A dialogue on environmental governance arrangements for the geological storage of carbon dioxide

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Reducing carbon dioxide emissions to the atmosphere

Australian Government

Department of the Environment and Heritage
Australian Greenhouse Office

Foreword

This paper has been drafted by the Australian Greenhouse Office, of the Department of the Environment and Water Resources (DEW-AGO), in consultation with the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) and members of the International Energy Agency Greenhouse Gas Research and Development Programme Monitoring Network (IEA GHG R&D Monitoring Network).

The paper presents topics for public consideration and aims to provide a representative and balanced treatment of the many regulatory related matters and options that arose in discussion on the first day of the IEA GHG R&D Monitoring Network's third meeting, held on 30 October 2006 in Melbourne, Australia. The discussion focussed on the monitoring, evaluation, reporting and verification (MERV) of geologically stored carbon dioxide (referred to in this paper as geosequestration).

It was reaffirmed at this meeting that geosequestration is one of the important ways of moving down the pathway of a low carbon future. The motivation behind drafting this paper is to discuss how geosequestration can be effectively delivered to a public that is still wondering how it all works.

The views presented in this paper are not intended to prejudice or pre-empt considerations on related matters, but rather to represent what was a healthy discussion on geosequestration governance arrangements. No text in the paper has been attributed to individuals or entities (including the Australian Government) and it does not represent the final views of all involved. All matters raised need to be considered within a larger context of domestic and international developments in the areas of climate change science and policy.

The paper contains three chapters. The first describes the policy context in which environmental regulators often find themselves operating in and offers some localised experiences from policy makers and regulators. The second chapter provides commentary from a facilitated dialogue on matters relating to MERV. The final chapter offers some closing observations on MERV.

Chapter One

Introduction

This discussion focuses on the application of geosequestration for the purpose of isolating CO_2 from the atmosphere and so help mitigate the adverse impacts of climate change.

Climate change has recently been described as the greatest market failure the world has ever faced[1]. Establishing a commercially sustainable pathway to the application of geosequestration is seen by many countries as one of the most important options to dealing with climate change.

Geosequestration is one of many mitigation strategies being explored to maximise the potential of the global community to avoid 'dangerous' climate change. At the low end of climate change projections, there is scope to adapt to the subsequent impacts. At the higher end of projections, there is a need to act in order to prevent dangerous levels of emissions. It is evident from the latest projections analysis that the anticipated consequences of global warming may be too severe for just adaptation or mitigation alone to be sufficient. It will probably require a combination of both.

The term 'dangerous' climate change stems from the United Nations Framework Convention on Climate Change (UNFCCC), and to date it has been largely defined by political judgements made within the context of national interests. The science continues to firm and provide evidence for such political judgements to be made.

With the Intergovernmental Panel on Climate Change's Fourth Assessment Report "Climate Change 2007" due for release soon, an increasing public awareness of the impacts of climate change is evident. This is especially true for the host country of the third IEA GHG R&D Monitoring Network meeting, Australia.

Climate change is a global issue and requires action so substantial and deep that it needs to accommodate the socio-economic and political circumstances of all countries. The challenge is how to engage all while still maintaining economic growth and development. Australia, for example, will be impacted upon over the coming decades due to its reliance on energy intensive industries and significant agricultural sector (which is experiencing its worst drought in over 100 years).

The objectives of global mitigation efforts

There are potentially many different and competing objectives that can be delivered by geosequestration, depending on the nature of the political judgements made. What does seem clear, however, is that a sequential introduction of low emission technologies (LETs) could be insufficient to

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[1] The Stern Review, November 2006

protect increasingly vulnerable emission stabilisation targets. It also appears insufficient to rely solely on market mechanisms to provide all of the answers.

This indicates that there is no ‘silver bullet’ to addressing climate change but rather there needs to be a combination of emission reduction strategies implemented in parallel over time (both technological options and policy mechanisms). The Carbon Mitigation Initiative Stabilization Triangles[2] framework describes such an approach, and presumes an objective of stabilizing emissions (rather than absolute emission reductions) at current levels by reducing total greenhouse emissions by at least 7 billion tonnes per annum within 50 years (and on an increasing emission base as population grows from 6.5 billion people today to 9 billion people by 2050). A combination of 15 identified emission reduction strategies (including CO_2 capture and geosequestration) are used to build seven stabilizing wedges to preserve a global CO_2 concentration of 550 parts per million by volume (ppmv). Larger wedges would be needed if the objective is to keep atmospheric concentrations of CO_2 below this level.

Recent IEA analysis[3] suggests that the CO_2 capture and geosequestration ‘wedge’ will need to deliver about 15-20% of the total mitigation effort (or emission reduction possibilities).

International scene for environmental regulations

Senior public officials from the United States of America (US), the United Kingdom (UK) and Australia presented on their national approaches to regulating the monitoring of geosequestration. This also included some discussion of progress being made by the EU.

Policy makers increasingly find themselves at the cutting edge of making recommendations with regard to the enabling infrastructure for geosequestration. There is a balance to be struck between over regulating (which would limit the extent to which geosequestration activity occurs) and under regulating (eg. for resource management only and not environmental management). Regulating with realistic expectations is important, especially when regulators acknowledge that geosequestration sites will likely experience some form of storage integrity failure (leakage to atmosphere or seepage from the reservoir into other strata) over time – albeit very small volumes, very slow rates and not instantaneously catastrophic. This suggests that such failures can be remedied in a timely and safe manner.

There is also little ability for any one geosequestration pilot or demonstration project to completely assure regulators of storage site integrity (in terms of storage security over potentially thousands of years) given the diversity of operational conditions and much shorter time frames than commercial projects. This may indicate value in bridging the pure research and development (R&D) focus of such projects with an ‘applied’ outlook of

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[2] Princeton Environmental Institute, Princeton University

[3] IEA Energy Technology Perspectives 2006 – Scenarios and Strategies to 2050

assisting regulators establish objective and science based performance criteria to enable the deployment of geosequestration in a safe and dependable manner.

It is also unlikely that CO_2 streams (to be injected) will be consistent in their levels of purity. This applies to CO_2 streams across different projects, or over time for any given project. Some impurities are likely to increase monitoring requirements (eg. H_2S, SO_2), whereas other impurities are likely to be less problematic. All of these circumstances need to be embraced within a regulatory learning process.

The United States of America

The US Environmental Protection Agency (EPA) oversees the Underground Injection Control (UIC) programme (which has been operational for over 30 years now). The programme includes permitting arrangements for all injected fluids (the EPA recommends that all geosequestration projects are authorised by permit) and subsequent greenhouse gas inventory obligations.

The UIC identifies individual states as the primary enforcement authority which operates under minimum Federal requirements (which states can expand if they choose).

In 2004 the EPA started exploring the options for regulating geosequestration and they established a working group to identify the options, publish proposals, review public comments and issue regulation. The UIC and subsequent EPA efforts could provide a substantial analogue for environmental regulatory agencies around the world looking to explore regulatory mechanisms for geosequestration.

The EPA regulatory oversight has as its development goals the protection of humans and the cost effective regulatory decisions which are fully protective of the environment. In order to be able to apply new and improved methods to protect the environment, the agency undertakes scientific and economic analyses to support regulatory decisions.

In a practical sense, the EPA's focus is on risk assessment and to ensure R&D activities essentially self regulate. The EPA's role is to determine the type of regulatory action required, and for geosequestration this includes the type of monitoring systems implemented, the areas of review and well construction. Modelling is extensively relied upon to aid permitting decisions.

The EPA has identified the following key technical questions which need to be addressed before geosequestration activities can be permitted (consistent with regulatory requirements):

- are storage mechanisms fully understood? (ie. regulation needs to address well siting);
- will there be leakage from the geosequestration system? (ie. regulation needs to address construction and cementing of wells);
- can the sub-surface CO_2 be monitored and verified? (ie. regulation needs to address monitoring including pressure, volume and temperature of injected fluids);

- can wells and long term storage and closure arrangements be permitted? (ie. regulation needs to address proper closure including financial responsibility for post closure care);
- will the EPA regulate for zero leakage or for a maximum permissible level of leakage?; and
- what level of remediation would be required to prevent leakage from abandoned wells close to the proposed geosequestration site?

The EPA has also considered inventories for geosequestration activities and has settled on the following high level principles:

- emission reductions are counted at the capture sites;
- fugitive emissions are accounted for throughout the capture, transport, injection and recycling; and
- emission reductions from enhanced oil recovery without monitoring systems will be counted as 100% emitted.

Australia

The Australian Government has made geosequestration a clear priority identifying Australia's preferred role as a 'market leader' in this field. This established the need for decisions surrounding MERV and the regulatory conditions required for it, which Australia is currently exploring.

Industry in Australia has also taken a progressive approach to demonstrating geosequestration, in response to current and anticipated future government policy. This suggests that issues surrounding permitting approvals will need to be resolved sooner rather than later.

Post site closure arrangements are recognised as potentially the most substantial barrier to the implementation of geosequestration. While industry already reports to regulatory authorities on health, safety and environment (the sufficiency for future geosequestration regulations still needs review), if regulators approve the closure of a geosequestration site that fails due to insufficient or inappropriate monitoring systems, public acceptance will likely evaporate for this important mitigation option.

The Australian Government recently announced substantial funding support for several geosequestration related projects (among others) through its AUD$500 million Low Emissions Technology Demonstration Fund (http://www.greenhouse.gov.au/demonstrationfund/index.html). These projects are due to commence operations soon, and so a MERV strategy needs to be developed for all of these projects - this is an important input into the debate on how commercial scale geosequestration projects should also be regulated.

The Australian Greenhouse Office, in the Department of the Environment and Water Resources, considers it important that state-based environment authorities be engaged in the development of MERV strategies to ensure consistency across regulatory frameworks. This paper is a first step in a shared dialogue to identify the principles and issues that need to be drawn out.

The Australian Government is supporting a trial geosequestration project called the Otway Basin Pilot project (OBPP). It aims to substantially increase Australia's capacity to monitor geologically stored greenhouse gas emissions under Australian conditions.

The OBPP is also an important project for regulators in that it is situated in a settled rural area, and is a relatively small and controlled project (injecting 100,000t CO_2). It affords regulators some flexibility to see how it all works (the project has been approved by the state of Victoria on the basis that it is an R&D project) and time to build confidence in its application. The project involves substantial stakeholder consultation (and has established a contact group) and engages regularly with the local community.

Further, the project is providing for emerging interests in geosequestration activities. The insurance sector, for example, is increasingly exploring the commercial aspects of geosequestration related products and services including assessments of reputational risk. The current concern for this industry seems to reflect more the operational health and safety risks (similar to most industrial activities) and not so much the integrity of underground storage (as it perceives the risk of sudden and accidental pollution is low).

The United Kingdom

The UK is currently focusing on the legal and regulatory barriers to geosequestration activities (such as supporting an amendment to the London Protocol to specifically include geosequestration). Given the UK's support for market mechanisms to encourage emission reductions, it is exploring how geosequestration can be recognised within the guidelines of the European Union Emissions Trading System (EU ETS). A publication on the monitoring and verification guidelines is expected soon, and will have an aim of maintaining the integrity of the overall EU ETS emissions cap (budget).

Similar to Australia's situation, the UK has several projects likely to commence soon (including financial investment decisions) and companies are requesting advice from authorities regarding what a monitoring system would need to look like.

Although the UK Government has not nominated a single entity as lead for assessing a monitoring programme, the British Geological Survey (BGS) is a source of expert technical advice and is demonstrating stewardship in this area.

The European Union (EU)

The EU Climate Change Programme (ECCPII) has also established a working group on geosequestration. In June 2006 it produced a set of recommendations including a review of the potential, economics and risks of geosequestration. The ECCPII will also identify the regulatory needs and barriers and explore the elements of an enabling regulatory framework for the development of environmentally sound geosequestration.

Further, at the end of 2007 the European Commission will produce a Communiqué on the permitting of geological sites including risk management site selection, operation, monitoring, reporting, verification and post site closure (including liability for leakage).

The IEA monitoring tool

The IEA monitoring tool (www.co2captureandstorage.info) is an example of a 'fit for purpose' system that can give regulators an appreciation of the extensive range of choice and state of knowledge of techniques for specific geosequestration sites (onshore, offshore, preinjection, injection, operation, site closure, subsurface, near surface and atmospheric).

The tool was developed by BGS to list and rank suitable technologies but is not prescriptive nor does it set conditions for monitoring. The aim of the tool is to identify a range of techniques that can image and track CO_2 in the subsurface, verify in situ mass of CO_2 and quantify leakage rates. It is important to be able to detect early warnings of leakage and understand better the potential health and ecological impacts of potential leaks.

There exists a great diversity of monitoring techniques – around 50 have been identified relevant for CO_2 monitoring within this tool. The techniques are categorised as follows:

- seismic;
- sonar;
- gravimetry;
- electric/electro magnetic;
- geomechanical;
- remote sensing;
- ecosystems; and
- others.

By characterising the storage site, monitoring over a defined period can identify conformance or non-conformance with expectations. This tool will provide guidance to interested parties on monitoring options but will not to determine how much monitoring over what timeframe is sufficient. These are largely the responsibility of policymakers and regulators, and are still to be defined and articulated. It may also be a practical reality that a storage site cannot be monitored forever and this becomes another critical consideration for enabling site closure.

Chapter Two

Facilitated dialogue

This chapter is based on a professionally facilitated afternoon of informed and free flowing dialogue, engaging a broad range of international and domestic environmental and industry regulators, CO_2 storage researchers, policy makers and industry.

A number of key matters were explored in relation to geosequestration and environmental regulations. For example:

- the extent to which public confidence in geosequestration may determine its future success as a mitigation option and as a fledgling industry. Also, the complexity of portraying regulatory decisions to a public still wondering how geosequestration works;
- the nature of existing regulatory analogues that may have relevance to geosequestration activities including the nuclear energy sector, waste and mining industries, and the lessons that can be gleaned;
- the capacity of monitoring technologies to deliver on the fundamental elements of geosequestration deployment. For example, what are the threshold performance parameters that need to be observed within the two monitoring frameworks of assurance (which generally includes atmospheric and near sub surface or soil gas sampling) and integrity monitoring in the deep sub surface;
- the minimum performance standards to be imposed on operational storage sites, including the development of performance standards for pilot projects (which is a relatively controlled research environment) and commercial scale projects (which are less likely to conform to previously established laboratory expectations); and
- the preferred type of liability regime to be adopted by regulators (ie. strict liability or negligence with respect to the risks associated with failure of storage integrity).

Consistent with the overall concept of ‘acceptability’ is the nature of the premiums that insurers, politicians and the community will place on the perceived risks of geosequestration activities – and the ability of regulators to accommodate these values in a relatively light handed way.

A regulator’s environment

The current extent of experience among environmental regulators in geosequestration activities seems to vary from granting approvals for R&D activities (usually at pilot scale), recommending to Ministers the conditions in which permitting approvals might be based for significant projects (large financial investments in projects requiring full environmental impact assessments) to issuing regulatory permits (as per the UIC).

While R&D approvals seem to require less regulatory compliance (due to the small scale of most activities and matching any high probability of failure with low adverse consequence), the nature of the approval process for geosequestration will continue to evolve over time as both scale and the number of activities increase.

Technical expertise in geosequestration is not often found among the regulatory community and so there is a need to cross reference the regulatory debate. How to skill up in a comprehensive and timely way will be a key challenge for all environmental regulators. This will likely create a high propensity to compare prospective geosequestration arrangements with existing and parallel activities (such as waste management and protecting potable drinking water etc). Some of these regulatory analogues have over 30 years of experience to draw upon, and depending on a particular country's approach to regulatory development, can provide invaluable and relevant historical experience.

For example, the UIC programme could be seen to be particularly relevant to countries with similar governance and market arrangements, where there is also similarity in terms of regulatory requirements.

Also, many regulators are already familiar with approving the injection of waste substances underground (ie. under mining and petroleum legislation). It is the coordination of the various processes that is important, including how people are consulted and informed when making regulatory decisions. This means identifying clear objectives through the regulatory processes, and building trust through transparency and efficient and accessible communication tools.

Regulators seek to deliver on a number of objectives, including identifying and understanding the most chronic risk of incident and the options for mitigation, remediation and/or rehabilitation. For example, the four key considerations of an environmental impact assessment include:

- identifying the key environmental values that are to be protected from a likelihood of 'dangerous' failure (such as minimising or preventing damage to climate; contamination to groundwater etc);
- understanding what the key risks are and how they can be managed and/or mitigated (this includes defining what the role of monitoring is as a management tool);
- securing commitments (from the operator) to the agreed options for mitigation, remediation and/or rehabilitation; and
- ensuring consistency with existing regulatory mechanisms and procedures, and providing transparency in their review (including the development of a standards based monitoring system).

There should be multiple mechanisms to either prevent leakages and/or contamination to the environment and/or allow for their effective management. The regulatory performance standards that industry will ultimately be persuaded to accept will likely reflect at a minimum the expectations of the broader community. While industry typically reflects on the impacts of regulation from an economic perspective, the broader community will sometimes impose broader (and often less well defined) objectives. For example, intergenerational equity is often cited for activities taking place today that endure over generational timeframes, but aspirations are rarely articulated within that context.

In a presentation at the 2006 IEA Greenhouse Gas Technologies Conference in Norway, the formation of community expectations was presented as a function of the perceived benefits of undertaking geosequestration activity (including environmental values such as benefits of storage to mitigating the impacts of global warming, socio-economic benefits of continued fossil fuel use etc) less the perceived risk levels of geosequestration activity (including a combination of a ‘dread’ factor should something go wrong and a general fear of the unknown).

Regulators are well aware of how essential community confidence in geosequestration will be in deciding how to regulate related activities and that building community confidence is an ongoing and resource intensive process. It is often a dynamic iterative process whereby public preferences change over time according to the public’s level of understanding and the nature of events that occur in the interim. The consequences of leakage may also change over time (the impacts on climate change of leakages today may be relatively benign when compared to the same rate of leakage in a hundred years time).

Like the community, regulators also need to build confidence in geosequestration applications.

Challenging conventional wisdoms

While industry may have well evolved environmental, health and safety permitting regimes for the extraction and/or injection of substances in the geological sub-surface (such as wastes, minerals, petroleum, oil and gas legislation), these may not necessarily be directly applicable to CO_2 storage as the long term containment of pressurised fluids underground presents a range of new considerations. This has unique implications from a monitoring perspective, particularly for long term stewardship.

It was observed that over the medium term the scale of geosequestration could be prospectively many times more than the current levels of oil and gas production and this raises some serious questions about water displacement, adequacy of pipeline infrastructure to optimally connect captured emissions (and location of sources) with CO_2 storage.

As an example, Australia’s storage potential of $125MtCO_2$ per annum translates to about 900 million barrels per year of supercritical CO_2 (or about 2.5 million barrels a day). This is equivalent to re-injecting for storage purposes about 50% of the country’s total annual oil production. This may be a relatively conservative estimate if extended globally.

The potential for large scale deployment of geosequestration signifies a need to either further integrate environmental areas into existing legislation to accommodate geosequestration activities or to consider separate regulatory approaches to geosequestration deployment. It is evident that the regulatory community (including individual government departments) understand very well their own regulatory responsibilities, but to avoid regulatory overlap there may be value in having one focal point within government to facilitate and coordinate a whole of government approach to regulatory approvals.

Regulators recognise that they are often charged with ensuring delivery of broader objectives than just the safe implementation of the activity at hand (eg. provide assurances to the community rather than just regulate for the anticipated adverse impacts of an injection stream).

This often means that no fixed views can be held about what the extent of the monitoring systems should be to provide the community with the assurances that policy objectives can and are being met. What is often required is a flexible approach that addresses the causes and considers the environmental effects of specific adverse events. It is the nature of the risks that will drive the regulatory conditions that define what monitoring systems need to be in place.

Further, the establishment of a monitoring system for geosequestration will need to deliver on the overall policy decisions surrounding its implementation. This includes consideration of what role technologies are expected to play (a minor or major mitigation role in terms of scale and duration) and how they will be given effect (ie. through mandated requirements, carbon taxes or subsidies, trading registries etc).

As atmospheric concentrations of CO_2 increase overtime, the earth's capacity to absorb further emissions will be diminished. Future CO_2 emissions will therefore have increasingly and proportionately larger impacts on climate change. This may signify the need for early action on geosequestration despite the potential for leakage.

In addition to the environmental impact, there is a financial risk associated with even small leakage rates. For example, if 1% of 2,000 $GtCO_2$ storage[4] leaks over 100 years, at a carbon dioxide price of US\$40tCO_2, this could equate to a liability with a net present value of greater than US\$250bn (at a 3% social rate of discount).

It would seem that political decisions will largely decide whether or not the public benefit of geosequestration deployment exceeds the likelihood that the cost of liabilities will be realised. This will ultimately depend on political decisions that go to define what "dangerous climate change" is, as well as the perceived costs and risks of action (relative to inaction) that is in a nation's interest.

A major challenge for regulators is to try to strike a balance between ensuring the integrity of CO_2 containment from a number of perspectives and acting early enough to realise the benefits to the atmosphere of isolating the CO_2.

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[4] IPCC's most conservative storage potential estimate.

Integrity of CO_2 containment

The effectiveness of applying geosequestration activities to reduce the rate of emissions from fossil fuel use to atmosphere will depend on the ability of future governance arrangements to deliver some fundamental outcomes.

One of these outcomes is a socially acceptable performance target for rates of emission leakage. Such a target would encompass multiple policy objectives that governments deem important.

There is broad acceptance among regulators that there is no perfect storage site or injection stream. What is less accepted is the regulatory approach that should apply to such activities. For example, should geosequestration be regulated as a 'perfect' site (ie. forced to meet laboratory standards) recognising that there will be a high likelihood of some form of non-catastrophic (ie. small and slow rate of leakage) storage integrity failure at some time in the longer term, or should it be regulated for an 'acceptable' performance and so be designed to optimise the remedial possibilities of expected and manageable storage integrity failures.

The term 'rate' implies magnitude and frequency relative to a time unit. The IPCC suggests the following aspiration rate: a 90-99% probability that the fraction retained will exceed 99% over 100 years and/or a 66-90% probability that the fraction retained will exceed 99% over 1000 years.

While public confidence will require establishing an acceptable leakage rate for storage sites, agreeing to a performance target will remain a challenge given the difficulty of measuring the environmental and economic impacts of anthropogenic emissions at any point in time. This uncertainty could potentially result in over-regulation of geosequestration activity. An alternative approach may be to pragmatically progress the implementation of geosequestration through the concept of best practice.

The best practise approach appears to have been embraced in Canada where the Federal Government (through Environment Canada) – in agreement with the provinces – has started to develop non-prescriptive protocols specific to CO_2 storage environments (such as saline aquifers, enhanced oil recovery, enhanced gas recovery, and enhanced coal bed methane) offering quantification procedures based on best practice. Jurisdictions then use these in their own approvals procedures.

Environmental regulators generally consider it important to mirror regulatory conditions for geosequestration activities with comparable mechanisms for existing analogues as far as is practicable to do so (an alternative is to hold other analogues to a similar level of requirement as could be expected of geosequestration activities).

It has been noted that analogues to geosequestration activities already exist under minerals, petroleum and oil, and gas legislation. Examples of this include the decommissioning of old injection wells and the economic lives of oil and gas projects (which span over about 25 years). This is in contrast with CO_2 storage projects that need to maintain their storage integrity over hundreds if not thousands of years, and involve injecting large volumes (not extracting) of high pressure CO_2 for long periods of time (say 40+ years).

A substantial regulatory challenge is coupling the technical scope to detect, quantify and attribute leakages from a storage site with the need for early abatement action. Some of these aspects will not always be deliverable either due to the scale of leakage (ie too small a volume or too slow a leakage rate) or simply that such requirements extend beyond the scope of current technology (quantification). In such circumstances, regulators still need to ensure compliance with the overall policy objectives, and in the case of geosequestration, this is the large scale isolation of emissions to atmosphere from fossil fuel use.

For example, the single most important critical success factor for geosequestration is selecting an appropriate storage site. This means characterizing the site well, understanding what the risks are to CO_2 containment and monitoring these risks to provide the information needed to remedy any adverse situation well before it occurs. If during injection non-conforming events occur relative to the modelling, then injection activities would cease and enhanced monitoring processes commence.

Key design considerations - monitoring, evaluation, reporting and verification (MERV)

A key question is how much data is sufficient to satisfy regulatory expectations of baseline establishment (ie. volume and nature of injection stream) and subsequent CO_2 plume management. This may suggest that more intensive and continuous monitoring systems are required early when upfront data requirements are high (when undertaking complex risk assessments) and less integrated systems required later if (and when) it has been established that the site is behaving predictably after injection has ceased.

In exploring the options for establishing MERV systems, there seems a general consensus by discussion participants that the onus of proof should rest primarily with the operator. In giving effect to this, the following considerations may apply:

Monitoring – the regulator would publicly publish performance standards, agreed protocols or best practice guidelines (on matters such as fluid pressure, volume, temperature, leakage and seepage).

Evaluation – assessments would need to be provided to governments (or accredited regulatory agencies) for approvals and permitting processes, and be consistent with the above information generation protocols and requirements.

Reporting – governments (or accredited regulatory agencies) would need to provide guidelines to operators on minimum reporting requirements.

Verification – in order to prove compliance with performance and reporting standards, and to maintain certification of storage integrity, the operator would need to have its monitoring results independently verified. The establishment of accredited and reliable independent verification resources would be required.

Post site-closure arrangements – the above operational compliance arrangements for MERV would serve to establish minimum expectations among regulators that the integrity of the site over time has been maintained at an acceptable level. If the site is verified as not being worthy of closure, then this presents serious issues not only to the public authority (who may seek compensation for damages, commitments for remediation and/or rehabilitation) but may also stifle or prevent an eventual efficient transfer of ownership from private to public interests.

The long term ownership of stored CO_2 and liability for future leakages remains an area of uncertainty. There seems to be a general view, however, that it should be government that accepts responsibility for the long-term liability (post closure) as it alone will have the endurance, the resources and responsibility to protect national interests.

Accounting – greenhouse gas accounting is already a policy requirement for most industrial applications and is used to inform government, the public and markets. In the case of geosequestration this would at the very least have to confirm that the stored CO_2 is not re-entering the atmosphere, or if it does, be able to quantify and attribute it to a source.

Technologies will therefore need to be able to detect and measure even small amounts of leakage, which may be hard to distinguish from other natural and industrial sources in the atmosphere. This makes atmospheric monitoring essential for accounting purposes and public assurance.

Industry development – regulators are well aware that the geosequestration industry is in a very nascent stage and future regulatory requirements could choke or adversely affect its market structure. For example, although firms could be vertically integrated, it seems unlikely that it would be to the benefit of a competitive geosequestration industry for an oil and gas producer, fossil fuel generator and/or industry to establish upstream and downstream subsidiaries to produce (capture), distribute (transport), operate (inject) and market a CO_2 storage facility (which may need to be made accessible to all emitters capturing their CO_2). In any case, whatever the structure a fledgling geosequestration industry may evolve into, it will need to allow for the appropriate attribution of liability and transfer of ownership of CO_2.

Chapter Three

Closing observations

A substantial effort is still required before policy makers, regulators and technicians have a shared vision as to what the end state should be for monitoring, evaluation, reporting and verification systems. It is likely to require all interests to articulate positions on the following considerations (among many others) and a process of dialogue and negotiated compromises ensue:

- public and private sector appetites to realise the benefits and/or underwrite the risks associated with geosequestration investments;
- economic cost of geosequestration deployment;
- technical and intertemporal scope of MERV options;
- nature of environmental services being delivered (ie. climate change, water quality etc) and the extent to which society relies upon them; and
- social willingness to pay and the general public's acceptance of risks.

The following principles intuitively revealed themselves in the broader discussion and may serve to provide a discipline to further exploring the above issues:

- equity (who bears the intergenerational risk?);
- efficiency (is this commercially attractive?);
- independence (of assessment and the public will demand this);
- dependability (is there permanent CO_2 isolation from atmosphere?);
- transparency (needs to be science based, inventory reporting);
- flexibility (objective site by site requirements);
- consultation (all stakeholders, general public); and
- others (compatibility, consistency, comprehensiveness etc).

This dialogue on MERV clearly served to help establish professional connections between environmental regulators, technicians and policy makers, both domestically and internationally. For example, there was general consensus and enthusiasm among Australia's federal and state public officials to work more closely together to ensure a consistency of regulatory approach and to share a continuously expanding knowledge base.

The basis of design of a regulatory framework was clearly identified as a crucial point for regulatory consideration – what are policy makers trying to deliver on, what are regulators trying to ensure compliance to, and is the technical scope of scientific knowledge sufficient to implement in a timely manner.

There were many parallels identified with many other regulatory processes (or analogues) such as waste and mine dumping issues.

There is an acute awareness that community standards will change over time and transparent and open regulatory processes are essential to bringing along the community. This is a very powerful message and suggests that regulators need to be flexible and not too prescriptive (ie. promoting objective based management depending on the component being considered).

A dichotomy also exists between the monitoring requirements for a market (say for resource management) and for environmental outcomes (say the protection of environmental values). The extent to which monitoring and verification systems for health and safety can deliver on the economic and environmental aspects is still to be tested at a commercial scale.

Finally, ambitions of stabilising future atmospheric concentrations may require geosequestration to be applied before theoretical consensus can be reached on relevant leakage rates and time frames for storage integrity.