
- permitting and acquisition of storage rights rests on adequacy of models to accurately project geological storage capacity, plume size and behaviour;
- the local public and health and safety regulators need confidence in monitoring methodology and remediation techniques to trust that any leakage could be detected and remediated; and
- project developers require confidence that CCS will be legal and profitable under a future climate regime and that they will be able to manage their liability.

Table 3: **Key unknowns for development of CCS regulations**

	Unknown
Capture and transport	1. Capture reliability, cost, energy penalty
	2. Effects of varying purity of CO_2 streams
Geological storage	3. Geological performance (leakage risk profiles) in a variety of geological settings and reservoir types
	4. Basin-scale impacts (fluid displacement, induced seismicity)
	5. Adequacy of models to predict reservoir performance at scale
Geological storage: operation and long-term stewardship	6. Monitoring methodology, detection limits
	7. Remediation techniques, costs
Socio-political and climate considerations	8. Industrial organisation
	9. Public acceptance
	10. Climate regime/incentive structures

[8] More details on the impact of key CCS unknowns can be found in the IRGC workshop report downloadable from http://www.irgc.org/Expert-contributions-and-workshop.html

CCS regulation must evolve as scientific and technical knowledge expands. An evolutionary regulatory process is required because full-scale CCS projects are urgently needed (and must be regulated), but key uncertainties prevent design and implementation of a comprehensive regulatory framework at this time. The first stage, essentially underway, will consist of several dozen full-scale CCS projects worldwide, operated under existing regulations modified to account for specific features of CCS. The second stage in the evolution of CCS regulation will use data from these early projects to design general CCS regulations to manage widespread commercial deployment.



Courtesy of BP

5.1. Learning from pilot projects

A dozen or so full-scale demonstration projects[9] are urgently needed, worldwide, to create the knowledge base upon which a comprehensive CCS regulatory framework can be built. Just such an initiative has been proposed by the EU, and commercial-scale projects are also in the planning stages in the US and Australia. However, because these early projects will be carried out in a variety of jurisdictions, under a variety of (perhaps insufficient) funding mechanisms, there is a substantial risk that, despite the best intentions, these early projects could be completed without providing the scientific and technical underpinnings needed for wide-scale deployment. To avoid this outcome, early projects should emphasise the collection and sharing of technical data to support decisions regarding regulatory framework, indemnification, liability transfer and operational standards [Wilson et al., 2007].

There is a substantial risk that, despite the best intentions, early projects could be completed without providing the scientific and technical underpinnings needed for wide-scale deployment

To obtain maximum learning value, early projects should:

- include a diverse portfolio of project types to prevent perceived “winning” technologies from domination;
- take place in a variety of geological settings;
- include comprehensive, well funded scientific and technical programmes;
- be characterised by extended regulatory and legal flexibility to maximise potential for learning by doing;
- provide transparent operation and fully public data availability; and
- be comprehensively and comparatively evaluated by independent reviewers.

[9] Unlike many current pilot projects that are small and short-term, these demonstration projects should operate on a commercial scale (a project must capture, transport, and inject a million or more tonnes of CO_2 per year) for time periods long enough to test for basin-scale responses in the reservoir.

Wellhead, In Salah Gas, Courtesy of BP

Full transparency and careful evaluation of results and experience from early full-scale CCS projects is crucial

Policymakers will need to institute specific policies and incentives to get early full-scale demonstration projects started; it is vital that these policies and incentives require projects to fully meet the objectives outlined above. Furthermore, care must be taken in designing incentive structures so as not to encourage the wrong things. For example, policy should reward CO_2 emissions avoided, not CO_2 stored. Governments or other actors may need to specifically subsidise site characterisation, monitoring, modelling, and verification programmes for these early projects to ensure that the research programme supports the development of general regulatory and legal frameworks for widespread deployment. Results from early projects are vital for development of geological, geophysical, geochemical and modelling methods necessary for effective site monitoring and verification (M&V) protocols, as well as mitigation and remediation plans [Wilson et al., 2007]. Thorough site characterisation and careful management for these early sites is also imperative, as poor site performance or accidents at early sites could cause disproportionate damage to the reputation of the technology.

Full transparency and careful evaluation of results and experience from these early full-scale CCS projects is crucial. An independent review group, with strong skills in project evaluation and decision analysis, could be convened under the auspices of a respected international organisation to provide a comprehensive, integrated summary of results from early CCS projects worldwide. This summary would facilitate development of general geological storage governance by bridging jurisdictional boundaries and providing policy makers and the public with an independent assessment of the technology.

Early CCS projects will require liability coverage. Apart from those risks related to climate change, all other CCS risks can be related to existing insurance experience. Insurers are likely to assess CCS project liability from three perspectives: Environmental Impairment Liability Coverage; Directors and Officers Liability; and, anything related to "impacts from climate change" (with this third already emerging as a source of legal action). Risks related to climate change present particular problems to the insurer and the insured: first, there is no clear damage definition, i.e. no well-defined impact; second, there is no universally accepted cost, and therefore compensation; and third, there is currently no legal regime on which to base claims. Early CCS projects that receive special treatment regarding liability considerations (e.g. government risk sharing) should, in return, make commitments to transparency regarding project performance, data availability and independent assessment of risks and performance.

5.2. Making the transition to general geological storage governance

A general regulatory framework for commercial-scale CCS, designed for transparency and ease of implementation, and based on the results of early full-scale demonstration projects, must be created for large-scale deployment. The transition from an early to a mature regulatory framework could be accomplished through continuous improvement within existing regulatory bodies; however, it may require the creation of institutional mechanisms to coordinate and integrate emerging knowledge and establish the long-term regulatory and legal framework. In either case, the goal is to guard against becoming locked into a suboptimal regulatory structure that was appropriate for early demonstration projects but is not conducive to widespread commercial deployment of CCS. In practice, both systems are likely to exist alongside one another, and there will be considerable experience from commercial CCS projects that will inform revisions of the underlying regulatory and institutional environment.

The goal is to guard against becoming locked into a suboptimal regulatory structure that was appropriate for early demonstration projects but is not conducive to widespread commercial deployment of CCS

The two-stage regulatory model presents several challenges. First, uncertainty over the ultimate shape of the regulatory framework creates concerns for the public, project developers, and project financial underwriters. A transparent, well-structured institutional mechanism to guide the transition could mitigate these concerns. Second, establishment of a date associated with the second stage of the process could be perceived, or abused, as a delaying tactic. Third, regulatory agencies around the world are seriously under-funded, which could create uncertainty over the commitment to review and revise initial procedures.

5.3. Assigning regulatory responsibility

Regulatory responsibility will vary worldwide due to differences in institutional architecture. Some functions will be assigned to local or state agencies and others administered at the national or regional level. There will also be a role for international coordination. Industry would prefer to operate under internationally harmonised protocols, and this becomes crucial if sites span international borders. Off-shore projects will be subject to international and regional regulation to an even greater extent than on-shore projects. Tight international regulatory coordination faces trade-offs with looser national or regional regulatory networks that could be nimbler in adapting to emerging technology.

Krechba. Courtesy of BP

Even those who would prefer to see the entire CCS regulatory framework coordinated at the EU (in Europe) or the Federal level (in the US, Australia, and Canada), to promote consistency, acknowledge that member states, provinces or states are likely to regulate matters related to site selection, ecological and human heath, and permitting, due to subsidiarity rules, property rights law, national emissions goals, and other factors. For example, in Australia, CCS is linked to energy policy, over which states have sovereign decision power. A benefit of this arrangement is that significant geological knowledge resides at the state level. A concern, however, is that regulatory capacities and funding levels vary tremendously between states.

Assignment of regulatory responsibility for injection, and for in-situ health, safety and environmental concerns is less clear-cut. Local regulators will probably play an important role in many jurisdictions. However, national (US, Australia, Canada) or regional (EU) environmental agencies could set minimum performance and technical standards for site characterisation, injection, M&V, remediation, and site closure requirements even where these will be administered at the local level. Environmental regulations must be coordinated and streamlined with industry regulations. Australia is taking a lead in this area [AGO, 2007].

International harmonisation of minimum standards and protocols is an important goal to be pursued as experience with CCS expands; it is more likely to be successfully achieved through persuasion and development of horizontal international networks of technical experts and regulators than through formal instruments such as international treaties. Private insurance rules also have a potentially powerful harmonising effect, as do GHG accounting standards linked to climate regimes.

5.4. Resolving long-term liability and responsibility issues

CCS requires CO_2 to remain in storage for hundreds or thousands of years; well beyond the lifespan of essentially all commercial endeavours. Regulations must therefore be created to manage issues of long-term liability and responsibility, including:

- Who will be liable;
- What penalties are likely to be imposed;
- What types of liabilities are relevant;
- How will long-term management and oversight be financed; and
- Which regulatory agency will oversee long-term stewardship?

Public assumption of long-term responsibility will most likely be required at some point after site closure, conditional upon proof that CO_2 storage is stable and behaving predictably. The logic is that nations are the only entities that can make credible commitments over such long time periods. If this model is implemented, regulations will need to specify the technical requirements both to qualify for ownership transfer and for when the transfer may take place. Researchers envision that a geological storage (GS) site, depending on reservoir capacity, would operate for 10 to 40 or more years before closure. After site closure, a post-closure interim period should be required, where the operator retains liability and monitoring verifies site stability. Post-closure liability period durations of several years to several decades have been suggested by various authors. In practice, a shorter period might be appropriate for a site that met performance goals during its operation period, while a longer period might be required for a site where performance did not align with performance goals or modelling projections. Transfer to public ownership at the end of the post-closure period would be conditional on the site behaving as expected; otherwise industry would retain ownership to remediate as necessary.

Expenses for long-term care of CCS sites must be funded during site operations

Slow long-term leakage would create liabilities within a climate regime even if it presents no health or environmental hazard. Understanding how diffuse leakage will be monitored and accounted for, and who is financially liable (the party generating the CO_2, the party injecting the CO_2 for storage, or the national government), will impact industrial organisation of CCS [de Figueiredo, 2007]. These decisions will have implications for all actors within the industrial chain, for those who insure site operators, and for those who take the investment and operational decisions, particularly in jurisdictions that include the concepts of public and directors' liability. Policymakers will need to provide technically grounded guidance on acceptable levels of CO_2 leakage from storage, and on definitions of leakage.

Expenses for long-term care of CCS sites must be funded during site operations. Several potential models to fund long-term care of CCS projects have been proposed. Operators could pay into a national stewardship sinking fund [Rubin et al., 2007], or an operator could pay into a dedicated fund for each site although, if each site must accumulate enough money to cover a worst-case remediation scenario, this would be unnecessarily expensive. If CCS is generally effective it would be more efficient to pool risk. Liability framework trade-offs are complex, but linking funding of long-term CCS liabilities to the industries that generate CO_2 will allow cost internalisation by the industry. Additionally, it is wise for industry as a whole to maintain responsibility, because of inevitable information asymmetries: even with high levels of transparency, industry will know more about CCS than regulators and the public. Insurance companies could play important roles in structuring the financial mechanisms to cover long-term liabilities.

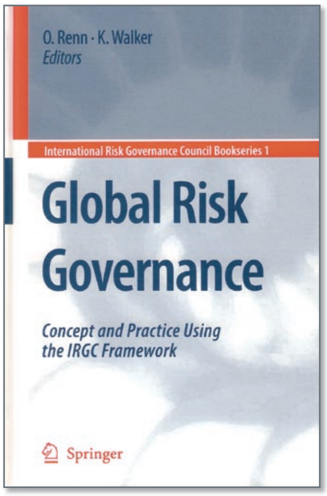
If a government is to assume long-term liability, should the same regulatory entity that is responsible for permitting through closure also assume long-term oversight responsibility? Industry would prefer the continuity of a single regulator: however, a second party would be more objective in assessing whether to accept transfer of liability to the public.

Public perception will be strongly influenced by experience with early projects, making careful siting and operation crucial

5.5. Working toward public acceptance of CCS

CCS proponents will need to earn the public's trust. Public acceptance will be necessary for widespread CCS deployment: to obtain public subsidies for early projects; to negotiate property rights issues to create large and legal storage units; to secure siting approvals; and, to resolve questions regarding public assumption of long-term post-closure liability. This issue is a significant unknown, as the public has not yet formed a firm opinion of the technology [Palmgren et al., 2004; de Best et al., 2006; ACCSEPT, 2007]. At this impressionable stage it is vital that actors who hope to see CCS achieve its climate change mitigation potential take care to ensure: reliable performance at early CCS sites; assignment of regulatory responsibility to trustworthy agencies; and, effective, transparent and science-based risk communication by regulators and industry.[10]

Public perception will be strongly influenced by experience with early projects, making careful siting and operation crucial. These projects must have broad science and technology components designed to answer key regulatory questions and their results must be publicly available. Assignment of regulatory responsibility to competent and trustworthy bodies or agencies will be paramount in assuring the public that the technology is deployed with adequate oversight and safeguards. Mature regulatory frameworks for CCS must incorporate effective risk communication to engage and educate the public, involve all stakeholders in risk-related decisions, and build confidence in the institutions governing CCS [IRGC, 2005]. This responsibility falls on both industry and regulators. Industry's conduct in the early stages of CCS will strongly influence public perception. Efforts to secure public assumption of long-term liability must take care to avoid damaging the industry's credibility. Arguments to transfer responsibility from project operators to the government too quickly, too completely, or without adequately funding post-transfer care, run the risk of undermining public acceptance. Finally, the public acceptance necessary to negotiate solutions to issues of long-term stewardship can only stem from the engagement and understanding that will grow out of political commitments to a climate regime (combined with increased CCS visibility from early projects).



[10] For more discussion of effective risk communication see *Global Risk Governance – Concept and Practice Using the IRGC Framework* [Renn & Walker, 2008]

5.6. Making CCS financially viable

Due to the high capital costs and long planning horizons of CCS projects, policy makers will need to implement sufficient and stable incentive structures to directly encourage CCS. Carbon cap and trade systems, such as the Kyoto compliance market, are one approach. While market-oriented strategies have many advantages, a serious disadvantage is that this approach appears unlikely to generate a strong and stable price signal quickly enough to stimulate the inclusion of CCS in a meaningful percentage of the more than 500 Gigawatts of new coal-fired electricity generation projected to be built before 2020 [EIA, 2007]. Commercial CCS projects are estimated to require sustained market prices averaging €30 per tonne of CO_2 avoided [Kema, 2007] (with construction costs putting constant upward pressure on that figure). Phase I of trading in the EU has seen allowances trading well below that level, and, while reductions in allocated quotas are expected to produce substantial and sustained price increases, questions remain over whether a cap and trade system can create the financial certainty needed for investors to promptly commercialise CCS in the power generation sector where large-scale emissions reductions are needed most urgently.

Development of a regulatory framework is necessary but not sufficient to catalyse CCS deployment. Economic and political barriers will also need to be addressed

A more direct approach to stimulate the commercialisation of CCS would be setting sectoral performance standards for electricity generation, mandating that some significant percentage of electricity be carbon free or meet specific performance standards. California's Greenhouse Gas Performance Standard [SB 1368, 2006] requires utilities' long-term electricity contracts to meet emissions standards of new natural gas combined cycle plants. It is hoped that this standard will help to encourage low-carbon power plant development to serve California's increasing electricity demand. The advantage of sectoral performance standards is that they are technology-neutral – allowing the market to choose which technology to build – and they allow for a more stable investment climate for constructing the large and costly infrastructure that technology such as CCS will require.

While the primary purpose of this policy brief is to explore the development of regulation to safely and successfully run CCS projects, such regulation is tightly bound to uncertain future climate regimes and to other incentive structures necessary to render CCS profitable. Thus, the development of a regulatory framework is necessary but not sufficient to catalyse CCS deployment. Economic and political barriers will also need to be addressed. In fact, regulations governing acceptable leakage rates, climate liabilities, and long-term stewardship cannot be finalised in the absence of a climate regime.

VI Policy recommendations

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The raison d'etre for CCS is to enable continued use of fossil fuels in a carbon emission constrained world. Benefits include economic competitiveness, energy security and a non-disruptive transition to low-carbon energy systems. The objectives of CCS are clear: CCS must be able to safely sequester large amounts of carbon dioxide (billions of tonnes) for a long time (hundreds to thousands of years). In order to abate atmospheric CO_2, CCS should maximise CO_2 emissions avoided. To achieve these objectives:

1. CCS regulation must:
- Establish a framework encouraging responsible operation and investment;
- Balance stability and predictability with flexibility and adaptability to new scientific information;
- Be based on solid technical findings; and
- Provide ease of implementation for both regulators and industry.

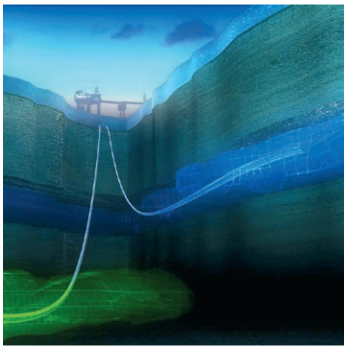
2. A diverse portfolio of full-scale CCS demonstration projects should be brought online as rapidly as possible, with broad government support. Demonstration project diversity and transparency should be encouraged through incentives and supported by regulatory framework development. For maximum learning value these projects should:
- Provide scientific and technical answers to key regulatory and legal concerns;
- Include a diverse portfolio of project types;
- Take place in a variety of geological settings;
- Operate transparently, with data fully available publicly;
- Employ harmonised monitoring, measurement and verification standards to enable cross-comparison of technologies; and
- Be subject to comprehensive and comparative assessment, with assessments made available to the public.

3. Site selection requirements for early sites must be especially rigorous, as this is the single most potent risk management technique. Furthermore, poor performance at early projects could cause disproportionate damage to the reputation of the technology. Licensing of these early storage sites should include demonstration of long-term predictable containment.

4. An evolutionary approach to developing CCS regulations should be adopted. Early CCS projects should be regulated under modifications to existing regulations. Results from early projects can then be used to create generalised CCS regulations to efficiently manage commercial deployment.

5. With the objective of building a regulatory framework for CCS, the following activities can and should be undertaken now:
- Public engagement and education;

- Development of generalised site selection guidelines;
- Development of generalised M&V protocols;
- Development of GHG accounting protocols for CCS;
- Improvement and standardisation of modelling techniques;
- Development of necessary modifications to existing regulations;
- Negotiation of specialised arrangements for long-term liabilities at a limited number of early sites; and
- Creation of financial incentives to get full-scale demonstration sites up and running.



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6. The following activities, vital for creating a mature CCS regulatory framework capable of managing widespread commercial deployment, cannot be completed until comprehensive, integrated technical results from early deployment are available:

- Determination of performance standards for geological storage;
- Establishment of links to carbon markets;
- Resolution of climate liability issues;
- Passage of legislation to structure long-term responsibility and liability for CCS sites, including mechanisms to fund long-term stewardship; and
- Establishment of an adaptive regulatory framework.

7. Full transparency and careful evaluation of results and experience from early full-scale CCS projects is crucial. An independent review group with strong skills in project evaluation and decision analysis should be convened, under the auspices of a respected international organisation, to provide a comprehensive, integrated summary of results from early CCS projects worldwide.

8. Political and economic barriers to CCS deployment must be addressed to create conditions where project financial backers can have confidence that investment decisions made now will earn a satisfactory economic rent, that a predictable regulatory framework will apply, and that liability issues will be resolved.

9. Effective risk communication by both regulators and industry is vital for public acceptance of CCS. Also, the public should be immediately and transparently informed of any event that indicates a problem with CCS. Any leakage or accident at an early stage in the development of CCS could have a long-term impact on the reputation of CCS: such events are better managed by open admission than by attempts to limit knowledge of them.

10. Development of a regulatory framework is necessary but not sufficient to catalyse CCS deployment. Economic and political barriers will also need to be addressed. In fact, regulations governing geological storage site performance, climate liabilities, and long-term stewardship cannot be finalised in the absence of a climate regime.

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Appendix

Commissioned authors and international teams for IRGC workshop on regulation of geological storage of CO_2 held in Washington DC, March 2007

- A Dialogue on Environmental Governance Arrangements for the Geological Storage of Carbon Dioxide, The Australian Greenhouse Office, (Canberra, Australia)
- A Proposal of Regulatory Framework for Carbon Dioxide Storage in Geological Formations, Semere Solomon, Beate Kristiansen, Aage Stangel, The Bellona Foundation (Oslo, Norway); Tore A. Torp, Olav Karstad, Statoil Research Center (Trondheim, Norway)
- Attributes of an Effective Regulatory Regime for CO_2 Geological Storage, Iain W. Wright, BP International, (UK)
- Regulatory and Policy Needs for Geological Sequestration of Carbon Dioxide, Edward S. Rubin, Sean T. McCoy, Jay Apt, Carnegie Mellon University, (Pittsburgh, US)
- Regulating Carbon Dioxide Capture and Storage, M.A. de Figueiredo, H.J. Herzog, P.L. Joskow, K.A. Oye, and D.M. Reiner, Massachusetts Institute of Technology, (Cambridge, US)
- Attributes of an Effective Regulatory Regime for Carbon Capture & Storage, George Peridas, Natural Resources Defense Council, (Washington DC, US)
- Carbon Capture and Storage: Risk Governance and Rent Seeking, Carlo C. Jaeger, Potsdam Institute for Climate Impact Research, (Potsdam, Germany)
- An International Regulatory Framework for Risk Governance of CO_2 Capture and Storage, Shalini Vajjhala, Resources For the Future (Washington DC, US); Jenny Gode, Swedish Environmental Research Institute (Stockholm, Sweden); Asbjorn Torvanger, Center for International Climate & Environment Research, (Oslo, Norway)
- Regulation for CCS Beneath the UK Off-shore and on-shore, Stuart Haszeldine, University of Edinburgh (Scotland)
- Environmental Impairment Liability Insurance for Geological Carbon Sequestration Projects, Christina Ulardic, The Swiss Reinsurance Company (Swiss Re), (Zurich, Switzerland)

All of these papers can be downloaded from http://www.irgc.org/Expert-contributions-and-workshop.html

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