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POLICY GROUP
TECHNICAL GROUP

Report on the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide

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CSLF IS GOING GREEN*

REPORT ON THE WORKSHOP ON RISK AND LIABILITY OF GEOLOGIC STORAGE OF CARBON DIOXIDE

Note by the Secretariat

Background

The CSLF, in collaboration with the International Energy Agency and the Global CCS Institute, conducted a workshop in Paris on July 10 and 11, 2012 to improve understanding of geological risks associated with CO_2 storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. The outcome is this report.

Unclear financial liability for geologic storage, particularly in the long-term, post-closure project phase, can be a barrier to investment in Carbon Capture Utilization and Storage (CCUS) in many jurisdictions. Such financial liability depends, in part, on the geologic risks. Recognizing this interdependence, the Technical Group Risk Assessment Task Force (RATF) asked the CSLF Policy Group for guidance on what information should be provided by geoscientists in order to address financial liability. This workshop was conducted in response to that request.

Attendance in the workshop was by invitation only and included experts from around the world with diverse backgrounds required to address geologic storage risks and liabilities and their relationship. The agenda allowed ample opportunity for discussion, and all attendees were encouraged to contribute to all discussions. The agenda included sessions on each of the issues and perspectives necessary to address the relationship between risk and liability.

Action Requested

The Policy and Technical Groups are requested to consider the report and recommendations from the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide.

* **Note:** This document is available only electronically. Please print it prior to the CSLF meeting if you need a hardcopy.

Report of the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide

Paris, France, July 10 and 11, 2012

Table of Contents

EXECUTIVE SUMMARY

This report is a summary of the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide (CO_2) held in Paris, France on July 10 and 11, 2012. The relationship between the risks of geologic storage and the financial liability of those conducting such storage is critical to the commercialization of Carbon Capture Utilization and Storage (CCUS).

The purpose of this workshop was to improve the understanding of geological risks associated with CO_2 storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. After an opening session to set the scene of the broader issues, six substantive sessions were held.

Session 1: Introduction and Scene Setting

Senior representatives of the three sponsoring organizations defined the broader issues and related those to the overall context of CCUS deployment. They made several key points:

- Deployment of CCUS is a critical global need.
- CCUS deployment faces significant business challenges.
- It is vital to balance risks and opportunities in order to ensure deployment.
- Progress toward CCUS deployment is too slow, but can be put back on track.
- Risk communication is critical.
- Information on geologic risks is needed for liability decision making.

Session 2: Geological Risks

This session addressed how geologic risks are measured by geologists and geological engineers. Several presentations addressed how geological risks are estimated in different regions, the current state of knowledge about the risks of geologic storage, and how these risks vary by region. This was followed by an open discussion of the issues. Comments participants made in this session included:

- Geoscientists have a specific definition of risk that multiplies the probability that an event will occur with the consequences of that event. Liability may occur if a consequence is considered a harm.
- Risk may change as a function of time and is partly a function of the pressure in the underground formation into which the CO_2 is injected. Risks are expected to increase with pressure during injection and then level off. Once injection ceases, the pressure decreases and risks diminishes. This relationship, however, may not occur if existing wells penetrate the storage formation.
- Risks and initiatives to address them differ regionally. In Australia, many risk assessment have been conducted in different formations. North America has different risk issues from elsewhere in that millions of oil and gas wells have been drilled, Enhanced Oil Recovery (EOR) with CO_2 has been found to have high potential and much of the subsurface is privately owned. In Europe, a large share of the injection may take place under the ocean. In China and other developing countries, risk assessment is in an early stage of development.

Return to Report Contents Page

- While much is understood about geological risks, geology is complex and the current state of knowledge has limitations, including in the understanding of:
  - Long-term storage behavior;
  - Interaction of different storage facilities;
  - Induced seismicity; and
  - How risks interact, especially in non-EOR situations.
- Work to improve the state-of-the-art of geologic risk assessment is taking place globally.
- Methods are available to mitigate actual geologic risks, for example, for stopping any leakage.
- Public perception of risk is very different from the actual risks as geoscientists estimate them. The public tends to focus on low-probability but high-consequence events.

<u>Session 3: Industry Perspective</u>

This session addressed business risks and potential liabilities, how these are evaluated for business decisions and what this means to the different industries. An open discussion followed brief presentations. Comments made by participants included:

- Risk analysis and management must cover the entire project life cycle from pre-injection, through injection and closure to post-closure. Mitigation plans must be in place before injection starts and must have two key aspects, the prevention of leaks and containment in the event of a leak.
- Many independent safeguards need to be in place, some of which are passive and always in place, and others that are active and only implemented when they are needed.
- Risk analysis is an inherent part of site characterization and selection. The total level of risk needs to be low enough with adequate safeguards in place or available to make a site acceptable.
- From a business perspective, liabilities cannot be either unlimited in size or indefinite in term.
- Electric utilities have to deal with many risks as part of normal operations. As they gain experience with the risks related to CCUS, they will learn to manage those risks.
- Regulatory risks are always greater when regulatory frameworks are immature. Some regulators do not yet understand the complexities of CCUS.
- The value chains for CCUS and how these will allocate business risks have yet to be developed.
- International standards for CCUS may help develop confidence in CCUS
- Creating public support for CCUS will be a challenge and the security of geologic storage is just one issue. Trust and credibility by those involved in CCUS is critical to public support for CCUS.
- While most liabilities during project operation are insurable, the post-closure period is not; liability needs to be transferred to the government during that phase.

<u>Session 4: Economics of Liability</u>

This session considered liability for geologic storage, how risks are valued and how the industry insurance and banking sectors address liabilities. A discussion followed scene-setting speakers from industry, government, insurance and investment banking. Points made by participants included:

- The probability of leakage from a properly-selected storage formation is not great and, if there are leaks, there are ways to deal with them. EOR with CO_2 is better understood and has lower costs than geologic storage without EOR.

- Methods exist to quantify the potential financial damages from geologic storage and can be used for industrial, financial and regulatory decision making.
- Geologic storage must be treated as a business. If CCUS is high risk and low return, it will not be viable.
- How the financial risks are allocated the CCUS value chain has not yet been determined, in part because how the commercial value chain will be organized has not been determined.
- The market for insurance coverage during the operational phase of storage has developed just recently and premiums are coming down.
- The insurance industry can cover many aspects of geologic storage, but no insurance coverage will be available for long-term, post-closure storage.
- When injection is taking place, money is coming in to the project to cover liabilities. When injection stops, however, the money stops. Whatever is done to mitigate risk after that has to be financed from money that was set aside earlier.
- Investors will not now finance a large CCUS project, but perhaps will in the future. Lenders will not take unquantified liability risks on storage.
- There are operators who will store CO_2 underground and get paid for that.

Session 5: Government and Policy Responses

This session addressed government policy, the issues encountered by governments in addressing liability and their approaches to risk and liability. Discussion followed speakers from several governments and multilateral development banks. Comments made by participants included:

- Governments throughout the world are working to address issues of risk and liability, each in a way that reflects local circumstances and legal-regulatory frameworks. Different countries have different appetites for taking on the risks of CCUS projects.
- While multilateral development banks have not yet been asked to fund CCUS projects, they have high environmental standards and are working with their client countries to build capacity and assess opportunities. Issues of long-term liability will have to be addressed in any projects they finance.
- Standards should promote efficiency and reduce costs. The motivation should be to demonstrate to the financing community what the future economic value will be.
- Liability relief is a form of subsidy, but it is a very modest one.
- If the carbon price were right, we would have no problem getting CCS projects financed. The perception that you might lose all the CO_2 and face the prospect of losing everything you were paid in the form of allowances for storing the CO_2 is astonishing.

Session 6: How Safe is Safe Enough?

This session pulled together the different strands of the previous discussion AND was divided into two parts. The first part addressed what will make the public be and feel safe and comfortable with CCUS. The second part addressed what will make investors comfortable. Comments made by participants included:

- Public acceptance is a challenge and so is risk communication about geologic storage. “Safe enough” is what people believe is safe enough. Still, it is important to communicate what we understand about risks and to convey the benefits of CCUS, for example, jobs. Engage communication professionals. Words matter and precise words matter most.

- It is important to be transparent and have dialogues with both the public and regulators to show that any risks are manageable.
- Most public expectations about an "acceptable" leakage rate are for essentially no leakage. To date, no leakages have been reported and it is important to keep it that way, but CCUS will be judged on its worst performers.
- There is no unique "public." Sometimes it is the public at large; other times, it is just those impacted by a specific project site. For now, we can primarily focus on specific regulators and communities.
- NGOs are very well trusted by the public, more so than industry and governments. Environmental NGOs have diverse views about CCUS, some based on opposition to fossil fuels. NGOs can be invited to help advance CCUS, but many probably cannot be won over.
- Some CCUS proponents have different interests. It's hard to get to a common message. If CCUS proponents do not have a common message they will lose to opponents.
- The only good answer to the question of what will make investors comfortable is "perfectly safe. There will be no earthquakes, no leaks, no aquifers despoiled." We must strive for excellence.
- Risk and liability issues don't matter unless there is an assured revenue stream. Energy companies deal with risk every day. They are highly professional in this.
- Geoscientists can provide needed information on which to base investment decisions, for example, for permitting, performance improvement, de-risking storage and reducing cost.

Recommendations

Based on the discussions in the workshop several recommendations can be made:

- Organizations involved in the workshop should take all opportunities to highlight that, based on research and current experience, risks associated with storing CO_2 can be managed.
- Conduct another workshop on risk and liability in the Asia-Pacific region.
- Continue and expand capacity building for regulatory institutions.
- Consider the role of international or national standards for geologic storage of CO_2.
- Conduct a dialogue with the insurance industry about coverage for geologic storage.
- Consider ways to enhance and support public outreach on geologic storage.
- Government and industry should conduct further research, development and demonstration to resolve remaining technical uncertainties in geologic storage.

1. INTRODUCTION AND BACKGROUND

This report is a summary of the discussions and conclusions from the Workshop on Risk and Liability of Geologic Storage of Carbon Dioxide (CO_2) held in Paris, France on July 10 and 11, 2012. This workshop was convened jointly by the Carbon Sequestration Leadership Forum (CSLF), the International Energy Agency (IEA) and the Global Carbon Capture and Storage Institute (Global CCS Institute). The relationship between the risks of geologic storage of CO_2 and the financial liability of those conducting such storage is critical to the commercialization of Carbon Capture Utilization and Storage (CCUS). Actual, calculated or perceived risks of geologic storage and the liabilities that result from those risks will be central to the legal framework for CCUS; to business decisions about whether and where to proceed with CCUS projects; and to the design, operation and closure of those projects. The relationship between risk and liability, however, is at present often poorly defined or understood and this, in itself, adds its own layer of risk for CCUS project developers and public policy decision makers.

The importance of liability has long been recognized. The CSLF-IEA recommendations to the G8 developed in November 2007 and approved by the G8 heads of state in July 2008, for example, contained the following recommendation regarding liability, which it recommended be completed by 2010:[1]

b. Long Term Liability: Priority – 2010

A framework addressing liability is required for the injection and post-injection phases of a storage project. This includes, but is not limited to, sub-surface property rights, joint liability where there are several operators injecting into the same formation, processes for assessing and resolving potential conflict between CO_2 injection and hydrocarbon production, transboundary movement of CO_2, and timeframes associated with liability.

7. *Governments should clearly define a liability regime for the operational, closure and post-closure phases of a storage project. The regime should also address:*
   - *Government assumption of long term liability to Governments for the post-closure phase.*
   - *The timing of the transfer of liability to Governments for the post-closure phase.*
   - *Implications for surface and sub-surface transboundary movement of carbon dioxide.*
8. *Governments should develop clear licensing and permitting systems for storage projects. Such regulations should address procedures and responsibilities to ensure safe closure and provisions for post-closure monitoring, and remediation, if necessary.*

Since those recommendations were made nearly five years ago, progress has been made in defining geologic risks and in promulgating legal and regulatory frameworks for liabilities caused by those risks. Yet, in many jurisdictions throughout the world, these frameworks are far from complete or even absent while the public debate about CCUS continues. The recommended completion date in the recommendation above was clearly not met. A result is that, not knowing the full range of possible financial consequences, potential developers of CCUS projects involving geologic storage are hesitant to undertake those projects.

[1] CSLF and IEA, "Results from the Calgary Workshop, November 27 and 28, 2007, 3rd Workshop, Near-Term Opportunities for Carbon Capture and Storage," December 2007.

One reason why liability frameworks have not been implemented is that the public and government decision makers may not be fully informed of the state of scientific knowledge and engineering capabilities regarding geologic storage of CO_2. At the same time, the geoscientists who produce that information may not be fully aware of how best to convey their findings to the public or to policy decision makers. Indeed, this workshop was held at the request of the CSLF Risk Assessment Task Force, which is composed of geoscientists, and which wanted to know how it could best produce information of use to policymakers.

Workshop Objectives and Structure

In order to address those concerns, on July 10 and 11, 2012, the CSLF, IEA and Global CCS Institute jointly held a Workshop on the Risk and Liability of Geologic Storage at the offices of the IEA in Paris, France. The purpose of this workshop was to improve understanding of geological risks associated with CO_2 storage and their relationship to financial liabilities. This information is needed by governments to make decisions on liability management frameworks and by industry to make investment and operating decisions. The workshop also discussed how risk and liability information can be communicated effectively. The outcome is the present report.

Attendance was by invitation and included experts from around the world with diverse backgrounds required to address geologic storage risks and liabilities and their relationship. The 62 participants included representatives of governments, industry, academia/research, multilateral institutions, law firms, financial institutions, NGOs and consulting firms. The agenda allowed ample opportunity for discussion, and all attendees were encouraged to contribute to all discussions.

After an opening session which set the scene of the broader issues, six substantive sessions were held:

- Session 2. Geological Risks
- Session 3. Industry Perspective
- Session 4. Economics of Liability
- Session 5. Government and Policy Responses
- Session 6. How Safe is Safe Enough?

In addition, prior to the workshop, several background documents were sent to each of the participants.[2] Each session had several short presentations to provide a framework for the issues followed by discussion open to all participants. Presenters were encouraged to keep their presentations short and were given the option of not using PowerPoint slides.

[2] These documents were: Carbon Sequestration Leadership Forum, "Risk Assessment Task Force, Phase 1 Report," November 2009, which provides a geosciences perspective on risk assessment for geologic storage of CO_2, including methodologies used for risk assessment; Industrial Economics Inc., "Valuation of Potential Risks Arising from a Model, Commercial Scale CCS Project Site," February 2012, which is an assessment of the potential financial damages from a proposed carbon capture and storage project; International Energy Agency, "Carbon Capture and Storage Legal and Regulatory Review, Edition 2," May 2011, which is an overview of the status of legal and regulatory frameworks for Carbon Capture and Storage in jurisdictions around the world, with a special emphasis on liability; and West Virginia Carbon Dioxide Sequestration Working Group, "Report to the Legislature," July 1, 2011. The "Report to the Legislature" is an example of the type of report a government task force may prepare for a legislature considering carbon capture utilization and storage policies. It covers liability and a range of other policy considerations. These documents may be downloaded from http://cslforum.org/meetings/workshops/paris2012.html. The report on valuation of risks is also summarized in Appendix C.

Workshop Scene Setting

Representatives of the three sponsoring organizations defined the broader issues to be addressed in the workshop and related those to the overall context of CCUS deployment. These representatives were:

- Charles McConnell, Carbon Sequestration Leadership Forum
- Bo Diczfalusy, International Energy Agency, and
- John Scowcroft, Global Carbon Capture and Storage Institute.

They made several key points:

Deployment of CCUS is a critical global need. CCUS is a key component in the transition from traditional uses of fossil fuels to a more sustainable global fuel mix. CCUS, however, is not just required for coal-based facilities such as power plants; it is needed for facilities using all fossil fuels. In the United States, for example, the market share of coal in electricity production has decreased from 50% to 39% since 2009. Mostly, that coal-fired power generation has been displaced by natural gas generation. The switch to natural gas reduced CO_2 emissions, but it did not eliminate them. Fossil energy is projected to be a large part of the global energy mix for the foreseeable future. Fossil fuels must therefore become a responsible choice for both the market place and the environment.

In June 2012, the IEA published the third edition of its Energy Technology Perspectives report.[3] This 700-page report examines several long-term scenarios (through 2050) for the development of a broad range of energy technologies needed in every sector for globally-sustainable energy. That report considered several scenarios leading to increases in the average global temperature of 2°, 4° and 6°Celsius. The impacts of the 4° and 6° Celsius increase scenarios were extreme and, in the case of the 6°Celsius increase, were globally disastrous. CCS is shown to be vital to avoiding these severe outcomes. The question is not whether we deploy CCS, but how.

CCUS deployment faces significant business challenges. Among these challenges are:

- The large investments required in each project and correspondingly large risks;
- Budget challenges facing governments planning to co-invest in CCUS demonstrations;
- Integration of the CCUS value chain and allocation of risk along that value chain; and
- Incompleteness of the legal-regulatory framework for CCUS, including liability.

The issue of risk is central to the business case for CCUS. Important questions must be addressed. Why would anyone take on the risk of investing in CCUS? What sort of limitations on risk would I require? How do we assess risk, and how do we manage it?

It is vital to balance risks and opportunities. There needs to be a different way to consider risk as it relates to CCUS. The usual way people think about risk is just to consider the downside, but there also is an upside, which is the value that CCUS creates. Enhanced Oil Recovery (EOR) is one way to create that value. The United States made an effort to use EOR as a means of providing value for CCUS. A few years ago, it was estimated that opportunities in the United States for using CO_2 for EOR were limited. The U.S. Department of Energy, however, studied that more closely through its various research laboratories and extended its estimates from 15 to 20 years of CO_2 storage capacity from EOR to more than 100 years. It is now estimated that EOR onshore can provide up to 40 percent of U.S. oil demand,

[3] International Energy Agency, *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*, OECD, Paris: June 2012.

Return to Report Contents Page

with the possibility that even more could be supplied offshore. The question now being raised in the United States is whether CO_2 can be made available to all those EOR formations. While not all countries will have similar opportunities, some will, and all must look for ways to create value from CCUS and offset risks with opportunities.

Progress toward CCUS deployment is too slow, but can be put back on track. Many of the technologies needed to address climate change are on track for timely deployment; this, however, is not the case for CCUS. Even so, there are still ways for getting it on track. One absolute necessity is to develop a legal and regulatory framework that gives some security to investors. Progress towards such legal frameworks varies by country.

The IEA has updated its 2010 Technology Roadmap for CCS.[4] That Roadmap proposes to implement needed legal-regulatory frameworks in OECD countries by 2020 and in non-OECD countries by 2030. Means of resolving liability concerns needs to be a key element in these legal frameworks.

Risk communication is critical. It is important to answer the public's questions simply and honestly. Try to answer these questions your neighbors may ask: "Will the CO_2 leak?" We need to be able to answer, "No." If they ask: "Is it safe?" we need to be able to answer "Yes." By analogy, if an expert on bridges is asked if a bridge will collapse, that expert could go through long analysis, but the answer needs to be "No." We need, as experts in CCUS, to be in a position to have confidence in being able to answer "No, it won't leak" and "Yes, it is safe." What are the technical issues and how can we communicate these to policy people? This workshop begins the dialogue between the technical and policy communities.

Still, it is important to be careful. As one participant put it: "I used to tell people that the risk of a nuclear disaster was once every million years; but now, after Fukushima, they say that I didn't tell them that this was the year."

Information on geologic risks is needed for liability decision making. While a great deal of work has been done on CCUS by policy analysts, sometimes there is confusion over what risk and liability mean in the context of CCUS. In particular, there are different meanings of the word "risk" as used by different people in different contexts as it relates to CCUS. We hope to understand each other better as a result of this workshop.

Organization of this Report

Sections 2 through 6 summarize the presentations and open discussion in each substantive session. The summaries of the open discussions consist of comments made by the participants. The purpose is to provide a sense of the discussion. The comments are organized by topic rather than by how they came up in the flow of the discussion. While every effort was made to be accurate, the record of the comments is based on notes taken at the workshop and does not reflect exactly what was said nor who said what. An attempt was been to present all of the viewpoints; in some cases there are disagreements among the views expressed. **The views presented are those expressed by participants in the workshop and do not reflect the views or policies of the Carbon Sequestration Leadership Forum, the International Energy Agency or the Global Carbon Capture and Storage Institute or any of their members.**

Section 7 provides conclusions and recommendations.
Appendix A lists the workshop participants.
Appendix B presents the agenda.
Appendix C summarizes a report provided to participants on the cost implications of risks of CCS.
Appendix D has the PowerPoint slides for those scene setting presenters who chose to use them.

[4] International Energy Agency, *CCS Technology Roadmap, 2012*, OECD, Paris, 2012.

Return to Report Contents Page

2. GEOLOGICAL RISKS

This session addressed how geologic risks are measured by geologists and geological engineers. In specific, it was to address the following questions:

- What are the geologic risks and local hazards associated with storing CO_2?
- How can we estimate the magnitudes and probabilities associated with these risks?
- What are the means by which these risks can be managed?
- What are the "known unknowns"?

This session was led by George Guthrie, Chair of the CSLF Risk Assessment Task Force, who gave an overview presentation on the work of this CSLF Task Force. This was followed by presentations by four speakers who discussed how geological risks are addressed in different regions. Taken together, these presentations provide a good overview of the current state of knowledge about the risks of geologic storage including what is known and not known and how this varies by region. The discussion afterward in this session shows the reaction of diverse stakeholders to this state of knowledge.

Speakers

Session Leader
George Guthrie, U.S. Department of Energy, National Energy Technology Laboratory
***(**See presentation, Appendix D)*

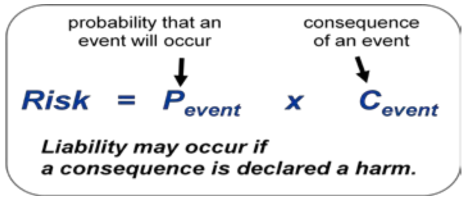
The charter of the CSLF Risk Assessment Task Force, established in 2006, was to examine risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term storage of CO_2. These include risks associated with CO_2 near-term (injection) processes (including fracturing, fault re-activation, induced seismicity) and risk associated with long-term processes related to impacts of CO_2 storage. Potential impacts considered by the Task Force include:

- Impingement on pore space not covered under deed or agreement;
- Impingement on other subsurface resources;
- Change in local subsurface stress fields and geomechanical properties;
- Impact on the groundwater and/or surface water;
- Elevated soil-gas CO_2 in terrestrial ecosystems;
- Return CO_2 or other displaced gases (such as methane) to the atmosphere; and
- Accumulation in poorly-ventilated spaces or in low-lying areas subject to poor atmospheric circulation.

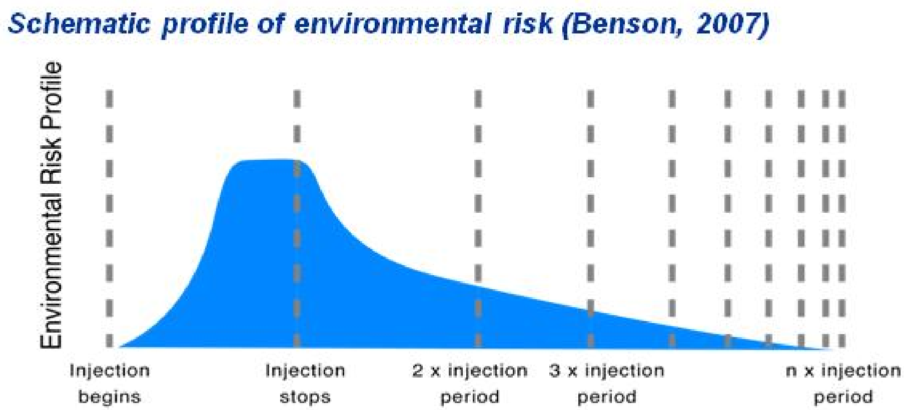
The Task Force produced its first report in the fall of 2009. One of the major conclusions of that work was that the link between risk assessment and liability needs to be recognized and considered. It is important to establish clarity in the discussion between the technical and policy communities as well as with potential investors. Such clarity is needed to establish confidence in our ability to demonstrate to all stakeholders that CCUS can be safe and effective.

Geoscientists have a specific definition of risk that relates to the probability that an event will occur and the consequences of that event. In specific:

Return to Report Contents Page



Risk may change as a function of time and is partly a function of the pressure in the underground formation into which the CO_2 is injected. It is widely believed that risk may increase with pressure during injection, but once injection ceases, the pressure will dissipate and risks diminish. This evolution implies variation of risk over the different phases in a geologic storage project: injection, post-injection and long-term stewardship. This is shown in the figure below.



A variety of factors—including multiple trapping mechanisms that hold the CO_2 in the storage reservoir—give geoscientists confidence in the security of storage at a well-selected site. But developing a science-based quantitative understanding of the evolution of risk can build confidence in other stakeholders that business models can be developed for wide deployment of CO_2 storage. Quantitative risk assessment can also facilitate effective monitoring strategies that verify the predicted performance of the site. Risk assessment quantification is particularly complex because it needs to account for an entire geological system, not just the storage formation. Efforts are currently underway to do that, for example, through the US Department of Energy's National Risk Assessment Partnership (NRAP), which is conducting both site-specific and basin-scale analyses.

Australia Perspective
Matt Gerstenberger, CO2CRC *(See presentation, Appendix D)*

Risk assessments have been conducted for several geologic storage projects in Australia and others are currently underway. Various methodologies have been used including RISQUE, Registers and other qualitative assessments. In Australia, there has been intensive interaction between regulators and operators and, as a result, regulators have been able to be very specific about what is required. There are a limited number of experts, however, who can communicate intelligibly to non-experts on the risks of CCS.

Geologic storage risk assessment is heavily dependent on reservoir simulation techniques, which are widely applicable, but other modeling methodologies may also potentially be used such as static models and expert elicitation. Decisions based on these techniques, and expert elicitation, in particular, are only as good as the techniques. As yet, no models are good for predicting where the CO_2 plume will go.

Geologic risk involves significant interdependencies, which need to be understood. Risks are not independent of one another. Induced seismicity and leakage/migration through a fault are examples of correlated risks. Moreover, efforts to mitigate one risk may have an effect on other risks. In addition both the amount of CO_2 stored and storage capacity are dependent on economics (e.g., a carbon price) and thus risk is also dependent on carbon price.

Many kinds of uncertainties are associated with geologic storage. Some can be managed; others are more random and cannot be managed. Several key uncertainties still need to be addressed:

- The long-term storage formation behavior—does risk truly decrease steadily over time?
- What will be the effects of greater storage in formations in the same proximity?
- How do the uncertainties change over time?
- How big a risk is induced seismicity?

North American Perspective
Stefan Bachu, Alberta Innovates – Technology Futures

North America presents different risk issues than the rest of world. Long-term liability is much more of a concern in the U.S. and Canada. Owners of land in the U.S. own everything under their property to the center of the earth. In Canada, the government (provincial in the provinces and Federal in the territories and offshore) owns most of the subsurface. This makes the issue of CCS quite different in these two countries. In both countries, a new development is the production of shale oil and gas though hydraulic fracturing. Shale is often a cap rock for CO_2 storage reservoirs, which may present a future risk for CO_2 development.

Legacy wells are another issue. Millions of oil and gas wells have been drilled in North America, many of which have been mapped or otherwise recorded. In the North Sea, 16,000-17,000 wells have been drilled, but in the U.S., over a million have been drilled in Texas alone, and in Canada the number is several hundred thousand. The assumption is often made that reservoir pressure—and therefore risk—increases during injection and declines after injection ceases.[5] That may not be the case where existing wells intersect the CO_2 storage formation. If these wells cause CO_2 to migrate, risk may actually decrease and then increase again over time as the migrating plume encounters defective wells.

EOR operations, in particular, will occur in regions where there are many existing oil and gas wells. In addition, the requirements of EOR are quite different from geologic storage. CO_2 EOR operations are not transitioning to geologic storage in the United States. Each is subject to a different regulatory agency and must therefore meet different requirements. EOR is subject to state regulation. Geologic storage, on the other hand, is subject to U.S. Environmental Protection Agency regulations, which are much more stringent and expensive to follow. This added burden poses a substantial barrier to using CO_2 EOR operations for geologic storage.

Still another issue is the impact of multiple CO_2 injection operations in the same basin. If someone were to ask today whether CCS is unsafe, and will it leak, the answer would be, “No.” We do not know, however, what impacts one CCS operation will have on other operations. What will happen, for example, 50 years from now, when other CO_2 injections have occurred in that same basin?

[5] As pictured in the graphic on the previous page.

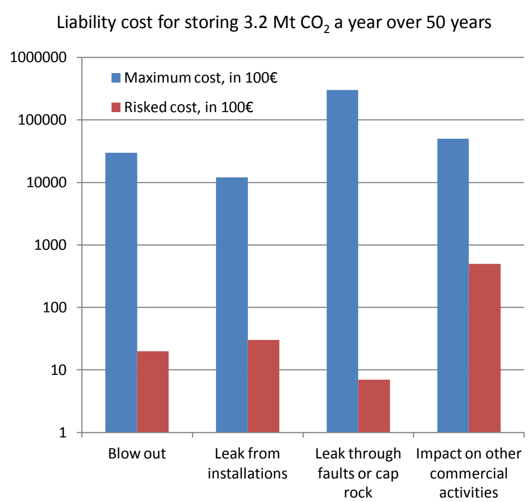
European Perspective

***Hallvard Hoydalsvik, Gassnova sp** (See presentation, Appendix D)*

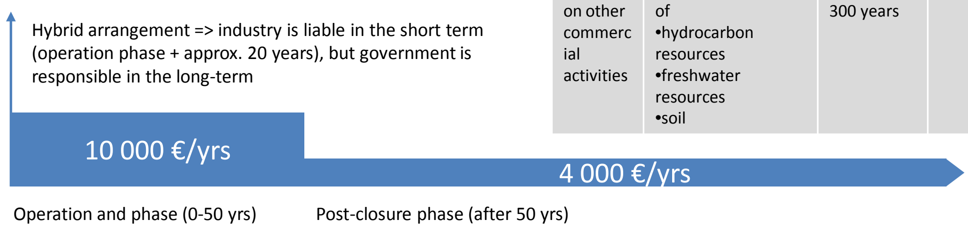
Gassnova conducted a probabilistic risk assessment of the Johansen Formation, a deep (3000 m) saline formation in the North Sea. This formation might not be representative of all storage of CO_2 in Northern Europe, but it is representative of such storage facilities in the North Sea. A detailed methodology was used to identify risk factors and calculate the geologic risks and the financial consequences (that is, liabilities) over the life of the project. We calculate frequency and probabilities for where plumes can go. We consider remediation. No old wells are in the area. The risk is from the injection wells and of leakage from the facilities. We assume the owners will bear this risk and that any leakages will come to the surface not just after closing the site, but 200 years later. It will be a slow seepage, not a major leak, and will continue for hundreds or thousands of years, but without much damage in any one year.

The estimated liability is €10,000 per year during the project life and €4,000 thereafter. See figure below. Overall, we think it is safe to store CO_2 in such deep aquifers in the North Sea and other places. Still, even if the risk is low, it may be too much for a business to take on such risk particularly regarding the time perspective of hundreds of years into the future.

LIABILITY COST DRIVERS



Category	Potential cost drivers	Estimated timing of occurrence	Liable stakeholder (suggested)
Blow out	New injection well Killing well Relief well Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during operations and transfer, O&T)	Industry
Leak from installati ons	Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during O&T) >70 yrs (through plugged wells	Industry
Leak through faults or cap rocks	Remediation Surrender allowances Termination of activities New CO_2-storage	After 220-2500 years	Authorities
Impact on other commerc ial activities	CO_2 contamination of •hydrocarbon resources •freshwater resources •soil	After 150-300 years	Authorities



China and Developing Country Perspective

***Qi Li, Chinese Academy of Sciences** (See presentation, Appendix C)*

Three CO_2 geological storage projects are currently in operation in China. Two are for EOR and one stores the CO_2 in a deep saline formation. Various types of health, safety and environmental (HSE) studies were conducted for these projects. In addition, China is conducting research on geologic storage through international cooperation with Australia and the United States. Several Chinese institutes are

Return to Report Contents Page

involved in HSE associated with CCUS. These include the Institute of Rock and Soil Mechanics (IRSM) of the Chinese Academy of Sciences, the CNPC Chinese Academy of Environmental Projection and the Research Institute of Safety and Environmental Technology.

Lessons have been learned from the experience of analogous storage operations such as acid gas reinjection, enhanced oil recovery and natural gas storage as well as geological storage of CO_2. We have studied such storage operations in other countries, particularly in Canada.

China IRSM is currently developing a methodology to be used for geologic risk management. This methodology should cover both the geologic space where CO_2 is to be stored and how risk changes over time. It should address various types of risk indicators, for example, local environmental health and safety, ecology, ground and surface water contamination or disruption. Which risk indicators should be included is still being worked on. The recommended methodology so far incorporates several different methods and criteria which should be tailored for different types of geologic storage. Several questions currently remain unresolved, however, in developing this methodology.

Discussion

The open discussion addressed several different topics ranging from the current state-of-the-art of geologic storage as discussed by the speakers to the difference between public perception and science. Below is a summary of some of the comments made during the discussion.

Current State-of-the-Art

- A lot of science is being done in geologic risk assessment, but we need to move from the science to engineering.
- The simple P x C formulation of risk does not fit complicated sites where different risks strongly interact. More sophisticated risk models need to be developed for those.
- There are places offshore where the consequences of risks are minimal, but from a European perspective we need to look at a broader range of sites.
- Historically, CO_2 was used for EOR because it was naturally available for EOR at low cost. Today some anthropogenic CO_2 is used for EOR. This is important because it shows that EOR use can go forward even where natural CO_2 is not available.
- We oversimplify the risk of storage by just focusing on EOR. We need to consider a much wider scope of CO_2 injections and their interaction with geology. Many stresses will arise from multiple injections, well beyond what we have seen from EOR. While we can say that CO_2 risks from EOR injections are not great, we need to consider CO_2 injections on a much larger scale.

Risk Mitigation

- We have experience with producing water from geologic formations that are above the storage formation as a way of stopping leakage, and it works, at least on a short-term basis.
- One company involved in several CO_2 injection operations engaged an independent expert organization to assess risks by identify probabilities and consequences. It identified a number of technical risks, but the company identified and implemented safeguards to reduce the probability of those events. Ultimately, however, the risk that it could not reduce was regulatory. Its projects are experienced delays due to regulatory risk.

Risk and Opportunity

- Maybe we should call this workshop: Risk, Liabilities and Opportunities. If we don't see the opportunities, we can tie ourselves in knots worrying about risks and liabilities.
- Why would you risk something? Because you can make a profit.
- How do we combine sustainable biomass and deep coal-bed methane recovery with CCS? It is worrisome that so much emphasis is on risks and liabilities without considering the opportunities.
- Countries with a lot of experience with oil and gas production have more confidence about the safety of such operations.

Public Perception vs. Science

- The public tends to focus on low-probability but high-consequence events, such as the oil well spill last year in the Gulf of Mexico. We should differentiate between our engineering approach, and the public perception of risk. Public perception, however, may affect policy makers and insurance companies.
- We cannot control the public perception of risk. As with hazardous waste, we cannot guarantee that no leakage would occur. The technical risks are minimal, but liability may be based on public perception. Private companies are not going to manage this.
- The risk of something happening and the fear of something happening are different. Who is our voice to respond to public fear?
- We need more projects and technology deployed to show people CO_2 storage is not so dangerous. Independent validation also helps.
- You may talk to the public, but from time-to-time something that is highly publicized will happen to dramatically change their impression. The event does not even have to be local. When a seismic event occurs someplace else, we get questions from the public in areas where seismic events have never happened. So communicating about CCS is not just a one-shot effort and it is not just communicating about your own projects. What some third party does can affect your project and how you need to communicate about it.
- Risks as seen by whom? From a practical view point, we can say leakage risk is small, and it is safe, in comparison to other oil and gas operations. But how will your wife react when she finds out that stored CO_2 is under your house?

3. INDUSTRY PERSPECTIVE

Participants were asked to address the following questions in this session, moderated by John Scowcroft of the Global CCS Institute:

- What are the business risks and potential liabilities arising from geologic storage?
- How are the business risks and liabilities of geologic storage evaluated for investment and operating decisions?
- What do these mean to the different industries involved in geologic storage?
- How are similar very long term risks and liabilities addressed in analogous operations?

There were two presentations to stimulate discussion, one from the perspective of the oil and gas industry, and the other from the perspective of the electric power industry.

Speakers

Oil and Gas Industry Perspective
Bill Spence, Shell *(See presentation, Appendix D)*

Shell has attempted to develop or is in the process of developing ten CCS projects. Developing projects for us and others has been fairly straightforward to date in the sense that Company A transports CO_2 through Company A's pipeline to Company A's storage field. The risk is all with Company A. It will become significantly more complicated in the future when there are multiple CO_2 sources, pipelines and storage reservoirs all connected together in a network.

Risk analysis and management must cover the entire project life cycle from pre-injection, through injection and closure to post-closure. Mitigation plans must be in place before injection starts. The plan must have two key aspects, the prevention of leaks and containment in the event of a leak. We need to have a response ready in the event of a leak. Much of the work of managing risks is done before injection begins. Throughout, we need to communicate with the government, regulators and landowners. Each stakeholder focuses on different types of risk.

Many independent safeguards need to be in place, some of which are passive and always in place, and others are active and only implemented when they are needed. Many of those safeguards need to be put in place before a leakage event occurs ("pre-event"). Often, these safeguards are actually natural characteristics of the site and their presence is part of the site selection process. Other safeguards are implemented only if and when an event occurs ("post-event"). We call our detailed assessment of the safeguards before and after a problem a "bow tie" analysis because, illustrated graphically with the event in the middle, it looks like a bow tie.

Risk analysis is an inherent part of site characterization and selection. The total level of risk needs to be low enough with adequate safeguards in place or available to make a site broadly acceptable. Site selection mostly identifies passive safeguards, which are actually characteristics of the site. The characterization of storage formations looks at risks in great detail, often using data from analogous storage operations. During storage site operation, measurement monitoring and verification (MMV) enables detection and response to a problem with effective active safeguards. When enough active and

Return to Report Contents Page

passive safeguards are in place and the risk is low enough, then we can say, "No, they won't leak" and, "yes, it is safe."

From a business perspective, liabilities which are set by legislation cannot be either unlimited in size or indefinite in term.

We did not manage well our relationships with one local community where we planned to inject. A small town was above the storage field. For them, there was no reward from having CO_2 underneath their town. For those ultimately sitting over these storage fields, there is very little risk, but most are unwilling to accept that there is little risk. We learned a valuable lesson: there needs to be a local benefit and we need to explain what we plan to do well in advance.

Power Industry Perspective
Richard Esposito, The Southern Company (See presentation, Appendix D)

Electric utilities are sometimes described as risk adverse; but, in fact, we have to deal with many risks as part of our normal operations. Utilities are both risk analytic and risk curious in how we deal with risks. For example, one of the more risky types of facilities we operate is a hydroelectric plant. Think of the damage downstream from a dam breaking and causing flooding. That damage is much greater than what would occur from CO_2 leakage and we are used to managing that greater risk.

As we gain experience with the risks related to CCS, we will learn to manage those risks as well. We are already experienced with some similar risks. For example, many coal-fired power plants are beginning to look like chemical plants as we added complex emission controls—similar to capture. Pipelines for CO_2 are less risky than transporting electricity, but there are some commonalities in managing the flow of a product, whether it be electricity or CO_2. Similarly, we inject waste water underground, and are comfortable with it. We also store nuclear fuel rods, ash and gypsum for long periods.

Utilities are accountable to a wide range of stakeholder—public utility commissions and the general public. The risk of not having stakeholder support may not kill a project, but it can delay a project. We tell people we are capturing CO_2 and selling to an EOR operator. One problem is false risk perception. For example, this article in a local newspaper:

> *"What if the pumping of all this exhaust gas deep underground causes a huge explosion, releasing a noxious toxic cloud of coal gas that gets ignited above ground, barbecuing the surrounding area?"*
>
> E. Downs Green, Gulfport Mississippi, quoted in the Sun Herald Newspaper.

Regulatory risks for utilities are real. Some regulators do not know what to make of the complex permit applications for CCS. Risks are always greater when the regulatory and permitting frameworks are immature. We need to educate regulators and get a dependable framework for going forward. Uncertainties associated with unknown long-term financial risks—beyond the life of a CCS project—pose a barrier.

One question we are asking is how to set up relationships with owners and operators of storage fields. If a CO_2 storage field fails, does that mean the coal-fired plant where the CO_2 is captured has to be shut down? The risks associated with off-site storage will require new business models. Several business models are possible: pay-to-take, team with a storage company, own and operate ourselves. We are trying to learn about which model would work best. To an extent, it depends on whether EOR is a possibility. If it relates to reliability, we want control—we would do capture. For transportation and storage, we might farm it out.

Discussion

Comments made by participants during the discussion included the following:

Business of CCS

- It is imperative that industry have the opportunity to earn an adequate return commensurate with the risks it takes on CCS. A profit potential makes a lot of difference on how seriously consider taking risks. If there is not a carrot at the end, why take the risks?
- You can see risks in everything and paralyze yourself; but if you see a potential profit, you are willing to take some risks to make the investment and profit.
- One can challenge the premise that industry will take risks only when there is a potential profit. For example, there is an acid gas (CO_2 and hydrogen sulfide) storage operation near Edmonton, Alberta. It has operated for 30 years, and nobody protests, even though they live near it.
- In the case of electric utilities, what if a power operator delivers the CO_2 to a third party and another party actually stores the CO_2? Who gets the carbon credits for capturing and storing CO_2? In the event of problems, who is the liable party? These complexities have not yet been sorted out by industry or policy makers.

Standards

- What about standards? Are there agreed methodologies on how to quantify risks, and how to identify acceptable mitigation responses? Can we quantify financial exposure, and can we use financial hedging mechanisms, or do we need a physical mitigation method?
- Regulations differ from country to country and jurisdictions within countries. Industry- wide standards may influence regulatory decisions, but they don't have the force of law. Regulators decide.
- We should be pro-active in the development of standards. Having standards is a major advantage in communication. We need to have standards and to defend them vigorously.
- We should develop ISO standards that are broadly recognized, but not developed by any one company, or any one stakeholder. [Note: The International Organization for Standardization (ISO) is already working on developing a standard for CCS.[6]]

Trust and Credibility

- It all comes down to a matter of trust. How, as businesses, do you create enough trust to do CCS for many years and for many projects?
- We must ask: how do you generate trust in industry? Public opinion polls show industry and governments are nowhere near the top of those the public trusts. NGOs as well as universities and research scientists are trusted much more. The world does not want to hear industry say CCS is safe. Industry must collaborate with NGOs and regulatory agencies to develop consensus views.
- Industry has a tendency to do exactly what is required but no more. If anything bad happens, it will set the industry back the same way that nuclear accidents set back that industry.
- How do we get approval of the regulator that CCS is safe? We are often running ahead or along with the regulator. We want the regulator to be comfortable that what we are proposing is safe. Absent regulation, do we feel comfortable with the safety of what we are proposing?

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[6] TC 265 Carbon dioxide capture, transportation, and geological storage. See http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=648607.

- In relicensing a power plant, we engaged the local community—their voices were heard; they became involved and invested in it. They supported the relicensing.

<u>Public Opinion and CCS</u>

- CCS has developed a negative profile because some NGOs were opposed to fossil fuels in general, not CCS itself. What we tell newspapers as advocates gets twisted. When the NGOs are against you because they oppose fossil fuel, we don't know what to do.
- Many in industry charge that CCS is an immature technology as a reason not to do it. Industry claims of the immaturity and risk of CCS give lots of ammunition to CCS opponents.
- The kinds of messages that industry conveys are very important. If there is lots of profit, companies get very assertive about the safety of a process that will employ people.
- CCS at a new site is harder to develop than a retrofit at an existing storage facility. Employees can help educate their friends about what is going on with a retrofit.
- Is there a general recognition of global warming? I don't think so. I believe it, but I'm not sure the majority of the people in the world agree.
- What do I say if my wife is concerned? Surveys show women tend to view CCS as more dangerous than men.
- We are caught in a dilemma. We need to execute demonstration projects to be able to point to the data such projects produce. But we can't build more demonstrations because we don't have the data.
- We must paint a different picture around the risk issues, focusing on how CCS will produce jobs and clean energy. We also need to define CO_2 as a valuable product for EOR. When CO_2 is a product, of course, you don't want it to leak or cause seismic problems.
- It's important that we take a strong stand for CCS with the public and with regulators. If we don't take stands, others will hijack the issue. We need to be able to speak from facts and data.

<u>Long-term Liability</u>

- There is an injection phase, closure phase, and post-closure phase. We want to be able to show that what we predicted would happen has happened, and then turn over the long-term liability to the government—when we get to the post-closure period. We think the period should be performance-based, rather than a specified number of years.
- How do we make good for leakage—ton-for-ton by capturing CO_2 from another source? Internally, we have calculated the costs of risks and find them relatively low.
- We fool ourselves if we think our businesses are free from contingent liabilities all around us. They all have to be judged against the potential risk. If we want private investment in CCS, we have to limit liability to some extent.
- Liability risk was not created by NGOs. The industry was resisting being forced to capture CO_2. Some industry lawyers raised the issue, but never specified exactly what risks they were talking about. NGOs took up the concern.
- Most risks are insurable over the shorter term. The government has to ensure for the very long term.

Return to Report Contents Page

4. ECONOMICS OF LIABILITY

This session was moderated by Bernard Frois of CEA, France and addressed the following questions:

- What is the definition of liability in the geologic storage context?
- How are risks valued in various industries?
- What do we know about the liabilities for geologic storage of CO_2?
- How do the insurance industry and the banking sector assess geologic storage liabilities?

Four speakers addressed various aspects of these issues prior to the open discussion.

Speakers

CCS Liability in the United States: Examples of Federalism at its Best and Worst
Eric Redman, Summit Power *(See presentation, Appendix D)*

A number of questions have been raised concerning the safety of CCUS including operational, long-term and health and safety risks. At the same time, there is substantial evidence that CO_2 concentrations in the atmosphere are rising and that climate change is real. Any risks from carbon sequestration need to be balanced against those realities.

Evidence from natural eruptions of CO_2, such as Crystal Geyser in Utah, which erupts every few hours, indicates that any leak of CO_2 from a sequestration well would not be a hazard to human health. Moreover, the probability of leakage from a properly-selected storage formation is not great and, if there are leaks, there are ways to deal with them. We have had many leaks of natural gas, which is much more hazardous to life than CO_2.

EOR with CO_2 is better understood and has lower costs than geologic storage without EOR. In North America EOR with CO_2 was originally seen as a temporary bridge to larger CO_2 storage opportunities in deep saline formations. Opportunities for EOR with CO_2, however, are turning out to be much larger.

We have a “crazy quilt” of differing regulations of CCS in the United States with each state creating its own legal and regulatory framework. This contrasts with nuclear energy, for which there is only one national law governing liability. Attempts to enact CCS liability limits are not likely to be enacted at the Federal level.

EPA regulates anthropogenic CO_2 but not natural CO_2. Over 90 percent of all oil produced with CO_2 was produced in Texas. The Texas state government approves the injection of CO_2 for EOR and otherwise regulates EOR. For example, Texas has eliminated liability for underground trespass through migration of the CO_2 into adjoining areas. EOR projects get a tax break, but have to conduct m onitoring.

Non-EOR storage of CO_2 is treated differently and legislation is being passed in various states to address this. Surface owners are usually paid something up front, and then are paid more if injections are actually made. Companies such as C12Energy and others are purchasing pore space for future use. Local communities are getting excited about becoming storage areas, much like when wind farms are built.

A consensus is building on state CO_2 liability regimes. The operator of the storage bears liability during injection until the CO_2 plume has stabilized. Most states are willing to assume liability after this and sometimes require fees to create a fund for dealing with leaks. There are forced unitization laws that prevent hold outs from blocking leases of surrounding areas for storage. The operator has liability until it passes to the state.

Insurance is available for all of the risks of operating CCS except for long-term liability after stabilization of the plume. Companies get insurance for hazardous waste storage. Several insurance companies are willing to offer either primary or secondary insurance. This market has just developed recently and premiums are coming down. Site geology is critical to managing risks. The figure below shows how various risks can be addressed.

Risk Phase	Risk Category	Potential Adverse Event	Insurance Available	Geology Critical	State Assumption of Liability
Operations	Transportation	Pipeline Rupture	✔	✕	✕
Operations	Sequestration	Leakage	✔	✔	✕
Operations	Sequestration	Groundwater Contamination	✔	✔	✕
Operations	Sequestration	Induced Seismicity	✔	✔	✕
Long-Term	Post Closure	Leakage	[✕]*	✔	[✔]**
Long-Term	Post Closure	Groundwater Contamination	[✕]*	✔	[✔]**

* Insurance available following end-of-injection in finite increments; trusts, escrows also possible.
** Several states with comprehensive CO_2 storage rules have some assumption of liability after a period of post-injection monitoring when plume is "stable"

What are the likely damages from a CCS project? A recent report[7] developed an estimate based on publicly-available information for a proposed project in Texas, using a 50-year injection period and a 50 year post-injection period. The expected value of damages was estimated at $7.3 million of damages, which is far lower than the limits commercially available for pollution legal liability insurance policies for CO_2 storage projects. Appendix C is a summary of this report.

Estimating Potential Health and Environmental Damage
David Rutland, UK Department of Energy & Climate Change

[7] This is the Industrial Economics, Inc. report cited in footnote 2 and available for download at http://www.globalccsinstitute.com/campaign/2012/06/valuation-potential-risks-arising-model-commercial-scale-ccs-project-site. Appendix C is a summary of this report.

The UK government is offering considerable support for the development and deployment of CCS. In addition to support for R&D, FEED and construction costs the electricity market is also being reformed to incentivize production of all forms of clean electricity including CCS. Legislation has been passed to allow for the storage of carbon dioxide, including unifying the ownership of the seabed for storage purposes. UK has implemented EU CCS Directive. Current UK policy is to limit storage to the offshore area only.

Storage liability is a major issue for those considering investment in CCS. The most significant issue is the liabilities attached to carbon offsets in the highly-unlikely scenario that carbon dioxide leaks from the store to the atmosphere. The avoidance of these offsets will help provide the necessary financial incentives for CCS, but in the highly unlikely event of leakage from the storage site the financial consequences could be substantial. Ultimately, the risks attached to CCS must match the commercial rewards available. This appears not to be that case at the moment. Storage only receives part of the value for CCS, but bears the full consequence of leakage. The value of the risk also likely to appreciate over time in line with the value of carbon offsets. Capture and transportation receive money for their services. If CO_2 leaks after 100 years, the financial risks of that leakage might migrate along the value chain, but the value chain has not been established in CCS. The UK Government has been trying to understand the financial consequences of leakage. The main conclusions are that the major risk is from structures that penetrate the storage formation such as wells. Any leakage can be mitigated using established industry techniques and effectively cap the maximum exposure of the operator. Leakage through faults more of a technical challenge, but for a suitably selected site in the North Sea the probability of significant leakage is negligible.

Role of the Insurance Industry
John Scott, Zurich Global Corporate[8]

CCS projects consist of number of discreet, but interlinked activities including CO_2 capture, transport and storage. These are each typically operated by different companies in consortia, each with different appetites for risk. There are also a number of key phases during the life of a CCS project which present different types of risk. When CO_2 injection is taking place, money is coming in. When CO_2 injecting stops, however, the money stops. Whatever you have to do after that point, in terms of funding operations or payments to the State, or other third parties has to be financed from money that was set aside earlier.

The different regulatory and legislative regimes around the world create different liabilities and obligations for CCS operators. In Europe, for example, the CCS and ETS Directives set requirements for surrendering allowances that have to be sold, if any stored CO_2 leaks. In addition operators are also required to set aside “Financial Security” and pay some money through an appropriate “Financial Mechanism” to the ”Competent Authority” of a Member State to take over long-term storage liability of a stable CCS site. Regulations and legislation that cover CCS are jurisdiction-specific and therefore there is no "one-size-fits-all" approach for CCS operators. In some places, governments are prepared to accept long-term storage risk, for example, Australia and Alberta; in others, the onus is on the operator, as in Europe. Furthermore, some jurisdictions are more litigious than others and therefore the consequences for operators' liability may require a different funding approach, for example, proposed legislation in the USA (Casey and Enzi, "Carbon Storage Stewardship Trust Fund Act" of 2009).

During the operational injection phase of a CCS project, most risks are manageable through a combination of risk management approaches. These include practical risk management (in the siting, design and operation of the store), contractual risk transfer to parties most able to manage risk and risk

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[8] John Scott is the Chief Risk Officer of Zurich Global Corporate. This article reflects the personal view of the author and not necessarily that of his current employer.

transfer off-balance sheet through self-insured retentions (SIR) or insurance available today in the insurance market. "Standard" property and casualty (P&C) onshore and offshore insurance products would cover many different aspects of the CCS value chain including power generation activities (capture), pipeline transportation (onshore and offshore) and offshore construction, exploration and injection operations. Specialised insurance products, which are not so widely available e.g. CCS liability insurance can also cover particular risks related to CCS such as pollution event liability, business interruption, control of well, transmission liability and geo-mechanical liability.

In the immediate closure and post-closure phases of a CCS project, there are other risk management challenges, such as uncertainty around the final costs of pre-planned activities (decommissioning, monitoring and verification actions). Operators will not be able to transfer these "certain" costs, but would need to separately build up a fund to defray them. This is common practice in the oil and gas and mining industries, but is not currently permissible under the EU CCS Directive which demands "up-front" financial security to be put in place. In addition, in the European North Sea fiscal regime there are currently no tax benefits of decommissioning a CCS project, unlike oil & gas projects that currently benefit from some tax benefits and the opportunity to build up decommissioning funds over time. Insurance can only play a limited role in transferring the risk of cost-uncertainty of some pre-defined decommissioning activities, or cost items, e.g. crane barge hire, through the use of structured financial products [e.g., a Geologic Sequestration Financial Assurance (GSFA) policy]. Again these are not widely available in the insurance market place and only certain insurers would have the ability or appetite to write these covers.

The insurance industry can help with many aspects of CCS, but no insurance coverage is currently available for long-term storage. Many outstanding issues must be addressed before insurance could be considered as an approach to long-term storage risk transfer. These include the multi-year nature of the risk, the difficulty of pricing the risk (unknown future price of carbon, lack of claims experience etc.), the identification of the peril or trigger (how to define when a "leak" has occurred and what the public liability or property damage is). Although innovative risk transfer solutions involving the insurance industry and government could be investigated, significant issues remain such as insurer risk appetite, competition law and commercial viability.

Some work is being done by the insurance industry in the UK through the Climatewise insurance industry association in partnership with the CCSA to address these issues. If these cannot be resolved, then for the CCS industry to progress in the European Union, Member States will have to take the long-term storage risk themselves, or share them (on a limited basis) with CCS operators. Alternatively, if this is not acceptable, then the CCS and ETS Directives may need to be renegotiated and amended.

Investment Perspective
Axel Wintrebert, Société Générale

Investors would not be prepared to finance a large CCS project as of today though it does not mean it could not be done in the future. There are kinds of risks a lender would not be willing to take such as unproven technology and insurability which would result into potential unquantified liability risks. Solving these risks is a pre-requisite to financing. Other questions: How does the value chain between capture, transport and storage get organized (regulatory framework and contractual arrangement between companies)? Who captures, who transports, and who stores the CO_2? How to address CO_2 volume risk that could create huge swings in revenues? Who is going to pay ultimately for the CO_2? Is the ultimate payer creditworthy?

Cost is an issue. MASDAR had us work on CCS scheme to capture the CO_2 and inject it into oil fields belonging to ADNOC. We had to model the cost of building several capture plants and the cost of

Return to Report Contents Page

building the transport network to the oil fields. The price to cover all costs and a reasonable return would have to be on average around $100/ton for carbon. No one is willing to pay that much, so the scheme was greatly reduced.

On top of the technical studies, it is worthwhile to gather lawyers, bankers, and policy makers to consider how to structure a CCS project. We spent quite a lot of time evaluating CCS projects. We concluded in the case of the mandate with MASDAR that segregating capture from transport was the most appropriate solution in terms of risk allocation and flexibility to expand the industry (as opposed to finding someone who would handle CCS as an integrated entity).

The capture and transport sides of CCS should be fairly safe from a technical and insurance perspective. Thus, this part is easily financeable from a liability perspective. Still, there is a big question on the storage. Considering volume risk, we recommended MASDAR to set up a single CO_2 Buyer, in order to benefit from a "portfolio effect". The Single Buyer purchasing CO_2 from many companies is best placed to mitigate volume risk (upstream) and deliver to the storage company stable CO_2 volumes (downstream).

In conclusion, financing storage is probably not possible for now until issues listed above are resolved and commercial profitability is established.

Discussion

Comments made by participants during the discussion included the following:

<u>Government versus Private Responsibility</u>

- If CO_2 migrates into ground water, it carbonates the water, but people are also concerned with other minerals that that the CO_2 activates. In the United States, states force you to stop injecting if ground water contamination is detected, and impose fines if the plume has not stabilized. There have been instances in the U.S. of contaminated ground water by substances other than CO_2.
- You need a way to fund long-term liability by the government. The risks involved in getting CO_2 underground are much less than not storing it. If there are disparities between the risks and benefits, the state should get involved to socialize the costs.
- When does long-range storage begin and insurance end? Tens of years, perhaps beyond the lifetime of the company. Insurance takes effect after a year, with annual renewals. Insurance may get claims for asbestos that are based on insurance policies issued 30 years ago.
- If capture and storage takes place over 50 years, the developer should be liable during that period. In Alberta, the province takes over liability after stabilization of the CO_2 plume.

<u>Transactions along the CCS Value Chain</u>

- There are operators who will store CO_2 underground and get paid for this service.
- Several questions may be asked. Have you thought about how a storage operator would cover its capital expenditures to take your CO_2? Will you commit to reliable production of CO_2? We started thinking about the value chain, based on these questions. An aluminum smelter, for example, would ask if your proposed storage site can be operated without affecting his smelter operations.
- A single buyer would not take onerous liabilities. Is there a mismatch? You are supposed to deliver a certain amount of CO_2 to us; if you don't, you are liable.
- If you have one project upstream and one project downstream, this is a difficult issue. If the volumes of CO_2 are high enough, we can deal with the financing by having one single buyer.

Return to Report Contents Page

- Suppose a power plant that has contracted to provide CO_2 for EOR, but shuts down for maintenance. Will there be temporary storage facilities from which it can provide the CO_2?
- What about excess layers of cover? What role can hedging play in offsetting some long-term storage issues? A wrap of contracts may create a financeable project.

Return to Report Contents Page

5. GOVERNMENT AND POLICY RESPONSES

Participants in this session, led by Juho Lipponen of the International Energy Agency, were asked to address the following questions:

- What are the motivations behind government policy?
- What issues do governments encounter legislating and regulating risk and liabilities?
- What approaches can governments use to regulate risk and liability for geologic storage?
- Are there lessons to be learned from analogous situations?

Several speakers from different regions and as well as from two multilateral development banks addressed these issues followed by an open discussion.

Speakers

Australia

Ian Cronshaw, Australian Delegation to the OECD

Australia has been active in supporting CCS through the IEA, the CSLF and the Global CCS Institute. Australia has a number of policies and legislation at both the Federal and state levels to support CCS, for example, the Federal government recently passed a bill to facilitate offshore storage. It recognizes that long-term liability is difficult for a private company to deal with. Once injection ceases offshore, there is a 20-year closure period, and then the Federal government assumes the liability provided that the operator has complied with its obligations.

The Gorgon natural gas field development offshore from Western Australia is expected to cost $40 billion. However, the gas contains around 20 percent CO_2. Hence any development plan had to include stripping and sequestration, which is intended to occur below the LNG plant on Barrow Island, off the coast of Western Australia. Liability for long-term storage needed to be addressed. Both state and Federal governments will share the liability 20 years after injection, subject to a number of conditions.

How we treat our uranium mines may also be relevant. A levy is put on the uranium to fund decommissioning. That may be precedent for long-term storage.

Australia just enacted a carbon tax at the beginning of July, literally last week, which is equivalent to €20 per ton of CO_2. In a carbon intensive economy such as Australia, a major policy move like this was not simple, nor easy, but it will incentivize lower carbon investments.

North America

C. Michael Smith, Interstate Oil & Gas Compact Commission (IOGCC)

The IOGCC is a consortium of U.S. state governors. In 2002, the IOGCC created a task force to study CO_2 opportunities for EOR. The task force produced a report in 2005 that showed large opportunities. A 2007 report by the IOGCC developed model legislation. Some of our states have adopted variations of this legislation.

In 2010, we also completed a study of feasibility of the CO_2 pipeline infrastructure in the U.S. and Canada. This report examined the existing pipeline infrastructure for EOR and considered differences between pipelines for natural gas and CO_2. Natural gas pipelines cannot be converted to CO_2, for example, because they are different sizes and require different materials. A lot of the natural gas pipeline rights of way, however, are available for installation of CO_2 lines. This report also considered how state and federal regulations could interface. Lastly, it looked at the business value chain. How can CCS become a money making proposition? It costs about €600,000 per kilometer to build a CO_2 pipeline. It must make economic sense or it can't be done.

We considered "long term" to be 10 years. Operators of EOR operations are liable for 10 years after the end of operations, subject to monitoring.

Gerald Hill, Southern States Energy Board (SSEB)

The SSEB is a compact commission serving 16 states as an energy advisor. SSEB became involved in carbon management ten years ago and is currently managing two storage fields as demonstration projects. Since 2009 the Cranfield, Mississippi project managed by the SSEB for the DOE's Regional Carbon Sequestration Partnerships have injected and monitored 5.5 million tons of injected CO_2. About 2 million has been recycled. We are learning a lot about CO_2 storage in an oil field undergoing enhanced oil recovery. We are soon starting operation of an integrated power plant capture and storage operation where CO_2 captured from Alabama Power Company's Plant Barry coal fired power plant will be injected into a saline formation located near Citronelle, Alabama.

We are also looking at CO_2 infrastructure. Where there is an existing CO_2 infrastructure for EOR, CCS has an opportunity to move forward based upon CO_2 utilization and market forces. We are also looking at situations where the CO_2 backbone exists, but you need another pipeline to get to it. There are some states that have storage fields, but no CO_2 infrastructure. We are looking at all three situations.

In the United States, there is an opportunity for implementing policy from the "top down," from the Federal government, but also an opportunity for "bottom-up" policy development by the states. In the U.S., we don't see anything coming "top down" from the Federal level in the near term. Therefore, we are considering what we can do from the "bottom up" as state initiatives. Let us compare the "no action" scenario with development of CCS projects that are market driven. We see a few states where there is an opportunity for economic development spurred by CCS. We want to maintain the momentum.

Europe

Raphael Sauter, European Commission

A regulatory framework is crucial for CCS. The EU Directive on the geological storage of carbon dioxide ("CCS Directive") was adopted in 2009 as part of the EU climate and energy package. This Directive establishes a legal framework for the environmentally safe geological storage of CO_2. As with all EU Directives, it must be transposed into national legislation by all EU Member States. Transposition had to be completed by June 2011.

The overall objective of the CCS Directive is to ensure the safety of CO_2 storage by risk management throughout the CO_2 storage life cycle by including site selection, operation and post-closure. As a first step, a geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant environmental or health risks exist. This must be determined by a thorough characterization of the site pursuant to criteria specified in the CCS Directive. For the operation phase, the Directive provides for requirements on CO_2 stream composition,

Return to Report Contents Page

monitoring, reporting, inspection and corrective measures in case of leakage or significant irregularities. Prior to the transfer of responsibility to the state, all available evidence needs to indicate that the stored CO_2 will be completely and permanently contained. The standard for transfer of liability is hence performance based. Liabilities related to the geological storage of CO_2 are regulated in different legal instruments in the EU. There is a specific EU Directive on environmental liability which covers any damage to protected species and natural habitats, water and land. Liability for climate damage as result of CO_2 leakage to the atmosphere is covered under the EU ETS Directive. If there are any leaked emissions, the operator of the storage site has to surrender allowances. In order to ensure that liabilities can be covered at all times, an operator must show valid and effective financial security before it can begin injections, and the financial security must be periodically adjusted to take account of any changes to site-specific risks and estimated costs. Different instruments and mechanisms may be used to establish the financial security, e.g. deposits, bank or corporate guarantee, insurance. Each instrument has different implications on certainty, flexibility and costs which need to be considered when making a choice on how to establish the financial security. It is up to the Member State to determine the most appropriate instrument and mechanism. Before the transfer of responsibility, a financial contribution needs to be made to the competent national authority; it needs to cover at least 30 years of post-transfer monitoring.

A robust regulatory framework that covers all risks and liabilities is a key element for public acceptance of CCS and a pre-condition for its deployment. Risks for a well-selected, well-operated site should be rather low and equally the potential financial burden for the operator.

Sergio Garribba, Italian Ministry of Economic Development

Coal use for power generation is expanding in Italy. Four new coal-fired power plants are under design or in construction in Italy and the government decided that these plants must have room for CCS facilities. Italy identified a national entity for reviewing CCS. We seek involvement of local communities. The European Union has 27 members and we think there should be coordination with other EU members. We assume Europe may want to embrace the same level of coordination as for other elements of cooperation.

There is disagreement in Europe on the cost of CO_2. It is too low to finance CCS projects. There is a fund for nuclear, and something is needed for CO_2. There is a project financed by our major electric utility. A 350 MW power plant using coal is being planned, and we are identifying a storage facility. The price of electricity can reflect the costs of CCS facilities.

Multilateral Development Banks

Natalia Kulichenko, World Bank

No country has requested a World Bank loan for a CCS project, but the World Bank is doing capacity building on CCS. World Bank loans are guaranteed by national governments thus hedging Bank financial liabilities for technical or financial non-performance of projects. However, the Bank reputational risk related to non-performance of projects supported by Bank loans and guarantees is taken very seriously..

In the course of assessing projects for potential investment, the Bank considers whether proposed technologies are technically and economically viable. In funding projects the Bank considers operational risks and considers technologies viable that have been in operation for at least 5 years. The Bank adheres to strong environmental safeguard standards. Responsibilities for long-term liabilities are evaluated on a project-by-project basis, and the Bank responsibilities for the project, defined in project legal agreements, typically cover a period of project construction and don't extend until the end of the project life-time (the point, at which long-term liability would start). The Bank doesn't assume long-term liabilities itself, but it assures that this issue is addressed during the project appraisal process. What will be the potential implications for World Bank lending for a CCS project? Specific criteria have not yet been developed for CCS projects, but specifics on such criteria are yet to be defined due to the fact that there is no experience on lending or providing guarantees on CCS related projects.

Annika Seiler, Asian Development Bank (ADB)

CCS or CCUS is in its early stages of development in our region and we have not yet confronted these issues in a real-life situation on any project. ADB has mainly been working with the People's Republic of China (PRC) and recently with countries from South East Asia. Activities mainly focused on capacity strengthening on CCS technologies, knowledge dissemination, identification of barriers, and formulation of strategies to enhance further CCS development. We have not been active in CCS regulatory issues so far. However, we have started working with the National Development and Reform Commission, the relevant apex body for CCS policy making in the PRC, on formulating a comprehensive roadmap for CCS/CCUS demonstration and deployment. ADB sees a necessity for a wider dissemination of the conclusions and report of this workshop especially in key emerging economies of our region such as Indonesia and the PRC. ADB is willing to sponsor such a workshop as part of its ongoing CCS activities in the PRC and could collaborate to organize it.

Looking ahead, ADB is interested in financing a CCS/CCUS pilot or demonstration project in one of its relevant developing member countries. ADB, however, has stringent environmental standards. Any project to be financed will have to be assessed with regard to the environmental risks and comply with ADB safeguard guidelines. The new accountability mechanism and ADB's public disclosure policy allow for stakeholders to comment on proposed loans. ADB cannot finance projects without adequate environmental impact assessment.

We further expect that knowledge institutions and international agencies like the CSLF, IEA and Global CCS institute will provide some key messages and perspectives to confront recent news items that CO_2 storage could trigger earthquakes, which otherwise could prove to be show stopper for CCS.

Discussion

The following comments were made by participants during the discussion.

<u>Standards</u>

- Standards should promote efficiency and reduce costs. The motivation should be to demonstrate to the financing community what the future economic value will be. Of course, standards that apply globally can contribute enormously to efficiency. The UN can convene stakeholders to develop standards, without dictating to them.
- The earlier reference to standards was to non-binding standards developed by an industry and stakeholders. It is very important that these be voluntary codes of conduct; standards should not be prescriptive.
- Standards are legally binding, versus guidelines, which are advisory. We need to be careful not to get prescriptive about how CCS projects should be evaluated, planned and operated. Whatever we develop should be "descriptive" rather than "prescriptive."

<u>Liabilities</u>

- Different countries have different appetites for taking on the risks of CCUS projects.
- The European Commission's CCS Directive had to be transposed to the legislation of member states. It was not difficult to transpose the liability provisions of the Directive.

- Where there is higher density of human population, siting and liability issues become much more difficult. Australia, Canada and the U.S. have the advantage of having large regions without many people.
- Several companies are willing to do storage as a business and take the liability. The risks and liability of CCS can be taken by companies if they see potential for profit.
- We did an analysis of relief from liability for CCS projects, somewhat like what was done for nuclear projects. Liability relief is a form of subsidy, but it is a very modest one.
- China has a draft of CCS regulations, but it is very rough at this stage. We are doing our best to provide a scientific basis for CCS in China.

Incentives

- If the carbon price were right, we would have no problem getting CCS projects financed. The perception that you might lose all the CO_2 and face the prospect of losing everything you were paid in the form of allowances for storing the CO_2 is astonishing.
- We put in mandates on renewables and efficiency. CCUS is not helped by mandates. What we need is a carbon price. CCUS is starting to get some traction in the U.S. We see some movement in a few countries. But there should be more on the mandate side if the market isn't working.
- Some countries that are moving ahead have an interest in tapping their fossil fuel resources. The driver for CCUS is not carbon emissions. Those seeking economic opportunity are taking the lead.
- How are renewable energy projects moved? Should CCS have the same status as renewables?

Return to Report Contents Page

6. HOW SAFE IS SAFE ENOUGH?

This session, held on the second day of the workshop, was intended to pull together the different strands of the previous discussion: geologic risks, industry perspectives, the economics of liability, and government policy responses. There were no speakers; the entire session was open discussion after brief opening comments by the session leaders. The discussion, however, was divided into two parts. The first part of the discussion, led by two representatives of environmental NGOs, Paal Frisvold of the Bellona Foundation and George Peridas of the Natural Resources Defense Council, addressed what will make the public be and feel safe and comfortable with CCUS. The second part, led by Barry Worthington of the United States Energy Association, and Francois Kalaydjian of IFP, a French public research organization, addressed what will make investors comfortable. Both parts addressed those issues plus three common questions:

- What geosciences information can create comfort?
- What concepts and approaches for risk communication can be used?
- How can geosciences participate in effective communications?

Part 1: What will make the public be and feel safe and comfortable?

Paal Frisvold, Bellona Foundation

In Norway, CCS is a widely known concept which enjoys broad public. How did we get there and what can we learn from this experience?

In the 1990s, Norway was set to not meet its Kyoto commitments and that triggered a search for a way to meet our carbon mitigation obligations. Researchers in Statoil showed there was a possibility to permanently, store CO2 underground, a measure to avoid paying the Norwegian carbon tax. Thereafter, the NGO community drove CCS promotion to a large extent. In 1997, Bellona suggested to build six gas fired power plants with CCS to meet the rising energy demand in Norway. CCS also became widely known when it lead to a fall in a government coalition in 2000.

The petroleum sector is the largest industry in Norway. Many people have confidence in our engineers when they say they can store CO_2 safely. In addition, all storage of CO_2 in Norway takes place offshore, which reduces skepticism and opposition from local residents.

Bellona has drawn up country specific road maps for deploying CCS in Greece, Poland, Hungary and Rumania. Our experience show that we must be concrete and pragmatic in our approach, respecting the economics, politics and culture of each country as CCS will have different opportunities in each country. Additionally, the UK is a good example, where focus has been on job creation in high tech industries leading to increased foreign investments. CCS is also a catalyst for other technologies: Combining sustainably produced biomass with CCS can eliminate more carbon than once emitted, enabling us to reach carbon negative solutions. We need to start now to make this a reality for the future.

By focusing on the many positive aspects of what CCS can bring to the society as a whole, we have a better chance of avoiding an over-emphasis on risk and safety, compared to other similar industrial processes.

George Peridas, Natural Resources Defense Council

The Natural Resources Defense Council started looking at CCS extensively about 14-15 years ago. We approached the idea with caution but became convinced by scientific evidence that it could be done safely and effectively. CCS is not our preferred solution: we believe that efficiency and renewable energy should be utilized first, but CCS targets the existing and future fossil-fuelled base and as such is a valuable tool that can greatly help mitigate climate change.

There is no unique public. Acceptance of CCS is context-specific. Sometimes you have to deal with the public at large. In other cases, you don't have to convince the whole world, just those who are impacted by a specific project site. We might have to deal with CCS on a much larger scale eventually. But for the purposes of seeing early projects become reality we should focus on specific regulators and communities.

What do we have to provide to members of the public to make them feel safe and comfortable? More information is not always the solution. Convincing people of the serious threat of climate change does not always entail providing additional scientific evidence. Many people take cues from key thought leaders they trust or adhere to views that conform to their world view. Some communities are inherently comfortable with subsurface operations whereas others are skeptical. An honest, inclusive and open approach is crucial, as is an honest exchange in place of a campaign to "educate".

CCS comes with a burdened label. People have been injecting fluids underground for many years. But some people may still object to injecting CO_2. People who have been around oil and gas production generally are not afraid of CO_2. So far, CCS has an impeccable track record. We have had some excellent demonstration projects. One alleged incident recently generated headlines, but it was effectively explained. It is important that this remain so.

A well thought out regulatory framework is important, and we now have that in many countries. Fracking of shale gas formations took off in the United States without accompanying regulation, and should serve as a lesson against letting activities such as these run free without oversight. With CCS, we have largely put the regulatory framework in place first, before broad deployment, and this is wise. We do need, in particular, to think about the liability question however. What will liability relief accomplish? Will it push projects into development? It conflicts with the message and belief that CCS is safe and effective.

Discussion

The following comments were made by participants during the discussion.

<u>Public Acceptance</u>

- How can we get consensus on CCS and on geological storage in particular? There are two types of consensus: A broad social consensus. This is lacking in most countries. Social consensus on renewables is overwhelming. There is another type of consensus on specific projects by local communities. Local communities can see some of the benefits such as jobs or an improved local economy. This is possible.
- "Safe enough" is what people believe is safe enough. Convincing people that it is safe is hard, especially when everyone can go on the internet and find proponents of what they already believe. At the University of Texas, we are aiming at children whose minds on these issues have not been made up.
- Social acceptance is easier if people get a better idea of what CCS can do for them, keeping their industry viable. It is about engaging the public into believing in a significant technological solution.

The public really has to be engaged in finding the solution. Don't just give them assurances of safety. Let them participate in the discussion.

- Part of what is hindering acceptance is the lack of real CCS projects. We can show it is safe when we have 20 to 30 projects around the world where there have been no problems. It is important for developers to look for good storage sites with local communities that are supportive.
- Trust by the public has to be earned. Yes, there is a question of education, but it gets to the question of process. What you do to deal with safety, is very important. For example, you cannot describe incidents just as accidents.
- A survey was conducted in Saskatchewan, a relatively small Canadian province with a fossil fuel base. Coal provides 77 percent of electricity by a government owned electric company. People are concerned about the environment. Only 37 percent think they know how to fight climate change. In terms of what causes climate change, 95 percent of the population thinks climate change is underway. Most have heard of CCS, but most don't know exactly what it is. Only 39 percent want more electricity from coal, except for coal mining areas of the province. Gender is a factor—58 percent of men and 25 percent of women say they would not be concerned about a nearby CO_2 storage field. Most people know we are storing natural gas in the ground. They are uncertain about how to deal with climate change.
- Would people be concerned about whether CCS would impact their electric bills or would they be willing to pay more? Most people say they will pay more for electric bills for renewables.
- People who are opposed to CCS are opposed to it no matter what and they are usually in places where it will never be built, but the local community where CCS will be built is generally supportive, as long as it doesn't jeopardize them or their groundwater.
- With ground water, you must convince local people that CCS is safe. Regarding the ideologues, I don't think there is anything you can do.
- Some groups are skeptics about climate change and don't see any benefit in spending money to inject CO_2. A project in Ohio was blocked by a group with this view.
- In many cases, governments speak from both sides of their mouths. The energy ministry may speak in favor of CCS, while the environmental ministry says, "We are not so sure." It is important that government agencies communicate with a consistent voice.

<u>Views of the Environmental Community</u>

- If CO_2 is used to get oil out of the ground, some environmentalists are conflicted because they want to stop using oil. But the demand for oil is what it is. If oil can be produced by injecting CO_2, that's "greener" than developing new oil fields that don't need CO_2 to produce it. I don't get the argument that we shouldn't resort to EOR to produce oil.
- There are a lot of NGOs that are absolutely against CCS. I don't understand. Why do NGOs who want to reduce CO_2 emissions oppose CCS?
- Among NGOs there is a general dislike of fossil fuels. They believe we shouldn't be spending money to support production of fossil fuels. Technically, it might be possible to rely exclusively on renewables, but that is unlikely to happen in the short term.
- Views tend to be shaped by local exploration and production techniques, such as mountain-top removal. They see CCS as a lifeline to keep coal mining going.
- Why should an NGO get interested in CCS? How do you get them involved positively? NGOs choose from a hierarchy of policy issues. Fossil fuel production gets much more subsidies than renewables.

- NGOs differ and they have different views of CCS. We are not helped by industries saying, "we are going to do this." Some years ago, coal was desulfurized. It was costly, but necessary for public health. The signals we send are not always in the same direction.
- NGOs are very well trusted by the public, higher than industry and governments. Taking carbon out of the atmosphere is a powerful selling point.
- The NGOs can be invited to help advance CCS, but many cannot be won over.

Industry and CCS

- The methods for monitoring and accounting for injections of CO_2 should be well established. We shouldn't have to take the word of petroleum engineers and geologist who want to produce oil.
- People can be skeptical about being told that governments and companies can handle all this safely and healthily. Some say, "There is nothing that can possibly go wrong here." We should acknowledge that things can go wrong, but can be managed.
- Different industries with stakes in CCS sometimes take very different positions on important policy issues related to CCS. Industry needs to have a uniform message about CCS and CO_2. We have got to do what the NGOs do, and coordinate our message.
- Some CCS proponents have different interests. It's hard to get to a common message. If we do not have a common message, and rally around it, we are going to get beaten up by opponents.
- How does industry argue for limited liability while arguing that CO_2 is safe?
- We've been talking about CCS for coal and the electric industry. But steel, cement and gas processing are also important.
- We looked at CCS deployment through 2050. About 50 percent of carbon reduction could be dealt with by CCS. CCS deployment is very cost effective with some industries other than power in some countries.
- Part of reluctance of some German states to embrace CCS is that they don't want coal. Germany has heavily invested in renewables, but German industry needs to reduce carbon emissions with CCS.

Part 2: What will make investors comfortable?

Barry Worthington, United States Energy Association

The only good answer to this question of what will make investors comfortable is "perfectly safe. There will be no earthquakes, no leaks, no aquifers despoiled." We are striving for excellence. Earlier, we discussed the notion that CCS has to be safe. We expect everyone to commit to that. How do we communicate that?

If you look at opinion polls, the scientific community is most trusted. We can also mobilize engineers. Engage communication professionals. Words matter and precise words matter most. In the United States, the nuclear industry developed a list of 25 words to use and 25 words not to use. The general public likes "nuclear facility," but doesn't like "nuclear plant." "Nuclear waste" is a bad phrase, but "nuclear material" is a good phrase. We do need a common message. That may come out of this particular workshop.

Safety first. We must impose a culture of safety on the CCS development. When we look at the aftermath of the terrible events at Fukushima Daiichi we see that most of the world still embraces nuclear power. It is difficult to speak with absolute confidence about safety. Is it safe to continue to emit CO_2 as we have been doing? We also need to consider that.

What will make investors comfortable? Revenue streams. Risks and liability don't exist in a vacuum. There must be a revenue stream. Risk and liability issues don't count unless there is an assured revenue stream.

Energy companies deal with risk every day. They are highly professional in this. They deal with technology risk and financial risk. They are good at handling all kinds of risks except political risks. Ever since the time of Drake in the oil industry and Edison in the electric utility industry, nobody can model political risks. If political institutions decide to control emissions of CO_2, reducing those emissions will create an assured revenue stream.

Francois Kalaydjian, IFPEN *(See presentation, Appendix D)*

Investors will be made comfortable if an attractive business case is met, a clear and stable regulatory regime is established, technical risks are well managed enabling the public support.

Economics

Geoscientists can provide information that will give investors comfort, but a business case has to be established. CO_2 must have an attractive value. Currently in Europe, CO_2 has virtually no value, about €7 per ton—nothing, really.

We would like to get a full idea of storage capacity for getting a cost estimate of the tonne of CO_2 stored. The oil and gas industry has some guess about the size of storage capacity, but not perfect knowledge. You start eating the cake, but you do not need to know precisely the full size of the cake.

For CO_2 storage, we would like to know the exact capacity of the storage before we start injection, but we cannot. As for deep saline storage, in particular, you don't know much until you start injections. Yet, it is difficult to find investors who will spend money without better knowledge of potential storage capacity of their storage formation.

Regulatory Regime

There is need for regulatory certainty. For instance, France is no longer considered as a good country for producing oil and gas companies as for shale gas production the regulatory regime was changed all of a sudden.

Regulatory regimes are not all the same. In Europe, CO_2 storage has to be safe and permanent. There can be no leakage which is not necessarily the case in other regions of the world. What does that mean?

Risks

We cannot claim there is no risk. It's near zero risk. We have to show we can manage risk in such a way we can be trusted. We need to demonstrate that after 20 to 30 years of monitoring and further 20 years of surveillance there won't be any evidence of possible leakage. What level of inaccuracy can we accept? How to be safe enough? Clarity about these matters will improve with experience.

Information Provided by Geoscientists

Geoscientists can provide needed information on which to base investments, for example, for permitting, performance improvement, de-risking storage and reducing cost. Storage cost is often claimed to be small compared to capture cost. But there is need for substantial upfront investment. Geosciences can help in optimizing the economics. Offshore storage is more expensive, but least controversial. Geosciences can also help with communication, for example, showing how the plume will expand over time, which corrective actions or remediation techniques can be developed to solve potential problems that would arise and how safety increases with time. That will be important for allowing the transparent liability transfer from operating companies to public authorities under a regulatory framework.

There are stages in the permitting process—starting with characterization. The aim is to reduce the risk as close to zero as possible. Information from geosciences must be brought to the public during permitting. Geophysics and geochemistry must be used to help develop monitoring and surveillance techniques. Then we have to compare monitoring results with actual data over time. But we rely on numerical models to predict future performance of storage. What will happen in the long term? Geosciences have to improve the accuracy of the numerical models.

One question posed for this session was whether there are relevant examples of effective or ineffective communication for geologic storage ore from other fields. One example of effective communication is the Lacq project of Total in France. Communication for that project took time but was effective.

Discussion

The following comments were made by participants during the discussion.

Acceptable Leakage Rates

- In Europe, no CO_2 leakage is acceptable. But currently, we are emitting billions of tons of CO_2. So compare any possible leakage from storage fields with uncontrolled emissions.
- When people propose acceptable rates of retention, they often say you must prove you will have a 99% retention rate for 1,000 years. Their aim is actually no leakage. That would be very difficult to prove. People up models and argue about what they predict.
- As the “bow-tie” model shows, we have ways to deal leakage if it occurs.
- One storage reservoir we considered turned out to have less storage capacity than we needed, so we switched to using another reservoir. Just plain engineering was required to fix it, and we controlled it. It is the same with leakage.
- Consider how effective we are in storing CO_2. Today leakage from injected CO_2 is near zero. The EOR projects may recycle some injected CO_2, but they are different from other purely storage projects due to their economics.
- CCUS will be judged on the basis of its worst performers. So we must not let anything happen. We need some way of controlling any fly-by-night operators who don’t follow best practices.
- In the short term we can talk about active safety, and for the long term, passive safety. Fortunately, long-term pressure reductions make leakage less likely over time. In the short-term, there are remedial actions for leakage.

Analogies to Hydraulic Fracturing

- What is acceptable for hydraulic fracturing for natural gas? Is this a good analogue?
- Shale gas extraction leaks some methane. There has been quite a bit of study of emissions of methane through the process. It is not a good analogue to CO_2 capture and storage. Operators try to mitigate that. Methane is a valuable product and leaking it is like leaking money, so gas producers have a strong motivation to prevent it. There is technology available to handle that.

Regulation

- Markets don't work by themselves. They have to have active oversight and monitoring.
- We must provide clear, transparent information for the regulators – from scientists and NGOs. Without a transparent process, regulators have problems. Many regulators are very happy to do their job if they have good information.

Risk Communication

- We need to communicate what we understand about risk.
- Communication is a big job. Which organization should do it? It's not clear, but this warrants additional discussion. Be very careful who your messenger is.
- It is important to be transparent and have dialogue with the public to show that any risks are manageable.

Return to Report Contents Page

7. CONCLUSIONS AND RECOMMENDATIONS

The workshop brought together experts in different relevant fields to discuss risk and liability of geologic storage of CO_2. These experts came from the government, industry, NGOs and research/academic institutions. This section summarizes their perspectives and recommends next steps for addressing the issues identified in the workshop.

Conclusions: A Summary of Key Perspectives

Those attending agreed on the importance of developing CCUS. CCUS is not an option for either industry or society; it is a necessity. CO_2 emissions into the atmosphere are not acceptable to society.

Legal and regulatory measures to clarify long-term liability were seen as vital to the development and deployment of geologic storage. Such measures are being considered in many jurisdictions throughout the world, and each will be designed to fit the specific circumstances of that jurisdiction. Credible institutions are needed in each country to regulate and manage risks.

There was strong agreement that ongoing, informed, accurate and clear communications to the public, environmental NGOs, policy makers and regulators on the safety of geologic storage is necessary. This idea came up repeatedly in every session.

Although more work is needed to resolve remaining uncertainties, geological risks are increasingly well understood and manageable. This, in particular, needs to be clearly communicated.

The safety and security performance of geologic storage projects so far has been excellent. No leakages have been reported. It is vital that this strong performance continue in order to clearly establish the safety and security of geologic storage. Data from multiple projects is needed and industry must be transparent.

Industry repeatedly stated that it cannot have unlimited and undefined liabilities and cannot finance projects with such risks. Insurance companies are willing to cover many of the CO_2 storage risks during the life of a project, but not beyond. Political and regulatory risks associated with undefined liability are a major concern. Industry also needs an upside opportunity for revenue in order to have the incentive to do geologic storage, not just downside risk.

Recommended Next Steps

Based on the discussions in the workshop, several recommendations can be made, some of which were discussed in the workshop:

- Organizations involved in the workshop should take all opportunities to highlight that, based on research and current experience, risks associated with storing CO_2 can be managed. Such assertions are well supported by the current state of knowledge and experience with CO_2 storage to date and need to be unequivocally conveyed to a broad international audience.
- Conduct another workshop on risk and liability in the Asia-Pacific region. This should be coordinated with the Asian Development Bank and involve representatives of developing countries in the region as well as others. The substance can also build on the findings of this workshop.

- Continue and expand capacity building for regulatory institutions. The institutions that will regulate the safety and security of CO_2 storage and set or implement the terms of financial liability need a full and accurate understanding of geologic storage. Such capacity building is needed in both industrialized and developing countries.

- Consider the role of standards for geologic storage of CO_2. It has been suggested that such standards could possibly provide guidance for good practices for CO_2 storage and credibility that such storage can be safe and secure. Such standards are already being developed by the ISO.

- Conduct a dialogue with the insurance industry about coverage for geologic storage. It was reported in the workshop that several insurance companies are willing to insure certain aspects of geologic storage during the operational phase of storage. Such a dialogue could address the adequacy of the terms of such coverage and what further role the insurance industry can play.

- Consider ways to enhance and support public outreach on geologic storage. The importance—and current inadequacy—of such outreach was repeatedly raised during the workshop.

- Government and industry should conduct further research, development and demonstration to resolve remaining technical uncertainties in geologic storage. While much progress has been made, uncertainties remain, but these uncertainties can be reduced through further effort and this will further reduce geologic risks. Information on this work should be shared through international organizations such as the CSLF and Global CCS Institute. Such work should also further explore the link between geologic risks and financial damages and how this varies with circumstances.

Return to Report Contents Page

Appendix A
Workshop Participants

Name	Organization
Bachu, Stefan	Alberta Innovates - Technology Futures
Blakeway, Darrell	Bluewave Resources, LLC
Bertucci, Salvadore	Arcelor Mittal
Didier, Bonijoly	BRGM
Cronshaw, Ian	Australian Delegation to the OECD
Cugini, Anthony	DOE National Energy Technology Laboratory
Czura, Maciej	JESSICA and Investment Funds
Day, George	Energy Technologies Institute
de Lannoy, Rose	GDF Suez
de Vigan, Stephanie	Ecole des Mines de Paris
Diczfalusy, Bo	International Energy Agency
Dreux, Remi	GDF Suez
Dybwad, Carmen	IPAC-CO2
Esposito, Richard	The Southern Company
Florian, Federico	KFW IPEX-Bank GmbH
Foster, Scott	UNECE Committee on Sustainable Energy
Frisvold, Paal	Bellona Foundation
Frois, Bernard	CEA
Garribba, Sergio	Italy Ministry of Economic Development
Gerstenberger, Matt	CO2CRC
Guthrie, George	DOE National Energy Technology Laboratory
Hansen, Eirik Harding	Gassnova sp
Heiburg, Sigurd	UNECE Committee on Sustainable Energy
Herer, Clara	France Ministry of Ecology, Sustainable Development and Energy
Hill, Gerald	Southeast Regional Carbon Sequestration Partnership
Hilton, Robert	Alstom
Høydalsvik, Hallvard	Gassnova sp
Kalaydjian, Francois	IFPEN
Kulichenko, Natalia	World Bank
Li, Qi	Chinese Academy of Sciences
Lipponen, Juho	International Energy Agency
McKee, Barbara	US Department of Energy
McConnell, Charles	US Department of Energy
Nekhaev, Elena	World Energy Council
Nicot, Jean-Philippe	Bureau of Economic Geology
Osborne, Victoria	Striker Communications
Paterson, Andrew	CCS Alliance
Peridas, George	National Resources Defense Council
Perrette, Lionel	France Ministry of Ecology, Sustainable Development and Energy
Perrin, Jen-Luc	France Ministry of Ecology, Sustainable Development and Energy

Podkanski, Jacek	European Investment Bank
Price, Jeffrey	CSLF Secretariat
Raldo, Wiktor	European Commission
Redman, Eric	Summit Power
Rutland, David	UK Department of Energy and Climate Change
Ryo, Kubo	Research Institute of Innovative Technology for the Earth
Sauter, Raphael	European Commission
Scott, John	Zurich
Scowcroft, John	Global CCS Institute
Seiler, Annika	Asian Development Bank
Smith, Michael	Interstate Oil and Gas Compact Commission
Spence, Bill	Shell
Tait, Lachlan	Baker & McKenzie
Treanor, Sinead	ESB Energy International
Wintrebert, Axel	Société Générale
Worthington, Barry	United States Energy Association
Wroblewska, Elzbieta	Poland Ministry of Economy
Zakkour, Paul	Carbon Counts

Return to Report Contents Page

Appendix B
Workshop Agenda

<u>Tuesday, 10 July 2012</u>

8:30 AM **Registration**

9:00 AM **Session 1. Introduction and Scene Setting**
Objectives of Meeting and CSLF Perspective
Charles McConnell, US Department of Energy
Workshop Chair and Chair of the CSLF Policy Group

Welcome and IEA Perspective
Bo Diczfalusy, International Energy Agency

Global CCS Institute Perspective
John Scowcroft, Global CCS Institute

9:30 AM **Session 2. Geological Risks**
Discussion Leader: *George Guthrie, US Department of Energy and Chair, CSLF Task Force on Risk Assessment*

<u>Regional Panel</u>
Australia
Matt Gerstenberger, CO2CRC

North America
Stefan Bachu, Alberta Innovates – Technology Futures

Europe
Hallvard Høydalsvik, Gassnova sf

Developing Country – China
Li Qi, Chinese Academy of Sciences

10:15 AM Discussion
Participants

11:00 AM **Coffee Break**

11:30 AM **Session 3. Industry Perspective**
Discussion Leader: *John Scowcroft, Global CCS Institute*

Integrated Oil Company Perspective
Bill Spence, Shell

Power Company Perspective
Richard Esposito, The Southern Company

12:00 PM Discussion
Participants

<u>Tuesday, 10 July 2012 (Continued)</u>

1:00 PM **Lunch**

2:00 PM **Session 4. Economics of Liability**
Discussion Leader: *Bernard Frois, CEA and Chair, CSLF Task Force on Financing CCUS*

Estimating Potential Health and Environmental Damages
David Rutland, UK Department of Energy and Climate Change

Role of the Insurance Industry
John Scott, Zurich

CCS Liability in the United States: Examples of Federalism at its Best and Worst
Eric Redman, Summit Power

Investment Perspective
Axel Wintrebert Société Générale

2:40 PM Discussion
Participants

3:30 PM **Coffee Break**

4:00 PM **Session 5. Government & Policy Responses**
Discussion Leader: *Juho Lipponen, International Energy Agency*

<u>Panel on Proposed Policies & Legislative Approaches</u>
Australia
Ian Cronshaw, Australian Delegation to the OECD

North America
C. *Michael Smith, Interstate Oil and Gas Compact Commission*
Gerald Hill, Southern States Energy Board

Europe
Sergio Garriba, Councellor, Italian Ministry of Economic Development
Raphaël Sauter, European Commission

Multilateral Development Bank
Natalia Kulichenko, World Bank
Annika Seiler, Asian Development Bank

5:00 PM Discussion
Participants

6:00 PM **Adjourn for Day**

7:30 PM **Group Dinner**

Return to Report Contents Page

Wednesday, 11 July 2012

9:00 AM **Session 6. How Safe is Safe Enough?**
Discussion Leaders: *Paal Frisvold, Bellona Foundation*
George Peridas, Natural Resources Defense Council

Discussion: What will make the public be and feel safe and comfortable?
What geosciences information can create that comfort?
Participants

10:15 AM **Coffee Break**

10:45 AM **Session 6. How Safe is Safe Enough? (Continued)**
Discussion Leaders: *Barry Worthington, United States Energy Association*
Francois Kalaydjian, IFPEN

Discussion: What will make investors comfortable?
What geosciences information can create that comfort?
Participants

11:45 AM **Wrap-up and Next Steps**
Discussion Leader: *Barbara McKee, CSLF Secretariat*

Summary of Prior Discussion
Rapporteur: *Jeffrey Price, CSLF Secretariat*

11:50 AM Discussion
Participants

12:20 PM Final Wrap Up
Barbara McKee, CSLF Secretariat
Juho Lipponen, International Energy Agency
John Scowcroft, Global CCS Institute

12:30 PM **Adjourn Workshop**

Return to Report Contents Page

Appendix C
Summary of Report on
Potential Risks of CCS and their Cost Implications

Return to Report Contents Page

Carbon Capture and Storage: An Approach to Understanding Potential Risks and their Cost Implications[9]

Carbon Capture and Storage (CCS) is an important technology that can be used to prevent large quantities of carbon dioxide (CO_2) resulting from combustion or chemical processing from being released into the atmosphere. CCS integrates three steps: 1) separation (i.e., capture) of CO_2 from the exhaust streams of large sources and compression, if needed, 2) transport of the CO_2 to a storage location, typically by pipeline, and 3) injection of the CO_2 deep underground for permanent storage in a defined geologic formation. Once in that geologic formation, several well-understood geologic trapping mechanisms serve to keep the CO_2 there.

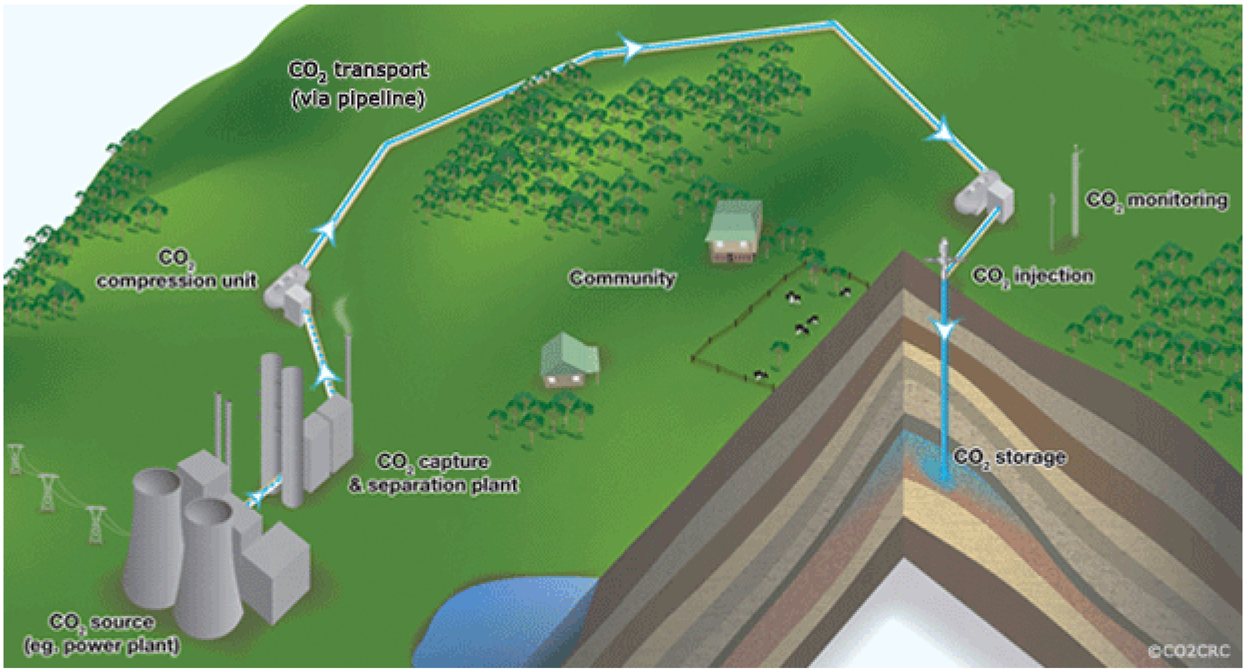


Figure 1. CCS prevents CO_2 emissions from entering the atmosphere and instead stores the CO_2 deep underground. Source: Global CCS Institute

The technologies for each of these steps are already used independently for different purposes in several common industries including natural gas refining, oil and gas production, and the manufacture of chemicals. Ongoing work focuses on improving the cost-effectiveness of capture, integrating the three steps, enhancing our understanding of the storage properties of the geologic formations, and providing reliable information for the development of appropriate commercial practices and government policies.

Any well-sited, well-operated CCS operation should have no incident. However, like any industrial operation, CCS has the potential risk for accidents that could lead to damages to human health or to the environment. Some potential types of damages are well understood in a power plant or oil field operation context, such as damages arising from health-related injuries from routine operations. Other potential damages stemming from the possible release of CO_2 are less well understood.

This brochure describes a recent project sponsored by a group of stakeholders involved in CCS to use established financial analysis methods to develop a good understanding of the magnitude, timing, and nature of potential financial impacts of the risks of damages to human health and the environment

[9] This report summary was made available by the Global CCS Institute and Chevron and will be published in brochure form by the Global CCS Institute.

associated with accidental releases from a CCS project. This analysis is intended to help industry make informed investment decisions, to be useful in the further development of laws and regulations governing CCS, and to better inform the public in whose communities CCS projects may be operated.

This analysis will also be useful in considering policies to address the long-term stewardship of CO_2 in geologic formations. CCS projects are long-lived. In a typical large project, CO_2 injection might take place over a 30-50 year horizon and the CO_2 must stay securely in the formation for much longer. Current or proposed regulations in various jurisdictions typically stipulate that responsibility for a CCS project resides with the developer for a specified period of years after injection ceases and/or until it can be demonstrated that certain criteria have been met. After this demonstration, responsibility may be explicitly transferred to a government body. Uncertainty about the ability to make this demonstration in a specified period of time is a significant up front concern for projects. Developers are concerned about the uncertainty of how long they will have to stay active in the project; the public is concerned about who will be accountable if something goes wrong many years out in the future, and project funders worry about the financial risk from this uncertainty. Both CO_2 pipelines and the capture facility must also be operated safely over the entire period they are used.

In an effort to demonstrate how potential financial damages can be estimated, a group of diverse organizations involved in CCS sponsored a project by a leading damages assessment firm, Industrial Economics Incorporated (IEc), to develop and test a method for valuing potential CCS risks. This method applies standard approaches used in the insurance and finance industries for risk assessment. The study estimates the scope, timing, and magnitude of potential financial damages associated with the capture, transport and storage portion of a planned CCS project over a 100-year period, including 50 years of injection and 50 years after the CO_2 injection has stopped. This study estimated the monetary costs to address impacts on people and the environment arising from accidental releases; it did not estimate the potential costs from facility construction or routine operation, nor potential costs associated with impacts to workers, business interruption, facility repair or similar private costs internal to the operator such as legal penalties or lawsuits. The final report based on this study was released in June 2012. [10]

The analytic method was applied to a set of real-world project plans and data, the Jewett, Texas FutureGen 1.0 project. This project was proposed as part of a formal screening process. Although the site was not ultimately selected as the finalist site, a detailed risk assessment was prepared for the final round of consideration. This risk assessment is publicly available and served as the basis for testing the method for estimating potential financial damages from a specific large CCS project. Although the risk assessment was very detailed, it was developed for the first stage of project development: site selection. Additional site characterization work such as drilling test wells and conducting local surveys would take place if the project moved forward for development. This further work would produce additional and more detailed information that would enable more precise estimates of risks and potential damages. Therefore, after careful review, the sponsors of the damage assessment decided that the analysis would use available data from similar industrial processes to develop a reasonable set of assumptions for the few key data types needed for a comprehensive damages estimation mode but not included in the published Jewett risk assessment.

This analysis indicated that the median estimated financial damages from a well-sited, operated, and closed CCS project at this site would be expected to be approximately \$0.15 per ton of CO_2 injected.[11] The final FutureGen 1.0 project was planned in Illinois; it was originally planned to cost roughly \$1.8 billion. Using this cost basis as a point of comparison, the magnitude of expected financial damages would be less than 0.04% of original project costs.

[10] Industrial Economics, Incorporated, "Valuation of Risks Arising from a Model, Commercial-scale CCS Project Site," Cambridge, MA, June 2012. This report may be downloaded from: http://www.globalccsinstitute.com/campaign/2012/06/valuation-potential-risks-arising-model-commercial-scale-ccs-project-site.

[11] The 'upper end' (95th percentile) damages estimate was approximately \$0.34 per metric ton.

The approach developed in this analysis, fitted to site-specific circumstances and available data, could be applied to other CCS projects. The types of information generated from this approach will be important to several groups. Project developers will be interested in using it early on to develop order-of-magnitude estimates for use in site selection and project design; later, when more detailed site information is available, these same developers can adapt the model to refine their project design and plan risk management strategies. Legislators and regulators will be interested in this kind of information in overseeing public safety and permitting. The financial and insurance industries will use this kind of information in assessing investment risk and designing financial risk management tools. The public will also use this type of information in assessing proposals for CCS projects in their communities.

How Does The Valuation Approach Work?

The approach developed for this study relies on a standard financial modeling procedure called "probabilistic simulation." The steps involved are very briefly described here but are presented in great detail in the IEc report. Essentially, IEc constructed a set of spreadsheets and connected them into a cohesive model. This model was used to generate a very large number of of scenarios that reasonably capture the range of possible outcomes from the modeled project given the underlying probability distributions and variability in impacts and associated damages. The results of the analysis can be used to estimate the probability that various potential damages amounts will be incurred.

Step 1: **Identify Relevant Risk Events**
The CCS risk of greatest concern stems from leakage of CO_2 at the capture facility, from the pipeline, at the injection well, or from the geologic formation deep underground used for storage. If such a "leakage event" occurs, it could result in human health or ecological harm. Extensive work has been conducted to identify the potential pathways for CO_2 leakage. For example, one such effort was spearheaded by the International Energy Agency and resulted in a publicly accessible risk scenarios database for CCS projects.[12] This database contains what is termed "Features, Events, and Processes (FEPs)" related to CCS projects. This database was developed using systems analysis to methodically identify roughly 200 generic FEPs that can be selected on a site-specific basis for use in risk assessment. As discussed in more detail below, this particular application of the model primarily relied on the identification of risk events as presented in a publicly available risk assessment.

Step 2: **Estimate Magnitude and Probability of Risk Events**
Standard risk assessments use data from a variety of sources such as equipment manufacturers, historical performance, scientific literature, and site-specific plans to develop quantified estimates of risks. In this case, such data was used to estimate the probability of releases and the likely size of such releases if they occur. These estimates reflect potential ranges of probabilities and sizes of releases. For example, a pipeline rupture could be a small crack that goes undetected for days, thereby releasing smaller amounts of CO_2 over a longer period compared to or a large hole that releases CO_2 at a greater rate but is detected quickly and stopped. Further, the probability of each these types of events may be different. Risk assessments often estimate the expected probability of a rupture or similar event that could cause damage, and the expected amount that will be released. The IEc team created a flexible model that allows for both a range of potential events and magnitudes and probabilities that they will occur. Sampled repeatedly and randomly over these ranges, the model estimates the range of possible outcomes.

Step 3: Develop Cost Relationships Indicating the Range of Potential Costs
IEc evaluated the effects of the potential types and magnitudes of releases identified in Step 2 and developed cost estimates for addressing them based on valuation methods from legal systems for accident compensation, natural resource damage assessments, and cost-benefit studies. In two cases, costs estimates could not be developed from real-world case studies: the cost of CO_2 emission allowance prices each year through 2112 (100 years) and the cost of repairing the wellbore in a deep well located at

[12] IEAGHG Risk Scenarios Database found online at: http://www.ieaghg.org/index.php?/20091223132/risk-scenarios-database.html.

Return to Report Contents Page

5,000 feet (1,524 meters). The project sponsors consulted among themselves and with experts to develop specific assumptions for these variables for use in testing the model.

IEc developed cost curves for each event type that reflect available information and the potential variability in the type and/or magnitudes of underling impacts. For example, the type, number and cost of human health impacts arising from pipeline release will vary depending on the location of the release relative to population centers. The model utilized cost data from a variety of sources, including (but not limited to) court cases, insurance payments, and remediation costs to provide a reasonable range of event-specific costs of damages to human health and the environment.

Step 4: Combine the Cost Relationships into an Integrated Model
IEc combined the data and relationships developed in the previous steps into an integrated spreadsheet model that generates damage estimates based on a random sampling of the underlying probability distributions and cost curves across all potential events and over a 100-year period that includes 50 years of injection and 50 years of post-injection monitoring.

In the ideal situation, a scenario is expected to look something like the shaded area in Figure 2, which shows the expected risk of leakage of CO_2 from geologic storage over a project's lifetime. It illustrates the expectation that at properly-sited, operated and closed CCS projects, the risk starts at zero, rises while early injection increases pressures in the storage formation, flattens during routine operation and then falls when injection ceases. The risk then further decreases over time to nearly zero as the injected CO_2 dissipates into the geologic formation and various geologic trapping mechanisms have more effect.

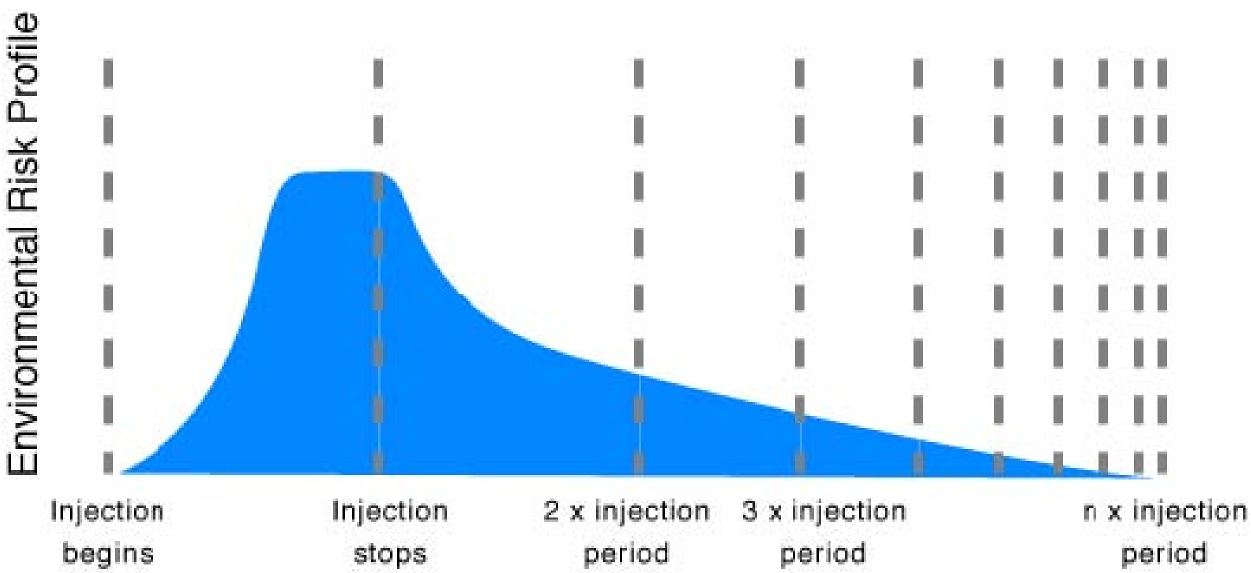


Figure 2. Hypothetical Example of the Variation of Risk over Time for Geologic Storage of CO_2.
Source: Adapted from Sally Benson, Stanford University.

In reality, this is just one possible outcome. A project may face unforeseen site conditions, such as an undetected old well or fault; operator error; or some other factor could come into play. Mitigation may be prompt or it may be delayed. The population characteristics around the site may change over time. The output from a single scenario is of one possible outcome but, if it is run multiple times with different possible assumptions, the model will produce multiple outcomes drawing on many possible combinations of the underlying conditions. This random sampling of the range of possible outcomes serves as the basis for a statistical analysis of the likely outcomes.

Step 5: Use Probabilistic Modeling to Explore the Range of Possible Costs
Monte Carlo simulation is a widely-used and well-accepted method for modeling uncertain financial outcomes. As discussed below, IEc constructed the model to use Monte Carlo simulation to generate, compile, and analyze an array of roughly 100,000 possible scenarios, a sample size that is large enough to generate confidence in the results. The model compiles the results from these scenario probability distributions of the cost of damages. These probability distributions illustrate the statistical range of possible outcomes from the modeled project.

Application to a Real World CCS Project

Estimates of distributions of financial damages were made for a proposed CCS project in Jewett, Texas in the United States. This project was one of several proposed as part of the US Department of Energy's FutureGen initiative. FutureGen is a public-private partnership that intended to build and operate an integrated CCS project in the US.[13] Announced in 2003, the original concept (FutureGen 1.0) established a competition to encourage entities to submit proposals for specific projects located at specific sites. This process was shared with the public through publicly available documents posted on the FutureGen website. The original set of submissions was narrowed to a group of four sites, one of which was the Jewett, Texas project.

Each of the four selected projects submitted a detailed Environmental Impact Volume (EIV) in order to continue in the competition. The EIVs were developed through a peer-reviewed process and provided detailed technical risk assessments for these specific locations. The EIVs were preliminary assessments based mostly on available data rather than new site characterization work (i.e., new seismic surveys, test wells). It was understood that once a final site was selected, additional site characterization work would be undertaken for project finalization and design. (Such additional site characterization was not expected in the published Jewett risk assessment given the stage of the decision process.) Still, the publication of the four EIVs was a valuable resource in developing approaches for evaluating economic risk. IEc reviewed the four candidate sites and determined that they provided enough information to test the model and to develop insights from the results. The Jewett, Texas site was selected and the risk assessment in its EIV was used as the basis for the test.

The proposed Jewett project included a 275 Megawatt Integrated Gasification Combined Cycle (IGCC) power plant on a site of about 75 acres (30 hectares) located in a rural setting with a low population density. Given the nature of the specific IGCC process, the plant would capture CO_2 and trace amounts of hydrogen sulfide (H_2S), a toxic gas that would not be present in most CCS projects. This mix would be transported through a 59-mile (95-kilometer) pipeline to another rural setting where up to three wells were planned for injection. The area around the injection wells was primarily used as ranchland and the project had acquired the right to use 1,550 acres (627 hectares) surrounding three potential injection wells. Figure 3 shows the layout of the Jewett project, including the capture plant, pipeline and injection sites for sequestration.

The site-specific characteristics were generally considered to provide a low-risk environment for a CCS demonstration in that the geologic formations included substantial reservoirs for injection and it appeared that there was a good and thick cap rock. Further it was located in a region that was sparsely populated with limited potential for biodiversity impacts.

The risk assessment for the Jewett site made quantitative estimates of the magnitude and probability of those risks deemed to have some potential for harm based on site characteristics and provided a qualitative discussion of those risks deemed not important at the site. This assessment was based primarily on information available at the time. Developing quantitative estimates for the remaining risks would have required additional advanced site characterization work. In order to apply the comprehensive model to the Jewett site, the study participants developed a "hybrid" case that included assumptions for the risks and/or variables which could not be quantified using data from the Jewett risk assessment.

[13] For a concise description of FutureGen see the FutureGen Alliance website: http://www.futuregenalliance.org/.

What follows is a brief description of how the data were included in or addressed through each of the steps of the model.

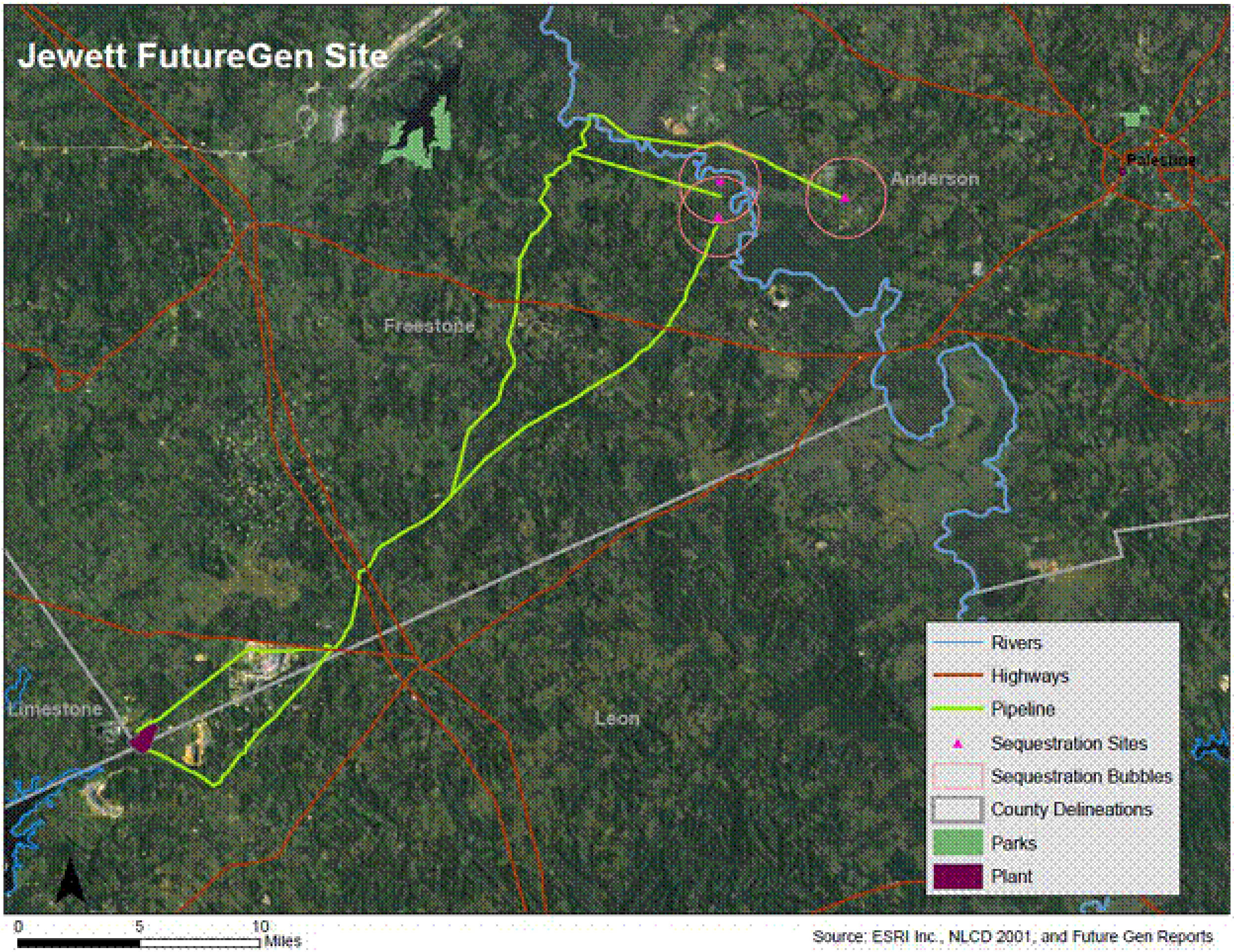


Figure 3. Overview of Jewett FutureGen Site

Step 1. Selection of Relevant Risk Events

The risk assessment was reasonably thorough and evaluated several potential events and mechanisms at the Jewett site associated with capture, transport, and injection through which CO_2 or H_2S could leak and was the primary source relied upon to select relevant events. The presence of H_2S was due to the separation and capture technology choice proposed at Jewett and would not be present in many CCS projects. IEc expanded the damages model to include H_2S consistent with risk assessment findings that releases of this substance at this site had the potential to cause human health and/or environmental impacts.

Step 2. Characterize the Magnitude and Probability of Risk Events

For most of the identified events and mechanisms, the FutureGen risk assessment quantified the magnitude of potential releases and the probability of their occurrence based on site-specific information. Event probability estimates not included in the original EIV, such as yearly rates of pipeline accidents and failure of separation /compression equipment, were addressed through review of comparable, publicly-available data and discussion with industry experts. Event magnitude information was also missing for a few types of events (e.g., the amounts and durations of release of injected gas from the deep well to groundwater at the surface and from the deep well to the atmosphere.) The project sponsors consulted among themselves and with experts to develop specific assumptions for these variables for use in testing the model.

Step 3. Evaluate the Potential Costs of Impacts
IEc considered technical literature and publicly-available databases to tailor their cost curves to the Texas site. For example, they reviewed Texas case law and other databases to determine certain costs related to human health damages. Potential groundwater damages were dependent in part on the background mineral content of the rock formations in the region, which was not included in the risk assessment. In that case, the project sponsors consulted among themselves and with experts to develop an average mineral content variable for use in testing the model.

Steps 4 and 5. Evaluate the Site Using Probabilistic Simulation
IEc conducted 100,000 model runs for the Jewett project. This large number of samples was used to help ensure that the resulting distribution of the probability of financial damages appropriately captured the effects of even low probability events.

Results
The median value of damages at this site from the 100,000 model runs are estimated to be US$7.3 million, as indicated in Figure 4. Total damages estimates for 95 percent of all model runs were below US$16.9 million. These estimates translate into approximately US$0.15 and US$0.34 per tonne of the total of 50 million tonnes of CO_2 expected to be sequestered at the Jewett Site. These estimates value all potential adverse events over the 100 years and are expressed in 2010 dollars.

The distribution of the damages shown in Figure 4 is for CO_2 only since that would probably be similar to most CCS projects. The distribution values were about 10-15% higher when potential leakages of H_2S were included. H_2S releases are the primary driver of human health effects in this case.
The model shows that more than 95 percent of the estimated damages at this site are due to potential releases from existing oil and gas wells at this site—risks that could be mitigated through well completion work or that would be avoided at projects that are not located in oil and gas production areas.
Risks associated with other types of events—at the sequestration site, at the capture plant, or from the pipeline—are negligible or very low. This result serves as a preliminary estimate but some remaining uncertainty regarding carbon prices and impacts have not fully assessed at the site. Such uncertainty could be reduced through further site characterization work.

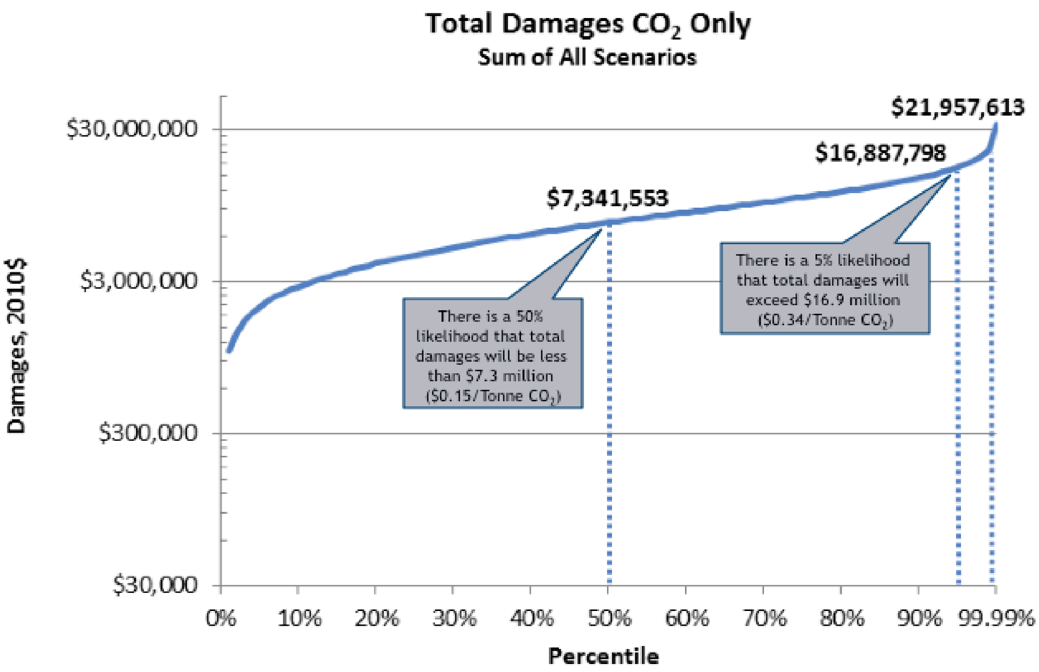


Figure 4. Estimated Jewett Project Damage Distribution for CO_2 Capture, Transport and Storage.
Source: Industrial Economics, Incorporated, "Valuation of Risks Arising from a Model, Commercial-scale CCS Project Site," Cambridge, MA, June 2012.

Conclusions

This study demonstrates that the financial risks associated with CCS projects can be quantified by standard analytical techniques. This challenges the widespread misperception that the costs associated with the risks of CCS cannot be quantified. It further shows how uncertainty can be explicitly taken into account.

This study demonstrates that well-sited and well-operated CCS projects can be expected to result in a relatively small potential financial risk for damages to human health and the environment compared to both the planned project costs and the benefits of such projects. Choice of the site is critical. Site characteristics—both the geologic factors that affect risk and the potential exposure of humans and the environment—are major determinants of risks. Although the results are based on a single early-stage project using generalized data, they give insight into the likely range of damage costs that can be expected at well-selected and operated projects.

Importantly, this flexible approach can be applied to projects at different stages of development. Early in project development, when detailed site-specific information is limited, general data from multiple sources can be used for site screening and selection. As site-specific, more-detailed and accurate data is gathered, this better data can be used to improve risk estimates, finalize site selection and design the project to minimize risks. As the project is implemented, the approach can be used to improve the safety of operations and avoid potential problems before they arise.

The application of the approach used in this study can help developers of CCS projects better site and design their projects to mitigate risk and confidently make investment decision. This information can be used by regulators and project developers to inform regulatory and permitting decisions and to establish regulatory timeframes and financial assurance mechanisms. The financial community can use this information to better evaluate project investments. Perhaps most importantly, this information can be shared with the public to build confidence in projects.

Appendix D
Presentations

<u>Session 2</u>
George Guthrie
Matt Gerstenberger
Hallvard Høydalsvik
Qi Li

<u>Session 3</u>
Bill Spence, Shell
Richard Esposito

<u>Session 4</u>
Eric Redman

<u>Session 6</u>
François Kalaydjian

Return to Report Contents Page

Geological Risks

Discussion Leader
George Guthrie: US Dept. of Energy
Chair, CSLF Task Force on Risk Assessment

Australia
Matt Gerstenberger: CO_2CRC

Europe
Stefan Bachu: Alberta Innovates–Technology Futures

Europe
Hallvard Høydalsvik: Gassnova sf

Developing Country
Li Xiaochun: Chinese Academy of Sciences

Carbon Sequestration Leadership Forum
www.cslforum.org

Technical Group's Risk Assessment Task Force

- **Initiated at London (Nov 2006)**
  - Charter: Examine risk-assessment standards, procedures, and research activities relevant to unique risks associated with the injection and long-term storage of CO_2
    - Risks associated with CO_2 near-term (injection) processes (including fracturing, fault re-activation, induced seismicity)
    - Risk associated with long-term processes related to impacts of CO_2 storage (including
- **Phase I report complete (fall 2009) (CSLF-T-2009-04)**
  - Multiple potential impacts considered
  - Several recommendations from RATF, including: *The link between risk assessment and liability should be recognized and considered*
- **Phase II initiated fall 2010**
  - Activities related to risk-liability include overviews on:
    - Enhanced Oil Recovery
    - Project phases (injection, post-closure, long-term)

Carbon Sequestration Leadership Forum
www.cslforum.org

Potential Impacts Considered by the Task Force

- **impingement on pore space not covered under deed or agreement**
- **impingement on other subsurface resources**
- **change in local subsurface stress fields and geomechanical properties**
- **impact on the groundwater and/or surface water**
- **elevated soil-gas CO_2 in terrestrial ecosystems**
- **accumulation in poorly ventilated spaces or in low lying areas subject to poor atmospheric circulation**
- **CO_2 or other displaced gases (such as methane) return to the atmosphere**

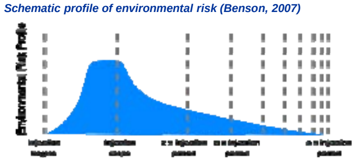
Risk relates to the probability that an event will occur as well as the consequence of that event; risk can vary over time.

probability that an event will occur — consequence of an event

$$Risk = P_{event} \times C_{event}$$

Liability may occur if a consequence is declared a harm.

Schematic profile of environmental risk (Benson, 2007)

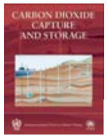


Geological factors tie to the probability that an event will occur, P_{event}.

Time evolution of risk may imply various regimes or phases of a project (e.g., injection phase, post-injection phase, long-term stewardship phase).

Return to Report Contents Page

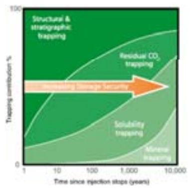
Broad knowledge base provides foundation for confidence in long-term geologic storage security.



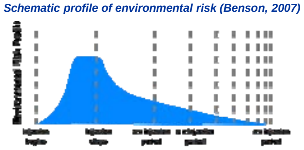
IPCC (2005)

*"Observations from engineered and natural analogues as well as models suggest that **the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years."***

Schematic evolution of trapping mechanisms over time (IPCC, 2005)



Schematic profile of environmental risk (Benson, 2007)



What do we know?

Multiple trapping mechanisms reduce CO_2 mobility over time

- structural/stratigraphic; residual; solubility; mineralization; sorption

Risk profiles should decline over time

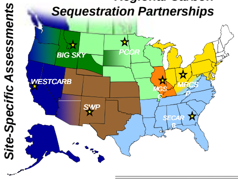
Broad experience base for effective site-characterization & operational strategies

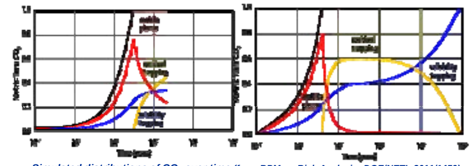
- Decades of successful operational experience (e.g., EOR, gas storage, …)
- Early successes with field demos (e.g., Sleipner, In Salah, Weyburn, Regional Carbon Sequestration Partnerships)

Several efforts are developing the quantitative basis for geologic storage security, including two in the US-DOE Program.

Site-Specific Assessments

Regional Carbon Sequestration Partnerships





Simulated distributions of CO_2 over time (from BPM on Risk Analysis; DOE/NETL-2011/1459)

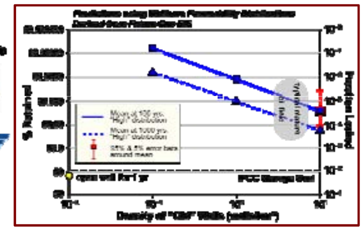
Broadly Applicable Tools & Trends

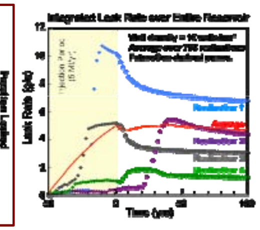
nrap
National Risk Assessment Partnership

NETL-RUA

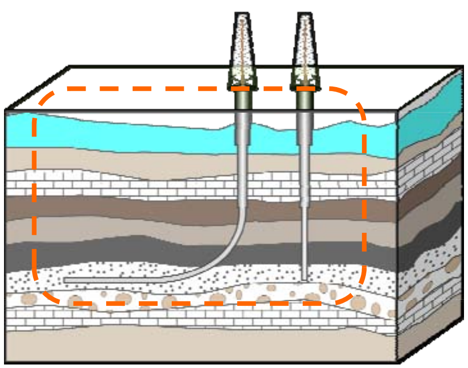
Los Alamos

Pacific Northwest





Predicting and assessing risks requires a consideration of the entire geological system, from reservoir to receptor.



Return to Report Contents Page

Uncertainties in CCS Risk Assessment

Matt Gerstenberger
Senior Risk Analyst
GNS Science &
Cooperative Research Centre
for Greenhouse Gas
Technologies (CO2CRC)

CO2CRC

Australia Risk Assessment

- Geodisc, Otway, Zerogen, Gorgon, Flagships (Carbonnet, SW Hub)
  - Heavy use of both RISQUE and Risk Registers
  - Qualitative probabilistic risk assessments
  - Strong interaction between operators and regulators
  - Operator advice on what is required for safe storage
  - Carbonnet: actively looking for existing methods

Risk Assessment

- P from Probability X Consequences
- Focus on P
- P ultimately boils down to
  - What do we know?
  - How well we know it?

  - Accurately understanding and reflecting the uncertainty in the risk is critical
  - How do we estimate uncertainties & how good are the estimates?
  - i.e., How could is the information we provide and how do we assess that.

Uncertainties

- Geological storage risk assessment is heavily dependent on reservoir simulation, however concepts apply across all disciplines
- Many different uncertainties and ways to describe them, two broad categories:
  - Aleatory – random and irreducible
  - Epistemic – ultimately reducible
- Maybe easier in CCS risk context to describe with:
  - Static geological model
  - Other parameter uncertainty (effective porosity, relative perm, etc)
  - Model uncertainty – basic set up of dynamic model (grid spacing, physical eqs, geochemical eqs)

Return to Report Contents Page

Addressing the Uncertainty

Two main ways uncertainty is estimated and incorporated into CCS risk assessment

1. Simulations (Primary emphasis in CCS):
   1. Probability distributions on parameters, Monte Carlo simulations, use of multiple static models, etc
2. Expert Elicitation:
   1. Key to a full exploration of the uncertainty
   2. We know the model predictions are not correct
      1. Structured expert elicitation can help to better estimate and incorporate that uncertainty
   3. Final result is only as good as the EE process used
   4. EU Guidelines on structured EE, etc.
      1. Structured elicitation, workshops, etc
      2. Expert selection
      3. Expert Bias (last two challenging to get around in industry application)

Interdependence of risks & the effect of mitigation on risk

- Risks are not independent of one another (e.g., induced seismicity and leakage/migration through a fault)
- Mitigation measures may have effect on risk in other parts of the system (e.g., additional injection wells: reservoir behaviour, financial risk, etc)
- Economics: capacity/volume stored is not independent of economics (i.e., carbon price) & hence risk

Key Uncertainties

- Long term behaviour
  - is it truly a steady decrease? Estimating change with time is key
- Volume scaling behaviour?
- Reservoir modelling: understanding if/how the uncertainties change with time (testing models beyond history matching)
- Induced seismicity

Return to Report Contents Page

Liabilities related to saline aquifer storage of CO_2

An example from the North Sea and the Johansen formation

GASSNOVA

Eirik Harding Hansen, Asset Manager, Gassnova SF
CSLF Workshop on Risk and Liability, Paris 2012

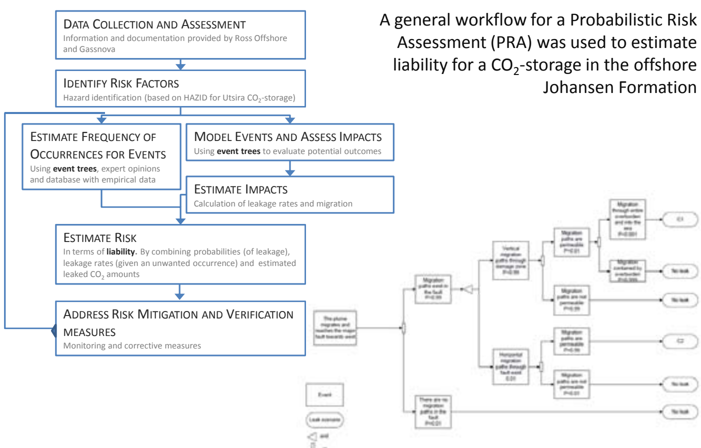
8/11/2012 1

Case study: the Johansen Formation

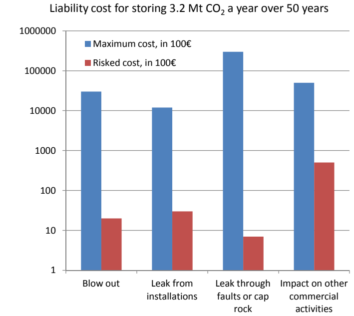
Key data	
Location	The northern North Sea (approx. 70-80 km offshore)
Depth	3000m
Storage formation	Johansen Formation
Storage formation thickness	80-180m
Primary seal	Lower Jurassic Dunlin Group
Secondary seal	The Brent and Viking Groups + shallower layers of Cretaceous and Tertiary age (>1700m)
Injection volume	3.2 Mt/yr for 50 yrs
Storage capacity	>> 160 Mt
Leakage risk	0.0101% of the injected CO_2

Outline (in black) of the storage complex and licenses (squares) in the area

A general workflow for a Probabilistic Risk Assessment (PRA) was used to estimate liability for a CO_2-storage in the offshore Johansen Formation



Liability Cost Drivers



Hybrid arrangement => industry is liable in the short term (operation phase + approx. 20 years), but government is responsible in the long-term

10 000 €/yrs

4 000 €/yrs

Operation and phase (0-50 yrs) Post-closure phase (after 50 yrs)

Category	Potential cost drivers	Estimated timing of occurrence	Liable stakeholder (suggested)
Blow out	New injection well Killing well Relief well Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during operations and transfer, O&T)	Industry
Leak from installati ons	Remediation Fatalities Surrender allowances Halt in operations	0-70 yrs (during O&T) >70 yrs (through plugged wells	Industry
Leak through faults or cap rocks	Remediation Surrender allowances Termination of activities New CO_2-storage	After 220-2500 years	Authorities
Impact on other commerc ial activities	CO_2 contamination of •hydrocarbon resources •freshwater resources •soil	After 150-300 years	Authorities

Return to Report Contents Page

Public Material

Recommended risk assessment method related to CO_2 geological storage in China

Qi LI and Xiaochun LI

IRSM, The Chinese Academy of Sciences

Wuhan, China

WORKSHOP ON RISK AND LIABILITY OF CO_2 GEOLOGIC STORAGE
Sponsored by CSLF, GCCSI and IEA
9 rue de la Fédération
15th Arrondissment, Paris, France
10 and 11 July 2012

Outline

1. Current status
2. Lessons and experience learned
3. Recommended methodology
4. Question and gap

1. Current status

CCS projects in Asia (till 2011)

CO_2-EOR in Jilin oilfield

CO_2-EOR in Dongying Oilfield

Shenhua CCS (storage in deep saline aquifer)

1. Current status

Projects related

- **CO_2-EOR in Jilin oilfield**
  HSE assessment done
- **Shenhua CGS in saline aquifer**
  Study from EPA's, and other regulations
- **CO_2-EOR in Dongying Oilfield**
  Towards fully understand and assess

Preliminary

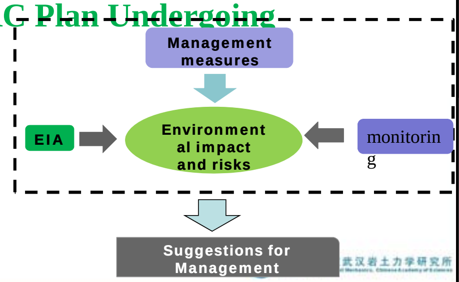
Towards full assessment

Return to Report Contents Page

1. Current status

International cooperation

- China-Australia Geological Storage of CO_2 (CAGS I): 2010-2011
- CAGS II started in 2012
- China-US CERC Plan Undergoing



1. Current status

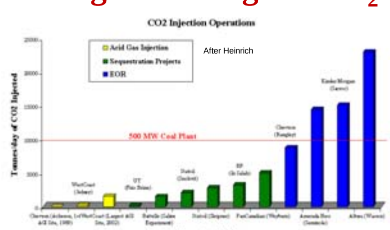
Major Involved Institutes

- Institute of Rock and Soil Mechanics (IRSM), *Chinese Academy of Sciences*
- Chinese Academy of Environmental Planning, *Ministry of Environmental Protection*
- Research Institute of Safety & Environment Technology, *CNPC*

2. Lessons and experience learned

Natural Analogues

- Acid gas re-injection (AGI)
- Enhanced oil recovery (EOR)
- Natural gas storage (NGS)
- Geological Storage of CO_2 (CGS)



2. Lessons and experience learned

EOR DB

Type and operator	Field	Location	Pay zone
CO2 immiscible			
Anadarko	Salt Creek	Natrona County, Wyo.	Lakota formation

Type and operator	Field	Province	Start date	Area, acres	No. wellsprod.	No. wells inj.
Acid gas miscible						
Apache Canada	Zama-Keg River	Alta.	6/04	3,840	12	12
CO2 miscible						
Apache Canada	Midale	Sask.	10/05	30,183	43	5
Devon Canada	Swan Hills	Alta.	10/04		5	1
Cenovus	Weyburn Unit	Sask.	9/00	17,280	320	170
Pengrowth Corporation	Judy Creek	Alta.	2/07	80	4	1
Penn West Energy Trust	Joffre	Alta.	1/84	6,625	33	15
Penn West Energy Trust	Pembina	Alta.	3/05	80	6	2
Hydrocarbon miscible						
Conoco Canada	Goose River	Alta.	4/87	2,847	36	14
Devon Canada	Swan Hills	Alta.	10/85	19,440	400	95
ExxonMobil Oil Canada	Rainbow 'II'	Alta.	7/83	320	2	
ExxonMobil Oil Canada	Rainbow 'AA'	Alta.	9/72	800	4	
ExxonMobil Oil Canada	Rainbow South 'B'	Alta.	8/72	490	8	3
Husky Oil	Rainbow KR B Pool	Alta.	6/84	2,500	69	11
Husky Oil	Rainbow South KR E Pool	Alta.	4/94	478	6	3
Husky Oil	Rainbow South KR G Pool	Alta.	5/95	240	3	2
Husky Oil	Rainbow KR F Pool	Alta.	6/96	1,920	38	11
Imperial Oil	Pembina 'G' Pool	Alta.	9/89	328	2	
Imperial Oil	Pembina 'K' Pool	Alta.	1984	126	1	
Imperial Oil	Pembina 'L' Pool	Alta.	1985	625	4	1

Return to Report Contents Page

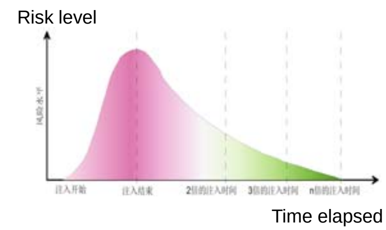
2. Lessons and experience learned

AGI DB

级分类	基本信息 (Basic Information)							
二级分类	项目概况 General briefing							
数据信息	项目编号	项目名称	开始时间	纬度	经度	国别	省县市	项目经费
数据信息英文	#	Project	start up time	Latitude	longitude	Country	County	Investm
注释							具体到最小行政级别	
	1242	Normandville	1997/9/29	55.002	117.466	Canada	Peace River Arch	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Canada	Peace River Arch	
	1409	Dunvegan	1996/1/1	55.999	110.529	Canada	Peace River Arch	
	[illegible]	Pouce Coupe	[illegible]	[illegible]	[illegible]	Canada	Peace River Arch	
	3750	Worsley	2002/5/20	55.338	[illegible]	Canada	Peace River Arch	
	[illegible]	Mulligan	[illegible]	[illegible]	[illegible]	Canada	Peace River Arch	
	312	Gordondale-Halfway	1995/12/21	55.875	-119.201	Canada	Peace River Arch	
	320	Gordondale-Belloy	1995/6/3	55.875	-119.291	Canada	Peace River Arch	
	1306	Eaglesham	2000/11/6	55.79	-117.706	Canada	Peace River Arch	
	997	Mirage	1995/10/2	55.86	-119.07	Canada	Peace River Arch	
	4512	Parkland	2001/2/22	56.056	-120.321	Canada	Peace River Arch	
	3340	Acheson	1989/6/29	53.547	-113.735	Canada	Peace River Arch	
	2001	Golden Spike Beaverhill Lake	1999/4/23	53.40	113.800	Canada	Peace River Arch	
	2469	Redwater	[illegible]	[illegible]	[illegible]	Canada	Peace River Arch	

3. Recommended methodology

- Space dimension to be covered
- Time dimension to be assessed



3. Recommended methodology

Matrix for CO_2 geological storage

Indicators
Local EHS risks
Noise, light and odour nuisance
Soil pollution
Ecology
Landscape
Waste products
Energy required
Biodiversity
Gaseous emissions
Groundwater and surface water contamination/disruption

Courtesy of Lancui Liu, CAEP

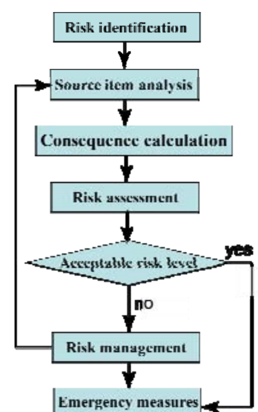
What should be included?

3. Recommended methodology

Method and Flow

- Modified Oldenburg's HSE Method
- AIST GSJ Method
- AHP Method
- Dynamic Programming Approach
- ……

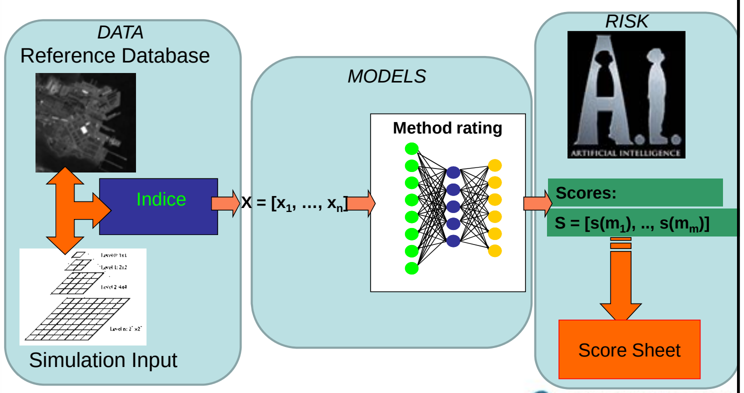
Methods and Criteria should be tailored for different types of geological storage.



Return to Report Contents Page

3. Recommended methodology

Assessment platform for CCS: CO2RISKEYE



4. Question and gap

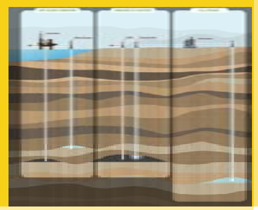
- The short- and long-term effect of spCO_2 in influencing geological structure are not well understood.
- Assessment need an indicator system and more theory research to support the analysis, but they are very lacked.
- Current methods do not exist to implement assessments upon which risk assessments depend.

Thanks for your attention !

"Frank is into carbon sequestration"

Return to Report Contents Page

CARBON CAPTURE AND STORAGE
RISK ASSESSMENT AND MITIGATION



CSLF Workshop

Paris, France

July 10-11, 2012

Shell Exploration and Production International

Bill Spence – Manager Strategic Issues

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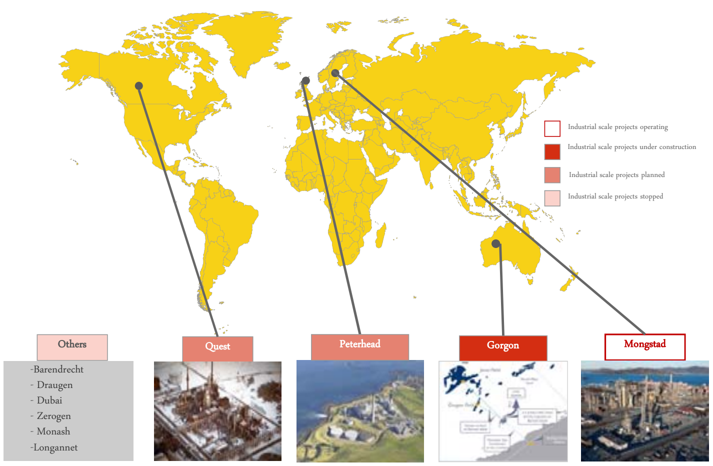
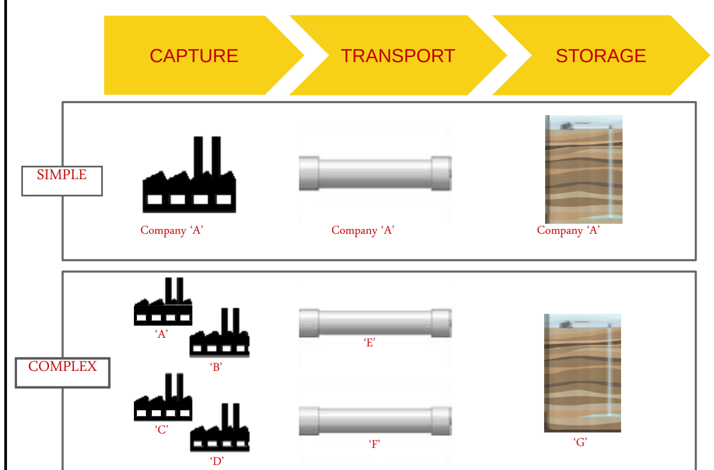
SHELL EXPERIENCE BASE – LARGE SCALE CCS PROJECTS

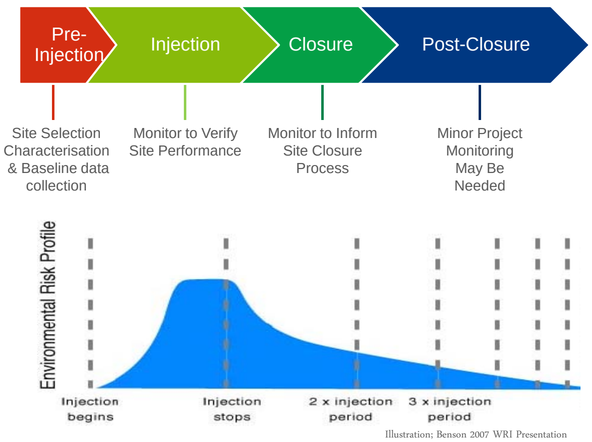


GOING FORWARD – COMPLEXITY WILL INCREASE

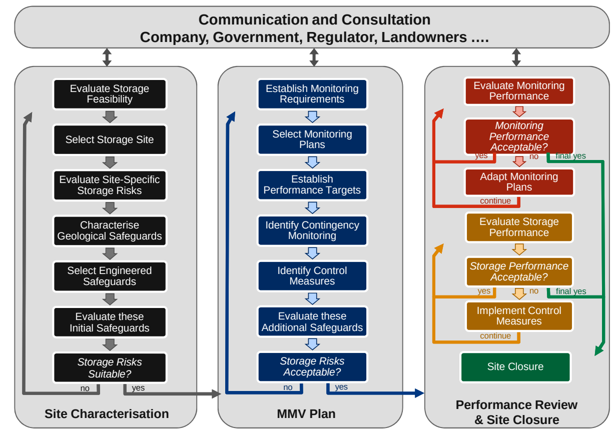


Return to Report Contents Page

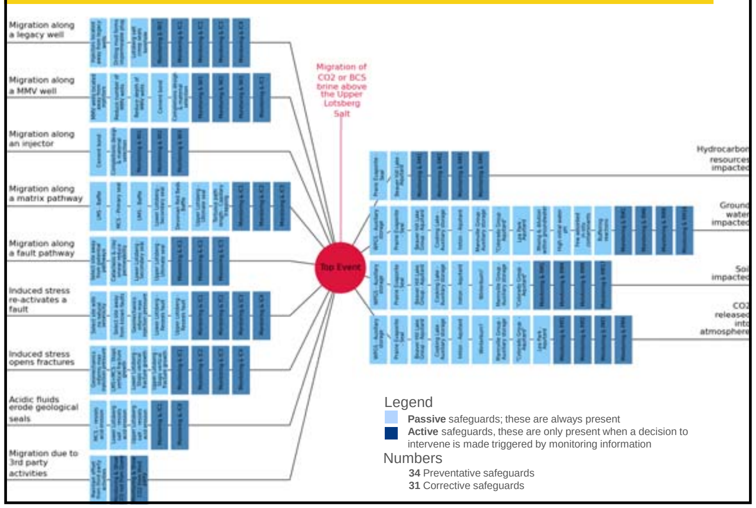
RISK ANALYSIS: MUST CROSS THE FULL PROJECT LIFECYCLE



CCS SEQUESTRATION WORKFLOW

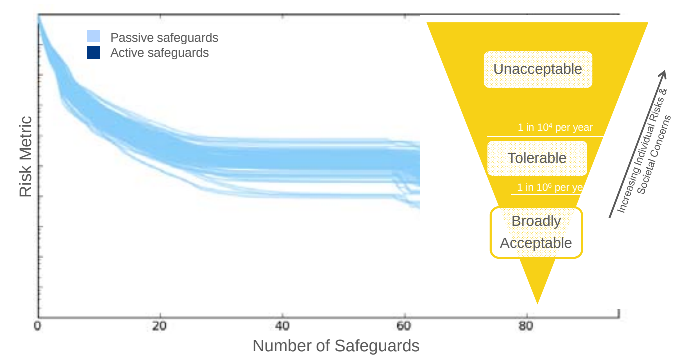


MANY INDEPENDENT CONTAINMENT SAFEGUARDS IN-PLACE



SITE CHARACTERISATION - RISK ANALYSIS

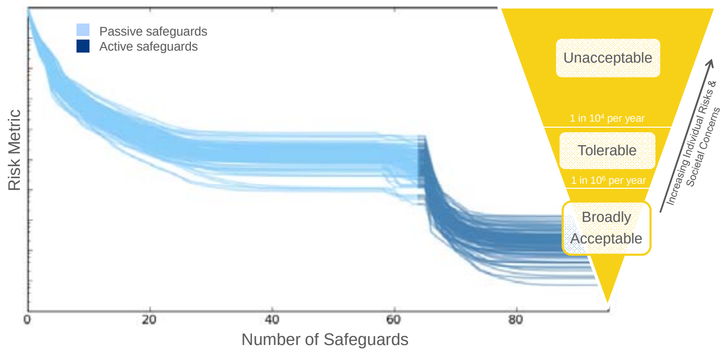
- Based on collective expert judgement
- Informed by appraisal data and feasibility studies



Return to Report Contents Page

MMV CONTRIBUTES TO RISK ACCEPTANCE

- Based on collective expert judgement
- Informed by appraisal data and feasibility studies



CCS COMMERCIAL VIABILITY SOLUTION SPACE

- **Commercial operators can not bear <u>unlimited</u> liabilities**
  - EU legislation proposes that operator will have to compensate for any leakage by providing emissions allowances, this could result in unlimited liabilities for operators.
  - There are uncertainties such as available technology/costs long term, scope of financial contribution for MMV at handover to government etc.
  - ⇒ Solutions include capping the emissions allowance repurchase price at level agreed pre injection and agreement on MMV costs

- **Commercial Operators can not bear <u>indefinite</u> liabilities :**

Recent legislation in some countries/ areas of the world have planned a handover of storage liabilities to local authorities at some points, however:

- ⇒ Transfer needs to be effective / clear cut (cf. EU ambiguities).
- ⇒ Criteria for transfer need to be pre-agreed & achievable ("stable condition").

SUMMARY

- Risk & Uncertainty needs to be addressed at every phase of the project
- Different stakeholders will focus on different risk elements
  - Landowners – HSSE, Containment
  - Government, Regulator – HSSE, Containment, Capacity and long term liability
  - Proponent - HSSE, Containment, Capacity, Injectivity, Financial, Long Term liability
- An Industrial Scale Integrated project needs to address them all
  - Site Selection – Reduction/elimination/isolation from risk
  - Site Characterisation – Reduction in uncertainty and remaining risk
  - MMV – Risk monitoring and mitigation
  - Site Closure – Risk Transfer

Return to Report Contents Page

EGU-CCS; risk comparison

- Electrical utilities are sophisticated in the identification, acceptance, and management of risk. We are both "risk-curious" and "risk-analytic".
Long-term risk presents more uncertainty.
- Utilities are accountable to a wide range of stakeholders such as the PSC, shareholders, customers, and the general public.
Utilities have significant exposure and reporting requirements related to investments decisions.
- Many uncertainties related to EGU-CCS, while not the same as "business as usual" activities can be compared; therefore more experience with CCS will make industry more comfortable with it.
  - *CO_2 capture can be compared to environmental controls such as FGD, SCR, bag-houses*
  - *CO_2 transportation can be compared to e-transmission & distribution as well as natural gas pipelines*
  - *CO_2 storage can be compared to wastewater injection*
  - *Long-term liability of stored CO_2 can be compared to storage of nuclear fuel rods, ash & gypsum, and hydroelectric plants*

EGU-CCS; other important risks

- The costs associated with EGU-CCS represent a greater obstacle to commercial deployment than the environmental risks.
CCS is hampered by the level of regulation with associated cost uncertainty which misalign CO_2 with the level of protection of air toxins.
- There is uncertainty related to future operational flexibility in bypass. Is the tail wagging the dog with geologic sequestration?
CCS is hampered by concerns with the requirement to reliably produce power.
- Risk associated with off-site storage will require new business models.
CCS is hampered by vertical integration with contractual relationships and complexity of partners with environmental and permit compliance implications.
- Risk always exists with immature regulatory and permitting frameworks.
Uncertainty exits with the integration of project development, operations, and finance.

Risks associated with false risk perception still exist

E. Downs Green, Gulfport Mississippi quoted in the Sun Herald Newspaper

"What if the pumping of all this exhaust gas deep underground causes a huge explosion, releasing a noxious toxic cloud of coal gas that gets ignited above ground, barbecuing the surrounding area?"

Return to Report Contents Page

CCS Liability in the United States:

Examples of Federalism at its Best and Worst

Eric Redman, President
Summit Power Group, LLC & Summit Carbon Capture, LLC

Carbon Sequestration Leadership Forum
Workshop on Risk & Liability
Paris ● July 10, 2012

A Cautionary Note on Limitations of the Format

"In August, the Columbia Accident Investigation Board at NASA released . . . its report on why the space shuttle crashed. As expected, the ship's foam insulation was the main cause . . . . But the board also fingered another unusual culprit: PowerPoint, Microsoft's well-known 'slideware' program.

"NASA, the board argued, had become too reliant on presenting complex information via PowerPoint . . . . 'It is easy to understand how a senior manager might read this PowerPoint slide and not realize that it addresses a life-threatening situation,' the board sternly noted."

From "PowerPoint Makes You Dumb"

By Clive Thompson

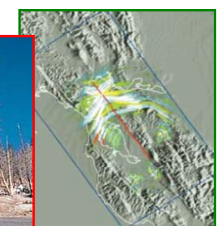
New York Times: December 14, 2003

Preliminary Matters, before turning to Liability Issues:

Some (entirely personal) observations on risks

Questions posed regarding CCUS safety

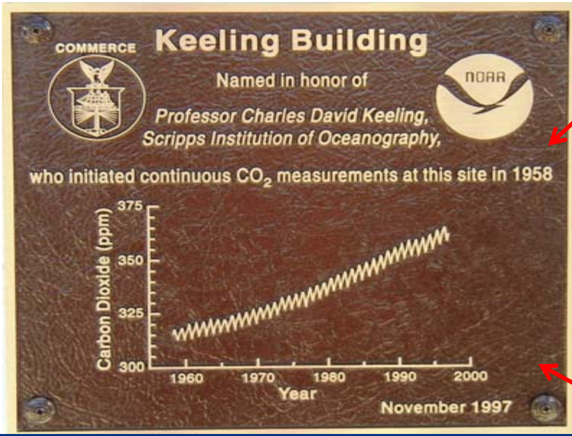
- **Operational Risks**
  - Induced seismicity
  - Corrosion and failure of well
  - Pipeline transport risk
- **Long-term risks**
  - Groundwater contamination
  - Leakage (wells or natural pathways)
- **Health and safety risks**



Slide courtesy of Lawrence Livermore National Laboratory

Return to Report Contents Page

Rising CO_2 concentration in the atmosphere is not a risk: it is a fact.



385 ppm

2010

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CO_2 escaping geological sequestration is a risk, but how large? How hazardous? How significant (and manageable) compared with the Keeling Curve's risks?

Video (42 seconds) of Crystal Geyser in Utah – erupting 1 to 3 times per day, venting about 40 tons per day of CO_2 from a natural aquifer. Drilled by accident in 1936 and not capped.

"A good analog for how CO_2 might leak from a bad well [until capped]."

– Dr. Julio Friedmann, Lawrence Livermore National Laboratory

(Put cursor on photo to play video)

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Preliminary Observations:

"Carbon sequestration isn't rocket science – it's rock science." *Dr. Julio Friedmann*

Mother Nature has sequestered gigatons of carbon for eons with almost no escapes

Geological injection of CO_2 is not *<u>really</u>* a major potential hazard to human health
- **CO_2 itself is not inherently hazardous (unless you & it are in a hole together)**
- **Risk of leakage (or earthquakes) from <u>properly</u> <u>selected</u> sites is small**
- **Monitoring techniques are available to detect any leakage, should it occur**
- **Mitigation techniques are available to halt any leakage, should they be needed**
- **Consider: Natural gas pipeline hazards & experience, and natural gas storage**

CO_2/EOR is secure & better understood (with lower net costs) than non-EOR CCS
- **Oil reservoirs are natural traps; have survived eons of seismicity without leaks**
- **CO_2/EOR doesn't over-pressurize reservoirs – that would be counter-productive**
- **In No. America, CO_2/EOR is a bridge to non-EOR CCS – a big, wide, long bridge**
- **Elsewhere, non-EOR CCS is seen as a (potential) bridge to CO_2/EOR**

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CCS Liability Regime in the United States: "Crazy Quilt Federalism"

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Return to Report Contents Page

Overview

For nuclear power, since 1957 the Price-Anderson Act has governed liability:

- **"The main purpose . . . is to partially indemnify the nuclear industry against liability claims . . . while still ensuring compensation coverage for the general public.**
- **"The Act establishes a no fault insurance-type system in which the first approximately $12.6 billion (as of 2011) is industry-funded. Any claims above the $12.6 billion would be covered . . . by the federal government.**
- **"[I]t was considered necessary as an incentive for the private production of nuclear power — this was because electric utilities viewed the available [commercial insurance] liability coverage (only $60 million) as inadequate."** -- *Wikipedia*

Attempts to enact an analogous Federal law for CCS have gone nowhere

As a result, CCS legal liabilities are generally determined by state laws:

- **Few states have enacted CCS liability (or other CCS) statutes, and these don't match**
- **Some states (e.g., Texas) have clear laws for CO_2/EOR but not necessarily for non-EOR CCS**
- **Federal government (EPA) has begun to regulate <u>some</u> (not all) CO_2 injections**

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CO_2 for Enhanced Oil Recovery – Texas example re: liabilities

More than 90% of all oil recovered with CO_2 has been recovered in Texas: 40-year history of injection, currently about 100 million tons total per year

State regulatory approval is required for EOR injections (both H_2O & CO_2)

Once approved, injections can proceed with no duty to remove injectant:

- This applies to both water and carbon dioxide, if injected to extract minerals
- Right to inject without duty to remove later: This creates an effective right of storage

In addition, top Texas court has effectively eliminated actions for trespass

- So long as injection was state-approved for mineral extraction, no migration into adjoining areas is actionable under the "reverse right of capture" doctrine

"Who owns the pore space?" is thus largely moot for CO2/EOR in Texas, but:

- Some cautious folks are nonetheless optioning storage rights from surface owners
- Texas does have a statutory sequestration standard (99% for at least 1,000 years)
- Texas gives tax breaks for capture & EOR use of CO_2 from power plants (HB 469)
- Texas requires monitoring/verification/accounting as a condition of these tax breaks
- Liability for escapes? Presumably with operator, but unlikely in EOR context

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Commercial CO_2 Storage Projects (non-EOR), State by State*

- In the U.S., there is a trend toward states (1) clarifying that pore space is owned by surface owners, and (2) providing for unitizing or pooling rights at a storage site
- This incentivizes surface owners; C12 Energy & others typically agree to pay owners a small upfront fee plus a royalty during injection operations
- This engenders support; C12 Energy has communities seeking to host commercial CO_2 storage projects
- Outside the U.S., surface owners often don't own the subsurface. They may see only risk of CO_2 storage. Where surface owners can own the pore space, incentives may change the viewpoint of the surface owners.
- *Information on this & following slides courtesy of C12 Energy -- special thanks to Daniel Enderton*

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Examples of Community Support Where Landowners Can Earn Revenue

Return to Report Contents Page

Risk and Liability in State CCS Statutory Schemes

- Consensus is building on state CO_2 storage liability regimes. With some exceptions, the storage operator will bear liability during (1) the operational phase of a project, and (2) a post-closure monitoring period, until the CO_2 plume is deemed to have become "stable."
- Commercial insurance policies are available to cover operational liability risks; these risks (while somewhat new) are often analogous to existing risk profiles and may be quantified through well-understood means.
- States with statutory schemes have proven willing to assume liability after post-closure monitoring period, and/or create agencies/entities to do so.
- Site geology is critical to minimizing risks; it will affect ability to procure cost-effective insurance and demonstrate non-endangerment following a period of post-closure monitoring.

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State	Pore Space Ownership	Aggregation	Long-Term Liability*
Kentucky	Surface Owner	Unitization (51%)	Public Entity (after 10+ years)
Louisiana	Surface Owner	Eminent Domain (75%)	Public Entity (after 10+ years)
Mississippi	Surface Owner	Unitization (Majority Interest)	Not the State
Montana	Surface Owner	Unitization (60%)	Public Entity (after 25+ years)
North Dakota	Surface Owner	Unitization (60%)	Public Entity (after 10+ years)
Wyoming	Surface Owner	Unitization (80%, petition to 75%)	Not the State

Note: For CO_2-EOR, many states have unitization, with liability remaining with operator

* State assumptions of liability after a period of post-injection monitoring typically based on a performance standard wherein plume must be "stable" before transfer

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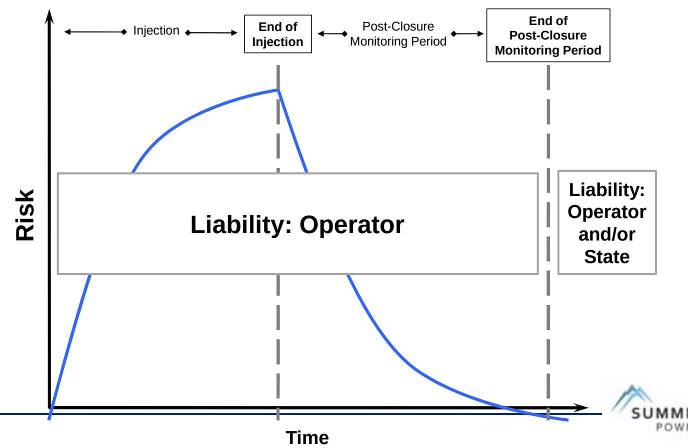
CO_2 Storage Subsurface Project Risk Profile



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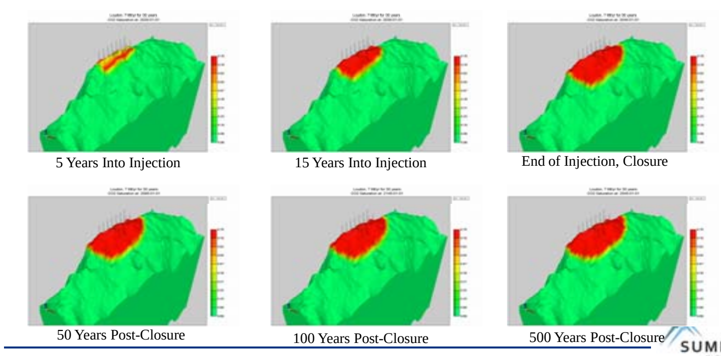
Geology Matters – An Example from C12 Energy

Leakage from reservoir to the atmosphere or groundwater contamination arises from CO_2 migrating vertically through wellbores or natural faults/fractures. Well chosen sites constrain CO_2 so that it doesn't migrate beyond project boundary and encounter leakage pathways that weren't fixed at the outset.



7 Mt/yr CO_2 Injection for 30 Years at the Loudon Anticline (Fayette County, IL)

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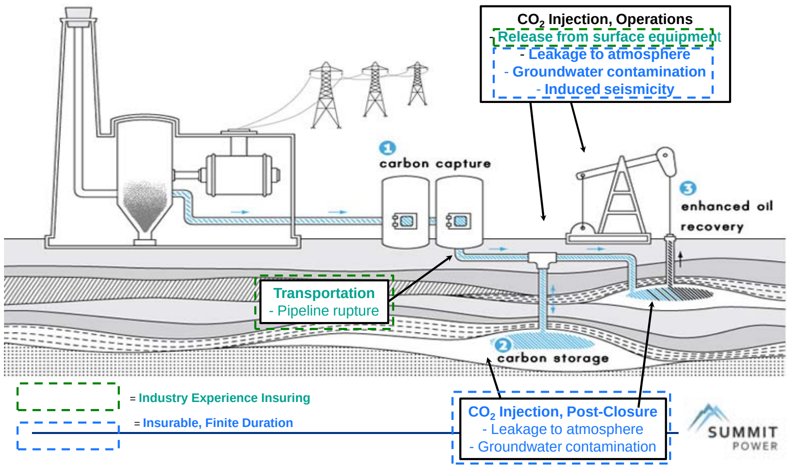
Return to Report Contents Page

Classification of Key CO_2 Storage Risk and Liabilities



Risk Phase	Risk Category	Potential Adverse Event	Insurance Available	Geology Critical	State Assumption of Liability
Operations	Transportation	Pipeline Rupture	✔	✗	✗
Operations	Sequestration	Leakage	✔	✔	✗
Operations	Sequestration	Groundwater Contamination	✔	✔	✗
Operations	Sequestration	Induced Seismicity	✔	✔	✗
Long-Term	Post Closure	Leakage	[✗]*	✔	[✔]**
Long-Term	Post Closure	Groundwater Contamination	[✗]*	✔	[✔]**

* Insurance available following end-of-injection in finite increments; trusts, escrows also possible

** Several states with comprehensive CO_2 storage rules have some assumption of liability after a period of post-injection monitoring when plume is "stable"

Liability Damages: The Industrial Economics Study

- Industry, government & environmental groups sponsored Industrial Economics, an expert in natural resource damage assessments, to estimate potential human health and ecological damages from well-selected & managed CO_2 storage project
- In 2012, IEc modeled a realistic project based on a site from the FutureGen process. The project was assumed to inject 50 million metric tons of CO_2 over 50 years and to have a 50 year post-injection period (for a 100-year analysis period).
- IEc estimated expected total damages arising from such a site to be $7.3 million (50th percentile) and $16.9 million (95th percentile).
- Equates to $0.15 (50th percentile) and $0.34 (95th percentile) per metric ton of CO_2.
- Estimates include human health and ecological damages from all credible potential adverse events, such as pipeline ruptures & subsurface leakage, over 100 years.

Total damages estimate at 95th percentile is far lower than limits commercially available for pollution legal liability insurance policies for CO_2 storage projects.

Reference: Industrial Economics, Inc. "Valuation of Potential Risks Arising from a Model, Commercial-Scale CCS Project Site." June 2012.

Pollution Legal Liability Insurance for CO_2 Storage

- CO_2 storage operators buy Pollution Legal Liability (PLL) insurance in addition to the standard liability insurance procured by most industrial businesses.
- PLL policies provide coverage for clean-up & remediation, third party bodily injury and property damage liabilities, and defense costs for covered conditions.
- Coverage includes contamination of underground source of drinking water (USDW); surface failure (e.g. pipeline leak); or subsurface failure (e.g. upward leakage or other subsurface release).
- Between five and ten PLL policies for CO_2 storage sites have been placed, and several more are pending, in the United States.
- ~10 insurers are currently willing to provide PLL policies for CO_2 sites, either as lead primary insurer or as excess carrier. A.M. Best ratings of this group of insurers range from A- (Excellent) to A++ (Superior).
- Each of the ~10 insurance carriers offers capacity of $10 million to $50 million.
- Total limits on policies placed in U.S. have ranged from $15MM to $200MM.
- As the market for these policies has developed over the past several years, insurance capacity has increased and premiums have come down.

Return to Report Contents Page

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* Generous contributors to, but not responsible for, this presentation; excellent contacts for those who would like to explore these issues more fully

Return to Report Contents Page

Renewable energies | Eco-friendly production | Innovative transport | Eco-efficient processes | Sustainable resources

CSLF Workshop on Risk and Liability of Geological Storage July 10-11, 2012, Paris

Session 6. How Safe is Safe Enough ? (cont'd)

Discussion leaders

Barry Worthington, USEA

Francois Kalaydjian, IFPEN

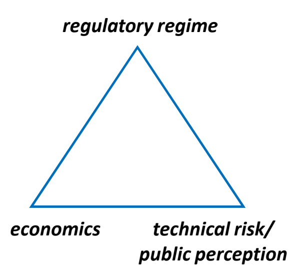
Questions

- What will make investors comfortable ?
- What geosciences information can create that comfort ?
  - What concepts and approaches for risk communication can be used ?
  - How can geosciences participate in effective communications ?
  - Are there relevant examples of effective or ineffective communications for geologic storage or from other fields ?

What will make investors comfortable ?

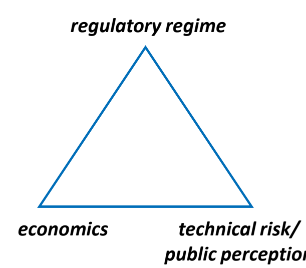
Safe enough ...

- for securing an attractive ROI (business case, value of CO2)
  - from 1 to 20 €/tCO2, CAPEX, geological uncertainty
- for allowing a transparent liability transfer from the operating companies to the public authorities (well stated regulatory framework)
- for minimizing technical risks and gaining public support



What geosciences information can create that comfort ?

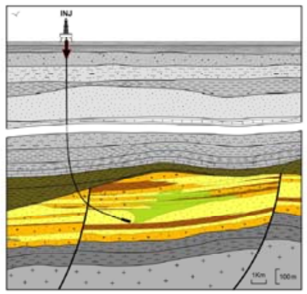
- Issues
  - improving performance
    - capacity, containment, injectivity, plume expansion, economics
  - permits
    - characterization, injection, closure, post-closure
  - derisking the storage
    - monitoring and surveillance, well and cap-rock integrity



Return to Report Contents Page

What geosciences information can create that comfort ?

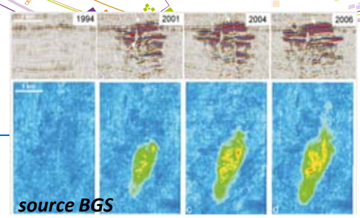
- **Safe and permanent storage –** To demonstrate that after 20-30 years of monitoring there won't be any evidence of a possible leakage.
- How to assess the long term behavior of a CO_2 storage ?
  - Monitoring / surveillance surveys
  - Use of gauges (surface, downhole)
  - use of a numerical simulator
    - observations vs simulations
- Acceptable leakage rate
  - Data acquisition – level of accuracy
  - Numerical simulations, prediction



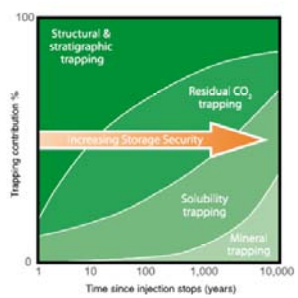
What concepts and approaches for risk communication can be used ?

- Zero risk cannot not be guaranteed
- Ensuring a long term safe storage requires to compare observations with predictions
  - decide about corrective actions, remediation techniques
  - setting up of both preventive and protective barriers.
- Regulatory framework : a stage-gate process
  - successive sanctions, no guaranty that the storage permitting process will pass all the gates
    - exploration : identification of a potential site;
    - characterization, design of the injection infrastructure
    - injection with monitoring and verification
    - closure: surveillance to calibrate the long term prediction of the storage safety and permanency.

How can geosciences participate in effective communications ?

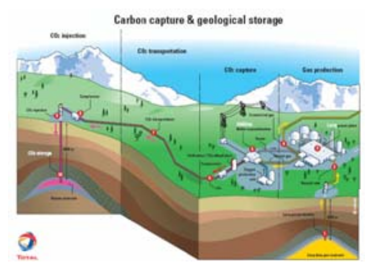


- CO_2 plume expansion with time
  - what is not seen is perceived as a threat
- Remediation
  - prevention
  - detection of leakage
  - remediation
- Safety increases with time
  - most of the events will happen during the first decades when the storage is fully instrumented and monitored
  - CO_2 dissolves and then sinks
  - CO_2 becomes less and less mobile



Are there relevant examples of effective or ineffective communications for geologic storage or from other fields ?

- The Lacq project (TOTAL)
  - communication took time but was effective
- Barendrecht ?



Return to Report Contents Page

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