# IEA GHG R&D Monitoring Network

Rick Chalaturnyk – University of Alberta
Kevin Dodds – BP Alternative Energy

# Joint Network Meeting Objectives

- Increase the communication and understanding between the networks
- Identify and prioritize key gaps that could be addressed by each network
- Ensure work is not being duplicated and leverage cross-network expertise
- Identify opportunities for collaboration
- Help refine each networks work programme for the next 3-4 years

# Review

- Review of previous network meetings
- An overview of the specific issues that the network is dealing with at the moment
- Initial thoughts about what the networks have to offer each other
- What the networks need from each other taking into account the results of the questionnaire

# Previous Monitoring Network Meetings

- Santa Cruz – 2004
  - The inaugural meeting of the Monitoring Network demonstrated that there is a large tool box of monitoring techniques that can be applied to both surface and sub-surface monitoring of $CO_2$.
- Rome – 2005
  - The second meeting focused on what were the monitoring requirements and how would they be defined with respect to risk and regulatory requirements.
- Melbourne – 2006
  - The third Monitoring meeting further enhanced the dialogue of regulatory and technical integration, with joint development of Monitoring, Evaluation, Reporting and Verification (MERV) guidelines.
- Edmonton – 2007
  - The fourth meeting provided developed regulatory protocols

# Santa Cruz - 2004

**Objectives**:

- Common understanding of the current state of the art
- Identify the available (MMV) techniques
- Assess limitations of (MMV) techniques
- *then*
- Develop a view of where technology needs to go in order to:

**Develop stakeholder confidence that injected CO2 can be monitored and verified and any leakage quickly detected.**

The workshop was attended by 57 delegates, from 38 different organisations and 7 different countries. The attendance list is given in Annex 1 for reference.

# Key Messages from Santa Cruz

- Public outreach is critical
- Substantial toolbox of monitoring techniques for monitoring in situ $CO_2$ movement and monitoring for surface and wellbore leakage.
- Seismic surveying proven capable of monitoring $CO_2$ movement at Sleipner and Weyburn.
- Monitoring of pilot projects can provide valuable information on advantages and limitations
- Monitoring costs will not add substantially to operational costs of an injection project
- Importance of baseline surveys

# Research Issues – Santa Cruz

- Due to plethora (..great word..)of monitoring techniques, new projects need guidance on what to measure and where..
- Such information can be provided by a safety and risk assessment of the injection site (if done early in project life..)
- Development of an "auditing" chart to enable right combination of techniques to be selected for a particular project

# Rome - 2005

- Objectives:
  - What are the monitoring requirements that need to be met
  - What sort of monitoring programmes are? needed to meet these requirements?
  - What do the regulators need to know in terms of the regulatory setting?

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[1] Regulatory bodies from a number of countries were approached to attend the meeting but many declined because at that time they did not consider themselves ready to comment. It is hoped that as the by the time the next meeting is held in autumn 2006 that more regulatory bodies might feel in a better position to discuss their needs.

  - Scenarios
  - 53 delegates

Acid Gas Scenario
Frio Scenario
Frio Discussion
Viking Graben Scenario

# Key Messages from Rome

- Meeting had not resolved all the questions posed in the objectives
  - Recognized that seismic monitoring is the most accepted tool for assessing the migration of $CO_2$ underground
  - Initial 3D survey followed by 2D high resolution
- Reinforced recognition that we (CCS community) need to demonstrate that it is possible to tell where the $CO_2$ injected into the ground has gone and how long it will stay there.
- Use of scenarios valuable because it allowed for focused discussion on a particular case – need to be well structured and sufficient time allowed
- More in depth discussion about project results (e.g. Frio, Nagaoka, …)

# Melbourne - 2006

Objectives

- Provide an integrated set of monitoring and verification (MERV) guidelines to encourage further public, regulatory and technical community discussion of wide scale deployment of CCS technology

Address the following questions:

What is a framework for MERV?

How do we provide assurance of storage integrity through well, seal and containment monitoring technology?

62 delegates from 10 countries…

# Melbourne – 2006

- Meeting was preceded by a one-day workshop on regulatory needs..
- Keynote speech: The Climate Change Context for CCS: Howard Bamsey, Deputy Secretary, Department of the Environment and Heritage.
- An NGO viewpoint on CCS, Regulation and Monitoring: Greg Bourne, CEO WWF Australia.
- US EPA Underground Injection Control programme experience: Elizabeth Scheele - US EPA
- A perspective on MERV for Australia: Gerry Morvell, Assistant Secretary Energy Futures, Department of the Environment and Heritage
- Insurance industry perspective: Peter Sengupta, Zurich Global Energy.
- Another country's experience with MERV: Steve Cornelius, UK Department for Environment, Food and Rural Affairs.
- **IEA Monitoring Tool: Andy Chadwick, British Geological Survey**.
- Goals of the OBPP monitoring programme + summary of other projects: Kevin Dodds, CO2CRC.
- Facilitated Discussions on Design of MERV Protocols and use in supporting the early trialling and eventual widescale deployment of CCS:

# Melbourne 2006

- What constitutes validation?
  - Affirmative data to validate model predictions,
  - Direct measurement of protected resources
  - What are we trying to quantify?
  - IPCC statement:

    It is very likely that the fraction of $CO_2$ retained is more than 99% over the first 100 years

    It is likely that the fraction of $CO_2$ retained is more than 99% over the first 1000 years
  - Protective of HSE criteria
  - Best possible practice: ALARP
  - Value of looking at retention not by percent
    - By mass
    - With time, by area, with pressure

# Melbourne 2006

- What retention can be predicted?
  - By natural analogues
  - Modelled – inputs from lab data, extrapolation of small scale observations, statistical approach
- What retention can be verified?
  - Accounting procedure
  - Point measurements
  - Integrated measurements

- Selecting the tools
  - Fit for purpose, all sites unique, select from MMV tool kit
  - Check up analogues
  - A procedure to follow that tailors test program for each site: Gateway process
- How do we set performance standards
  - Thresholds – what is action?
  - Issues of sensitivity, precision, accuracy, false assurance, false positives, need validated methods to provide public confidence

# Edmonton - 2007

- Since the inception of the Monitoring Network a significant amount of work has been done in this field.
- There are now a great number of very elaborate CCS demonstration projects occurring worldwide with each one developing and testing new monitoring techniques.
- Concurrently, there is also a great drive from many Governments to put in place the regulations needed to properly license and supervise CCS activities.
- This meeting hoped to review where we are with both aspects of CCS and identify what questions still need to be answered.

| DAY 1 – Regulations and Monitoring | | |
|---|---|---|
| 07.30 | **Registration/Coffee** | |
| 08.30 | **Introduction/Housekeeping:** | Brendan Beck and Rick Chalaturnyk |
| 08.45 | **"Albertans and Climate Change: Moving Forward"** | Honorable Rob Renner, Minister of Environment, Government of Alberta |
| 09.30 | **An ENGO viewpoint on CCS, Regulation and Monitoring** | Mary Griffiths, Pembina Institute |
| 09.55 | **Draft Quantification Protocol for Geological Storage Through EOR using $CO_2$ Injection – What Monitoring is Required?** | Brent Lakeman and Stephanie Trottier, Alberta Research Council |
| 10.20 | **Discussion/Questions** | |
| 10.35 | **Break** | |
| 11.00 | **Legal and Regulatory Guide for States and Provinces – IOGCC** | Rick Chalaturnyk, University of Alberta |
| 11.20 | **MMV : G8/CSLF and Canada-Alberta Task Force Activities** | Bill Reynen, Geological Survey of Canada |
| 11.50 | **Draft Regulatory Guidelines for Geological Storage of – $CO_2$ReMoVe** | Brendan Beck, IEA GHG |
| 12.15 | **Discussion/Questions** | |
| 12.30 | **Lunch** | |
| 13.30 | **Review of Acid Gas Regulations** | Stefan Bachu, Energy and Utilities Board |
| 14.00 | **Facilitated Discussion:** Are Acid Gas Regulations a suitable analogue for the development of Geological Storage Regulations? | |
| 15.00 | **Break** | |
| 15.30 | **Facilitated Discussion:** How to design and establish a suite of generic MMV protocols for $CO_2$ storage. | |
| 16.00 | **Facilitated Discussion:** What are the next steps to help expedite MMV arrangements and so assist in the wide scale implementation of CCS? | |

# Edmonton – 2007

- Project updates on Monitoring
  - Frio I and II
  - CSEMP
  - Penn West
  - Otway
  - Nagaoka
  - Midwest Partnership – Illinois
  - Weyburn
  - Westcarb

# Edmonton 2007

- Specific Session on a Technology – Seismic

| | |
|---|---|
| **A New Mode of Seismic Surveillance** | Leon Thomsen, BP |
| **Detailed $CO_2$ Injection and Sequestration Monitoring Through Crosswell Imaging.** | Mark McCallum, Z-Seis |
| **Design of Surface Seismic Programs for $CO_2$ Storage Monitoring** | Mark Egan, WesternGeco |
| **Discussion/Questions** | |
| **Break** | |
| **Passive Seismic: Listening for the Snap, Crackle, Pop!** | Marcia Couëslan, Schlumberger Carbon Services |
| **Employing Novel MMV Technology Integration Techniques To Increase Accuracy of Injection Monitoring.** | Eric Davies, Pinnacle |

# Edmonton - 2007

- Regulation is being developed in a number of regions around the world.
- Still some big regulatory issues to be solved, possibly the biggest and most contentious of which is when and how to hand over of the site to the national authority will occur.
- Encouraging to see the number of projects existing and planned and to see the wealth of monitoring techniques are being developed, tested and applied. As more projects are started and as current projects progress the availability of historic data will allow us to start to build monitoring standards and best practices which will improve our confidence in the technology and processes of CCS.
- Finally there were a number of questions that were raised throughout the course of the meeting that will need to be addressed:
  - How do you accurately locate and quantify the CO2 in the reservoir?
  - What do you do if a system parameter goes outside predicted values?
  - What additional information can seismic monitoring give us? When is it not applicable? Is it enough on its own and if not, what more do you need to complement it?
  - How much monitoring is required for different stakeholders and can the current monitoring techniques provide what the need?
  - How long do you monitor for? When and how does handover occur?

# Monitoring/Risk Assessemnt and the New Regulatory Network

Look back at Joint Mtg Objectives:

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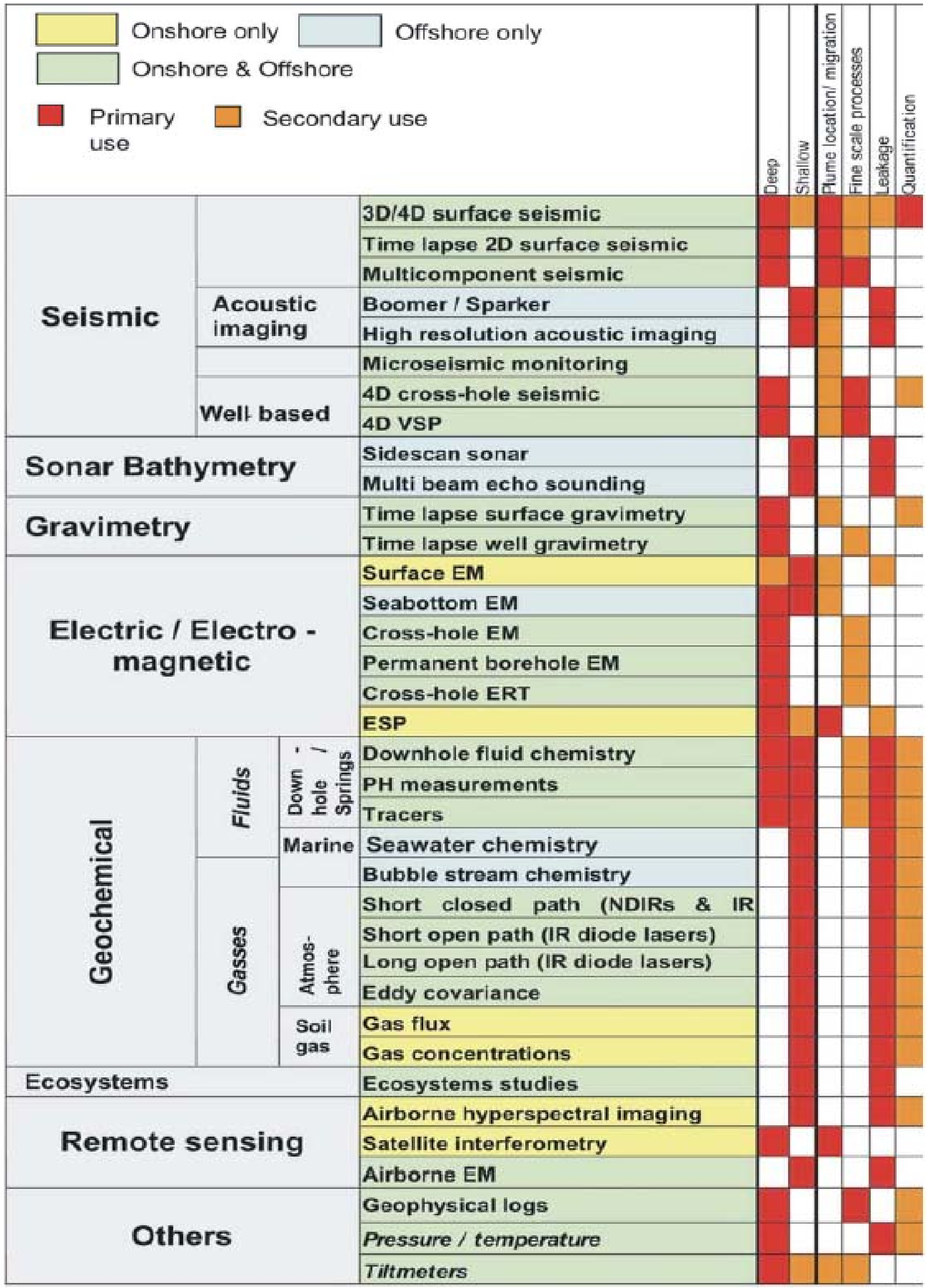
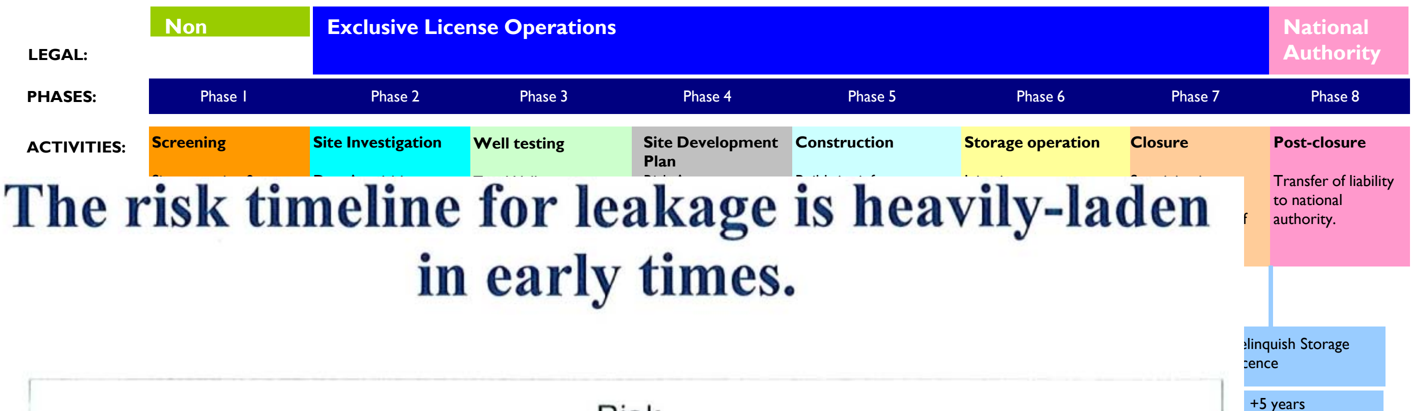
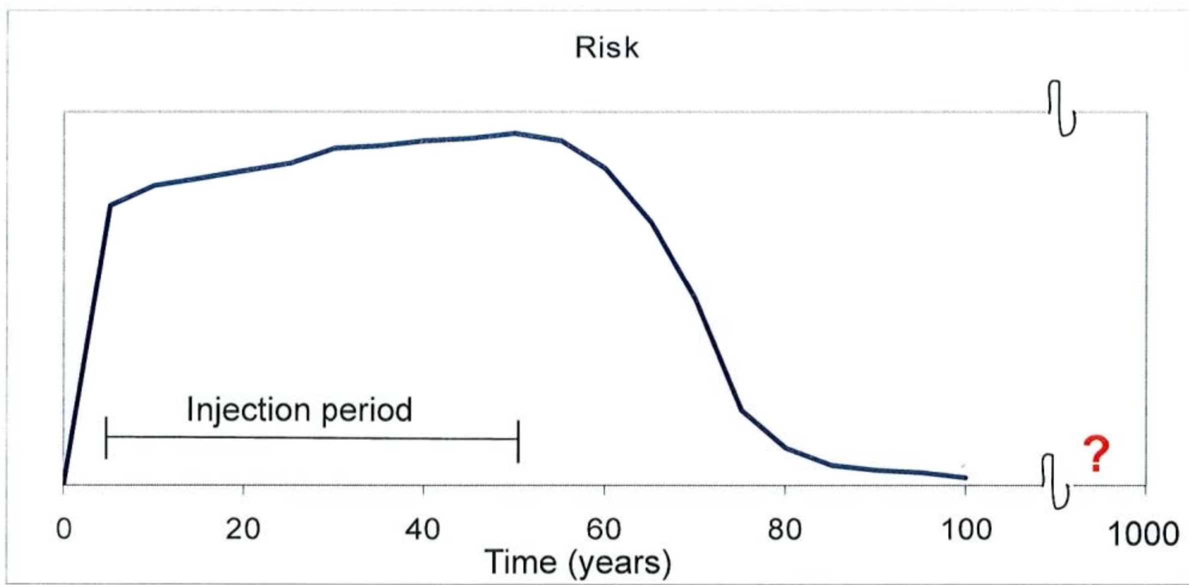



# IEA BGS Monitoring Tool.

# A (one of many) Regulatory Guide/Framework




**The risk timeline for leakage is heavily-laden in early times.**



$CO_2$

BRASSERIE

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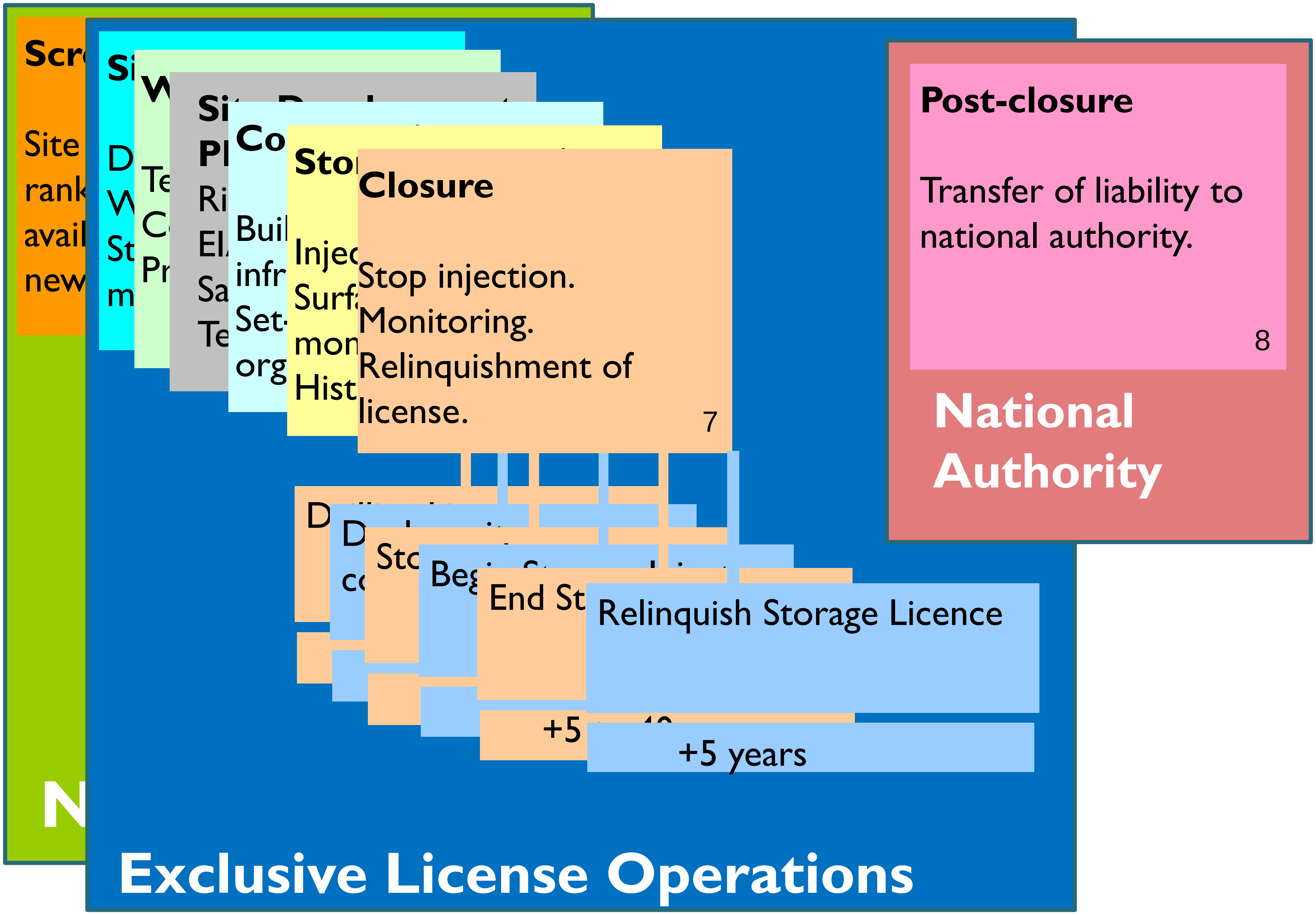

# Structure (as seen by CO2 ReMoVe)

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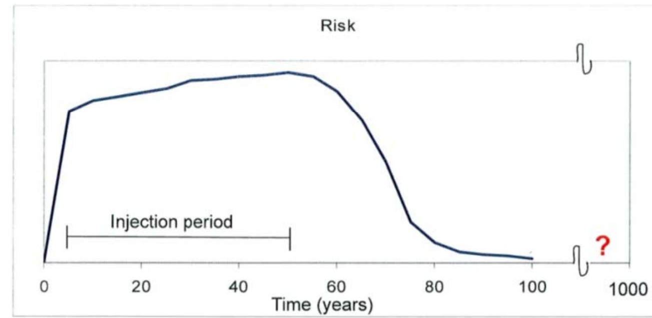


- Phases
  - Screening
  - Site Investigation
  - Well drilling & testing
  - Site development plan — **Site Selection**
  - Construction
  - Storage operation — **Operations**
  - Closure — **Closure**
  - Post-closure — **Post-Closure**

# Biggest Issue(s) currently facing Monitoring Network?

- To reach consensus, and not increase uncertainties on how treating risk assessment of CCS projects. Also to avoid too much of academic focus
- Need to demonstrate monitoring with more large-scale demonstration projects
- US Phase II (and III) pilot groups need to meet more frequently and focus on strategies for truly long term monitoring.
- Post closure issues.
- For risk assessment, common understanding about the input data needed to perform a full quantitative assessment, where these data can be gathered and what is expected from measurements/monitoring, modelling, labs tests
- To define what are the Best Available Technologies, to identify and promote innovative tools
- Test and probe different monitoring techniques to be used during CO2 storage project
- SCOPE issues:
  - What is Monitoring vs Site Characterization;
  - How/Whether to separate technically necessary (ie quantifiable risk) monitoring from Public Assurance monitoring
- Verification method, Regulation, International cooperation
- How to identify possible leakage pathways out of container
- Relating monitoring to all processes of storage

# Do you feel your network is addressing these issues?

- Awareness of the practical aspects could be increased
- Partly, with existing large-scale projects (Sleipner, Weyburn) but new monitoring projects are slow to start.
- I see a lot of focus on seismic and surface gas monitoring. Seismic is great for early site characterization but not cost effective or timely enough for long term commercial monitoring. Surface gas monitoring seems only there to pacify the public. By the time the gas reaches the surface it's too late! I think that we need for focus on technologies that will provide timely and cost effective updates on the subsurface location of the plume.
- To some extent in the 2007 meeting we had some discussion about that issue
- Partially.
    - The main gap is a lack of a "matrix" presenting the common interests among the three networks and the perspective they are dealt within each individual network. The objective should be to converge to a common outcome. For example, when a CO2 risk pathway is identified, is /are the simulation tools able to calculate it? Which output they provide? How this output can be then translated in probability of occurrence or severity of consequences
- For monitoring, BAT matter: yes, Innovative tools, still to be done
- Although a substantial suite of reliable monitoring techniques are available for application to CO2 storage, new and potentially more cost-effective approaches require testing
- Studying, discussion, meeting, having themed sessions, engaging regulatory community

# Do you have an understanding of the aims of the network(s) that you do not attend?

- 9 Yes's and 1 No

# What issues that are dealt with in each particular network(s) do you think could be relevant to another network?

- The understanding that all the aspects dealt with is part of the same overall process to quality $CO_2$ storage sites, and to secure high safety
- I think that wellbore integrity crosses all three networks and is very important
- For risk assessment, it would be managing a unit as whole with all its shallower formation and their associated different activities.
- For monitoring it would be using the existing oil and gas infrastructure.
- For monitoring, indicators of risks that can be direct or indirectly measured, monitored (on RA).
- Monitoring plan is part of risk management so communication is need between the RA and the M network
- Some monitoring techniques can be used to verify the well integrity and test the risk assessment results
- The RA+M connection is pretty obvious to me, as a Risk Assessor, but of course all 3 of them overlap and interrelate. That's inevitable and not a bad thing. Exactly what are the topics around which Networks should organize will and should always be a moving target. The joint RA+M meeting is a good idea … but that doesn't mean that this arrangement should be permanent! We have to see how issues evolve.
- Verification to wellbore integrity and risk assessment
- For Risk assessment, the role of risk process in driving monitoring strategy
- For wellbore integrity, integration of borehole integrity and seal integrity issues (rather than separate)

# How can issues that are common to more than one network be addressed?

- Use a generic time-line for developing CCS-projects, and ask the networks to advise on when to take action and how to progress the actions over time.
- Setup a joint meeting periodically to cover topics of common interest.
- Incorporate some inter-network panel discussions
- Creation of transversal working groups (few individuals dedicated to specific topics.
- Mailing group.
- Participating in a pilot in co2 storage in order to test the methodologies
- Review of outcomes of other network meetings within the alternate network meetings
- Identification of non-network issues relevant to other networks to be presented as part of review
- Summary of responses to alternate network issues
- Out of network meeting discussions.

# It has been proposed that a new Network is set up to look specifically at issues surrounding modelling? Do you think there is benefit in such a network?

- It is beneficial if the limitations and what to expect from modelling, are discussed not only within expert groups, but also spread to different stakeholders of CCS projects.
- YES. Modelling is a key component of all CCS projects and thus determining best practises in this area would be very useful.
- No. I'd rather see effort put into identifying economic monitoring methods that will work when the plants are at full capacity and the years after abandonment. Tools like InSAR are cheap and provide surface deformation measurements in the mm range but to date, the technology hasn't been widely deployed on early phase projects because the injections are to small.
- YES (quite a few times) and one Maybe
- YES, it is important to create a place where this community can meet, especially to perform benchmarking
- YES, a new network would be useful on this topic … but Modellers shouldn't be allowed to have more than 2 meetings in a row by themselves! Too susceptible to becoming remote from the "real world"; that is, from addressing issues that matter to other people.
- Simulation and modelling is very important for CCS. So, new network should deal with modelling and simulation.

## What other key issues - which are currently outside the scope of the networks - could benefit from further discussion and collaboration?

- Safety aspects of $CO_2$ transport infrastructure. Safety distances of $CO_2$ pipelines in urban environments seem to be a big challenge to handle.
- I'd like to see some regulatory workshops with people who can actually influence legislation. That will greatly reduce the risk uncertainty.
- Site integrity other then wellbore integrity.
- How can the input from scientist and engineers be better taken into account in the elaboration of regulatory aspects
- Site selection and Site characterization
- Legal aspects, cost and benefits, financial matters

# Phase I; Screening

- Non-exclusive activity to evaluate the practically and potential of storing $CO_2$ in an appropriate region by identifying, assessing and comparing possible candidate sites.
- Checklist Activities
  - Identify candidate $CO_2$ sources
  - Identify candidate storage sites and pipeline routes
  - Compile available information on the properties of the reservoir formation
  - Compile industry history of candidate storage sites
  - Perform preliminary capacity estimate of storage sites
  - Define extend of license area
  - Assemble documentation
- Milestone I: Apply for exclusive Site Investigation Licence

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# Phase II; Site Investigation

- Refine preliminary storage capacity estimates and to provide the geological information necessary to show that the site will perform effectively and safely.
- Checklist Activities
  - Refine the available information on the properties of the reservoir formation
  - Refinement of storage capacity estimate
  - Identify potential leakage pathways
  - Predictive flow modelling that includes reservoir, overburden and potential leakage pathways
  - Plan for drilling programme
  - Base line monitoring commences*
- Milestone II: Apply for exclusive Drilling Licence

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# *Baseline monitoring

- Needs to be initiated in good time prior to injection, exact timing (Phase II, III, IV) will be the responsibility of the licensee.
- Should include characterisation of the following systems over timescales that take into account seasonal and annual variation.
  - Geosphere;
    - Reservoir, underlying geology, and overburden.
    - Might include seismic data and drilling
  - Biosphere and local ecosystems;
    - Target species should be identified and monitored,
    - Potential for migration pathways to groundwater or local ecosystems should be identified.
  - Background fluxes;
    - $CO_2$, and $CH_4$ if appropriate, should be monitored at the storage site and any other relevant location,
    - Hydrological context should be understood.
    - Isotopic analysis of any background fluxes may be preferred as this is likely to help distinguish between background and injected $CO_2$.

# Phase III; Drilling and Well Testing

- To confirm and refine the site investigation and to provide basic data for predictive fluid flow modelling and capacity estimates.
- Checklist Activities
  - The drilling of test well(s)
  - Core extraction from test wells and analysis
  - Down hole logging of the test well
  - Pressure testing of the formation
  - The refinement of the reservoir models based on well data
- Milestone III: Declare the site commercial

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Uncertainty Management Plan

# Phase IV; Site Development Plan

- Plan operation and closure of the $CO_2$ injection site in detail.
- This phase also includes the completion of an environmental impact assessment
- Checklist Activities
  - A $CO_2$ storage risk assessment
  - Delivery of a catalogue of all the geological data obtained to the authorities
  - Design of injection facilities including number and location of wells
  - Development of site monitoring plan
  - Development of remediation plan
  - Development of well abandonment plan
- Milestone IV: granting of an exclusive Site Storage Licence

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# Phase V; Construction

- Construct the pipeline, injection facility and distribution system, and $CO_2$ injection well(s).
- Checklist Activities
  - Baseline monitoring
  - Storage operation planning and personnel training
  - Construction work tendering and the selection of sub-contractors
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- Milestone V: Start of injection of $CO_2$ into the storage reservoir

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# Phase VI; Storage Operation with Injection of $CO_2$

- Injection of the $CO_2$, evaluate how the site is performing compared to predictive models through Performance Assessment and evaluate the evolving risks through ongoing Risk Assessment.
- Checklist Activities
  - Injection of $CO_2$ according to the volumes and rates specified in the Site Development Plan
  - Execution of the monitoring programme* laid out in the Site Development Plan
  - Regular history matching of the data acquired through monitoring against the predictive models
  - Regular reporting to licensing authorities, local authorities and general public
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- The following measurements should be history matched against the predictive flow modelling.
  - Injected $CO_2$:
    - Mass, temperature and pressure of injected $CO_2$ should be measured continuously at each well throughout the injection period.
  - $CO_2$ inside the storage reservoir:
    - Temperature and Pressure.
    - Time-lapse imaging of the migration of $CO_2$ within the storage reservoir.
  - $CO_2$ outside of the storage reservoir;
    - Should detect any migration from the storage reservoir.
  - Surface fluxes of $CO_2$;
    - Periodic investigations of the site, and any area below which monitoring and modelling suggests $CO_2$ is distributed
  - Groundwater;
    - Contamination of potable water should be detected
  - Well Integrity;
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# *Monitoring Programme

- The monitoring program should also contain descriptions of the following:
  - Timing of surveys during Storage Operation phase;
    - Time-lapse surveys will need to be performed. Frequency of surveys should be described and justified.
  - Timing of surveys during Site Closure phase;
    - Monitoring will need to demonstrate the site is in agreement with predictive models.
    - Depending on the success of the history matching the frequency of monitoring surveys may be reduced.
  - Layout of surveys;
    - Taking into account land or marine use around the site, the geological nature and depth of the reservoir, location of faults, wells and other surface infrastructure.

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    - eg. geophone arrays, pressure and temperature sensors or fluid sampling systems.
    - Pads for gravity surveys, or markers for other key surveys may be installed.
  - Monitoring and modelling techniques;
    - A description of how monitoring techniques will be continuously reviewed to reflect the most recent best practice guidelines.
  - Detection limits and uncertainty;
    - The sensitivity of the monitoring techniques to detecting CO2 migration and leakage.

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# Phase VII; Site Closure

- Review and finalise the Safety Case for Long Term Storage Containment based on the results of the ongoing monitoring.
- This phase occurs between the cessation of injection and the transfer of liability from the licensee to the relevant national authority.
- Checklist Activities
  - Continued monitoring and history matching with simulation data
  - The compilation of an operational log that documents the history of the storage site
  - The compilation of a monitoring log that documents the history of the monitoring at the storage site
  - The removal of the surface infrastructure
  - The abandonment of the wells
- Milestone VII: Relinquishment of Site Storage Licence with transfer of liability to the relevant national authority

# Phase VII; Site Closure

- Review and finalise the Safety Case for Long Term Storage Containment based on the results of the ongoing monitoring.
- This phase occurs between the cessation of injection and the transfer of liability from the licensee to the relevant national authority.
- Checklist Activities
  - Continued monitoring and history matching with simulation data
  - The compilation of an operational log that documents the history of the storage site
  - The compilation of a monitoring log that documents the history of the monitoring at the storage site
  - The removal of the surface infrastructure
  - The abandonment of the wells
- Milestone VII: Relinquishment of Site Storage Licence with transfer of liability to the relevant national authority

# Phase VIII; Post Closure

- The post closure phase lasts an indefinite length of time and responsibility for a storage site and the trapped CO2 resides with the designated national authority
- Safety in the Post Closure Phase should not be based on the prerequisite need for a monitoring regime since this may be construed as placing an unethical burden on future generations to continue monitoring.

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- Degree of quantification?
- Spatial resolution?
- Number of Projects?