1st JOINT NETWORK MEETING

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ACKNOWLEDGEMENTS AND CITATIONS

The IEA Greenhouse Gas R&D Programme supports and operates a number of international research networks. This report presents the results of a workshop held by one of these international research networks. The report was prepared by the IEA Greenhouse Gas R&D Programme as a record of the events of that workshop.

The international research network on Risk Assessment, Monitoring and Well Bore Integrity are organised by IEA Greenhouse Gas R&D Programme. The organisers acknowledge the financial support provided by US EPA, EPRI and Oxand.

A steering committee has been formed to guide the direction of this meeting. The steering committee members for this meeting are:

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The report should be cited in literature as follows:

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The IEA GHG Joint Network Meeting

Executive Summary

This year the IEA Greenhouse Gas R&D Programme (IEA GHG) held the inaugural joint meeting of its three storage focused International Research Networks – the Risk Assessment Network, the Monitoring Network and the Wellbore Integrity Network. The event was held from the 11th to the 13th of June in New York, USA and was hosted by the US Environmental Protection Agency with support from EPRI and Oxand.

The aims of the meeting were;

- To ensure that the current Networks are working in the most efficient way without duplication or gaps between the Networks.
- To identify common areas that require the input from more than one network to see how this collaboration could be done in the most effective way.
- To set the framework for the future direction of the networks, both individually and as components of the overall storage programme.
- To assess the merit of a Modelling Network as a potential fourth IEA GHG storage network.

The meeting closed with each network presenting their final summary of the meeting with the main focus being on what issues to address in each network and with an overall wrap up from the IEA GHG.

The risk assessment network reviewed the network aims with a consensus that the network has been working toward achieving them. The network then went on to identify any gaps that need to be addressed by the network. There gaps were split into technical and network gaps.
The technical gaps that were highlighted were;

- Risks and quantification, in particular the risks of leakage into shallow marine environments and potable aquifers, and risks associated with co-contaminants. As well as the risks overall it was also stressed that the quantification of impacts specifically is a key area in need of further review.
- Risk assessment modelling, specifically understanding which different models and modelling techniques can be used specifically for the risk assessment process.
- It was noted that more could be learnt from the review of existing projects and that the network should do more with case-studies.
- Risk assessment communication, in particular identification and engagement of regulators, insurers, NGO's and the public.

For the network gaps the risk assessment group highlighted;

- Collaboration between the risk assessment network and the monitoring network given that monitoring is an integral part of the risk assessment process, and vice versa.
- Collaboration with the wellbore network, in particular the statistics, classification and causes of leakage through wells and how the influenced the risk assessment process.
- Communication with experts outside the network process with a current lack of information to help identify other groups/individuals in this field.

The monitoring network felt that the size, content and level of attendees for the network were excellent, however to improve the process it was suggested that it could address more specific topics or issues, provide more information before the network, and begin each network with a

review session to enable the attendees to be more prepared for the meeting and understand the context surrounding the topics to be discussed. The monitoring network identified a number of key issues to be addressed at the coming network meetings as follows:

- Monitoring for fault activation and pore pressure including issues surrounding CO_2 moving through a fault (how, why, when),
- Monitoring for dissolved CO_2 in situ,
- How to plan a monitoring programme?
- Innovative emerging monitoring technologies.
- How modelling integrates with monitoring?

To finish the discussion, the monitoring network chose to discuss the longer term aims of the network and to think about where the network would like to be in three years time. The main aims were to have; increased learning from current and new projects and to be closer to having quantitative performance limits for monitoring, informed by risk assessment.

The wellbore network identified a number of key issues to be addressed at the coming network meetings as follows;

- Some overarching wellbore questions on optimal abandonment practices, the range/type of wells which should be studied, demonstration of well performance, the impact of impurities in gas stream, and how to improve the history matching between lab and field experiments.
- Analysis of wellbore materials including steel and cement performance in the wellbore and the use of chemical sealants to stop formation leaks of CO_2.
- Evaluation of the range of wellbore modelling applications including; geomechanical models of well history, numerical models of well kill, and numerical studies of well leakage.
- Better use of case studies in wellbore integrity analysis.

In addition to these wellbore specific issues, the network also identified areas for collaboration with the other networks including the desire for information on well logs from the Nagaoka project, from the risk assessment network, and monitoring methods and requirements from the monitoring network.

With regard to the discussion of the proposed modelling network, the IEA GHG proposed an initial scoping study and preliminary meeting on modelling for the 2008/2009 period. The study and meeting will focus on reservoir and cap-rock modelling with the other modelling applications being covered in the existing networks. Modelling is inherently and closely linked to other networks and the potential continuation of a new network will be reviewed following the preliminary scoping study and meeting.

With regard to improving the network process a number of proposals were made for new networks including, a CO_2 infrastructure safety/risk network and a site characterisation network. The IEA GHG currently has two studies underway looking at these topics and will review the need for these networks following their completion.

To improve communication between the networks and external stakeholders a number of proposals were made. The suggestions included:

- Annual co-ordination of the steering committees where the agendas of each of the network meetings can be discussed and set questions/objectives for each other's meetings can be arranged.

- Network oriented reports from each network meeting on “learning points” for other networks. These would formalise the feedback and communication lines between networks.
- Cross-network working groups; set up to address specific issues for a limited time and with a specific remit.
- Linked network meetings; could be arranged over three days with each network having one individual day and one common day where cross-network issues can be discussed
- Future joint meetings; held regularly. These could be held every 3-4 years in person or more regularly via the internet.
- Closer coordination with those network members who interface with regulators – identify and anticipate key issues for networks to address.
- Networks to input to IEA CCS Regulators network.
- The networks could better identify, support and include experts that advise regulators.

The next steps following this meeting will be for the IEA GHG to pick up the actions mentioned, reflect and act on modelling discussions, coordinate steering committees, and combine storage networks mailing lists so that each Network will see the activities of the others.

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The IEA GHG Joint Network Meeting

1. Introduction

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The aims of the meeting were; to ensure that the current Networks are working in the most efficient way without duplication or gaps between the Networks, to identify common areas that require the input from more than one network to see how this collaboration could be done in the most effective way, and ultimately to set the framework for the future direction of the networks, both individually and as components of the overall storage programme. Finally, the joint network was asked assess the merit of a Modelling Network as a potential forth IEA GHG storage network.

The agenda and attendance list for the meeting can be found in Annex 1 and Annex 2 respectively.

2. Network Status Review

The first session of the meeting had the nominated chairs of each of the three networks give the current status and overview of their own network? Specifically the network chairs were asked to comment on:

- The state of the art work going on in their field,
- The specific issues that the network is dealing with at the moment,
- Their initial thoughts about what their network could offer the other networks,
- Their initial thoughts about what their network needs from the other networks.

2.1. Wellbore Integrity Network overview

The long-term ability of wellbores to retain CO_2 has been identified as a significant potential risk for the long-term security of storage facilities. To determine the integrity of wellbores and to design monitoring, evaluation and remediation methods for well bores, an analysis has to be performed on the CO_2 and wellbore interaction. Currently, the wellbore integrity network is looking at field situations where well bores have been exposed to CO_2 (such as existing EOR operations and natural CO_2 reservoirs) and in controlled laboratory experiments. In addition to physical analysis, the network is also looking at numerical modelling of CO_2 in the near-wellbore environment and in field-scale studies of multiple-well interactions. The network is also addressing how wellbore information is incorporated into a CCS risk assessment process as well as into CCS policy and regulatory developments.

More specifically, the network is examining;

- additional field investigation of well bores with long exposure to CO_2 and evaluation of leakage from legacy wells,
- the development and testing of new CO_2 resistant cements,

- the effects of casing and tubular corrosion on integrity,
- improving current monitoring and modelling techniques,
- steel and elastomer interactions with CO_2 and the likely effect on long-term CO_2 isolation,
- and the development of remediation methods and costs.

The network is also looking to gather additional information on the frequency of wellbore failures in practice which will directly inform the risk assessment network. Other areas where the wellbore network could interact with the other networks are in the development of risk-based assessments of wellbore performance with the risk network, and the development of monitoring techniques for detecting wellbore leakage of CO_2 with the monitoring network.

Ultimately the wellbore integrity network aims to develop a consensus document on the potential impact of wellbore behaviour on storage site performance.

2.2. Risk Assessment Network overview

The current focus areas of the risk assessment network that were covered at the 3rd risk assessment meeting in London are;

- to establish a common set of risk assessment terminology,
- decide how much site characterization is sufficient for a CCS site,
- Assess the prospects for quantitative vs. qualitative risk assessment,
- and the assessment of the FEP risk assessment process.

The key issues facing the risk assessment network over the next year are;

- the possible requirement for risk assessment guidelines, evaluating our confidence in the modelling results for CCS projects,
- a resolution of how long we need to monitor for after the cessation of CO_2 injection, whether the accident/worst case scenario risk assessment approach is a suitable risk assessment process,
- risk assessment communication to the public,
- and an assessment of whether current risk assessment processes are sufficient for the governmental and commercial management of CCS liability.

2.3. Monitoring Network overview

The most recent monitoring assessment meeting in Edmonton in 2007 looked at the collection of CCS demonstration projects occurring worldwide and the new monitoring techniques they are developing and testing and at the parallel drive from governments to put in place the regulations needed to properly license and supervise CCS activities.

This analysis of the current status of demonstration projects and regulation led to a number of unanswered questions in the monitoring network, specifically;

- how do you accurately locate and quantify the CO_2 in the reservoir?,
- what do you do if a monitored system parameter goes outside predicted values?,
- what additional information can seismic monitoring give us?,
- when is seismic not applicable?
- Is seismic enough on its own and if not, what more do you need to complement it?
- How much monitoring is required for different stakeholders?
- Can the current monitoring techniques provide what they need?
- And how long do you monitor for before handover occurs?

3. Breakout discussions on network reviews

Following the initial network overviews the group was split into their individual networks. The networks were asked to review the presentations and discussions relating to their network and to go over the points raised, to make sure nothing was left out and to expand on them if necessary.

3.1. Wellbore Integrity Review

The Wellbore Integrity breakout group felt there were a number of issues that were not mentioned. In particular there were some specific topics that the network needs to address. The issues raised were the need to find out more about;

- leakage into intermediate zones by CO_2 movement and brine movement,
- initial and end-state permeabilities for cement in wells, the use of steel and elastomers in the wellbore,
- impacts of the pressure pulse on wells and caprock and the attenuation of the pressure wave,
- the need to reconcile the differences between field results and lab results,
- and different types of corrosion and the role of corrosion inhibitors.

The Wellbore Integrity Network also identified information they need from the other two networks. From the monitoring network they need; information on the detection methods and impacts of leakage to intermediate zones, and detailed studies along individual wells, e.g. pressure communication and temperature sensors for significant flow and measurement of noise. From the risk assessment network, the wellbore integrity network needs to know how to move from the study of a few wells to the statistics of 1000's.

3.2. Risk Assessment Review

Overall the risk assessment network feel that they have identified knowledge gaps and helped direct research efforts but have not done enough work on risk management and mitigation strategies.

The network identified a number of specific issues that should be addressed. One issue was that CO_2 leakage is not the only risk associated with CCS, further analysis should be given to the risks of brine displacement, co-contaminants (e.g. sulphur species), mobilization of heavy metals, and earthquake inducement. Secondly, the network needs to look at risk assessment compared to risk management, this includes looking at variations in regional approaches to risk management. Finally the network needs to address a number of specific topics including the OSPAR ruling on no additions to the injectate, timescales of risk and the site specific component of risk, risk and vulnerability criteria, and the debate regarding risk vs. uncertainty.

3.3. Monitoring Review

The monitoring network came up with three keys areas that need further work;

- the definition of monitoring,
- storage security with and without quantification,
- and screening technologies by regulatory regime.

With regard to the definition of monitoring the network needs to; decompose monitoring into its specific purposes, identify who the target audience is, and overlay the IPCC guidelines appendix on monitoring with real case studies. The network may need a matrix of monitoring tools stating what they can do and where they are appropriate. This matrix could build upon the work done with the IEA GHG Monitoring Selection Tool.

In respect to quantification the network needs to define; the required sensitivity and certainty of monitoring tools and how to improve them, what degree of integration is required and the possible need for secondary monitoring processes. Experience from the oil and gas industry about the uncertainties inherent with the heterogeneities in geologic formations may well indicate that it is unrealistic to get full quantification. The network may also need a process to iterate modelling and measurements to provide reduced uncertainty and assurance of performance. Following on from this, it must be determined if we can have storage security without quantification?

The final area that was highlighted is the screening of technologies by regulatory regime. From a regulatory perspective can we categorise the monitoring that we need to achieve the given objectives. Keeping in mind there are two monitoring requirements, emissions accounting and storage security, what are the regulatory requirements? What technologies can meet the requirements? What accuracies and thresholds will be required? The two key regulatory questions are; how do you define the area of influence? And should we monitor a positive to report back that the performance is OK? How do we avoid over-prescriptive monitoring regulations?

It was also highlighted that with all these issues there is benefit in drawing from past experience from previous projects and from analogues.

4. Modelling

To start the discussions about a potential modelling network, an overview of the current status of modelling was given.

Modelling is a key component of CCS and is required to predict and understand what is happening in the reservoir and what will happen with the CO_2 into the future. Modelling was highlighted as a key issue to address from both within and external to the IEA GHG. Within the IEA GHG, modelling has been highlighted by the Executive Committee and each of the networks as a key issue that needs to be better addressed. External to the IEA GHG, modelling has been highlighted by industry, government and the public as a key requirement for CCS.

In the CCS industry, modelling has a number of applications including; static geological modelling of the reservoir, fluid flow, chemical reactivity, geomechanical behaviour, and CO_2 leakage through a well, amongst others.

The complexity of modelling should not be underestimated. Models in CCS need to address:

- Large ranges of timescales, from hours to thousands of years
- Large spatial scales of interest: from centimetres to tens of kilometres.
- Various areas of the site: reservoir, caprock, overburden, faults, wells, surface
- Natural heterogeneities, poor knowledge of the subsurface
- Various dynamic (& coupled) processes: fluid flow – geochemistry – thermodynamics – geomechanics – microbiology
- Uncertainty and sensitivity
- Site specificity

Only modelling can address such complex issues for enabling to make predictions but real data is necessary for model calibration and benchmarking. Given the number of projects that are now operational around the world there are case studies and the experience to underpin the network.

As mentioned previously, the existing IEA GHG storage networks have already highlighted the need for more activity in the field of monitoring. The wellbore integrity network identified; numerical models of wellbore geochemistry and geomechanics for providing long-term predictions, numerical models incorporating realistic permeability distributions for wells to evaluate the leakage potential of fields with multiple wells, integrated geomechanical and geochemical experiments/numerical models to capture the full range of wellbore behaviour, and long-term numerical modelling grounded in enhanced field and experimental data, as all being key areas for their network. The monitoring network at their recent network meeting, noted the importance of modelling in the various phases of CO_2 storage including; site investigation, drilling & well testing, storage operation, site closure. All monitoring measurements need to be history matched against the predictive flow modelling to verify that the CO_2 is behaving as is expected. The Risk Assessment network has also identified a link to monitoring with the last network meeting posing the question; how confident are we in modelling results? They also identified a need for modelling of physical, chemical, and mechanical phenomena in a way that can be useful for risk assessment.

To end the overview presentation the modelling chairs presented the results from the IEA GHG network survey that was circulated earlier in the year. The survey asked every person who had attended any of the three networks a number of questions about the network process. Included in the survey was the question: *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? If no, please comment*. Unfortunately there was only a limited response to the survey (18) however out of those who did respond, 72% were in favour of a modelling network with only 11%against.

5. Breakout discussions on modelling overview

Following the modelling overview the group was again split into their network groups to identify the areas in which modelling is currently looked at within their own network and where it could be looked at further in the future.

5.1. Risk Assessment Network Modelling Review

There was agreement within the Risk Assessment network that little work has been done to date on the specifics of process modelling. Generally it was accepted that detailed process modelling is vital although some thought that with sufficient site screening, detailed modelling may be avoidable.

There were two opposing viewpoints within the group as to how the modelling gap should be addressed. Part of the group felt that modelling processes in the geosphere merited a separate network whereas the other part of the group thought it is difficult to justify a modelling network because modelling is such an integral part of risk assessment. The second group felt that a separate network may have a detrimental effect on the Risk Assessment network and that it may be more appropriate to have Risk Assessment sub-group rather than a full network.

It was agreed that, if there is to be a new network, then the network needs a clear focus; the risk network must inform the new modelling network of requirements, i.e. modelling needs to be focussed on potential regulatory requirements and levels of sophistication.

5.2. Monitoring Network Modelling Review

The monitoring network felt that modelling of CCS is a specialized area and a modelling network would be good for sharing these challenges. The goal of the network should focus specifically on the process of modelling and not on peripheral issues that are covered in other networks. Up until now modelling has used tools from the oil and gas industry that were not designed for CO_2 storage, so another role of a modelling network could be to continue CCS specific model development. A new network could also look at how to communicate complex simulation results to the public.

The monitoring network defined four areas that modelling can address:

1. Benchmarking
    - Code validation
    - Analytical
    - Code comparison
2. Calibration
    - Lab/small scale comparisons
    - Some inversion
3. Validation
    - Occurs through monitoring
4. Long-term predictions
    - 1,000's of years

The third area was identified as the most import area for integrated between the modelling and monitoring networks with monitoring providing the data to calibrate the models. Data also must flow the other way with modelling providing the questions that monitoring needs to answer.

It was acknowledged by the network that until now they have not looked enough at issues surrounding modelling. Part of the reason for this is that historically there has been a lack of projects to demonstrate monitoring and modelling but things are changing. To conclude the monitoring network thought that regardless of whether the modelling network is created, the monitoring network needs increased focus on modelling and monitoring issues of CCS.

5.3. Wellbore Integrity Network Modelling Review

The wellbore integrity network can see a lot of areas where they could gain from a modelling network. The points highlighted were that a modelling network would help; with the development of geochemical and geomechanical models, with permeability models to evaluate the leakage potential of fields with multiple wells, and on long-term numerical modelling grounded in enhanced field and experimental data. They pointed out that modelling is core to a CCS project so it could be used to draw together the three existing storage networks.

The wellbore integrity network saw the creation of a modelling network as being similar to the wellbore integrity network which was formed from the risk assessment network. The group suggested that given modelling is such a wide subject with overlaps with some of the existing networks, that a modelling network would have to limit the scope of what they do and suggested that the focus should be specifically on reservoir modelling. They then made a list of possible things a modelling network could work on:

- Thermodynamic models
- Models of transport mechanisms in cement
- Develop an equation of state

- Help develop the understanding of geochemical reactions
- Help define transport phenomena
- Assist with history matching

6. CCS Phases

The third session of the Joint Network Meeting programme aimed to provoke thought about the practical application of information generated through ongoing CCS research and field projects and to identify potential gaps. An important consideration is whether the information generated through the networks is moving the state of art on CCS forward and supporting real-world deployment of CCS projects. The meeting again separated into groups for this session but unlike the previous two sessions, the groups were made up of people from all three networks. Each of the four groups looked at one of the four phases of a CCS project: site selection and permitting; site operation; site closure, and post-closure.

A CCS scenario was provided to the groups to ensure consistency. The scenario used was 1Mt of CO_2 storage in an onshore storage site utilizing an expired oil reservoir with 100 abandoned wells. Each group looked at what information/data is needed during each phase, i.e. characterize the site, generate a reservoir model, and perform a risk assessment, set up a monitoring programme, and plan remediation measures. The groups were asked to consider whether current information (in these categories) is sufficient to draw conclusions that support siteing, operation, and regulatory permitting decisions, if tools/ techniques which provide an appropriate level of confidence are available, and whether additional research/data is needed. If additional research was needed, the groups were asked to consider how it could be attainable, whether it is general or site-specific, and possible network contributions.

Throughout the discussions the groups were asked to keep in mind the three current networks in order to identify key issues to address within the networks and possible areas of collaboration between networks. Following this initial sessions, the groups were asked to identify any differences that would occur with a change of the scenario. Changes that were suggested were; larger volumes of CO_2, offshore storage, saline aquifer storage, EOR, storage/transport in a heavily populated area.

6.1. Phase 1: Site selection and permitting

The group looking at the first phase of a CCS project identified the key components of the phase as; capacity, injectivity, containment, risk, monitoring and future considerations. They also made some assumptions to help in the scenario analysis which were; the site chosen was the best site available, a due diligence study had been done, an EIA was not required, access rights had been granted, the regulatory requirements were known, and liability issues had been solved.

The data required in this phase included; the characterisation of the strata above and below the reservoir, information on any receptors within the project site such as potable aquifers or hydrocarbon reservoirs, all the existing oil field production and exploration data especially all the existing well data. With this data, a major uncertainty was seen to be the geochemical reactions and the effect they could have on injectivity and capacity; however the main risk for the scenario was seen to be with the 100 existing wells.

To help mitigate the risk associated with the wells the first priority would be to analyse the existing records about the site. The existing well data should provide information on the location of the well and give an indication as to its integrity. Some wells may need to be re-entered.

Assessing the current state of the wells should be accompanied by the development of a remediation plan in case a well leaks in the future. The well analysis process will be required to resolve the well liability issues that will exist. Some more thought needs to be given to performance standards for old wells, whether or not they are required, and if so what they should be.

For the alternative saline aquifer scenario it was noted that issues other than well integrity become of increasing relative importance.

6.2. Phase 2: Site operation

The group working on the site operation phase focused on the gaps in knowledge that could be an issue for regulators. The first issue was potential differences between the actual behaviour of a site and the predicted/modelled behaviour. It will be important for the regulators to have realistic expectations of the accuracy of predictions. The networks may be able to help inform them as to what realistic expectations are.

It will also be important for regulators to have an understanding about the limitations of monitoring. Key to this will be the tracking of the CO_2 plume as it migrates and whether seismic will be accurate enough or if other techniques will be required. Also relating to monitoring is the development of a suitable monitoring plan that is accepted by regulators. One concern is that regulators will ask for similar monitoring to that present at existing R&D sites which is unlikely to be repeated in commercial projects as it is likely to be far in excess of the minimum requirements. It was suggested that the regulators draw on external expertise to help in the verification of monitoring plans and that this could potentially be a role for the networks.

Other issues raised included; the well population and whether or not the project developers have sufficient info on abandonment conditions, triggers for remediation or action to define when the project operators needs to act, and the impacts of potential leaks from the site.

Following the analysis of the initial scenario the group looked at the impacts of changes to the scenario. If there was more CO_2 injected then the main issue would be the need to increase the number of injection wells. If the project included EOR then there are a number of questions including; do you perform retrospective storage site characterisation or do you stay as an oil producer, analysis must be done into the differences between an EOR site and a storage site, and can you get credits for the stored CO_2 in an EOR operation? If the site was in a populated area then you will require more assurance monitoring and a more thorough remediation plan, you will have more challenges with transport, the ground water impacts will drive regulation, and other underground activities will need to be considered. Finally, if storage was in a saline aquifer then additional information is needed for the site characterisation, and you will likely require more modelling and monitoring to be assured of storage security.

6.3. Phase 3: Site closure

The site closure group first defined what site closure meant and then decided on the aims of the phase. They defined closure as the period between when injection ends up to abandonment and handover. The aim of the closure session is to provide sufficient information to the regulator to allow hand over and to demonstrate that the risk associated with the site is within acceptable limits including; pressure stability, plume stability (not moving or moving predictably), and whether the site is leaking or not leaking.

To analyse the scenario, the group made a number of assumption including; the site has 2 operational wells to be abandoned and 100 abandoned wells (of various ages), the reservoir model has been updated during the operational phase, the operational model is large enough for long-term migration modelling and risk assessment, a thorough monitoring programme was implemented during operation, and abandoned wells have been approved for CO_2 storage.

The group then looked at the data that would be required during the closure phase in order to achieve the aim of assuring security. At the beginning of the phase it is important to know the pressure distribution in the reservoir at the end of CO_2 injection. Over the course of the phase the evolving pressure profile should be mapped as it reduces. It was suggested that the injection well could be used to monitor the pressure fall off. There was discussion about whether or not the injection wells will be abandoned before the closure period or whether they will be left available to use as monitoring wells. Pressure mapping will enable the operator to estimate the area of influence for post-closure time period. It will also be important to update the operational dynamic model as transient response disappears.

The operator should also be able to demonstrate that the CO_2 is not leaking through the cap rock or through any of the abandoned wells. With regard to the review of the performance records of the 100 abandoned wells there was disagreement as to the need to reassess well integrity at the end of the closure period. Well integrity issues at closure are controversial, some in the group believed that pressure in the abandoned wells should be monitored during operation and closure. Others believed that all abandoned wells will be signed off before operation begins therefore no more monitoring is required.

During the closure period, the risk assessment must be updated to establish the monitoring schedule and the duration of the period. This would initially use the monitoring data from the operational phase and will be updated with monitoring data from the closure period. Risk reduction measures may be necessary if closure monitoring identifies risk exposure. This may mean additional wells or intervention to bring the risk back within the accepted threshold.

Ultimately the group concluded that closure success is completely dependent on what is done in the operational phase and that you cannot recover in the closure period from failures to collect data in the operational period. They also made the point that more you inject and the longer you inject for, the more reliant you are on a good model and good validation.

Following the analysis of the closure phase the group looked at the potential gaps this highlights in the current network programme. They noted that currently integration of modelling is not addressed in networks and that there could be designated modelling individuals embedded within the other networks. In the risk assessment network it was thought that there needs to be a better discussion of operational risk vs. long-term risk and how they can be dealt with differently and they needs to establish criteria for the duration of the closure period. The well integrity network needs to better understand what will be required, if anything, during closure to validate well integrity and will also need to address the uncertainty associated with well integrity. The monitoring network needs to look more at closure monitoring and how to prove security before handover when the sensitivity of the tools decreases. The monitoring and risk assessment networks need to look more at history matching and what we mean by it and what we want from it. Somewhere in the networks there needs to be work done to look at the monitoring of abandoned wells and to look at the impacts of fracturing the cap rock. Finally we need far better communication between all the networks and the networks should get more specific on issues as we go forward and improve our knowledge.

6.4. Phase 4: Post-Closure

The post closure phase is probably the part of a CCS project that we know least about. The post-closure group therefore looked first to define the phase. The key question they saw was at what point does activity move into this stage from the closure phase? The key factors that should be taken into consideration when transitioning to post-closure were; plume stabilisation, reduced or diminished risks, and when no further monitoring is needed. The second consideration would be what happens at this point; transfer of liability to government body? Does the project still require occasional surface or USDW monitoring?

The group believed that post-closure would include the transfer of site liability to a governmental body along with a fund for remediation/mitigation if required. When the post closure phase is reached, models will be in existences that cover the monitoring requirements, plume migration and risk assessment. It will be an important that by the time of handover these models will have been validated/moderated to some degree. At the end of the closure period it is also likely that all wells would be plugged, preventing access and making re-entry difficult and costly if it were required.

If it is deemed that legacy monitoring would be required in the post-closure period then it would be important to learn from models and monitor those areas identified as higher risk. It is possible that risk increases post closure if the plume is still migrating and it begins to interact with more abandoned wells, but depending on classification of post closure phase it may not be able to commence if the plume is still moving.

Following the analysis of the initial scenario the group looked at the impacts of changes to the scenario. If there was a larger volume of CO_2 stored then there would be a larger plume to monitor which could result in increased leakage risk. Two key reasons for this increased risk would be due to the likelihood of encountering more wells and the increased chance of future human activity (residential development etc. taking place in the vicinity). It is also likely that stabilisation takes longer to occur.

If the storage was to occur offshore the intervention and access to wells would be much harder and more expensive, although there will likely be fewer wells to deal with, monitoring will more difficult and expensive, the environment requiring monitoring will be altered, migration / leakage may not be vertical which will increase the area for monitoring.

If the project utilised a saline aquifer for storage then there would be fewer wells to deal with, there might not be any structural trapping, and the lateral migration of the CO_2 could be less predictable due to aquifer flow leading to wider area of influence. In addition plume stabilisation could be prolonged necessitating monitoring during post closure or delay of post closure phase, and there is higher risk of leakage due to over-pressure of reservoir.

If the project was EOR you would potentially be looking at an increased number of wells which would increase the associated risk, however little else would change in the post closure phase. If the site was in a heavily populated area then the regulators may required more regular water testing, and possibly basement monitors for CO_2.

7. Network Summaries

This session provided an opportunity for the networks to discuss their observations from Day 1 and 2 and identify possible priority areas for collaboration and future work. The chairs of the networks were asked to give their thoughts about the direction that the Networks are going and on the key themes that they think need to be addressed. They will also be asked to present any new ideas about how the networks can better communicate and collaborate to get the most out of the network programme as a whole.

7.1. Wellbore Integrity Network - Future Programme and Summary

In the final wrap up session, the wellbore network choose to focus on what key issues should be presented at the next wellbore network meeting. These can be categorised into six general fields; overarching wellbore questions, materials, modelling, case studies, cross-network issues, and logistical issues.

The overarching questions to be addressed by the network include;

- What are optimal abandonment practices?
- What is the range/type of wells which should be studied in detail? What type of demonstration of well performance is necessary?
- What is the impact of impurities in gas stream on well integrity?
- How do you improve the history matching between lab and field experiments?

With regard to materials it was thought that there should be discussion into steel performance in wellbore integrity including issues relating to abandonment, milling, and corrosion (particularly in CO_2 transport). It was also mentioned that more investigation should be done into the use of chemical sealants to stop formation leaks of CO_2.

A number of different modelling areas should be discussed in relation to wellbore integrity. These range from geomechanical models of well history such as those performed at Weyburn, to numerical models of well kill, and numerical studies of well leakage such as those done by Oxand, Wertz and Schlumberger.

In order to address a lot of the issues highlighted it was suggested that more emphasis should be placed on the analysis of previous experience and case studies. A number of projects, operators, and researchers were identified that could help the aims of the wellbore network. It was suggested that Anadarko could present on their Salt Creek EOR field experience, CCP2 could present their 3rd well autopsy work, DNV could discuss subsea well-head penetration risk and benefit and CO_2 leakage, StatoilHydro could present the new results coming out of the recently launched Snovhit project, and AEP and Kinder Morgan could talk about the impact of impurities in gas stream and well integrity. It was also mentioned that the next well bore integrity network should include greater input from regulators and a review of the changes in regulatory systems in different areas/states/countries. This review should be timely as new regulatory data is expected to be released before the next meeting.

The wellbore network also identified some areas where input from the other networks would be beneficial. One particular input from risk assessment network was to provide details of well logs from the Nagaoka project before and after the earthquake events showing continual well integrity. They also highlighted information on monitoring methods and requirements from the monitoring network would be valuable.

As well as the above technical points, a couple of logistical points were made about the wellbore network. Firstly it was suggested that the meeting could benefit from less presentations and more discussion as it is discussion that is the most valuable. It was also suggested that there could be merit in developing an IEA GHG style report on the state-of-the-art wellbore practices.

7.2. Risk Assessment Network - Future Programme and Summary

The risk assessment network commenced their summary discussion with a review of the network brochure of the risk assessment network that had been produced by the IEA GHG in the lead-up to the joint network, in particular the stated aims and objectives of the network. Following the review there was concusses that the network has been working toward achieving aims. The network then went on to identify any gaps that need to be addressed by the network in the future. There gaps were split into technical and network gaps.

The technical gaps that were highlighted addressed; risks and quantification, modelling, communication, and case-studies and experience. The two risks that were specifically mentioned that need to be addressed were the risks of leakage into shallow marine environments and potable aquifers, and risks associated with co-contaminants. As well as the risks overall it was also stressed that the specific impacts should be looked at. The quantification of impacts in general was also identified as a key area in need of further review.

Risk assessment modelling was flagged for further discussion with a need to better understand which different models and modelling techniques can be used specifically for the risk assessment process.

Similarly to the wellbore integrity network, it was discussed in the risk assessment review that more could be learnt from the review of existing projects. Given the limited number of proposed projects as much information as possible needs be extracted out of existing projects.

Linking all these point together it was thought that a better understanding of risk assessment communication will be very important in the future. In particular, identification and engagement of regulators, insurers, NGO's and the public will all be crucial. It was noted that the technical gaps listed in this process were not ranked into any order of importance but that they should be ranked to enable the most urgent issues to be dealt with first.

For the network gaps the risk assessment group highlighted some areas where they could link with the other networks as well as linking to people and activities outside the network programme. Firstly, it was felt that the risk assessment network and the monitoring network were not sufficiently integrated as monitoring is an integral part of the risk assessment process, and vice versa. With the wellbore network, the major issues were seen to be the statistics, classification and causes of leakage through wells and how the influenced the risk assessment process. Some thought was given into how this current lack of communication could be overcome with suggestions of cross-network meetings, newsletters or webcasts as possible options. Communication with experts outside the network process was also seen as a weakness of the current programme with a lack of information to help identify other groups/individuals in this field. The network also saw engagement with the new IEA regulators network as a positive step.

7.3. Monitoring Network Future Programme and Summary

The monitoring network looked at their network meetings as they currently operate. It was thought that the meetings have good content with the right technical nature, it was thought they were of a good size which lends itself to open discussion, and it was thought that this discussion is the most valuable part of the network meetings. The network felt that the meetings do attract a good level of attendee but that there are other people who do not attend the networks who would be interested in getting the information.

The group then looked at how the monitoring network process could be improved. Firstly it was thought that the network could look to address more specific topics or issues at the meetings rather than the more general discussion that currently occurs. It was thought that this set of topics or questions would then make the scoping of the meeting much easier, with the scope dictated by the questions you are trying to answer and that this may help make measurable progress from one meeting to the next. It was suggested that more information could be provided before the network and that the network could begin with a review session at the start of each meeting.

There was call for a review of the current methods for announcing the meeting and communicating the results to ensure we are reaching the key people in the field. Following on from this point, it was stressed that the monitoring network is not an exclusive club, but can invite expertise in from outside the network. In particular this is important in increasing the involvement of modellers and regulators in some way in the network as these were two stakeholders that we felt to be missing from the network programme as it stands. However, the best way to gain involvement for these stakeholders was unclear.

Similarly to the other network reviews, the monitoring network saw it as important to look at the existing projects in the context of the network and to continue to review and keep up to date with project activity. This includes regional initiatives and any other activities that are supported by field data. One suggestion was to cherry-pick the most interesting parts of projects to present at the network meetings rather than waste time on subjects that people are already familiar with.
In the discussion of other projects and activities it was mentioned that as the network does not have an allocated budget of its own, the network could form linkages with projects that have budget to explore the issues we discuss within the programme. It was also noted that the network is in a good position to contribute to ongoing "transfer of knowledge" to regulators and industry.

The monitoring network looked at the need for better integration between the networks and came up with a number of suggestions that could help address the issue. It was noted that the networks could use representatives from one network representing the network at other meetings. Another first step was to have a cross-network registration and email invitation list so that every person in each network is at least aware of when the other networks are meeting and have the option to attend if it is relevant.

Specific areas for cross-network collaboration were identified. It was felt that monitoring network will always just focus on tools unless there is an integration of risk assessment element to give purpose and context. It was though that risk has to be a formal part of the monitoring agenda which has already began with risk assessment being discussed at the end of the monitoring network in Edmonton in 2007. It is also a combined risk/monitoring decision as to how long to monitor for.

One further issue that was raised in this session was that of site characterization and which network does it fit into? Does it warrant a network of its own or just more focus in the current networks? One suggestion was that site characterisation is just the front end of performance/risk assessment?

Following the analysis of the first two days of the joint network meeting and the monitoring network itself, the group came up with a short list of the specific issues that need to be addressed. The issues identified were; monitoring for fault activation and pore pressure including issues surrounding CO_2 moving through a fault (how, why, when), monitoring for dissolved CO_2 in situ, how to plan a monitoring programme, innovative emerging monitoring technologies, and how modelling fits into monitoring.

To finish the discussion, the monitoring network chose to discuss the longer term aims of the network and to think about where the network would like to be in three years time. The biggest development over the next three years would be increased learning opportunities from the additional projects that will come online in this time and from the additional three years of operation for the projects that are already underway.

8. Wrap up / Next Steps

The aims of the first joint network meeting were as follows:

- Review networks,
- Enhance links between networks,
- Identify Gaps, and duplication,
- Consider role of modelling in networks,
- Leverage cross-network expertise,
- Refine future focus and priorities of networks.

The IEA GHG storage networks bring together key international groups of experts to share knowledge and experience. Since 2004/05 the wellbore integrity network, the risk assessment network, and the monitoring network have been indentifying and addressing knowledge gaps in each field, and acting as informed bodies, e.g. for regulators, and assessing and managing the risks of geological storage. The work done by the networks benefits experts and wider stakeholders and has been built on the experts' time and inputs into the network.

With regard to the proposed modelling network, it is clear that there is a need for the IEA GHG to pursue some activity in the modelling area but there was no consensus on the need for a modelling network. From the discussion the IEA GHG proposed an initial scoping study and preliminary meeting on modelling for the 2008/2009 period. The study and meeting will focus on reservoir and cap-rock modelling with the other modelling applications being covered in the existing networks. They will provide a review of modelling tools and provide a source of advice to regulators and others. Modelling is inherently and closely linked to other networks and the potential continuation of a new network will be reviewed following the preliminary scoping study and meeting.

The review of the networks current structure and future focus and priorities was a very productive exercise and has provided the networks and the IEA GHG with a number of key points to take away and improve the already successful network programme. The joint network process has also improved the awareness of the other networks and should ensure that the steering committees formulate agenda for future network meetings with inter-network links and synergies considered.

Some areas flagged up as needs or gaps by the groups were not fully covered in the Networks' future activities. These included monitoring for other substances, quantification of CO_2 both from a leakage perspective and in situ stored, monitoring for leakage to near well intermediate zones, and cost issues. IEA GHG will consider how to address these.

Over the course of the three day meeting a number of options were proposed to add to the network process and enhance the communication between the individual existing networks. A number of proposals were made for new networks. The first proposed new network was the modelling network which will be considered again following an initial scoping study and meeting. The other two possible networks mentioned were CO_2 infrastructure safety/risk and site characterisation. The IEA GHG currently has two studies underway looking at CCS safety and site characterisation. Following the completion of these studies the need for additional networks will be reviewed. The IEA GHG may also use the networks to help review the work currently being done in the studies.

To improve communication between the networks and external stakeholders there were a number of proposals made. The suggestions include:

- Annual co-ordination of the steering committees where the agendas of each of the network meetings can be discussed and set questions/objectives for each other's meetings can be arranged.
- Network oriented reports from each network meeting on "learning points" for other networks. These would formalise the feedback and communication lines between networks.
- Cross-network working groups; set up to address specific issues for a limited time and with a limited remit.
- Linked network meetings; could be arranged over three days with each network having one individual day and one common day where cross-network issues can be discussed
- Future joint meetings; held regularly. These could be held every 3-4 years in person or more regularly via the internet.
- Closer coordination with those network members who interface with regulators – identify and anticipate key issues for networks to address
- Networks to input to IEA CCS Regulators network
- The networks could better identify, support and include experts that advise regulators

The next steps following this meeting will be for the IEA GHG to pick up the actions mentioned, reflect and act on modelling discussions, coordinate steering committees, and combine storage networks mailing lists so that each Network will see the activities of the others.

The next meetings for the storage networks and modelling will be;

- Preliminary Modelling Meeting – Orleans, 10 – 12 February 2009
- Risk Assessment Network – Melbourne 16-17 April 2009
- Wellbore Integrity Network – Calgary 12-13 May 2009
- Monitoring Network – Tokyo, 2-4 June 2009

IEA GHG would like to thank the hosts and sponsors, EPA, EPRI and OXAND. Special appreciation must be given to the chairs of the Networks and working groups who worked hard to bring out the results and conclusions in this meeting – Rick Chalaturnyk, Kevin Dodds, John Kaldi, Claudia Vivaldi, Craig Gardiner, Bill Carey, Isabelle Czernichowski and Gabrielle Marquette.

Annex 1 – Meeting Attendance List

Andrew Duguid	Schlumberger Carbon Services
John Kaldi	CO2CRC
Alan Belensz	NYS OFFICE OF CLIMATE CHANGE
Amanda Stevens	NYSERDA
Andrew Hewitt	Ontario Ministry of Natural Resources
Andy Nicol	GNS Science
Anhar Karimjee	USEPA
Anna Korre	Imperial College London
Atsuko Tanaka	AIST
Axel-Pierre Bois	CurisTec
Bill Carey	Los Alamos National Laboratory
Brendan Beck	IEA GHG
Brian McPherson	New Mexico Institute of Mining and Technology
Brian Strazisar	USDOE/NETL
Chiaka Shinohara	Japan NUS Co
Chris Hawkes	University of Saskatchewan
Claudia Vivalda	Schlumberger
Craig Gardner	Chevron Energy Technology Company
Curt Oldenburg	Lawrence Berkeley National Lab.
Dave Ryan	Natural Resources Canada
Don White	Geological Survey of Canada
Eris O'Brien	CO2CRC
Gabriel Marquette	Schlumberger
George Guthrie	LANL
Glen Benge	ExxonMobil
Grant Bromhal	USDOE/NETL
Gregory Myers	Shell E&P
Hans Aksel Haugen	Statoil
Hidemitsu Shimada	JGC
Hiroshi Wakahama	RITE
Hubert Fabriol	BRGM
Isabelle Czernichowski	BRGM
Ivan Krapac	IL State Geological Survey
James Brydie	ARC
James Sorenson	Energy and Environment Research Centre
Jean-Philippe Nicot	The University of Texas at Austin
Jérémie Saint Marc	Total
Jerome le Gouevec	OXAND
Johannes Leinbenberg	Sasol
John Gale	IEA GHG
John Litynski	U.S DOE NETL
Jonathan Koplos	Cadmus Group
Kevin Dodds	BP
Koorosh Asghari	University of Regina
Kris Ravi	Halliburton

Laurent Jammes	Schlumberger Carbon Services
Lee Spangler	Montana State University
Lisa Bacanskas	U.S EPA
Makoto Akai	AIST
Marc Lescanne	Total
Marcia Coueslan	University of Calgary
Martin Fasola	REPSOLYPF
Martin Jagger	Shell E&P
Martin Waterhouse	Sasol
Matteo Loizzo	Schlumberger
Michael Celia	Princeton University
Michael Parker	ExxonMobil Production Company
Narasi Sridhar	Det Norske Veritas Research
Nicolas Aimard	Total E&P
Niel Wildgust	IEA GHG
Norio Shigetomi	Mitsubishi Research Institute, Inc.
Norio Temma	AIST
Olivier Bouc	BRGM
Rabih Chammas	OXAND SA
Rajesh Pawar	Los Alamos National Laboratory
Ramgopal Thodla	Det Norske Veritas Research
Ray Knusden	Petroleum Technology research centre
Richard Rhudy	EPRI
Rick Chalaturnyk	University of Alberta
Rob Trautz	EPRI
Robert Finley	Illinois State Geological Survey
Ron Sweatman	Halliburton
Saeko Mito-Adachi	RITE
Shiro Ohkawa	Japan Petroleum Exploration Co., Ltd. (JAPEX)
Stefan Bachu	Alberta Energy and Utilities Board
Steve Benbow	Quintessa Limited
Steve Smith	Energy and Environment Research Centre
Tayfun Babadagli	University of Alberta
Tim Dixon	IEA GHG
Tjirk Benedictus	TNO
Toby Aiken	IEA GHG
Tony Espie	BP
Toshiyuki Tosha	AIST/GSJ

New York Skyline

Joint Network Meeting

11th-13th June 2008

New York, USA

Organised by

IEA Greenhouse Gas R&D Programme

Sponsored by
US EPA
EPRI
OXAND

11th June 2008 Day 1

08.00 Continental Breakfast Crystal Room 08.30 Registration Opens

09.00 to 09.30 Welcome and Introduction: John Gale, IEA GHG

Session 1: Network Status Review and Collaboration Thoughts
The chair of each network will give a review of the state of the art work going on in each field, an overview of the specific issues that the network is dealing with at the moment, the main areas of concern, and some initial thoughts about what the networks have to offer each other and what they need from each other taking into account the results of the questionnaire.

09.30 to 10.20 Wellbore Integrity Network: Bill Carey, LANL and Craig Gardner, Chevron

10.20 to 10.30 Questions

10.30 to 11.00 Break Crystal Room

11.00 to 11.50 Risk Assessment Network: John Kaldi, CO2CRC; Claudia Vivalda, Schlumberger and Rick Chalaturnyk, University of Alberta

11.50 to 12.00 Questions

12.00 to 12.50 Monitoring Network: Kevin Dodds, BP and Rick Chalaturnyk, University of Alberta

12.50 to 13.00 Questions

13.00 to 14.00 Lunch Gramercy Park

14.00 to 14.50 Panel Discussion involving Network Chairs

14.50 to 15.00 Questions

15.00 to 15.30 Break Crystal Room

Breakout Session 1: Review of Network Positions
This session will involve the group being separated into 3 smaller groups representing each of the individual networks. The groups will be asked to review the presentation and discussion relating to their network from the morning session and to go over the points raised, to make sure nothing was left out and to expand on them if necessary.

15.30 to 16.15 Breakout Groups

16.15 to 16.45 Group Results Presentations from Breakout Session 1

16.45 to 17.45 Discussion

Close Day 1
19.30 Dinner Sponsored by EPRI Gramercy Park

12th June 2008 Day 2 Continental Breakfast 08.00 crystal Room

Session 2: Modelling

This session will provide a review of the state of the art work going on in modelling, an overview of the modelling issues that networks are currently dealing with and modelling issues that are not being addressed by the current networks, and provide some initial thoughts about how a new modelling network or cross-network subgroup could contribute.

09.00 to 09.50 Modelling Overview: Gabriel Marquette, Schlumberger and Isabelle Czernichowski, BRGM

09.50 to 10.00 Breakout session 2 Introduction

This session will involve the group being separated into 3 smaller groups representing each of the individual networks. The groups will be asked to identify the areas in which modelling is currently looked at within their own network and where it could be looked at further in the future.

10.00 to 10.30 Breakout Session 2: Review of modelling within the current networks

10.30 to 11.00 Break Crystal Room

11.00 to 11.30 Panel Session - Group Results Presentations from Breakout Session 2

11.30 to 12.00 Panel Discussion - Discussion of the cross network modelling needs and the proposed Modelling Network.

Session 3: CCS Phases

The goal of this session is to provoke thought about the practical application of information generated through ongoing CCS research and field projects and to identify potential gaps. An important consideration is whether the information generated through the networks is moving the state of art on CCS forward and supporting real-world deployment of CCS projects. This session will be focused on the permitting/approval process for CCS projects as a way to identify key data/ research needs that will enable CCS projects to move forward.

12.00 to 12.15 **Breakout Session 3 Introduction**

Each group will be asked to look at one of the four phases of a CCS project: site selection and permitting; site operation; site closure, and post-closure. A CCS scenario will be provided to ensure consistency. For example, 1Mt of CO_2 storage in an onshore storage site utilizing an expired oil reservoir with 100 abandoned wells. Each group will look at what information/data is needed during each phase, i.e. characterise the site, generate a reservoir model, perform a risk assessment, set up a monitoring programme, and plan remediation measures. They will consider whether current information (in these categories) is sufficient to draw conclusions that support siting, operation, and regulatory permitting decisions, if tools/ techniques which provide an appropriate level of confidence are available, and whether additional research/data is needed. If additional research is needed, the group will consider if and how it is attainable, whether it is general or site-specific, and possible network contributions. Throughout the discussions the groups should keep in mind the three current networks in order to identify key issues to address within the networks and possible areas of collaboration between networks.

12.15 to 13.00 Breakout Session 3

13.00 to 14.00 Lunch Gramercy Park

14.00 to 15.00 Breakout Session 3 Continued

In the second half of the third breakout session, the groups are asked to continue their discussion and analysis of the original scenario but to also identify any differences that would occur with a change of the scenario. Changes that would be useful to look at would be larger volumes of CO_2, offshore storage, saline aquifer storage, EOR, storage/transport in a heavily populated area.

15.00 to 15.30 Break Crystal Room

15.30 to 16.30 Group Results Presentations from Breakout Session 3

16.30 to 17.30 Discussion

17.30 to 17.45 Day 2 Wrap up

Close Day 2

13th June 2008 Day 3 Continental Breakfast 08.00 Crystal Room

Session 4: Network Summary
The goal of this session is to provide an opportunity for the networks to discuss their observations from Day 1 and 2 and identify possible priority areas for collaboration and future work.

08.30 to 08.45 **Breakout session 4 introduction:** Network Work Programmes.
The fourth and final breakout session is to discuss near and long-term work programmes for each Network based on the discussions from the previous two days.

08.45 to 10.30 Breakout Session 4

10.30 to 11.00 Break Crystal Room

The following presentations provide the network chairs with the opportunity to report back from the Breakout session 4 as well as give their impressions on the previous two days. The chairs will be asked to give their thoughts about the direction that the Networks are going and on the key themes that they think need to be addressed. They will also be asked to present any now ideas about how the networks can better communicate and collaborate to get the most out of the network programme as a whole.

11.00 to 11.20 Wellbore Integrity Network: Bill Carey, LANL and Craig Gardner, Chevron

11.20 to 11.30 Discussion

11.30 to 11.50 Risk Assessment Network: John Kaldi, CO2CRC; Claudia Vivalda, Schlumberger; Rick Chalaturnyk, University of Alberta

11.50 to 12.00 Discussion

12.00 to 12.20 Monitoring Network: Kevin Dodds, BP and Rick Chalaturnyk, University of Alberta

12.20 to 12.30 Discussion

Session 5: Wrap up / Next Steps

12.30 to 13.00 Presentation on Future Network Options – combining, creating new networks or cross-network working groups, etc: John Gale, IEA GHG

13.00 to 14.00 Lunch Gramercy Park

14.00 to 15.30 Discussion of Day 3

15.30 to 16.00 Next Steps and Wrap up: John Gale, IEA GHG

IEA Greenhouse Gas R&D Programme

1st Joint Network Meeting

Co-organisers and sponsors: EPA
Sponsors: EPRI and OXAND

New York – 11-13 June 2008

IEA Greenhouse Gas R&D Programme

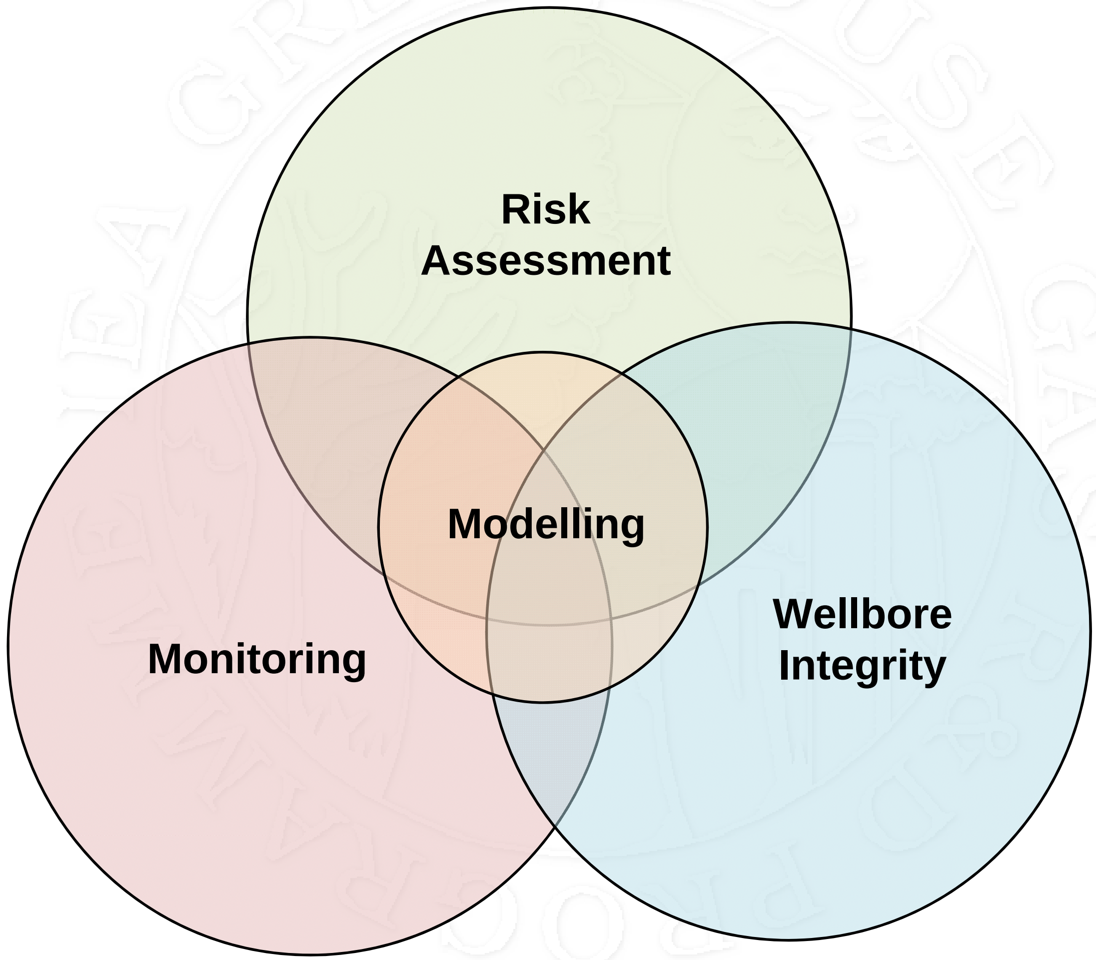
- A collaborative research programme founded in 1991
- Aim: *Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions.*
- Producing information that is:
  - Objective, trustworthy, independent
  - Policy relevant but NOT policy prescriptive
  - Reviewed by external Expert Reviewers
  - Subject to review of policy implications by Members
- Activities: Studies (>120); R&D networks :- Wells, Risk, Monitoring, Oxy, Capture, Biofixation; Communications (GHGT9, IJGGC, etc); facilitating and focussing R&D and demonstration activities
- Funding approx 2 million €/year (2.6 million $/year).

R&D Networks

- Bring together international key groups of experts to share knowledge and experience
- Identify and address knowledge gaps
- Act as informed bodies, eg for regulators
- CO_2 geological storage – assessing and managing risks
- Started in 2004/5
  - Monitoring Research Network
  - Risk Assessment Research Network
  - Wellbore Integrity Research Network

- Benefit experts and wider stakeholders
- but - depend on experts' time and inputs – valuable and widely appreciated

Storage Networks Overlap



IPCC Guidelines for GHG Inventories

- Apr 2006. Vol 2 Energy, Chp 5 - *CO_2 Transport, Injection and Geological Storage*
- Emission factor approach not possible - natural variability of storage sites and lack of empirical evidence – so approach based on **measurement and monitoring** and on a **site-by-site** assessment
- Methodology

  Site characterisation – inc leakage pathways

  ↓

  Assessment of risk of leakage – **simulation / modelling**

  ↓ ↑

  Monitoring – monitoring plan

  ↓

  Reporting – inc CO_2 inj and emissions from storage site
- For appropriately selected and managed sites, supports **zero leakage** assumption unless monitoring indicates otherwise

Joint Network Meeting

Aims

- Review storage-related networks
- Enhance links between these networks
- Identify any gaps, and duplication
- Consider role of modelling in networks
- Leverage cross-network expertise
- Refine future focus and priorities of networks

Workshop agenda

1. Networks status review and collaboration thoughts
   - Breakout session (by network)
2. Modelling
   - Breakout session (by network)
3. CCS project phases – application and role of networks
   - Breakout session (mixed)
4. Networks summary and future work
   - Breakout session (by network)
5. Conclusions and next steps

Breakout Groups

- For the three Network Specific Breakout groups the chairs and IEA GHG staff representatives will be as follows:
  - **Wellbore Integrity** – Bill Carey (Chair), Craig Gardner (co-chair), Toby Aiken (IEA GHG Staff)
  - **Risk Assessment** – John Kaldi (Chair), Claudia Vivalda (co-chair), Neil Wildgust (IEA GHG Staff)
  - **Monitoring** – Kevin Dodds (Chair), Rick Chalaturnyk (co-chair), Brendan Beck (IEA GHG Staff)

Breakout Groups

- For the four Cross-network Breakout groups the chairs and IEA GHG staff representatives will be as follows:

  - **Group 1** – Tony Espie (Chair), John Kaldi (co-chair), Neil Wildgust (IEA GHG Staff)

  - **Group 2** – Gabriel Marquette (Chair), Anhar Karimjee (Co-chair), Tim Dixon (IEA GHG Staff)

  - **Group 3** – Rick Chalaturnyk (Chair), Isabelle Czernichowski (co-chair), Brendan Beck (IEA GHG Staff)

  - **Group 4** – Dick Rhudy (Chair), Laurent Jammes (co-chair), Toby Aiken (IEA GHG Staff)

IEA Greenhouse Gas R&D Programme

www.ieagreen.org.uk

Wellbore Integrity Network

Bill Carey (Los Alamos National Lab)
Craig Gardner (Chevron Energy Technology Company)

1st Joint Network Meeting
11th – 13th June 2008

Network Origin and Charter

- The long-term ability of wellbores to retain CO_2 has been identified as a significant potential risk for the long-term security of geologic storage facilities
- Assess and communicate the state of knowledge, nature of research programs, and the research needs to understand the long-term integrity of wellbore systems in CO_2-rich environments

History of the Network

- Founded by Charles Christopher and developed in collaboration with John Gale
- Inaugural Meeting April 2005 – Houston
- 2nd Meeting March 2006 – Princeton University - NJ
- 3rd Meeting March 2007 – Los Alamos National Laboratory, Santa Fe NM
- 4th Meeting March 2008 – Schlumberger, Paris

Steering Committee Members

- Toby Aiken, IEA GHG
- Idar Akervoll, SINTEF
- Stefan Bachu, Alberta Energy Resources Conservation Board
- Bill Carey (chair), LANL
- Mike Celia, Princeton University
- Walter Crow, BP
- Rich Chalaturnyk, University of Alberta
- John Gale, IEA GHG

Network Objectives

- Determine impact of CO_2 interaction with wellbore materials on long term storage
- Bring together experts working on CCS
- Assess current level of understanding
- Develop R&D priorities
- Facilitate collaborative research efforts
- Collect and develop field experience

Objectives (Continued)

- Provide recommendations of field monitoring and integrity evaluation
- Provide recommendations for remediation
- Foster and provide leadership for experimental and numerical studies
- Provide guidance on policy and regulations

Workshop Format

- Invited presentations in focus areas
- Hour-long informal extended discussions following each focus area
- Breakout groups were used in first two meetings to develop approaches and philosophies surrounding a key issue
- A summary report of the presentations, discussion, and breakouts is written by IEAGHG staff

Wellbore Integrity Focus Areas

1. Field studies of CO_2 in the wellbore environment including EOR and natural CO_2 reservoirs
2. Field monitoring and evaluation methods
3. Remediation approaches
4. Experimental studies on cement-CO_2 interactions including new cement formulations
5. Numerical modeling of CO_2 in the near-wellbore environment and in field-scale studies of multiple-well interactions
6. Risk, Best Practices, and Policies and Regulations

Topics in Field Experience (1.)

- Practice and art of cement placement in the wellbore environment
- Case histories from EOR fields, acid gas disposal, and CO_2 reservoirs
- Case histories from sequestration sites
  - Weyburn, Penn-West
- Coring, sampling, and logging studies of wells with significant CO_2 exposure
  - (SACROC and CCP)
- Wellbore statistics from petroleum provinces
  - Alberta, North Sea

Topics in Monitoring & Evaluation (2.)

- Reviews of logging methods
- Role of sustained casing pressure as a wellbore failure indicator
- Research into enhanced acoustic logging methods
- Field studies of wellbore logging

Topics in Remediation (3.)

- Methods of remediation
- Experience with remediation

Topics in Laboratory Experiments (4.)

- Closed system cement alteration studies in CO_2-rich environments
- Open system flow-through experiments through simulated wellbore constructions
- New CO_2-resistant cement formulations evaluated

Topics in Numerical modeling of CO_2 and the Wellbore Environment (5.)

- CO_2 distribution and fate in the reservoir
- Effects of CO_2 on water saturation and possible desiccation of pore system
- Reactive transport modeling of CO_2-cement systems
- Simulation of CO_2 leakage through wellbore annulus or open hole
- Simulation of wellbore leakage with many wells
- Incorporation of wellbore integrity into risk assessment of CO_2 sequestration

Topics in Risk, Best Practices, and Policies and Regulations (6.)

- American Petroleum Institute recommended practices
- Mineral Management Service (MMS) regulations (particularly with respect to sustained casing pressure)
- Alberta, Canada regulatory framework
- European regulatory approaches
- EPA's Underground Injection Control program regulations
- Recommendations for best practices

Summary of Key Issues (1)

- Wellbore integrity problems exist in oil and gas operations (e.g., SCP). We need to develop a basis for evaluating leakage potential from legacy wells
- Laboratory experiments on CO_2-cement need to reconcile effects of key variables: confining pressure, fluid flow, matrix vs. interface flow, and effect of reservoir rock
- New approaches to wellbore remediation and methods to evaluate the potential costs of remediation are needed

Summary of Key Issues (2)

- New CO_2-resistant cements are in development and methods for evaluating their performance and determining their suitability are needed
- Casing and tubular corrosion may be more rapid than cement degradation but their role in integrity is unclear
- More sensitive and diagnostic logging and field monitoring tools are needed

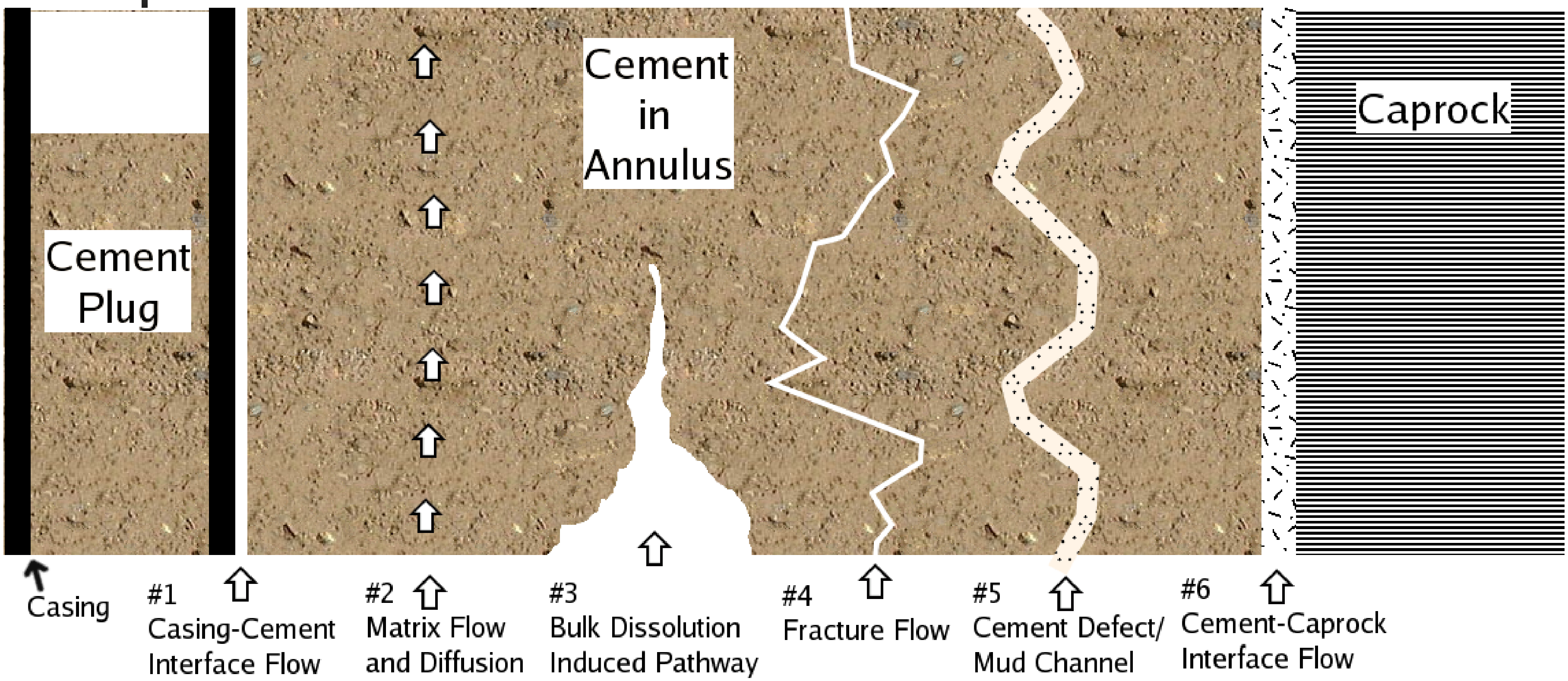
Summary of Key Issues (3)

- Numerical models of wellbore geochemistry and geomechanics need additional development for providing long-term predictions
- Numerical models incorporating realistic permeability distributions for wells are needed to evaluate the leakage potential of fields with multiple wells
- Integrated geomechanical and geochemical experiments/numerical models are needed to capture full range of wellbore behavior

Summary of Key Issues (4)

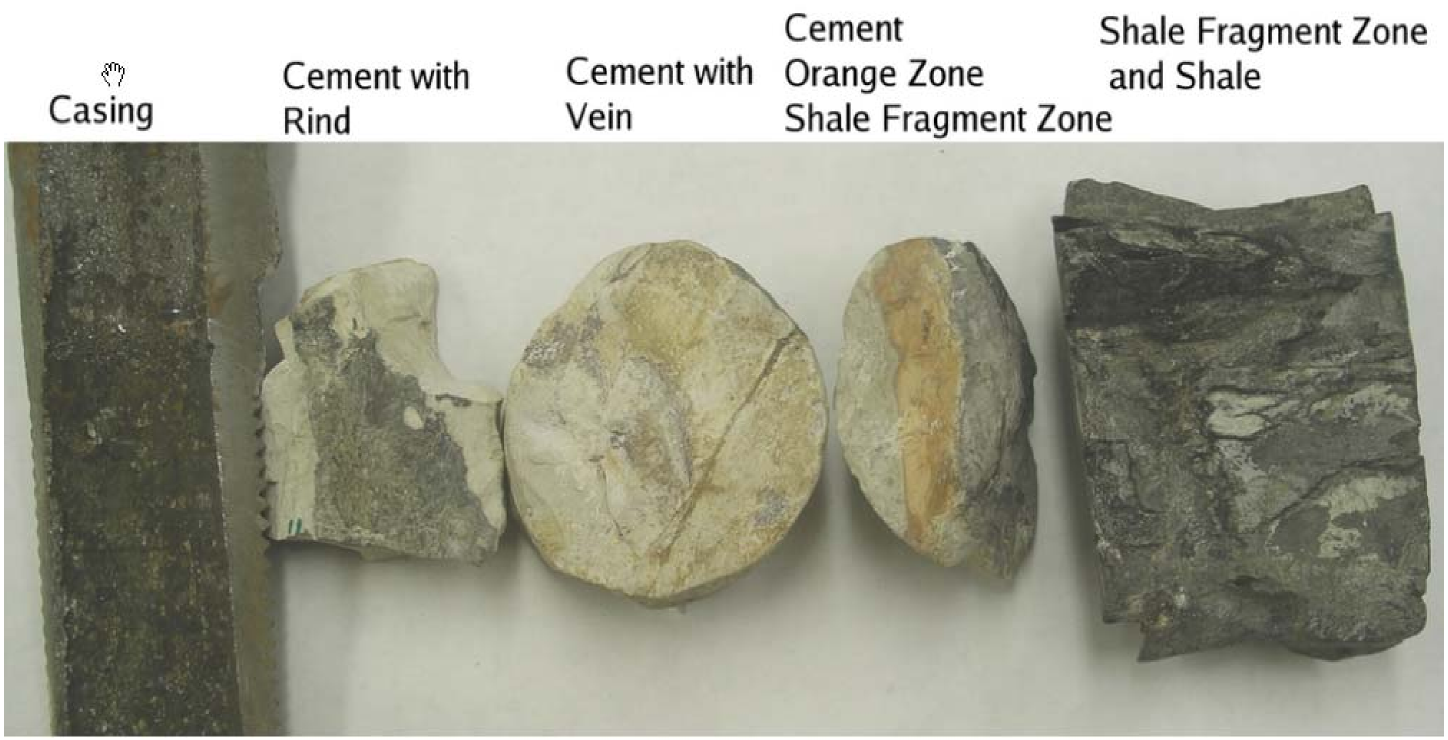
- Integrated field evaluations in fields with long CO_2 exposure are needed to develop logging/monitoring methods, understand mechanisms of CO_2-induced degradation, and assess effective permeability of the wellbore
- Data mining of the rich resources available in private companies and regulatory bodies should be a priority for developing a statistical basis for evaluation of wellbore performance

Some Details: Flow and Reaction in the Wellbore



- Reactions
  - CO_2-induced casing corrosion
  - CO_2-induced cement carbonation and dissolution
  - CO_2-induced caprock dissolution and precipitation
  - CO_2-induced precipitation of carbonate

SACROC: EOR field site

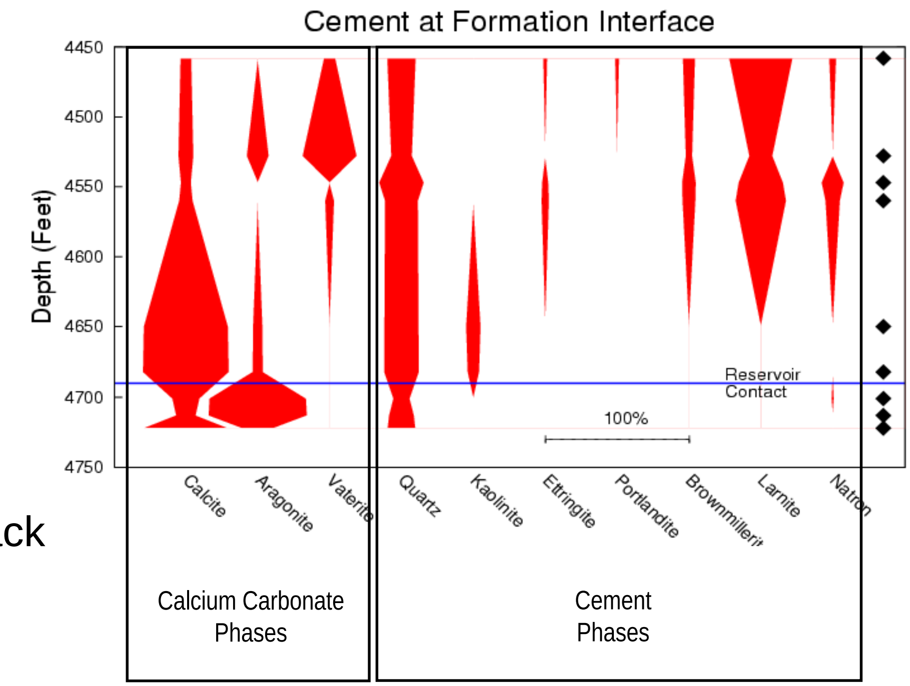


Cement samples showed carbonation but were intact. Could the limestone formation be buffering the effect of the CO_2 on the cement? Samples from a clastic reservoir were needed. Carey et al. (2007)

CCP2 Field Work

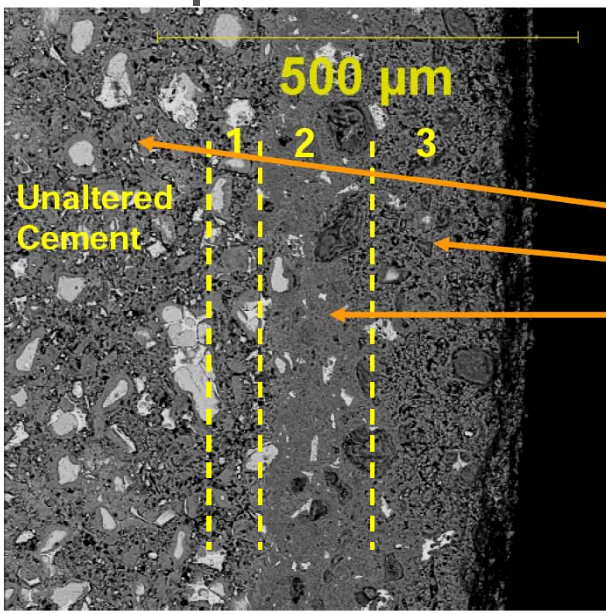
3 complete sections recovered
Casing in good condition

- A 30-year old wellbore barrier remains an effective hydraulic seal to CO_2 based on lack of sustained casing pressure, VIT results, and lack of casing corrosion.
- Conventional cement-fly ash systems can inhibit CO_2 migration even after carbonation of the cement
- All recovered cement samples have sufficiently low permeability and capillary resistance to act as effective barriers to CO_2 migration



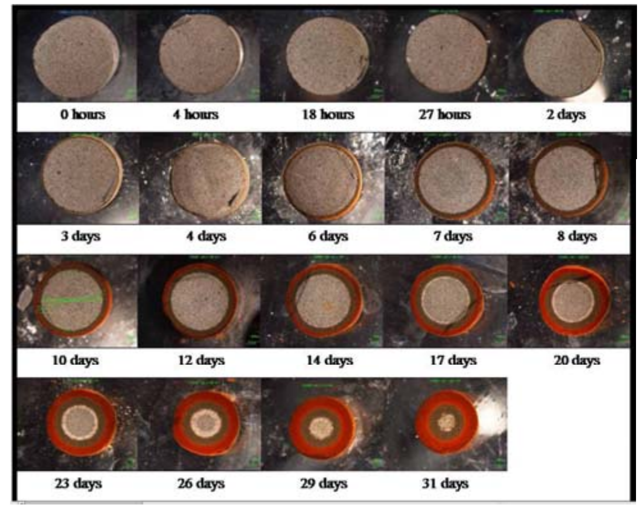
X-ray diffraction shows a progression from carbonated cement at depth to fresh cement

Experimental Studies



Kutchko et al. (2008)

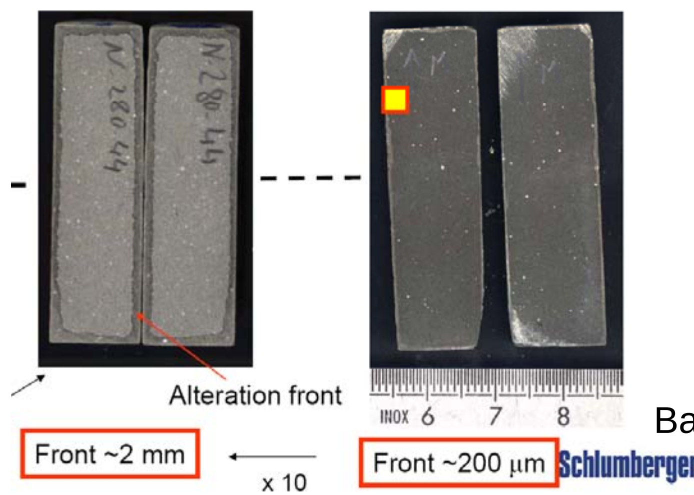
- **Mechanical Changes**
  - Microhardness (100 g):
    - Unreacted cement **64 HV***
    - Zone 3 **25 HV**
    - Zone 2 **127 HV**
- **Penetration Rate**
  - Initial rapid rate of alteration followed by a decrease in rate



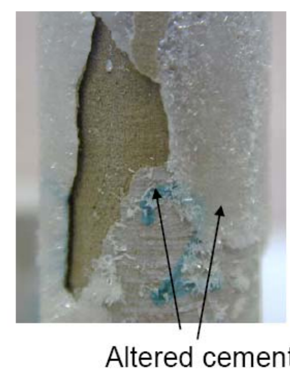
Duguid et al. (2005)

- Lab results vary from extensive reactivity (Duguid et al., Barlet-Gouédard et al.) to limited reactivity (Kutchko et al.)
- Field observations (Carey et al., SACROC) show CO_2-induced alteration similar in character to some lab experiments but without significant apparent CO_2 leakage.

CO_2 exposure: 2 days, 280 bars, 90°C

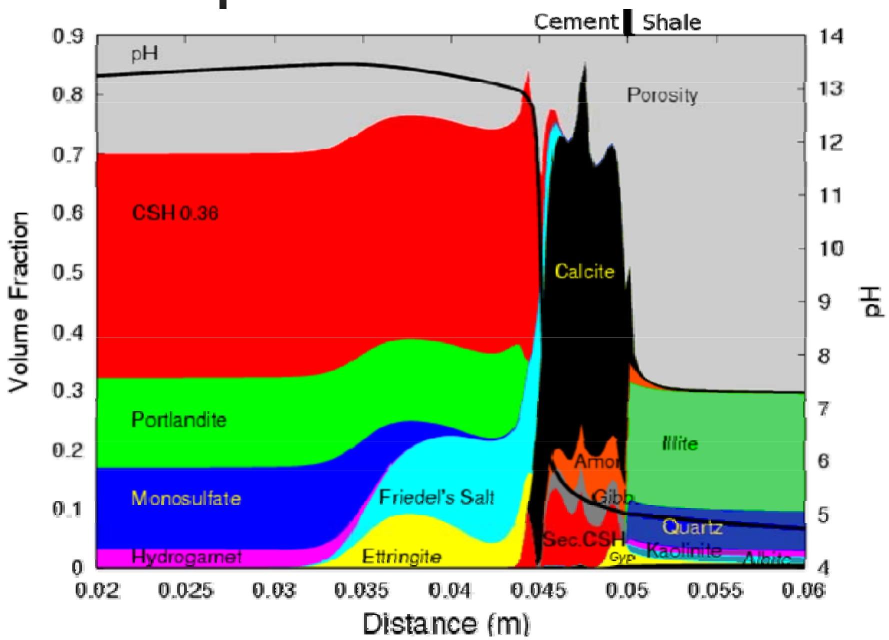


After 6 months in CO_2-fluids

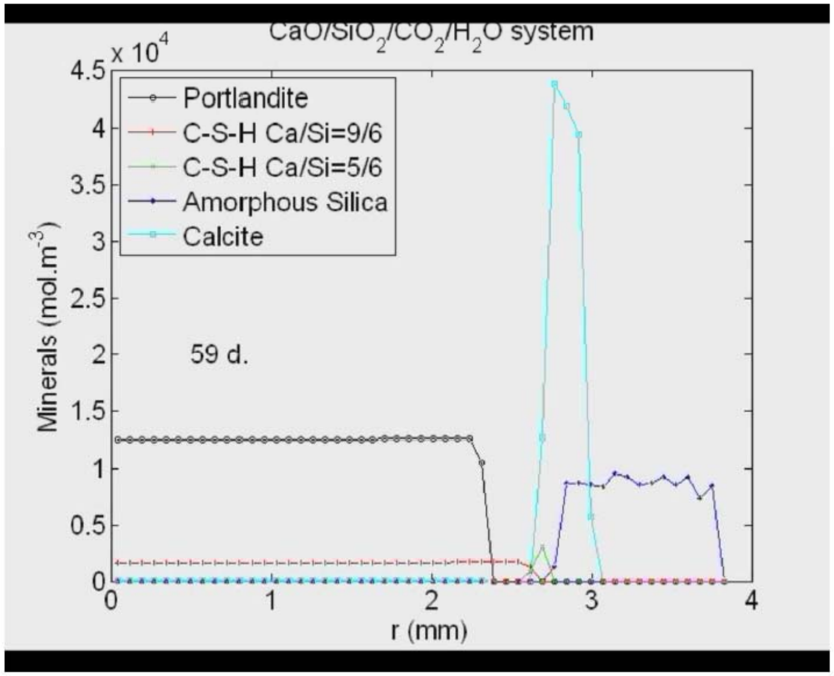


Barlet-Gouédard et al. 2007

Cement-CO_2 Numerical Models



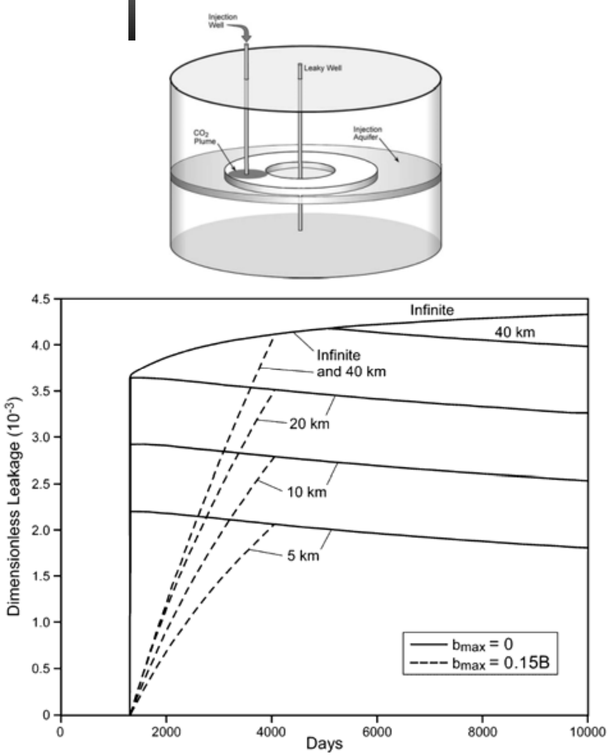
Carey et al. (2007)



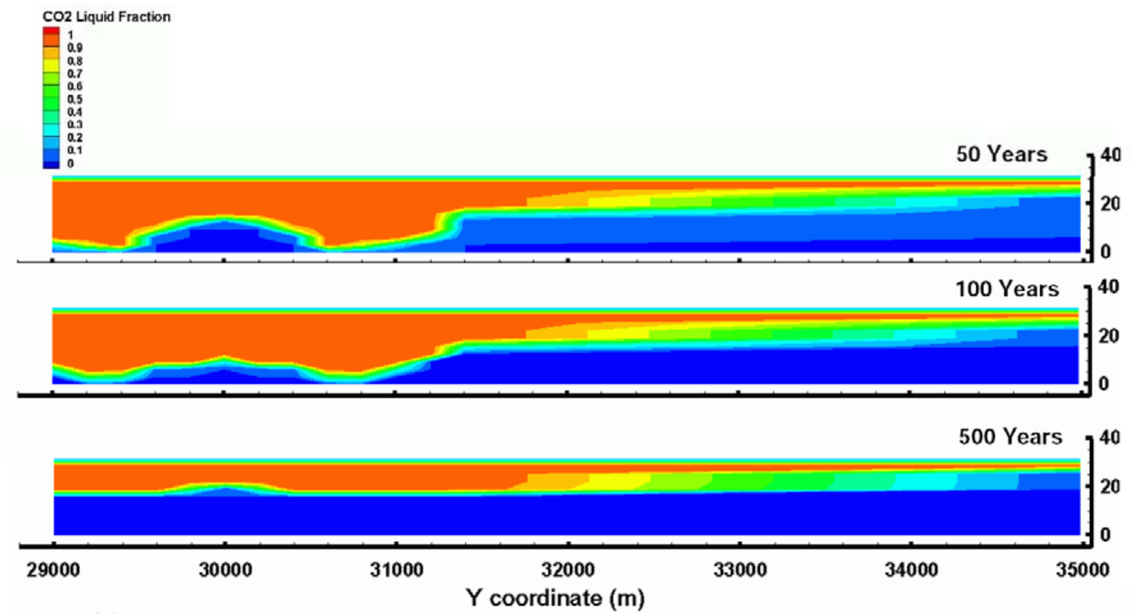
Huet et al. (2008)

- Numerical models reproduce key features of cement alteration
- Not yet capable of predicting permeability of cement system

Field-scale models



Nordbotten et al. (2005)



Pawar et al. (2008)

- Semi-analytical and numerical models available
- Poorly constrained effective wellbore permeability
- Unknown statistical distribution of leaky wells

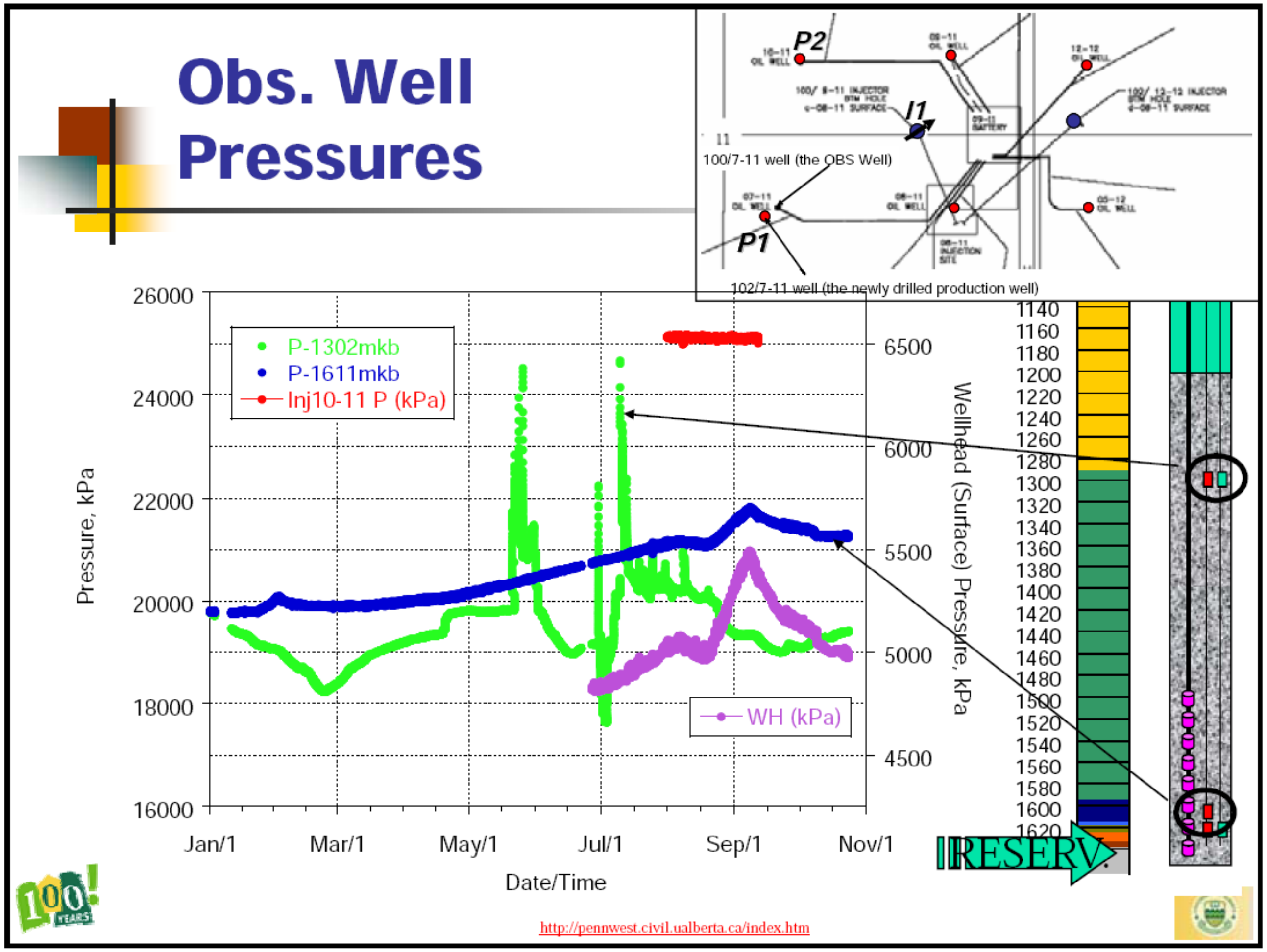
Risk

Field data and results summary.		
	Pembina	Zama
Number of cased wells	9860	607
Number of wells drilled and abandoned	1050	106
% of wells with cement data	40%	64%
% of wells with high DLP cement score	28%	20%
% of wells fractured	75%	2%
% of wells acidized	47%	80%
% of wells abandoned	12%	13%
% of wells with multiple completions	11%	55%
% of wells with extreme DLP	14%	28%
% of wells with extreme SLP	7%	18%
% of wells with extreme SLP and DLP	1.6%	4.3%

Watson and Bachu (2008)

- Surveys in Alberta evaluate risk potential but data on performance not available
- Several groups developing wellbore leakage modules in risk analysis

Monitoring



Penn West, Alberta, EOR; Chalaturnyk (2008)

- Integrated instrumentation package in observation well

Needs

- Information on frequency of failure
  - Well failure in new CO_2-EOR fields
  - Help in modeling potential leak rates
  - Informs Risk Assessment activities
- Assessment of steel and elastomer interactions with CO_2 and the likely effect on long-term isolation
- Costs and impacts of remediation
- Long-term numerical modeling grounded in enhanced field and experimental data

Interface with Other Networks

- Risk
  - We are working toward the development of risk-based assessments of wellbore performance
  - We are interested in the approaches being used by the Risk Network
- Monitoring
  - Our monitoring efforts are primarily for evaluation of wellbore integrity—less emphasis on detecting leaks

Network Future Goals

- Develop consensus (?) document on the potential impact of wellbore behavior on storage site performance

IEA GHG Risk Assessment Network

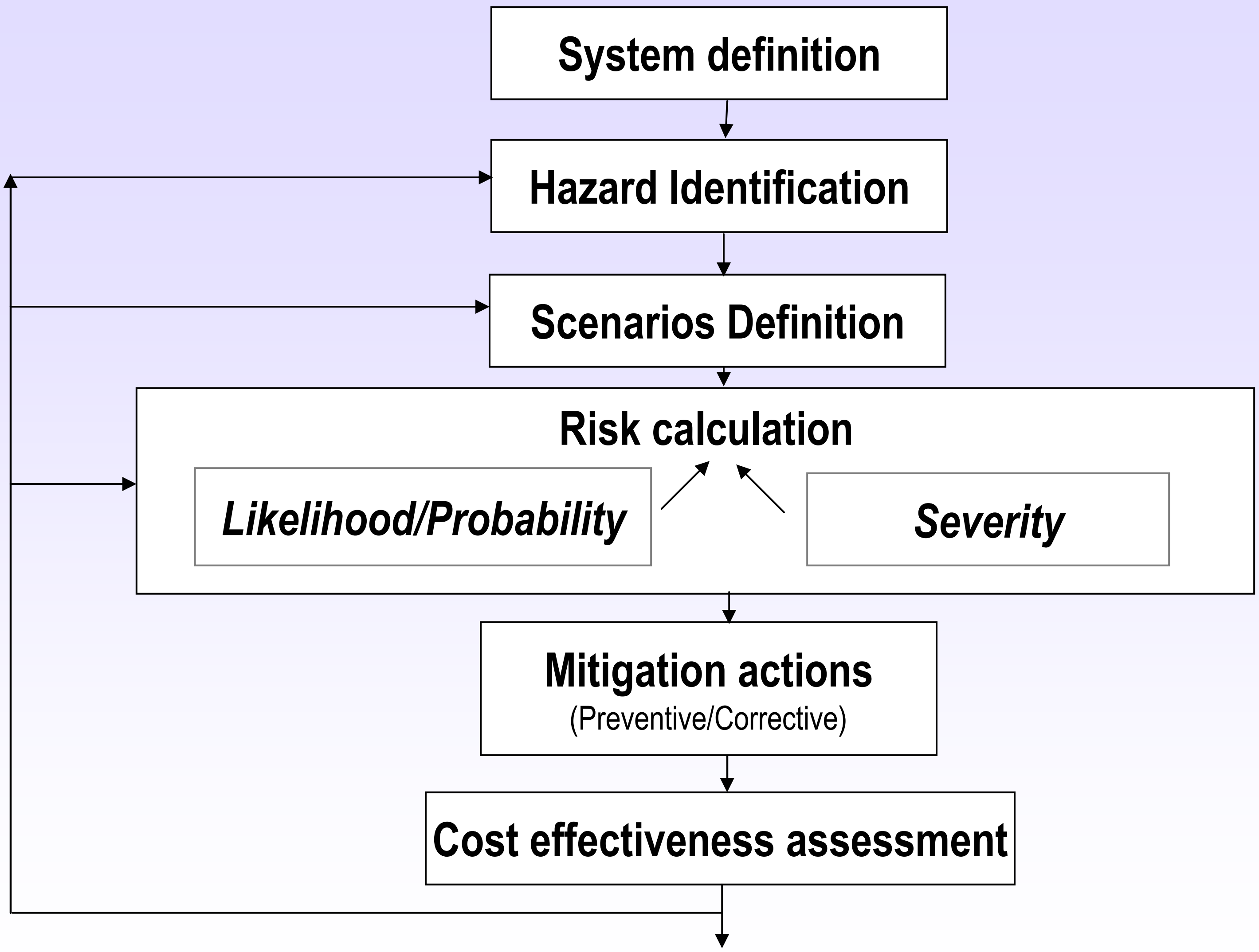
IEA GHG Joint Network Meeting, NY, June 11th – 13th, 2008

Claudia Vivalda
Schlumberger Carbon Services

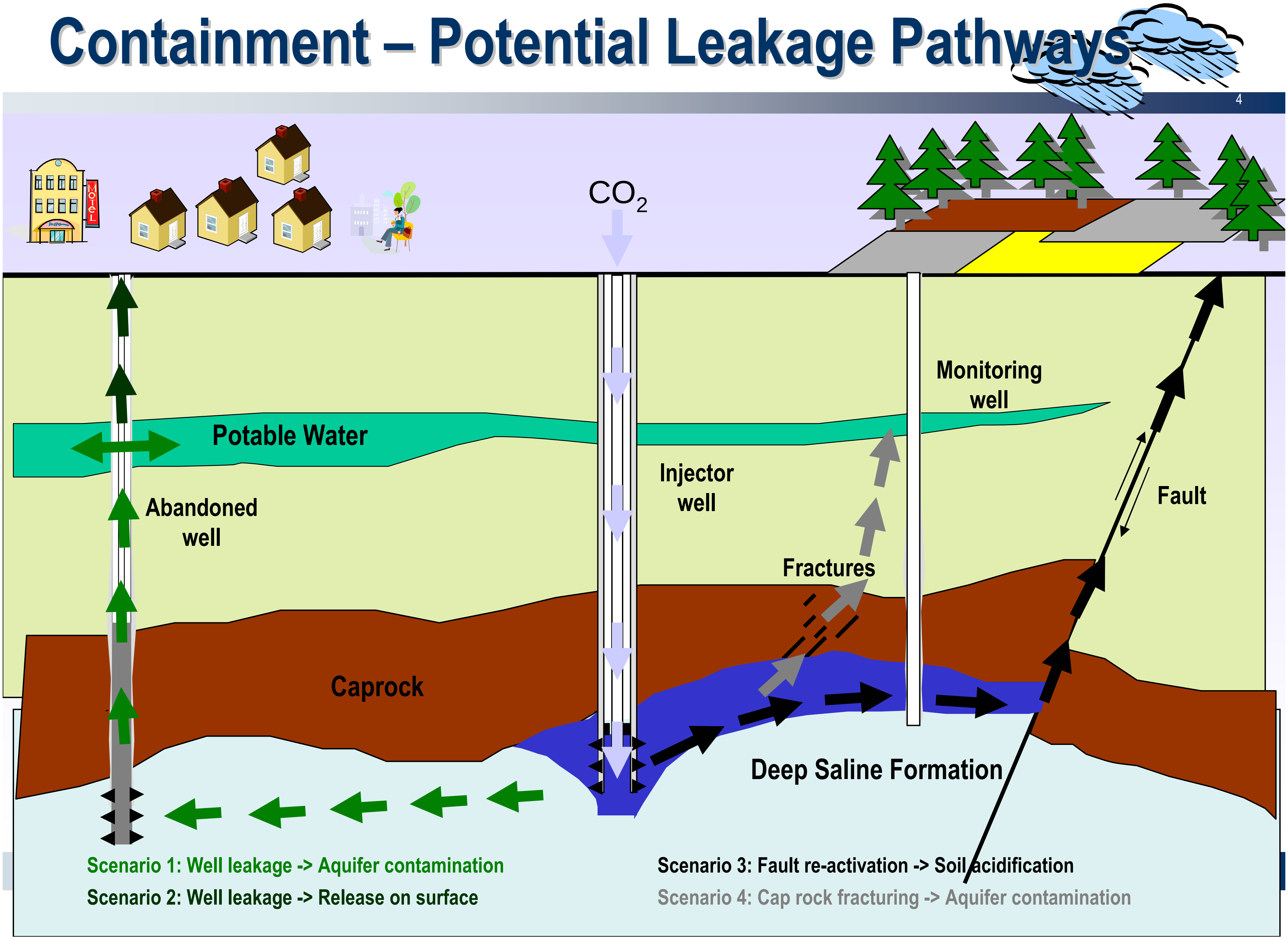
Outline

- Conclusions from the 3rd RA Network Meeting, August 15th -16th 2007
- State of the art review
- Questionnaire results – Risk Assessment Network Perspective

Risk Assessment Process



Containment – Potential Leakage Pathways



IEA GHG 3rd RA Workshop outcome

What we have achieved

- Made progress on issue on terminology
  - Work on this needs to go further
  - Work on Wikipedia idea
- Site characterization – How much is enough
  - Explored but can't answer the question
- Approached a consensus on QRA for CCS
- FEPs – One tool of many

IEA GHG 3rd RA Workshop outcome

Issues/Questions identified

- Guideline for RA / Documentation
- Explore requirements for experts/expert judgments
- How confident are we in modelling results
- How long to monitor for?
- Explore accident/worst case first
- How best to communicate

State of the art review

(From CSLF Risk Assessment Task Force Draft Report – not published yet)

- Risk Assessment Framework
- Risk Assessment Process and Tools
- Modelling for Risk Assessment

State of the art review - RA Framework

(From CSLF Risk Assessment Task Force Draft Report – not published yet)

IPCC Special report on CCS (2006): reference report;

- Identifies main **potential release pathways** for CO2 out of geological reservoirs and the kinds of hazards that could result from storage sites.
- Addresses the question of the **probability of release** according to various types of evidences, stating that "no existing studies systematically estimate the probability and magnitude of release across a sample of credible geological storage systems."
- Identifies the **main challenges** posed by risk assessment for CO2 geological storage,
  - **No well-established methodology** for assessing such risks exists;
  - Use of **FEP methodology** for assessing risks, intended to provide a comprehensive catalogue of the *risks* and their *mechanisms*, of *scenarios* describing possible future evolutions of the storage sites and of *models* to represent these scenarios;
  - Need to acquire **more knowledge about long-term well behaviour**;
  - Need to address **uncertainties** in the risk assessment models;
  - Potential to **learn from natural and engineered analogues** is emphasized.

State of the art review - RA Framework

(From CSLF Risk Assessment Task Force Draft Report)

London (2006) and OSPAR (2007) Convention risk assessment framework – 6 steps:

1. ***Problem formulation***: critical scoping step, describing the boundaries of the assessment;
2. ***Site selection and characterisation***: collection of site-specific data;
3. ***Exposure assessment***: description of the movement of the CO2 stream;
4. ***Effects assessment***: description of the response of receptors to CO2 exposure;
5. ***Risk characterisation***: integration of the exposure and effects information to estimate the likelihood of an adverse impact;
6. ***Risk management***: monitoring, planning, mitigation and remediation measures.

State of the art review - RA Framework

(From CSLF Risk Assessment Task Force Draft Report)

IEA GHG Environmental Impact Assessment Framework (2007) current gaps:

- The **quantification of the impacts** of a CO2 release and the estimation of its probability, which are site-specific;
- The **process** of conducting a **site performance assessment**;
- The **understanding of the health and environmental impacts** of a release of CO2 and impurities;
- The **management of liability**;
- The **balance of positive climate change mitigation impacts against negative local impacts**.

State of the art review - RA Process and Tools

(From CSLF Risk Assessment Task Force Draft Report)

Stenhouse et al (2006) classification of ***main methodologies*** for RA:

- scenario analysis;
- fault/event tree analysis;
- expert judgement;
- screening-level analysis.

Main uncertainties:

- parameter uncertainty;
- conceptual model uncertainty;
- modelling uncertainty;
- scenario/event uncertainty.

State of the art review - RA Process and Tools

(From CSLF Risk Assessment Task Force Draft Report)

RA Process and Tools based on Expert Judgment

Bowden and Rigg (2004) and recent updates:

- RISQUE Method:
  - systematic **quantitative process** based on the **judgement** of a panel of experts
  - **Key risk events identified** in a list and evaluated in terms of likelihood, consequences and time scale of occurrence.
  - Six **key performance indicators** computed and compared against acceptability criteria.

Wildenborg et al (2004); Maul et al (2004):

- FEP Database

State of the art review - RA Process and Tools

(From CSLF Risk Assessment Task Force Draft Report)

RA Process and Tools based on Modelling

Pawar et al. (2006)

- CO2-PENS tool aiming at **integrating in a system-level model** a number of **process-level models** representing:
  - the *storage reservoir*; the *cap rock*; the potential *release mechanisms*; the *transport of CO2* from the reservoir; the *release of CO2 in surface*.

Gerard et al. (2006)

- **quantitative RA** method applied to **wells**
- well decomposed in components
- **scenario** defined as a combination of properties of the different components, to which is associated a probability
- severity of a scenario evaluated based on the results of the modeling of fluids migration in the well to different targets
- for each scenario, the associated probability and the severity enable to **quantify risk** levels associated to well either during injection or abandonment phases

State of the art review - RA Process and Tools

(From CSLF Risk Assessment Task Force Draft Report)

Oldenburg et al. (2007)

- **system decomposition** into **process-level models**
- storage complex divided into **compartments**
- **likelihood of a leak** evaluated by estimating the probability that a leakage pathway encounters the CO2 plume on the one side, and a target on the other side
- CO2 flux across the pathway simulated through **deterministic simplified models**
- **impacts** of the release compared to **acceptable thresholds**. A level of risk is obtained by the product of the values of the probability and the consequences.

State of the art review – Modeling for RA

(From CSLF Risk Assessment Task Force Draft Report)

- **Gaus *et al.* (2008)** review the use of geochemical and transport models for CO_2 storage, and how they can be useful for assessing risks.
- **Birkholzer *et al.* (2006)** discuss modelling needs in the light of CO_2 release mechanisms shown by natural observations, stressing the importance of CO_2 migration along a fault and hydraulic fracturing in the cap rock.
- CO_2 leakage through wells:
  - **Nordbotten, Celia *et al.* (2006)** develop *analytical solutions* for the extension of the CO_2 plume in the reservoir and the potential for leakage through wells.
  - **Frenette *et al.* (2006)** present an *assessment and decision support strategy*, based on the evaluation of gas migrations through wells and components degradation, to evaluate *well leakage*
  - **Bachu *et al.* (2006)** study possible *indicators for CO_2 leakage along wells*.

State of the art review – Modeling for RA

(From CSLF Risk Assessment Task Force Draft Report)

- **Risks to Health and Safety**
  - **Duguid & Celia (2006)** suggest *analytical models* for representing *human exposure and estimating the level of risk* to humans.
- **CO2 behaviour and impacts** following a release:
  - **Bogen *et al.* (2006)** describe the coupled use of a *dispersion model* and a *GIS system* to detect potential areas where *CO2 accumulation* could reach critical levels and provide an estimate of the risk.
- **Risks to the environment** due to CO2 releases are seldom treated, partly because of the limited understanding of the impacts on the ecosystems of CO2 exposure (**IEA GHG, 2007**[b]).

State of the art review – Field cases

(From CSLF Risk Assessment Task Force Draft Report)

- **Sleipner**: *No risk assessment conducted prior to injection*. Lindeberg & Bergmo (2002) only simulate the long-term fate of CO_2. Findings: CO_2 to be totally dissolved after 5000 years and the maximum diffusion flux through the cap rock to be extremely low and to begin later than 100,000 years after injection.
- **Weyburn**: *Long-term behaviour of the CO_2 and leakage* assessed within a methodological framework based on the *FEPs* [Stenhouse *et al.* (2005)].
    - Quintessa FEP database initially developed for this application.
    - A number of simulations performed.
    - Fully probabilistic calculations find a 95% probability that the cumulative amount of CO_2 released after 5000 years will be less than 1% of the total amount stored (Walton *et al.*, 2004).
    - A deterministic model for transport in the reservoir with a probabilistic model for leakage through wells shows a maximum release of 0.14% of the total amount of CO_2 stored (Zhou *et al.*, 2004).

State of the art review – Field cases

(From CSLF Risk Assessment Task Force Draft Report)

- **Latrobe Valley** (Hooper *et al.*, 2005) and **Otway Basin** (Sharma & Cook, 2007) and **Gorgon project** (Chevron, 2005 and 2006) applied GEODISC approach (Bowden & Rigg, 2004) RISQUE.
- **CO2STORE** project: risk assessments have been realised for various sites.
  - **Valleys** (Chadwick *et al.*, 2006) and **Kalundborg** (Larsen *et al.*, 2007) case studies. Assessment mainly qualitative relying on Quintessa FEP database.
    - analysis of all relevant FEPs,
    - identification of the most important ones, and
    - the development of a few scenarios involving these major FEPs. These scenarios were simulated by numerical reservoir models.
  - For the **Schwarze Pumpe** case study, Schweinrich structure assessed according to the method recommended by Wildenborg *et al.* (2004) (Svensson *et al.*, 2005). Assessment more thorough than for the other two case studies; based on a *systematic screening of the TNO FEP* database and an evaluation of the interactions between the various events and processes, creation of safety scenarios that are then modelled.

State of the art review – Field cases

(From CSLF Risk Assessment Task Force Draft Report)

- **FutureGen** project. Four sites in competition submitted to a human health and environmental risk assessment as part of the **Environmental Impact Statement** (US DOE, 2007). Based on a *comparison with natural and industrial analogues and on expert judgement*,
  - a *semi-quantitative process* conducted to estimate potential CO2 release risks, at a site screening level.
  - *likelihood qualitatively discussed*, whereas the consequences of a release are quantitatively modelled.
- Two **sub-seabed formations** below the **Norwegian** continental shelf subjected to a *coarse risk assessment* with the objective of ranking the sites in terms of risk and functionality (Eldevik *et al.*, 2007). The process organised as an expert workshop and remains mainly qualitative:
  - identification of the *hazards* using a brainstorming session (*Structured What-If Technique*),
  - *selection of the three most relevant ones* for each formation, and the discussion of their *likelihood*, possible *consequences* and *mitigation measures*.

The exercise highlights the **lack of site specific data** at this screening level as a **barrier for risk assessment.**

State of the art review – Field cases

(From CSLF Risk Assessment Task Force Draft Report)

- **Mountaineer – Ohio River Valley** (Sminchak *et al*., 2006). Investigation of the **performance of the pilot site**: *qualitative screening* of the Quintessa **FEPs** database, designed to identify the potential critical events. Only a *few items* in the database *selected* and analysed in detail to emit *recommendations for risk management*.
- **MGSC Phase III, Decatur, Illinois** (Hnottavange-Telleen and Krapac, 2008). A **full performance assessment** of the storage site in progress. Injection and long-term storage are considered. Qualitative approaches using FEP and Risk registers and quantitative RA based on modelling are employed.

Questionnaire results

- **IEA GHG Network Programme** received **18 completed forms:**
  - 8 attended at least one wellbore integrity network, 5 attended at least one risk assessment network, and 10 attended at least one monitoring network.
  - 14 attended just one network stream, 3 attended 2 different network streams and 1 person attended all 3 network streams.
- **Questions**:
  1. *What do you feel is the **biggest issue** that your network(s) is facing currently?*

     Do you feel your network is addressing this issue? If so, explain how? If not, what are the gaps in your network(s) subject area that have not yet been addressed by the network(s)?
  2. *Do you have an understanding of the **aims of the network(s)** that you do not attend?*
  3. *What **issues** that are dealt with in each particular network(s) do you think could be **relevant to another network**?*
  4. *How can **issues** that are **common** to more than one network be **addressed**?*
  5. *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? If no, please comment.*
  6. *What **other key issues** - which are currently outside the scope of the networks - could benefit from further discussion and collaboration?*

Questionnaire results (1)

1) What do you feel is the biggest issue that your network(s) is facing currently?
2) Do you feel your network is addressing this issue? If so, explain how? If not, what are the gaps in your network(s) subject area that have not yet been addressed by the network(s)?

1) Reach consensus among different practitioners - 2) Focus on practical aspects in addition to academic issues

1) Common understanding of input data - 2) Common interest matrix

1) Development of injection well materials and practices - 2) Models for quantification well leakages

1) Development of a common methodology for risk assessment - 2) Work in progress

1) Work together with regulators - 2) Work in progress

1) How to distinguish technical monitoring (e.g. risk avoidance oriented) from public awareness monitoring - 2) Some work done

Questionnaire results (2)

Do you have an understanding of the aims of the network(s) that you do not attend?
Majority YES, 3 NOs

Questionnaire results (3)

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

- Different aspects concurring to the overall process to qualify CO2 storage sites and secure safety – Coherence to be sought
- Risk indicators that can directly or indirectly measured/monitored
- Necessary input data for risk assessment and their availability
- Link research in WI, RA, M
- Monitoring plan as part of risk management. Role of risk analysis process to drive monitoring strategy
- Short term monitoring to provide input to risk analysis and enable increase confidence or identify weaknesses
- Set up of monitoring protocols that are technically developed and field proven
- CO2 leakage detection methods
- Modelling physical/chemical/mechanical phenomena in a way that can be useful for risk assessment
- Ways to evaluate risks for well integrity
- RA vs cement's resistance to CO2

Questionnaire results (4)

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

- Setup a joint meeting periodically to cover topics of common interest / Common network meetings
- Incorporation of some inter-network panel discussions
- Creation of transversal working groups (few individuals dedicated to specific topics)
- Mailing groups
- In each network, identification of important crossover topics and use of a session for their discussion. Gap analysis
- Summary notes drafting
- Review outcomes from other networks meetings

Questionnaire results (5)

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? If no, please comment.

Majority YES. To:

- Share information
- Better description of the overall storage site
- Open to others than modellers

2 NOs:

- Crosscutting activity that pertains to all the existing networks
- Economic monitoring more important

Questionnaire results (6)

What other key issues - which are currently outside the scope of the networks - could benefit from further discussion and collaboration?
- Safety aspects of CO2 transport infrastructure - Regulatory workshops with people who can actually influence legislation - Influence of input from scientist and engineers in the elaboration of regulatory aspects - Regulatory tracking - Legal aspects, cost and benefits, financial matters - Ways to develop standard practices that are field proven as best practices - Site integrity in addition to wellbore integrity - Site selection and Site characterization

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_2ReMoVe**	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:

- 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

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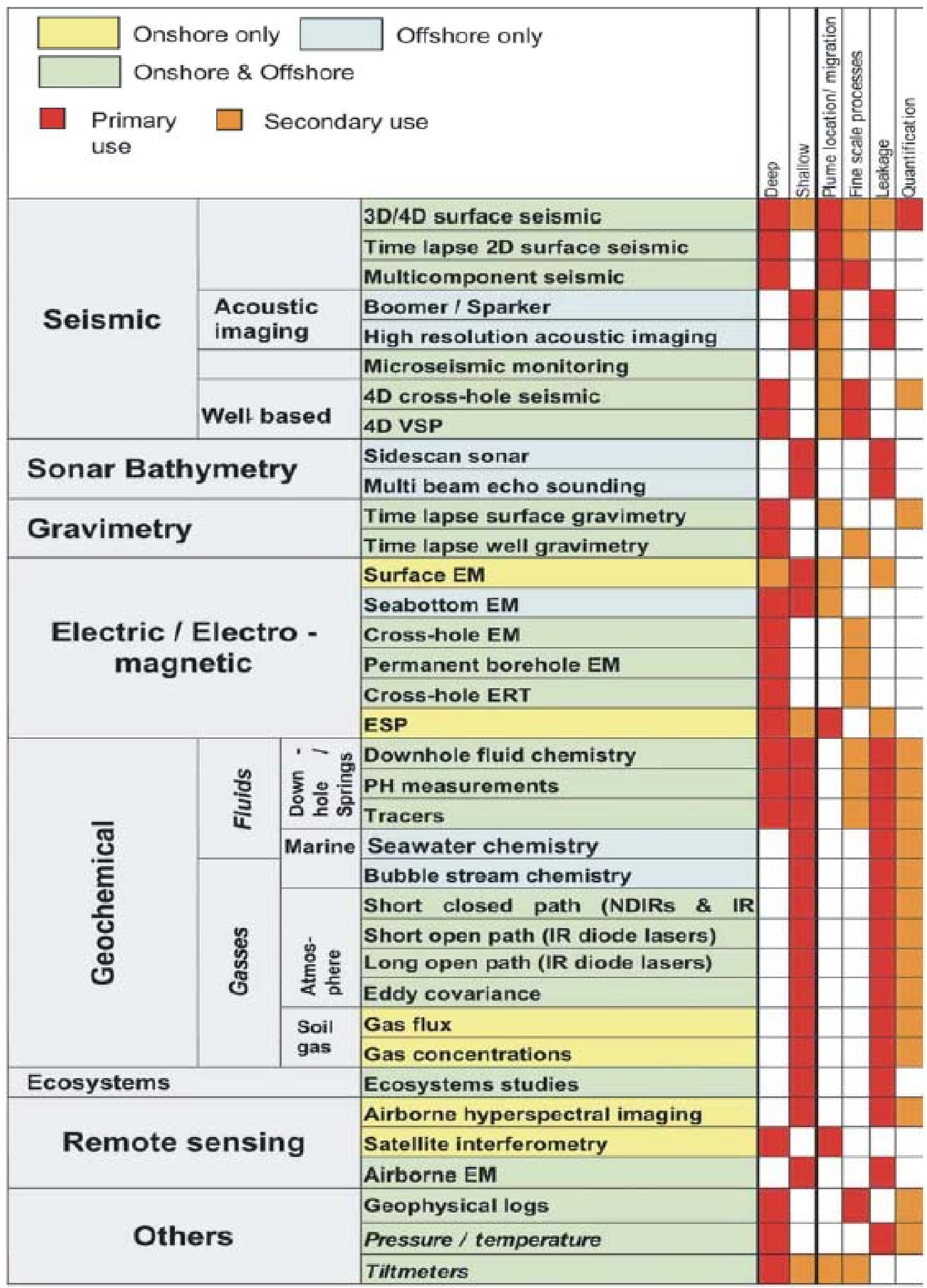
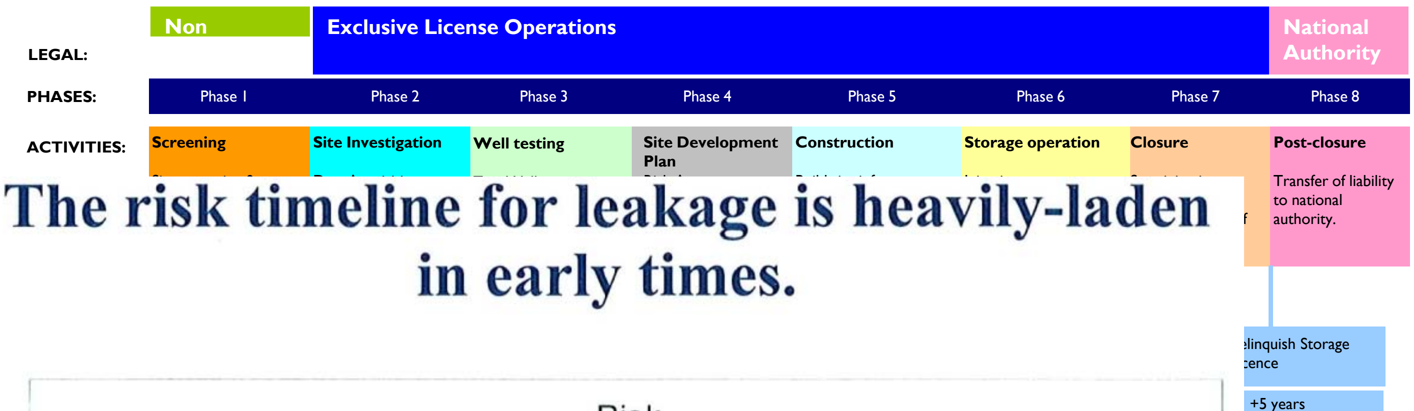
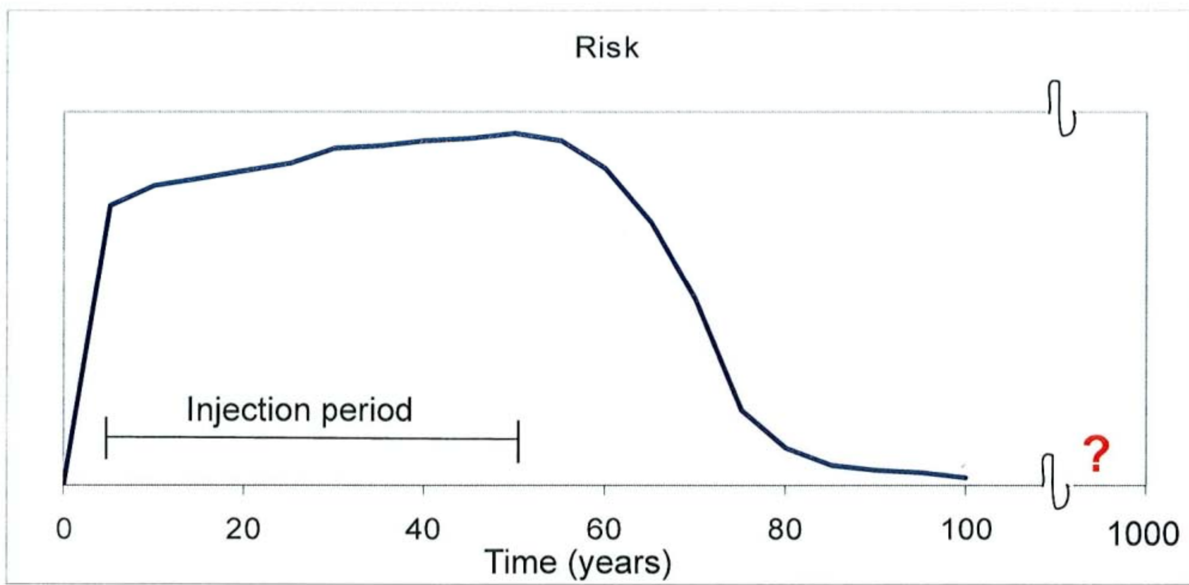
IEA BGS Monitoring Tool.



A (one of many) Regulatory Guide/Framework



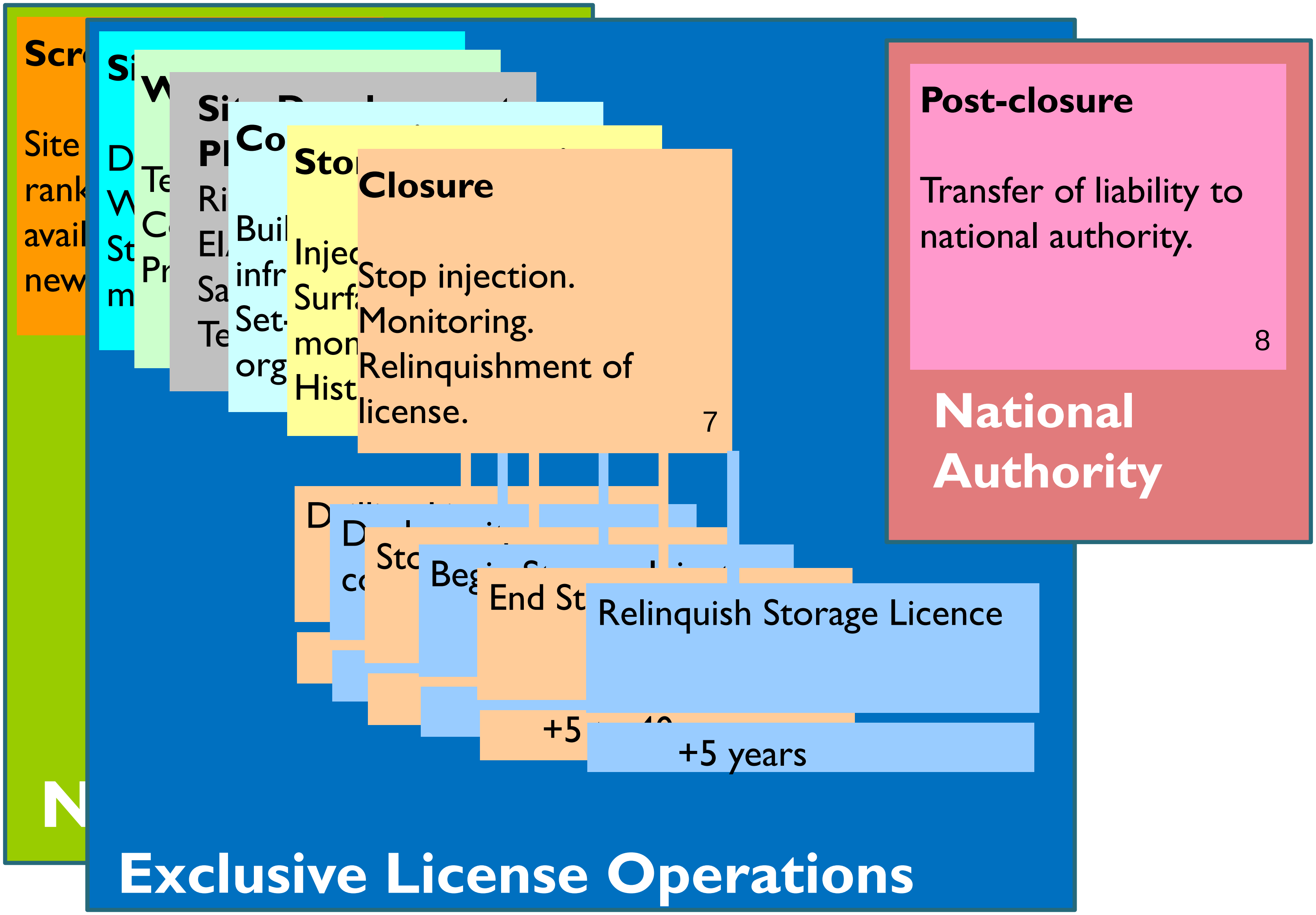
The risk timeline for leakage is heavily-laden in early times.



CO_2

BRASSERIE

A (one of many) Regulatory Guide/Framework



Structure (as seen by CO2 ReMoVe)

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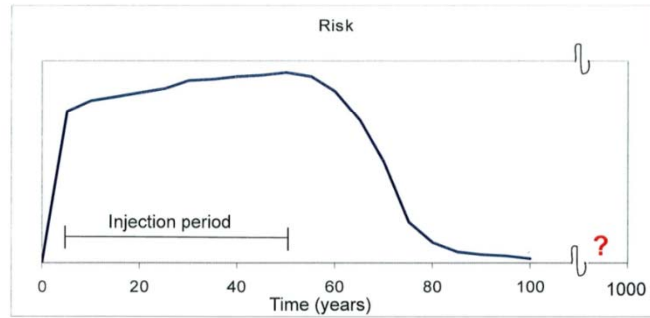

- Phases
  - Screening
  - Site Investigation
  - Well drilling & testing
  - Site development plan — **Site Selection**
  - Construction
  - Storage operation — **Operations**
  - Closure — **Closure**
  - Post-closure — **Post-Closure**

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 CO2 transport infrastructure. Safety distances of CO2 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
  - Monitoring of the impacts associated with construction activities
- 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
- Milestone VI: End of injection of CO_2 into the storage reservoir

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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;
    - Abandoned wells in the vicinity of the plume should be monitored

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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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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

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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?

Breakout Session 1
Risk Assessment Network

- CO_2 leakage not the only source of risk associated with CCS
- Brine displacement and drinking water
- Co-contaminants e.g. Sulphur species
- Mobilisation of e.g. heavy metals and potential risks associated with leakage
- Earthquake inducement

Breakout Session 1
Risk Assessment Network

- Risk assessment versus risk management
- Variations in regional approaches to risk management e.g. between Australia vs Europe or North America
- OSPAR ruling on no additions to injectate
- Timescales (cf Rick diagram). Site specific?
- Risk and vulnerability criteria: knowledge gap

Breakout Session 1
Risk Assessment Network

- Debate regarding risk vs uncertainty
- Debate about the relative merits of different types of risk assessment – qualitative, semi-quantitative or quantitative
- Communication of risk requires quantification to build confidence
- Use of worse case scenarios rather than probabilistic risks
- Expert panel

Summary

- Network has identified knowledge gaps and helped direct research efforts
- Not enough work done of risk management and mitigation strategies

Breakout Session 1
Wellbore Integrity Network

- Aspects missing from morning presentations, 1
  - Leakages to intermediate zones,
  - Permeability of cement system isn't completely understood,
  - Increased emphasis on steel and elastomers,
  - Flux of CO_2 as function of wellbore condition / type,
  - Risk associated with CO_2 vs. brine flows to shallower regions,

Breakout Session 1
Wellbore Integrity Network

- Aspects missing from morning presentations, 2
  - Impacts of pressure pulse on:
    - Wells,
    - Caprock,
  - Attenuation of pressure wave,
  - What are the end-state permeabilities for cement in CO_2 wells?
  - State of CO_2-brine as it encounters wells
    - pH, chemistry etc.

Breakout Session 1
Wellbore Integrity Network

- Aspects missing from morning presentations, 3
  - Pipe-cement experience shows good performance – requires further study,
  - Reconcile differences between field experience with some experimental results,
  - What role have corrosion inhibitors, as added to injection streams, played in wellbore integrity?
  - Translating production problems (e.g. SCP) into problems following abandonment,

Breakout Session 1
Wellbore Integrity Network

- Aspects missing from morning presentations, 4
  - Full life history geomechanical model,
  - Definition of initial state of cement sheath,
  - Long term creep of cement / formation impacts on well integrity,
  - Biological corrosion and behaviour,
  - Significance of dehydration induced by CO_2 injection,

Breakout Session 1
Wellbore Integrity Network

- Needs from Monitoring Network:
  - Leakage to intermediate zones:
    - Detection,
    - Impact,
  - Detailed studies along individual wells, e.g. pressure communication and temperature sensors for significant flow and measurement of noise,

Breakout Session 1
Wellbore Integrity Network

- Needs from Risk Assessment Network:
  - How to move from the study of a few wells to the statistics of 1000's?

Monitoring Network – Breakout Group 1

- Definition of Monitoring
- Quantification
- Drawing from other experience
- Screening technologies by regulatory regime
  - Two key regulatory questions
- Storage security without quantification

Definition of Monitoring

- We need to decompose monitoring to its specific purposes
- We need to identify who we are speaking to
- Perhaps we need a matrix of monitoring tools and what they can do and where they are appropriate
- Overlay IPCC guidelines appendix on monitoring with case studies

Quantification

- Quantification of CO_2 in the reservoir
  - To what degree of sensitivity?
  - To what degree of certainty?
  - What measurements to address these
  - To what degree of integration
  - May be a secondary process
- What does this imply for the measurements?
- Experience from O&G because of uncertainties inherent in heterogeneities may well indicate unrealistic to get quantification
- Process to iterate modelling and measurements to provide reduced uncertainty and assurance of performance
- Quantify leakage rather than volume ?

Draw from other experience

- What have we learned from analogue processes?
- Potential to screen monitoring recommendations for existing projects and assess their ability to meet requirements
- What would this process imply as optimum range, accuracies, sensitivities ?

Screen technologies by regulatory regime

- From a regulatory perspective can we categorise the monitoring that we need to achieve objectives?
- Keeping in mind there are two types emissions accounting and storage security.
- Per regulatory requirements
- What are key requirements
- What technologies suitable to answer questions
- What accuracies, thresholds etc
  - What monitoring tools have no application for regulators but may be used for other purposes?

Two key regulatory questions

- Concept of area of influence? How to define it Very open question, depends on modelling
- Should we monitor a positive to report back that performance is OK.

Storage security without quantification

- One strategy is to concentrate your monitoring at the reservoir and immediately above in seal and porous zone
- Implies active strategy of measurements that can provide confidence in performance
- Requires mitigation plans in place
- Does not require quantification as a primary goal
- Reduces near surface monitoring to public assurance role
  - In the case of leakage we then need to apply additional monitoring.

Joint Network Meeting
Session 2: Modelling

- Introduction – Neil Wildgust, IEA GHG
- Modelling Overview: Isabelle Czernichowski and Gabriel Marquette
- Breakout session 2
  - 10 – 10.30 Network group breakout
  - 11 – 11.30 Panel session – presentation of breakout session 2 group results
  - 11.30 – 12 Panel discussion

Aims of session 2

- Review of state of the art modelling
- Overview of modelling issues across existing storage networks
- Provide initial ideas on potential contribution of a new modelling network

Modelling overview for CO_2 storage

Isabelle Czernichowski-Lauriol
BRGM, Orléans, France
and Gabriel Marquette
Schlumberger, Paris, France

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Why Modeling ?

The ultimate goal is

risk management

which will rely on models

& surface/atmosphere monitoring

CO2 Storage Workflow

Pre-Operation Phase

Permitting

~ 3-5 year

Operation Phase

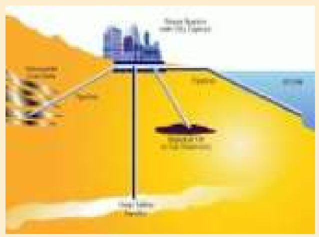
~ 10-50 years

Post-Injection Phase

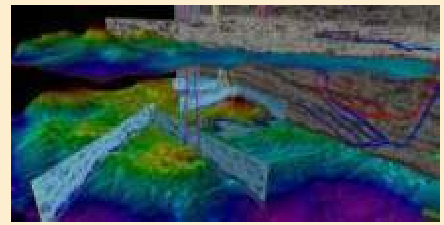
Transfer of Liabilities

~ 100+ years

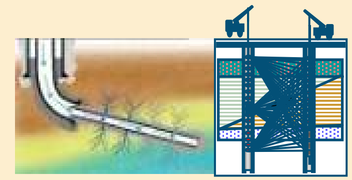
Site Selection



Site Characterization (SCP)



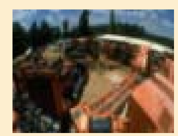
Field Design



Site Construction

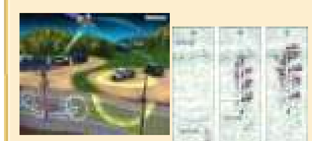
Site Preparation

Injection



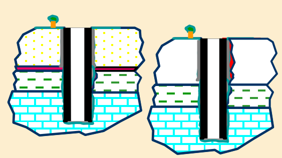
Monitoring (M&V)

- **Operation**

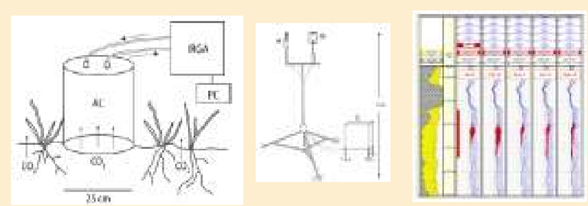


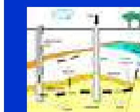
- **Verification**

Site Retirement Programme (SRP)



- **Environmental**

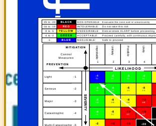




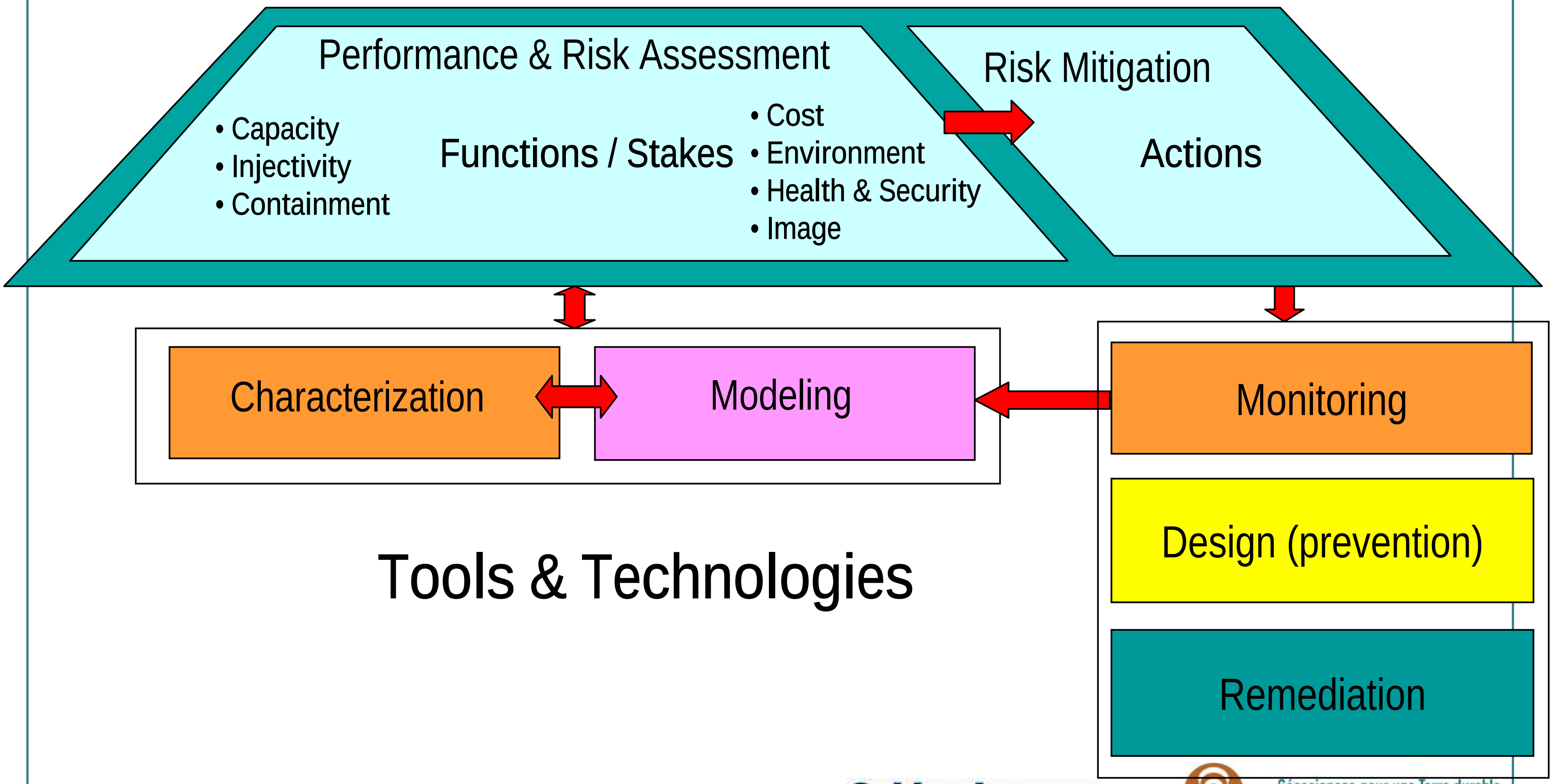
formance Management & F

Control System

Communication and Public



Role of Modeling in Performance (Risk) Management



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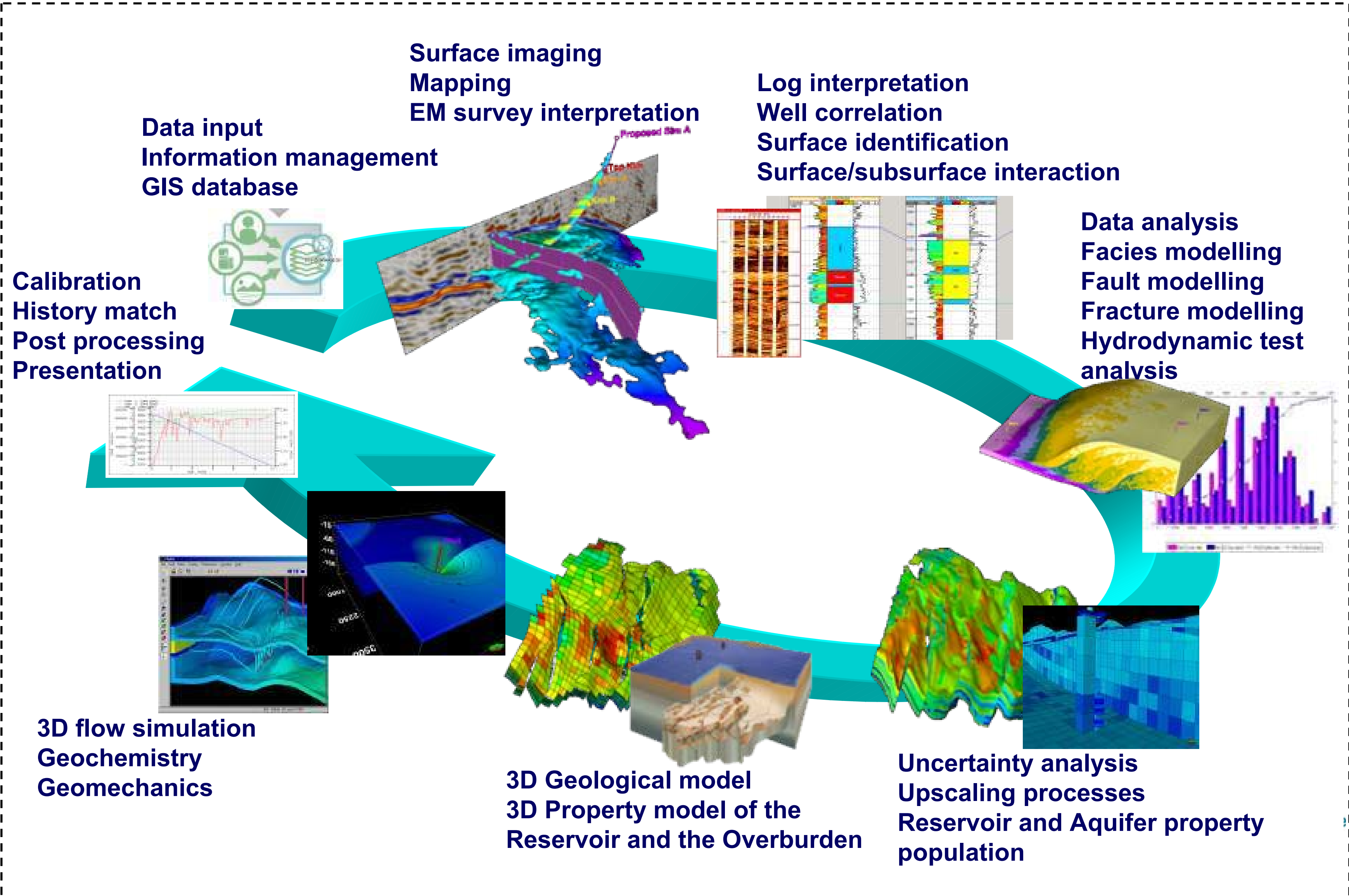
CO_2 Storage Site Modeling Workflow



Modeling is everywhere in CO2 storage

- Constant iterative process: measurements vs modeling
  - → as initial conditions
  - → (re) calibration
  - → predictive / fault detection
- At all phases: site selection/characterization, operation, closure, all providing relevant info to ensure model non-divergence

*could have been from Mr de La Palice

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Modeling Activity (Network or else): everybody wants it !

- IEA GHG ExCo: identification of the need
- IEA GHG Networks: see questionnaire
- Public Authorities: models as part of the regulatory framework
- Public: when all will be closed/unaccessible, almost only models will provide the answer

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Outline

1. Modelling is key for CO2 storage implementation
2. Modelling is very complex
3. Modelling examples
4. Previous initiatives of code comparison
5. Additional efforts needed
6. Towards a IEA GHG modelling network?

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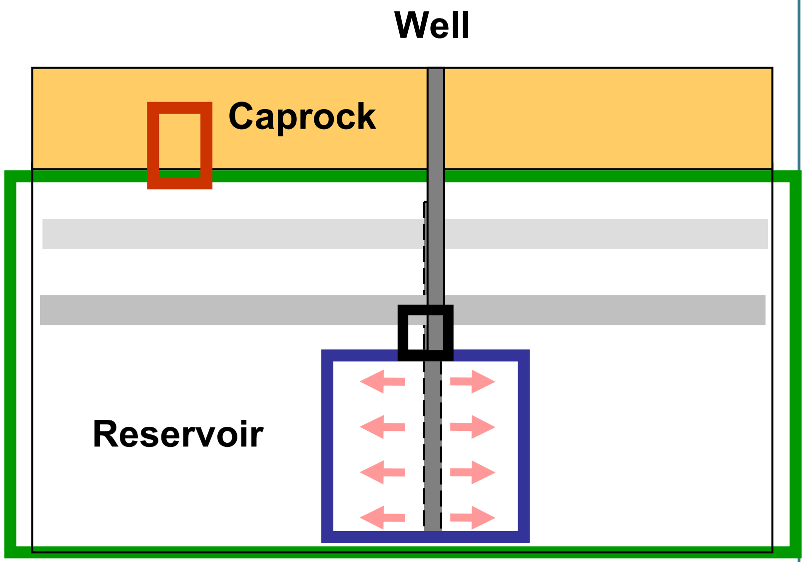
1- Modelling is key for CO_2 storage implementation

> **Top Necessity for:**

- Assessing the geological framework
- Assessing storage capacity, injectivity, integrity (caprock, faults, wells), risks (leakage, ground movement), impacts
- Advising monitoring (mutual impetus)

> **Only dynamic modelling enables practical conclusions**



> **Modelling will have a top importance in regulatory and legal frameworks**

e.g. draft EC Directive on CO_2 geological storage (23/01/2008)

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Draft EC Directive on CO_2 storage

Annex 1 CRITERIA FOR THE CHARACTERISATION AND ASSESSMENT OF STORAGE SITES

> Step 1: Data collection

- Sufficient data shall be accumulated to construct a *volumetric and dynamic three-dimensional (3-D)-earth model* for the storage site and storage complex

> Step 2: Computerised simulation of the storage complex

- Using the data collected in Step 1, a *three-dimensional static geological earth model* shall be built using computer reservoir simulators.
- The uncertainty associated with each of the parameters used to build the model shall be assessed by developing a range of scenarios for each parameter and calculating the appropriate confidence limits. Any uncertainty associated with the model itself shall also be assessed.

Draft EC Directive on CO_2 storage

Annex 1 CRITERIA FOR THE CHARACTERISATION AND ASSESSMENT OF STORAGE SITES

> **Step 3: Security, sensitivity & hazard characterisation**

- Security characterisation shall be based on dynamic modelling, comprising a variety of timestep simulations of CO_2 injection into the storage site using *the three-dimensional static geological earth model(s)* in the computerised storage complex simulator constructed under Step 2.
- Multiple simulations shall be undertaken to identify the sensitivity of the assessment to assumptions made about particular parameters. The simulations shall be based on altering parameters in the *static geological earth model(s)*, and changing rate functions and assumptions in the dynamic modelling exercise. Any significant sensitivity shall be taken into account in the risk assessment.

> **Step 4: Risk assessment**

- The risk characterisation shall be conducted based on the hazard (step 3), exposure and effects assessment.
- It shall include an assessment of the sources of uncertainty.

Draft EC Directive on CO_2 storage

Annex 2 CRITERIA FOR ESTABLISHING AND UPDATING THE MONITORING PLAN

- The data collected from the monitoring shall be collated. The observed results shall be compared with the behaviour predicted in dynamic simulation of the 3-D-pressure-volume and saturation behaviour undertaken in the context of the security characterisation pursuant to Article 4 and Annex I Step 3.
- Where there is a significant deviation between the observed and the predicted behaviour, the 3-D-model shall be recalibrated to reflect the observed behaviour.
- Where new CO_2 sources, pathways and flux rates are identified as a result of history matching and model recalibration, the monitoring plan shall be updated accordingly.
- Post-closure monitoring shall be based on the information collected and modelled during the implementation of the monitoring plan

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1- Modelling is Key for CO2 storage implementation

But « *how confident are we in the modelling results we are generating for CCS projects?* »

(Quotation from Risk Assessment network)

2- Modelling is very complex

- Large timescale range of interest: from hours to thousands of years
- Large spatial scales of interest: from cms to tens of kms
- Various compartments: reservoir, caprock, overburden, faults, wells, surface
- Natural heterogeneities, poor knowledge of the subsurface
- Various dynamic (& coupled) processes: Fluid flow – Geochemistry – Thermics – Geomechanics – Microbiology
- Uncertainty and sensitivity
- Site specificity

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> Only modelling can address such complex issues for enabling to make predictions

- Numerical & Analytical approaches
- Need for efficient computing algorithms and machines
- Conceptual modelling is very important
- Mutidisciplinary teams are needed (all fields of geosciences, mathematics, computer sciences)

> But real data is necessary for model calibration and benchmarking

- Lab & Field experiments
- Field monitoring
- Comparison analytical / numerical models
- Comparison between various numerical codes

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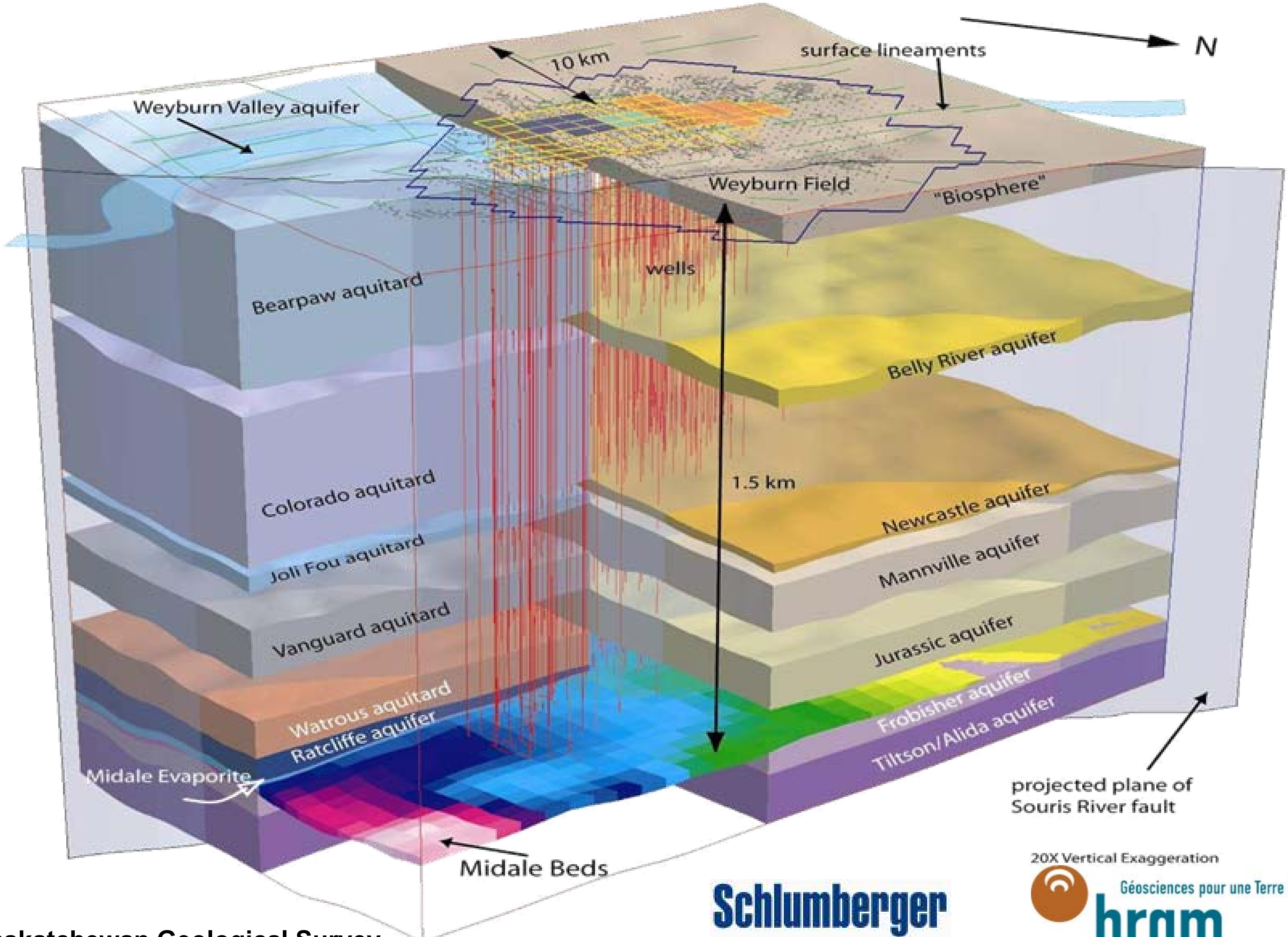
3- Modelling examples

To illustrate why we need models, how complex they are, why we should improve them to increase confidence

- Static geological model
- Fluid flow
- Chemical reactivity
- Geomechanical behaviour
- CO_2 leakage through a well – analytical model

Weyburn Geological Model (Phase 1)



Saskatchewan Geological Survey

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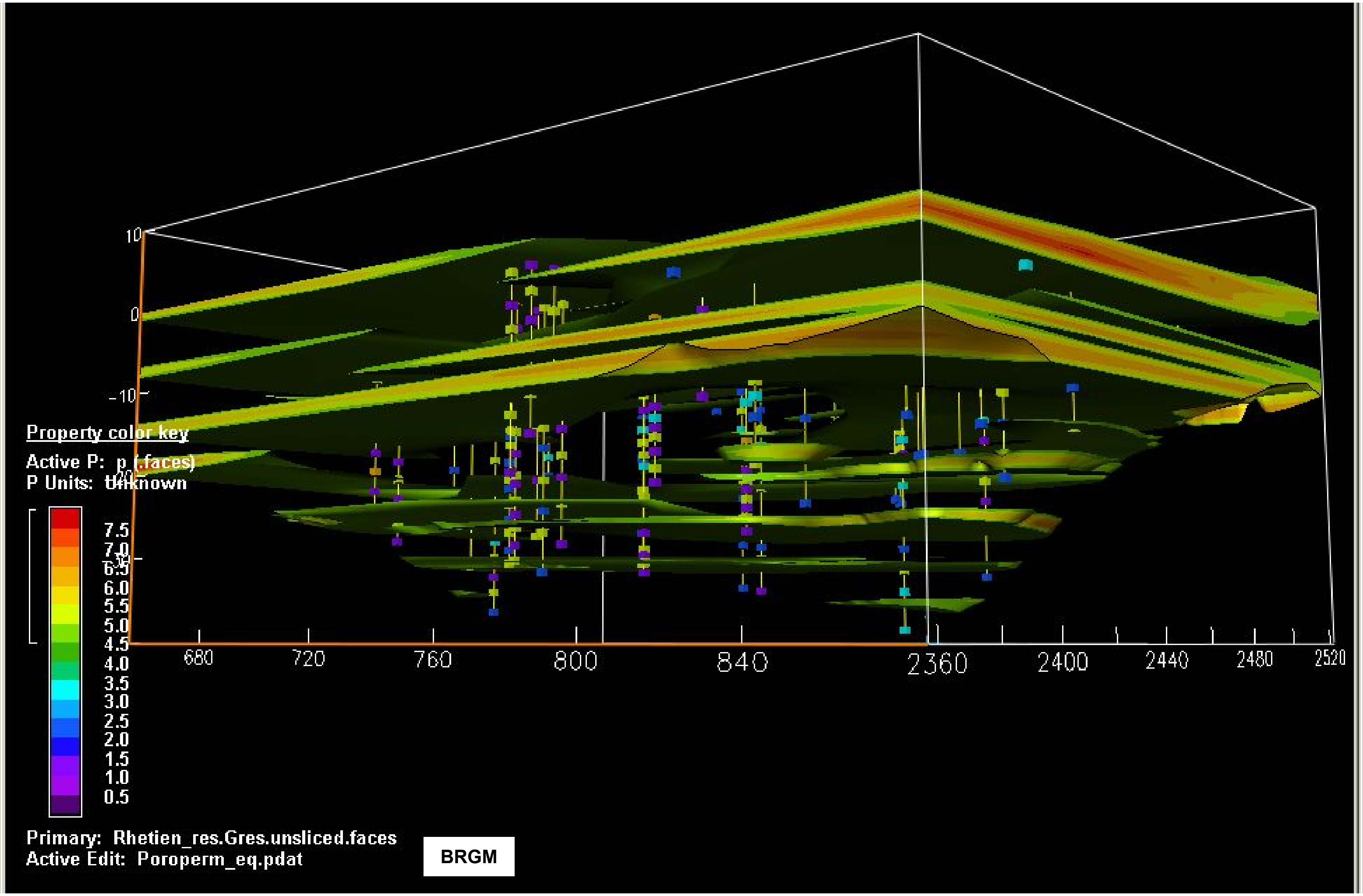
Rhaetian sandstone reservoir in France (Lorraine)



Quality index of the sandtone, based on porosity and permeability (good for storage over 5)

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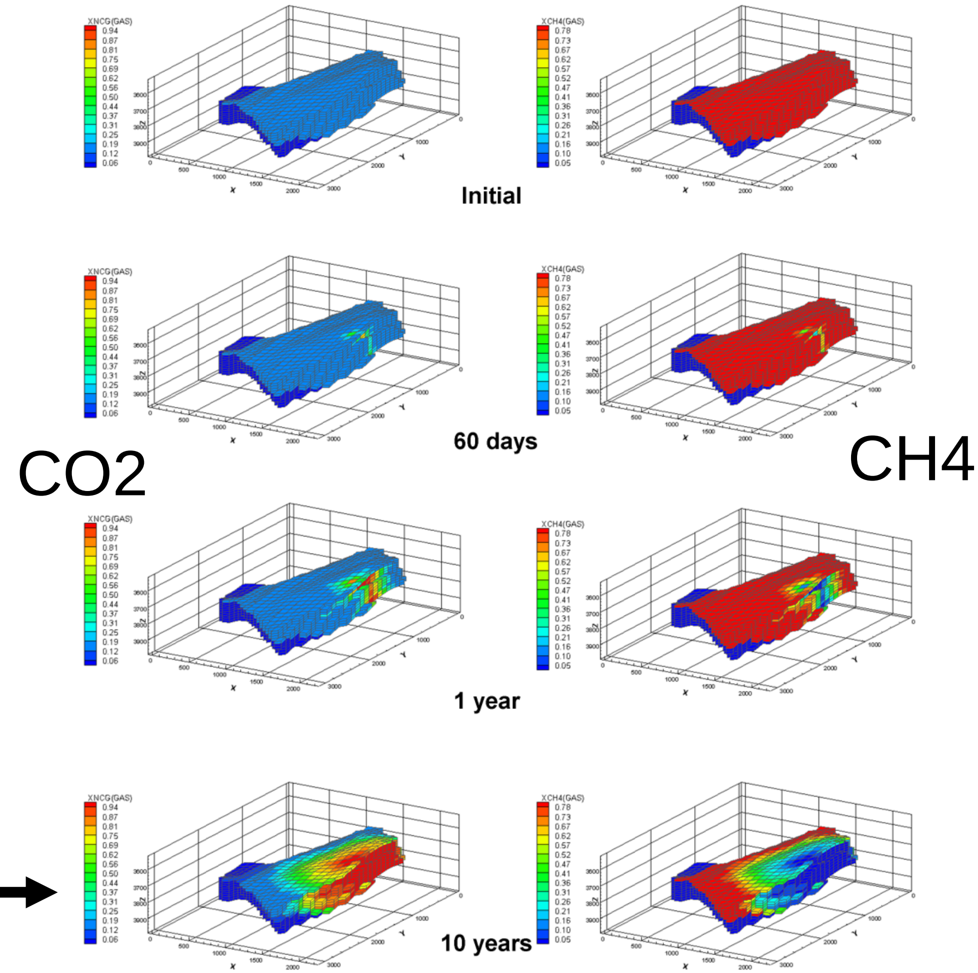
3D model of CO_2 injection in K12-B

(Audigane et al. 2007, AAPG special publication on Carbon Dioxide Sequestration in Geological Media)

- **Enhanced Gas Recovery scenario envisaged**
- **CO_2 can flush CH_4 through permeable regions of the reservoir**
- **10 kg/s injection**
  - K12-B6
- **2 x 1 kg/s production**
  - K12-B1 and K12-B5

After 10 years of CO2 injection and CH4 recovery →



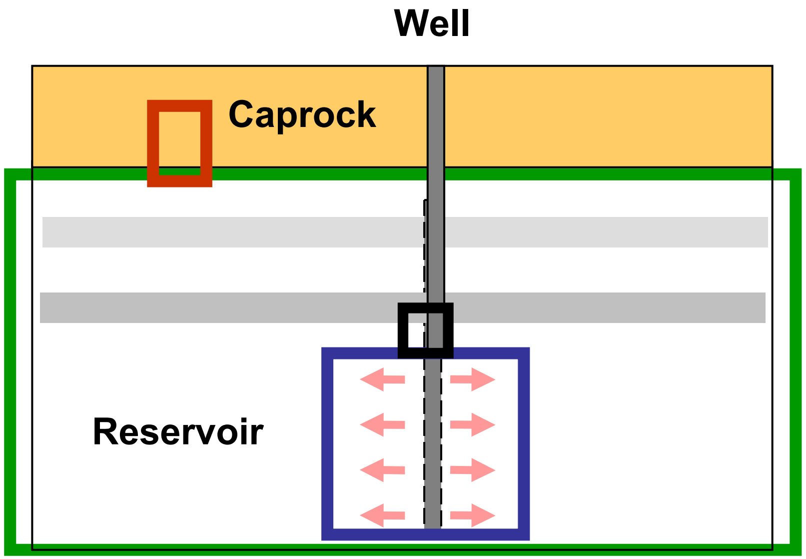
Modelling chemical reactivity: 4 cases

> **CO_2 fate in the reservoir:**
- 2D flow and geochemical modelling, Sleipner
- Toughreact

> **Caprock integrity:**
- 1D diffusive model, Sleipner
- PhreeqC

> **Injectivity**
- 1D radial model from the injection well, Paris basin
- Toughreact, Scale2000

> **Wellbore integrity**
- 1D diffusive model across cement
- Toughreact



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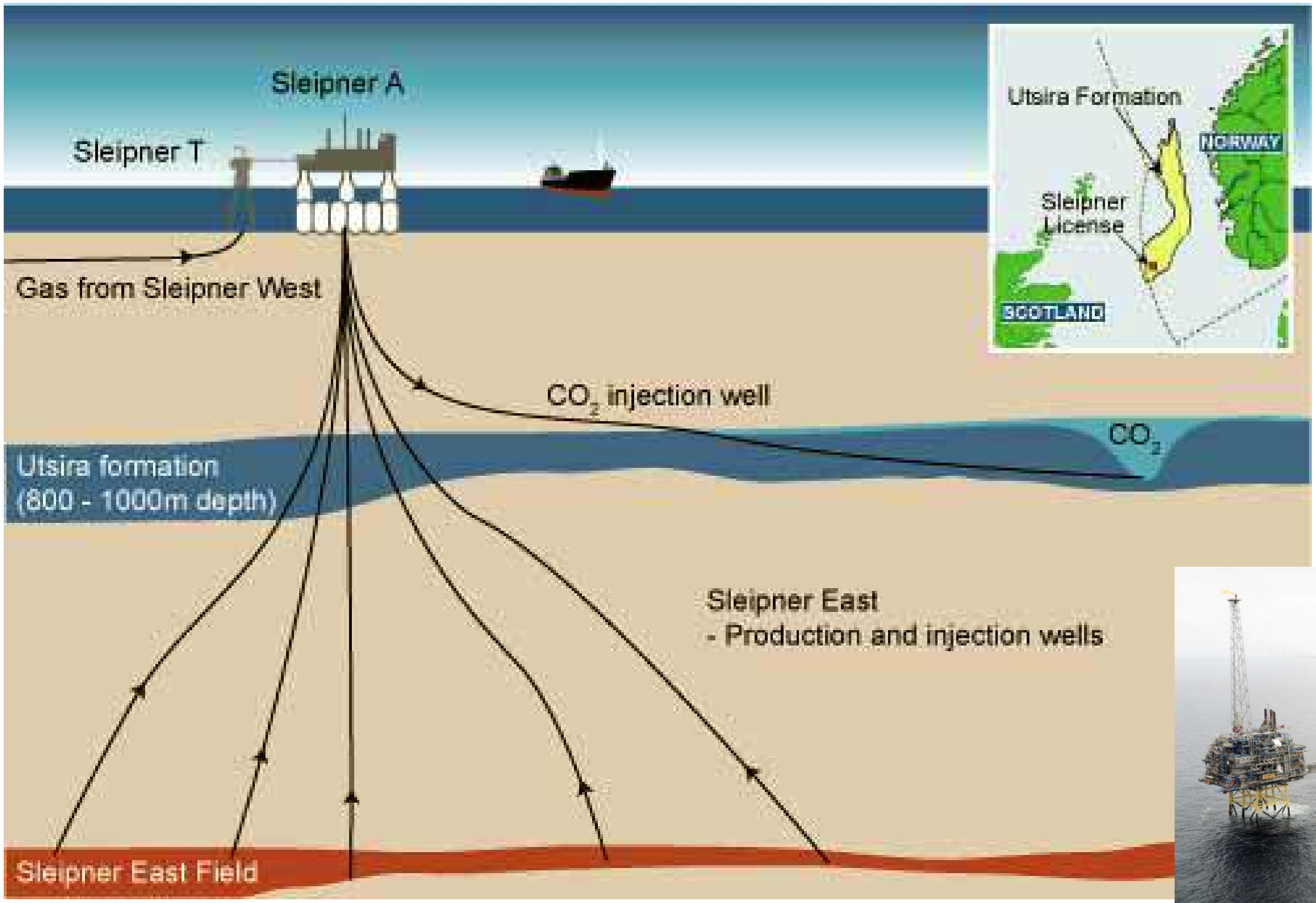
The Sleipner CO_2 storage project



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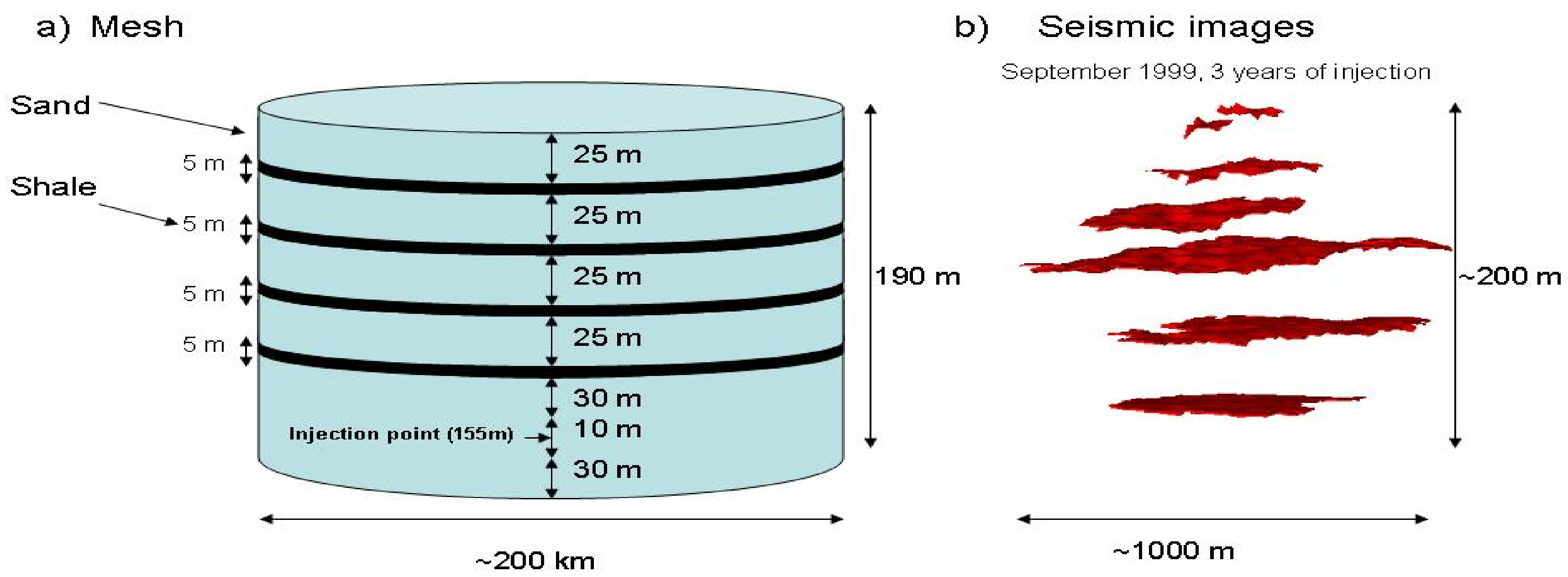
2D model of CO_2 injection at Sleipner

(Audigane et al., Am. J. of Sc., Sept. 2007)



- 184 m thick reservoir formation with alternance of sand layers and shale layers
- Vertical 2D mesh with a cylindrical geometrical configuration, centered around an injection point located 155 m beneath the top
- Mesh: 22 layers in the vertical and 52 cells in the radial direction with logarithmic progression

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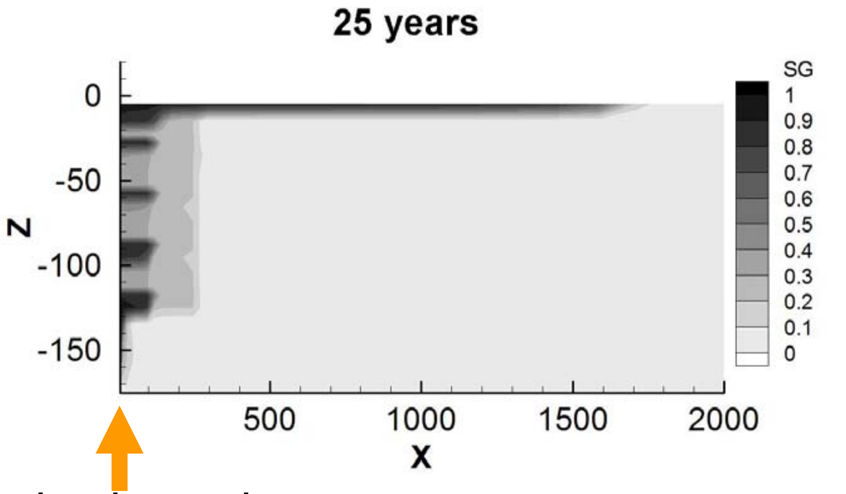
CO_2 migration after 25 years of injection

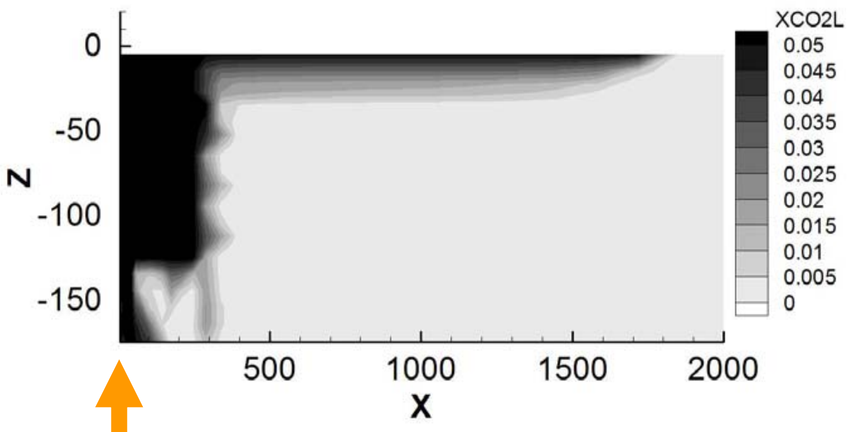
(Audigane et al., Am. J. of Sc., Sept. 2007)



Injection point

Concentration of supercritical CO_2 in the reservoir

Note the accumulations under the Shale layers



Injection point

Amount of dissolved CO_2 in the water (mass fraction)

- Above the injection point maximum saturation is reached
- At the edges we see lower saturation ranges

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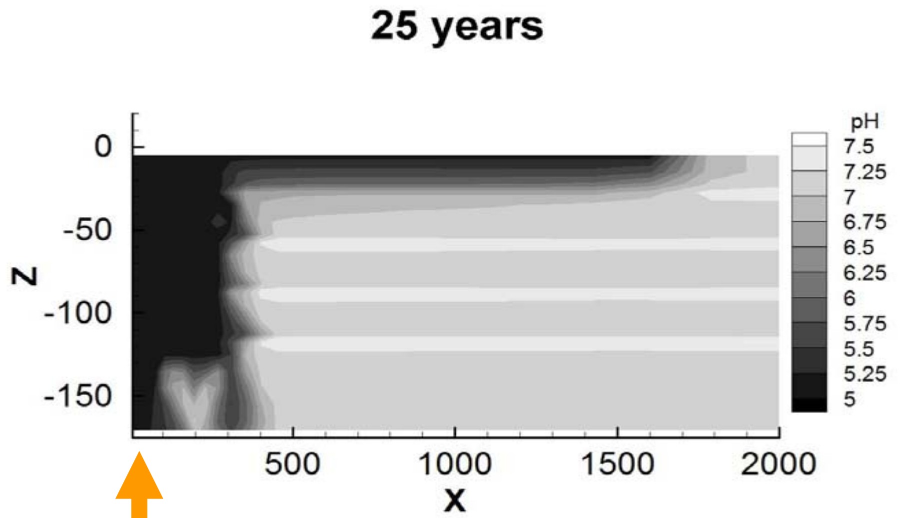
Effects of CO_2 dissolution after 25 years of injection

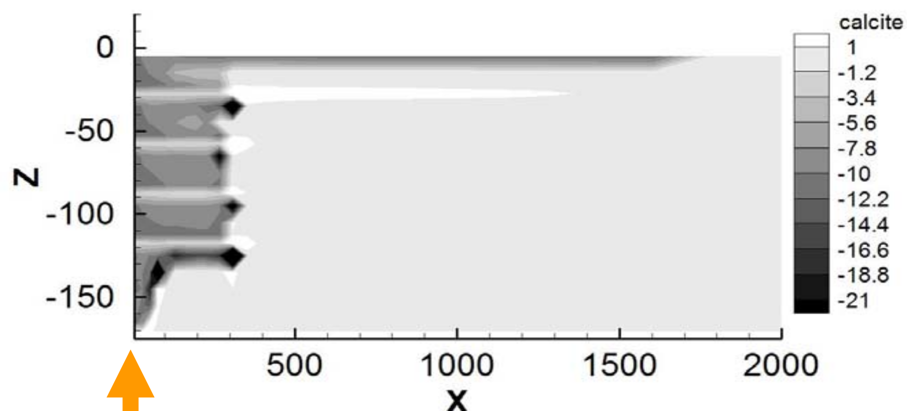
(Audigane et al., Am. J. of Sc., Sept. 2007)



Injection point

pH change of the water due to CO_2 dissolution.

However pH doesn't decrease below 5.13, due to buffering by calcite dissolution.



Injection point

Calcite dissolution (mol/kg^3) in the acid water.

The dissolution of calcite is <u>less pronounced in the shales than in the sands</u>. However *some calcite precipitates below each shale layer* at the interface between the CO_2 saturated brine and the initial brine, due to mixing of different waters in these regions.

The negative sign corresponds to mineral dissolution

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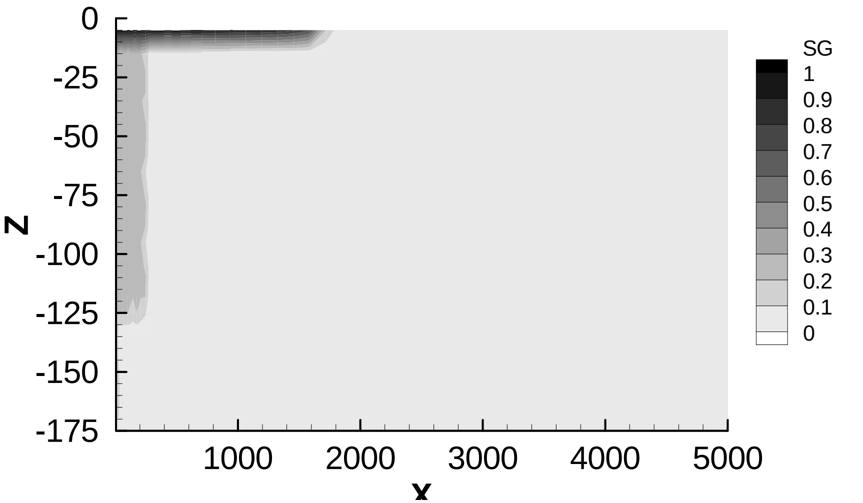
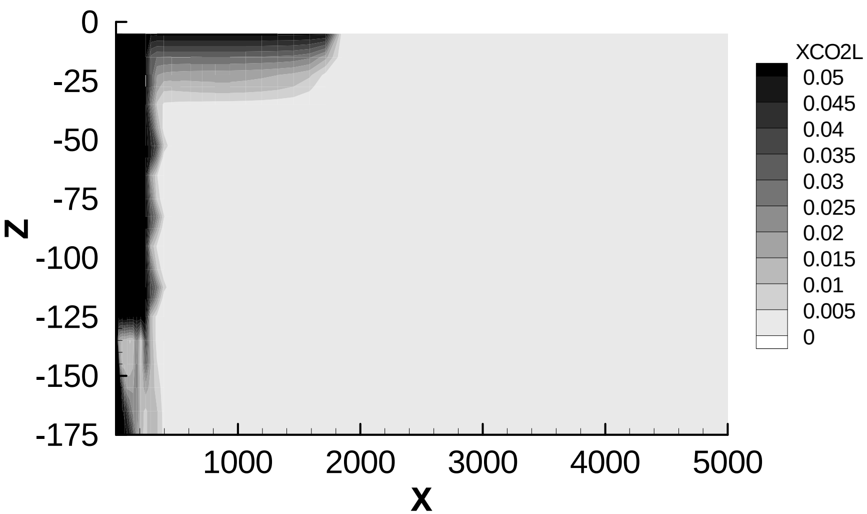
CO_2 migration after 50 years with injection only in the first 25 years



Concentration of supercritical CO_2 in the reservoir

Note how almost all CO_2 has moved to the top of the reservoir



Amount of dissolved CO_2 in the water (mass fraction)

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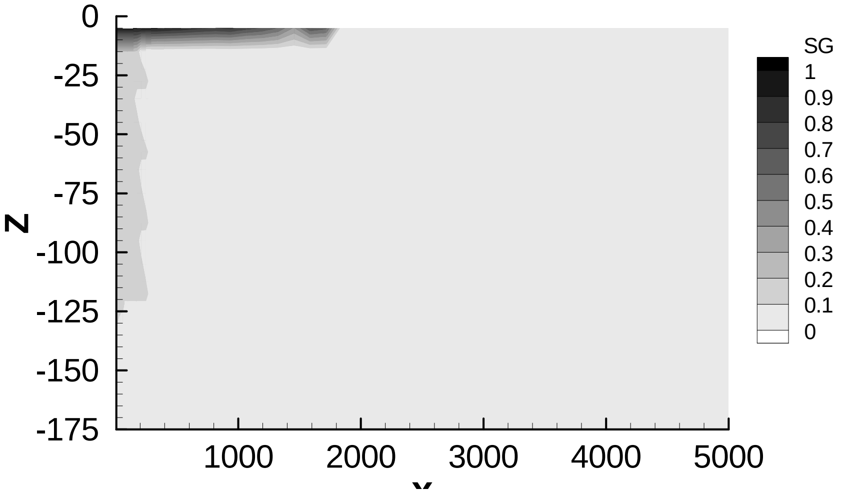
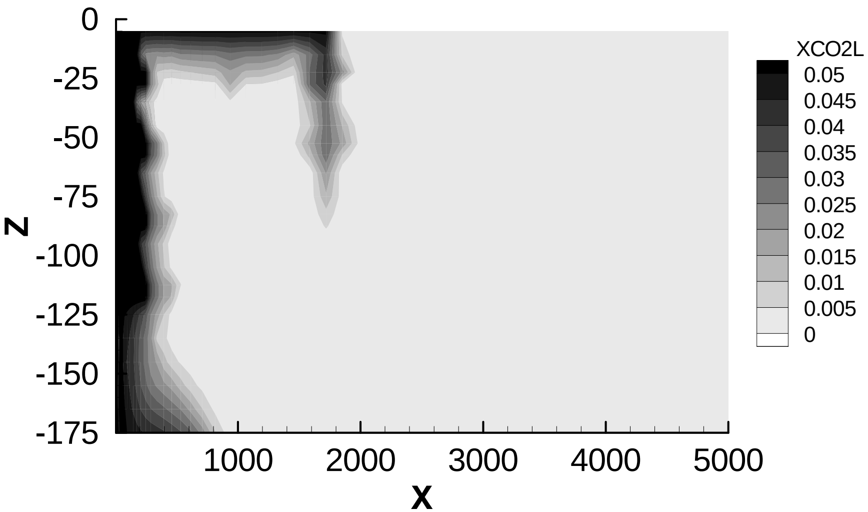
Similar, but after 1000 years …

(Audigane et al., Am. J. of Sc., Sept. 2007)



Concentration of supercritical CO_2 in the reservoir



Amount of dissolved CO_2 in the water (mass fraction)

Note that brine with dissolved CO_2 migrates downward as it is approximately 10 kg/m3 denser than brine without CO_2.

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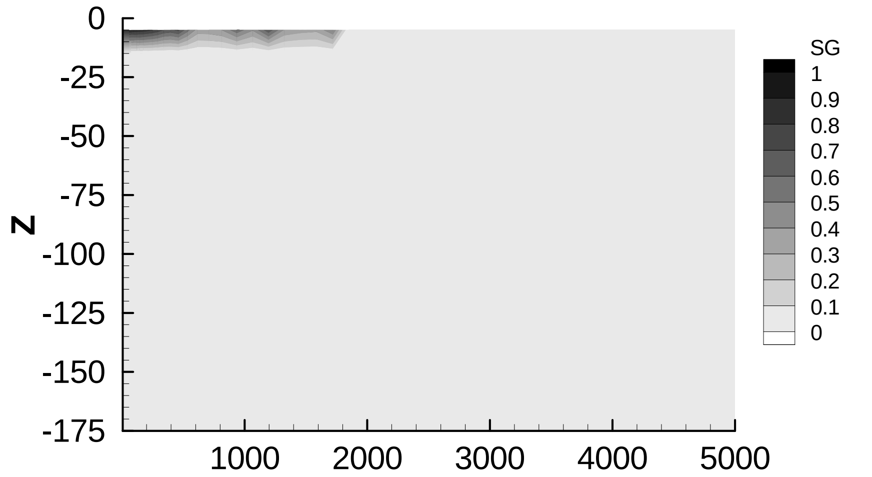
… After 2000 years …

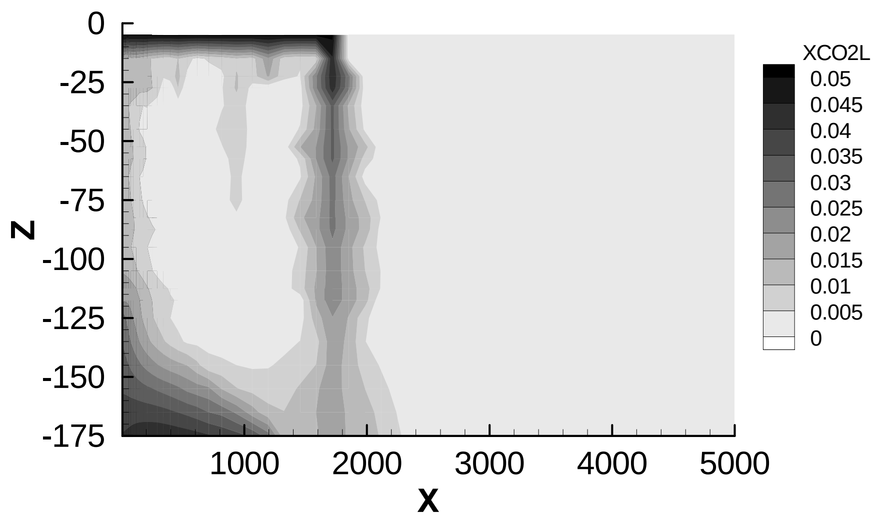
(Audigane et al., Am. J. of Sc., Sept. 2007)



Concentration of supercritical CO_2 in the reservoir

Note how almost all CO_2 has dissolved already.

The CO_2 plume extends to a maximum radius of 2,000 m around the injection well.



Amount of dissolved CO_2 in the water (mass fraction)

Note convection induced by density gradients

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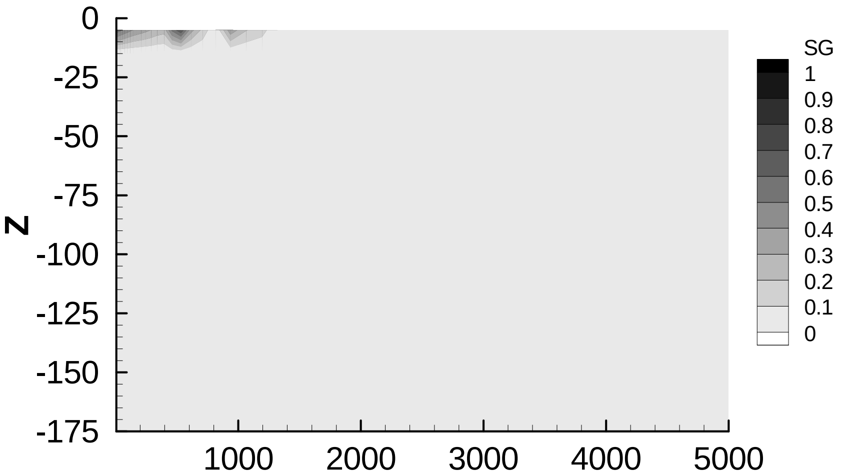
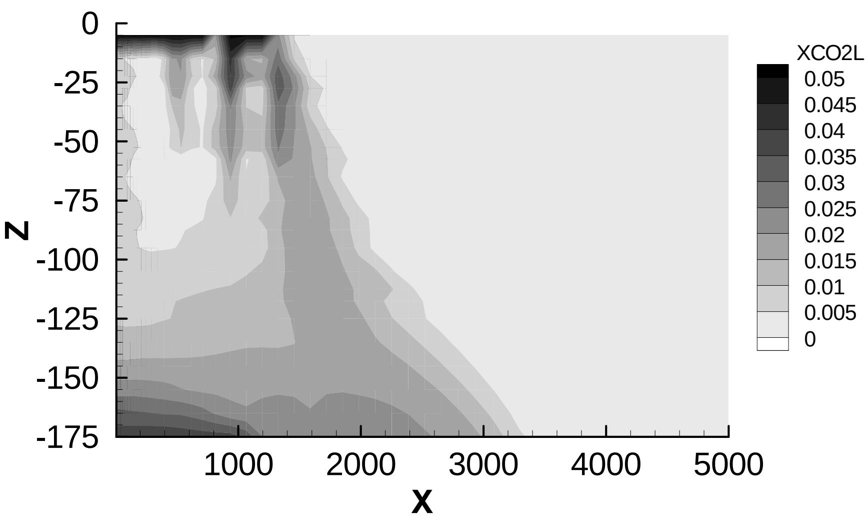
… After 5000 years …

(Audigane et al., Am. J. of Sc., Sept. 2007)



Concentration of supercritical CO_2 in the reservoir

Note how almost all CO_2 has dissolved already.



Amount of dissolved CO_2 in the water (mass fraction)

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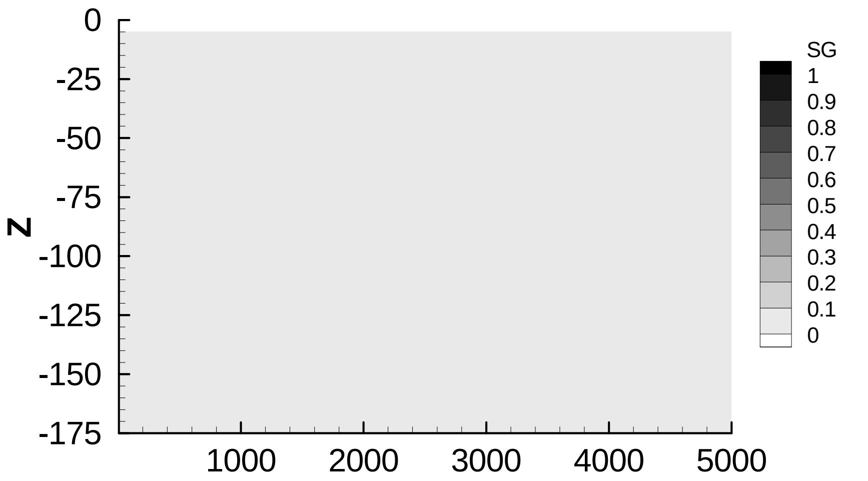
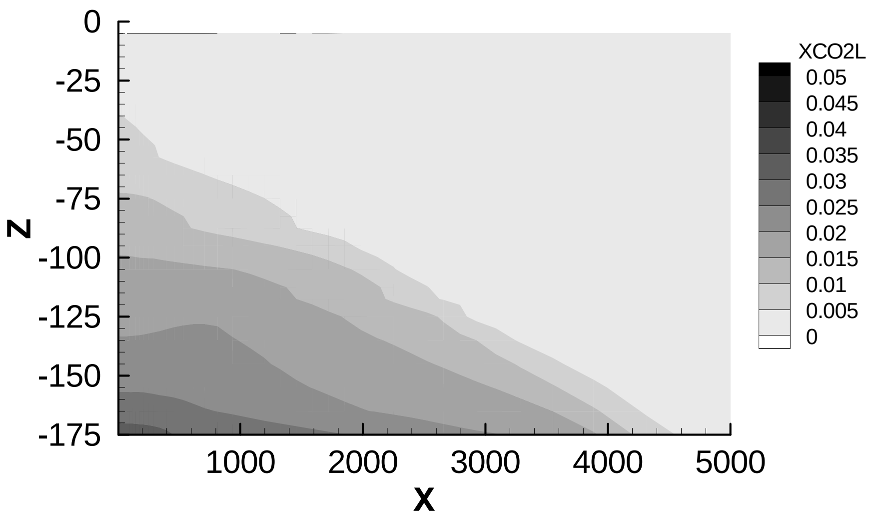
And finally after 10000 years

(Audigane et al., Am. J. of Sc., Sept. 2007)



All supercritical CO_2 has dissolved, there is no more free CO_2 in the reservoir



Amount of dissolved CO_2 in the water (mass fraction)

Dissolved CO_2 accumulates at the bottom of the reservoir with a lateral extent of 4.5 km around the injection well

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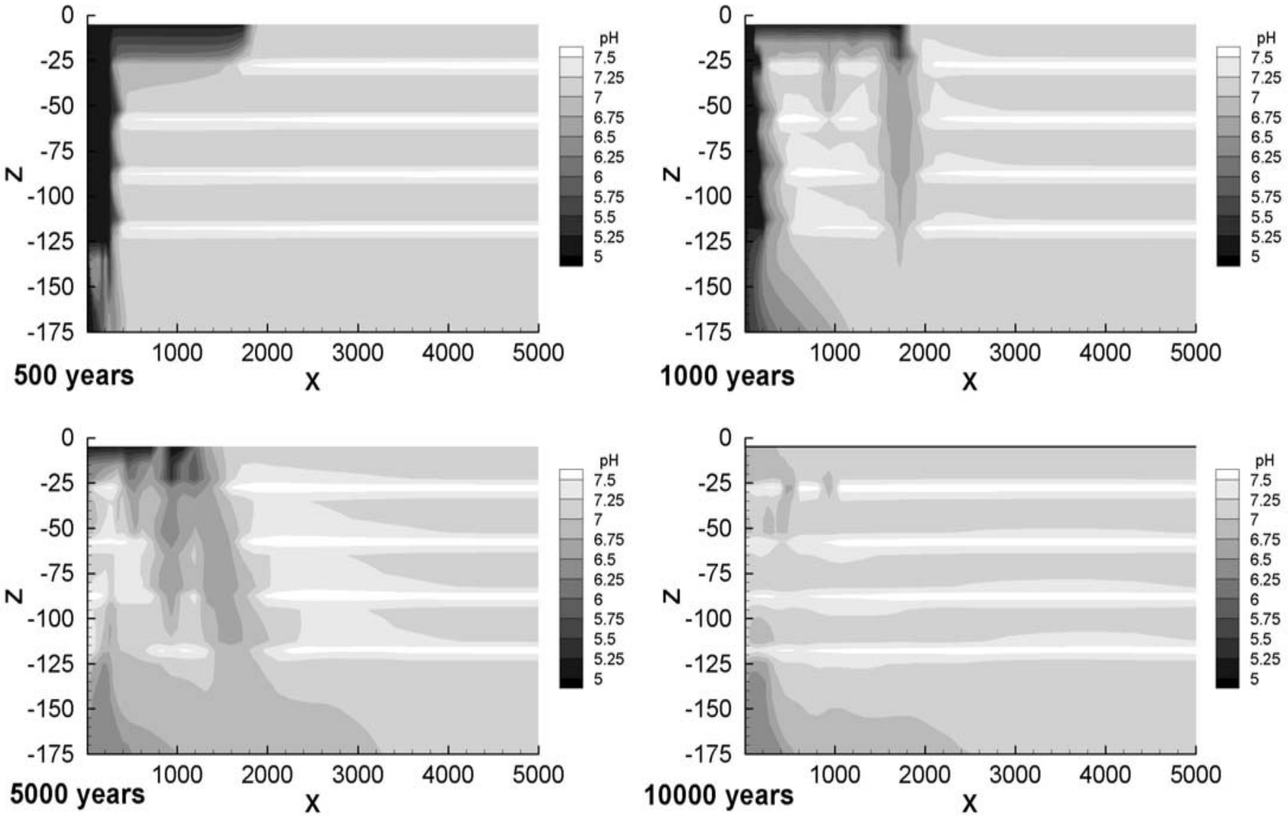
Development of the pH in the reservoir over time

(Audigane et al., Am. J. of Sc., Sept. 2007)



Dissolution of CO_2 increases the acidity of the brine, but is buffered by carbonate dissolution
Maximum decrease of pH is 5.13.

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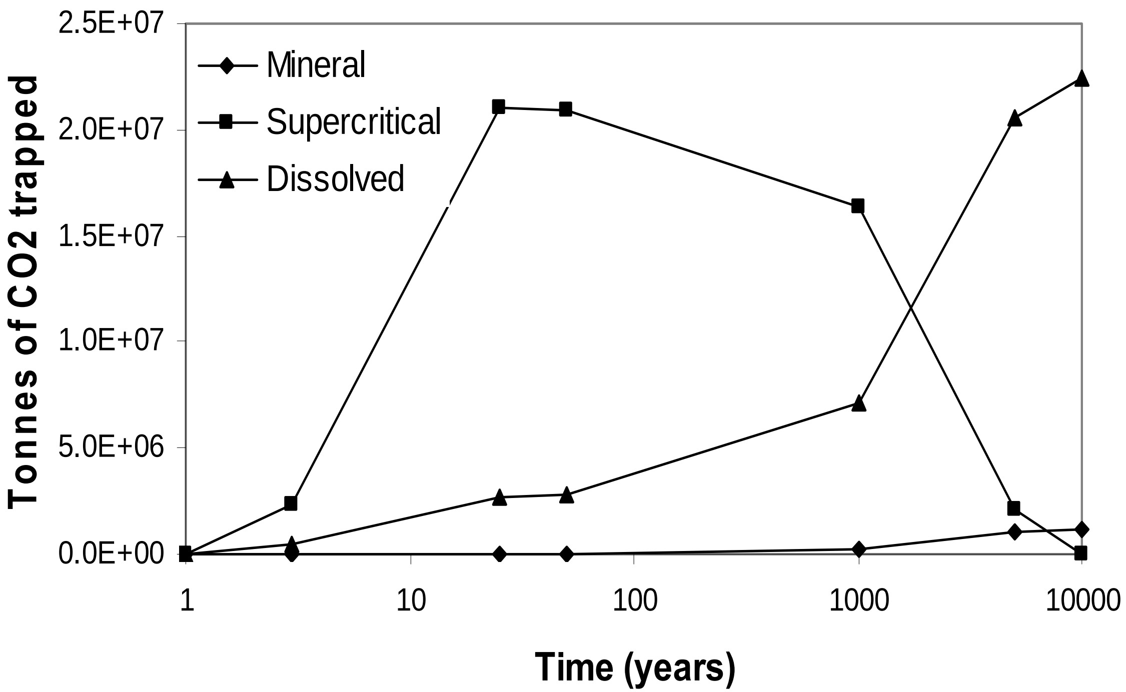
Amount of CO_2 stored

(Audigane et al., Am. J. of Sc., Sept. 2007)



Total amounts of carbon dioxide present as a free (supercritical) gas phase, dissolved in the aqueous phase, and trapped in carbonated minerals (dawsonite mainly).
Dissolution trapping plays a major role in the long term, while mineral trapping is minor at Sleipner.

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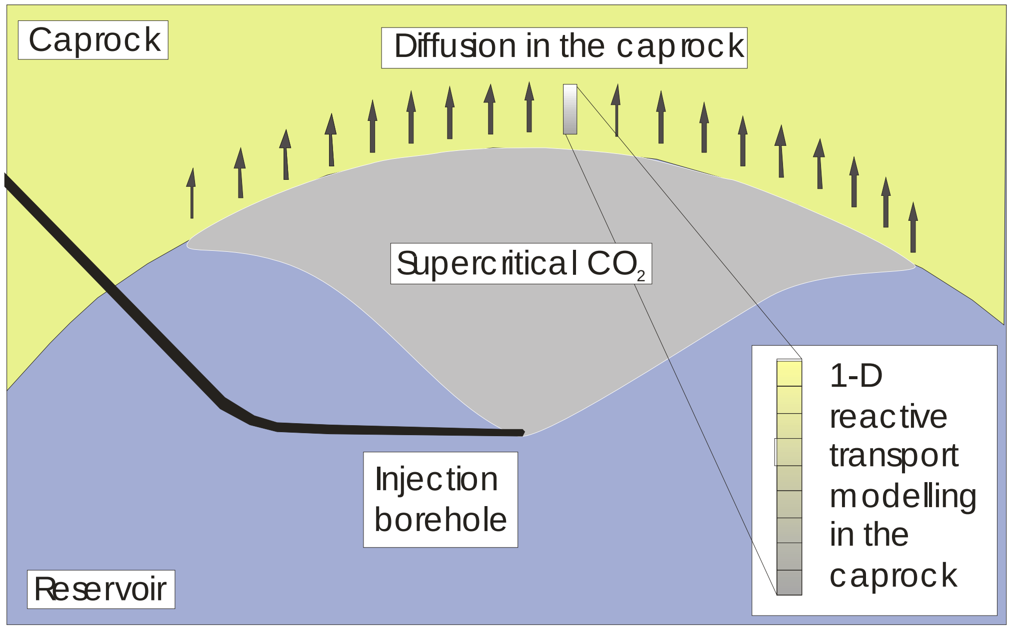
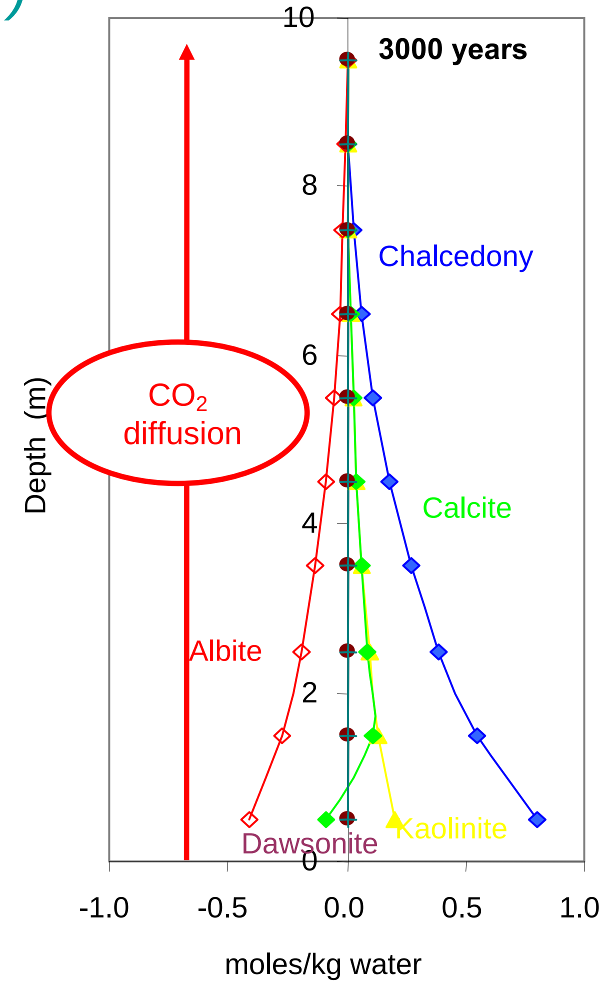
Long term predictions of caprock reactivity at Sleipner

(Gaus et al., 2005, Chem. Geol., 217, 319-337)





> Approach taken

- 1D-reactive diffusion modelling (kinetics included)
- PHREEQC2.8 code

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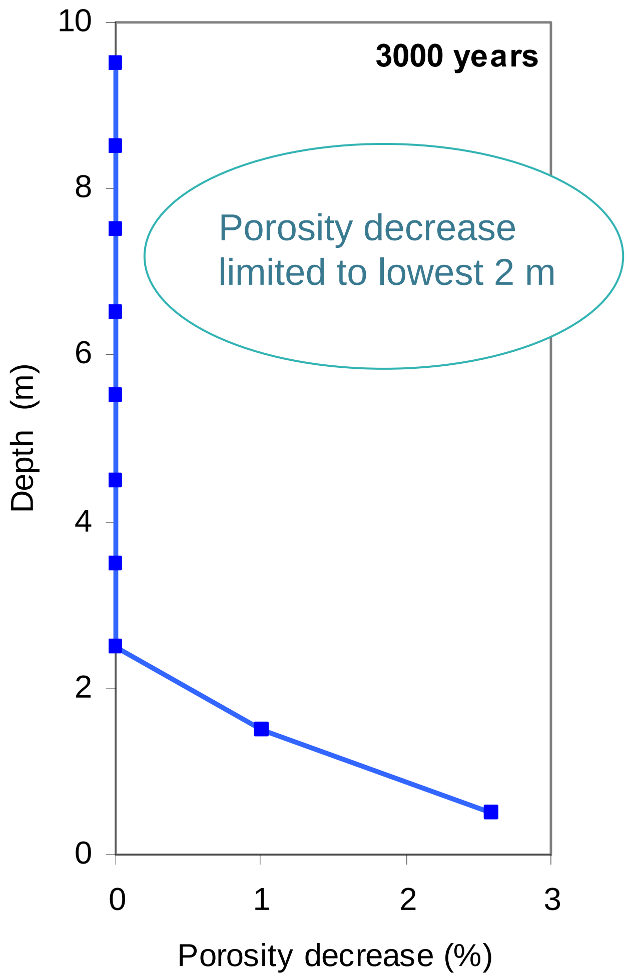
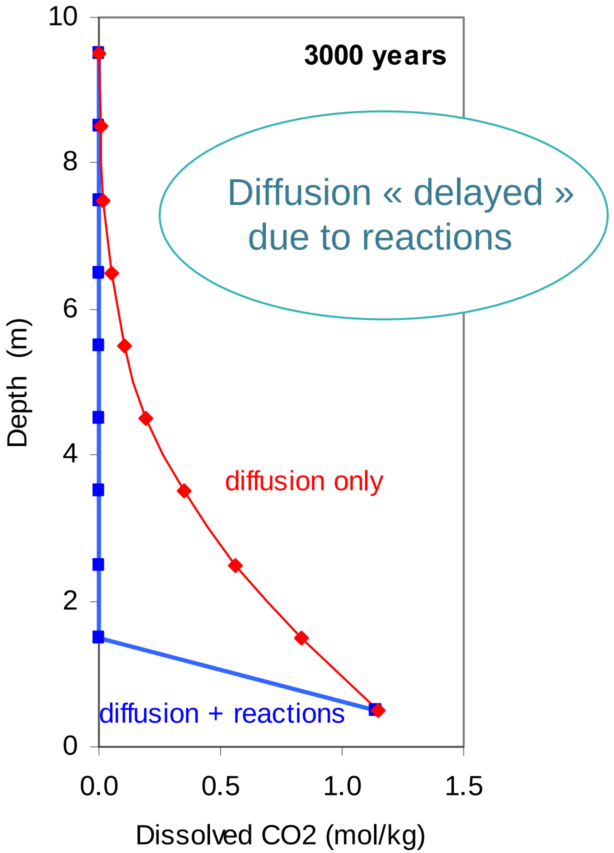
Porosity and diffusion profiles after 3000 years

Porosity change profile



Diffusion profile



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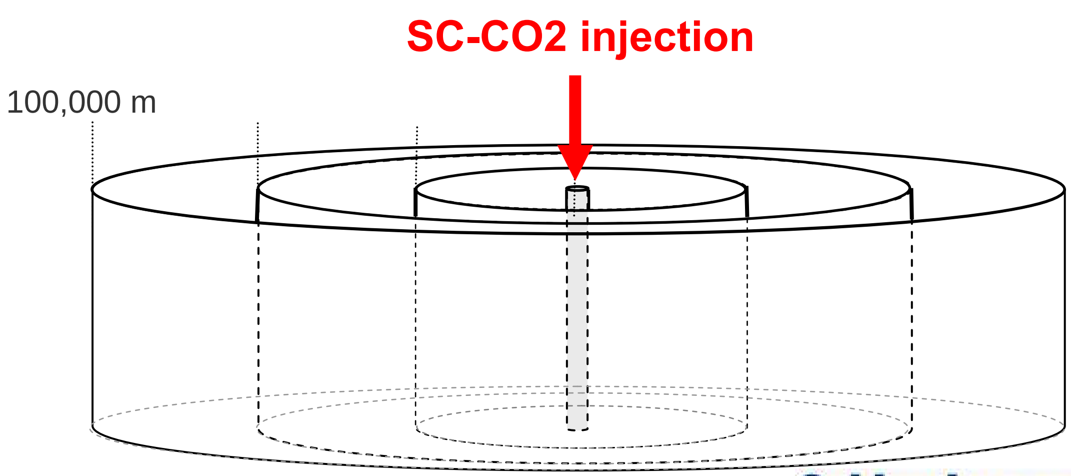
CO_2 injectivity

André et al., 2007, En. Conv. Mgmt., Volume 48, Issue 6, 1782-1797

> Evaluate the geochemical reactivity induced by injection of SC-CO_2 in the Dogger limestone, Paris basin

- **Injection of dry & pure supercritical CO_2**
  - TOUGHREACT based on TOUGH2 – (Xu et al. 2004) (LBNL)
- **Near-well dry out and desiccation phenomenon with high salinity**
  - SCALE2000 (Azaroual et al. 2003) (BRGM)



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Changes over time at 1 meter distance from the well

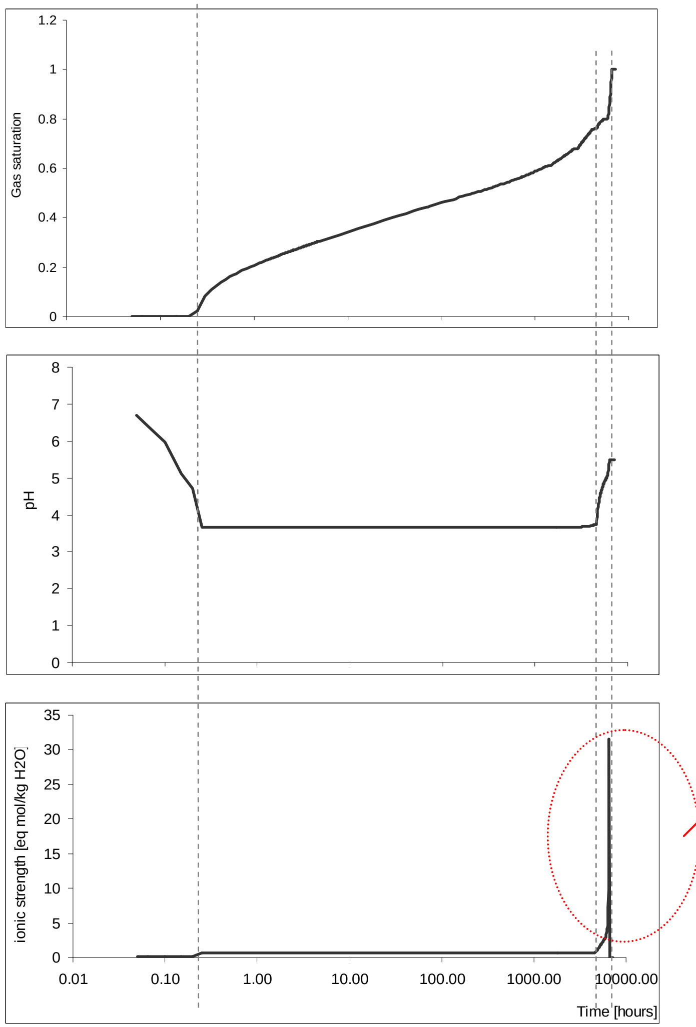
(CO_2 injection rate: 10 kg/s = 0.3 Mt/y)

Phase 1 **Phase 2** **Phase 3**

Sg

pH

Ionic Strength Eq mol/kgH_2O



0 0.10 1.0 10. 100. 1000 10000

Time (h)

> **Three periods identified:**
- Single phase : brine
- Two phases
- Single phase : supercritical CO_2 (dry out)

Out of the Debye Hückel Formalism: Ionic Strength >0.5

USE OF SCALE2000
To calculate correct Index of Saturation for precipitated minerals

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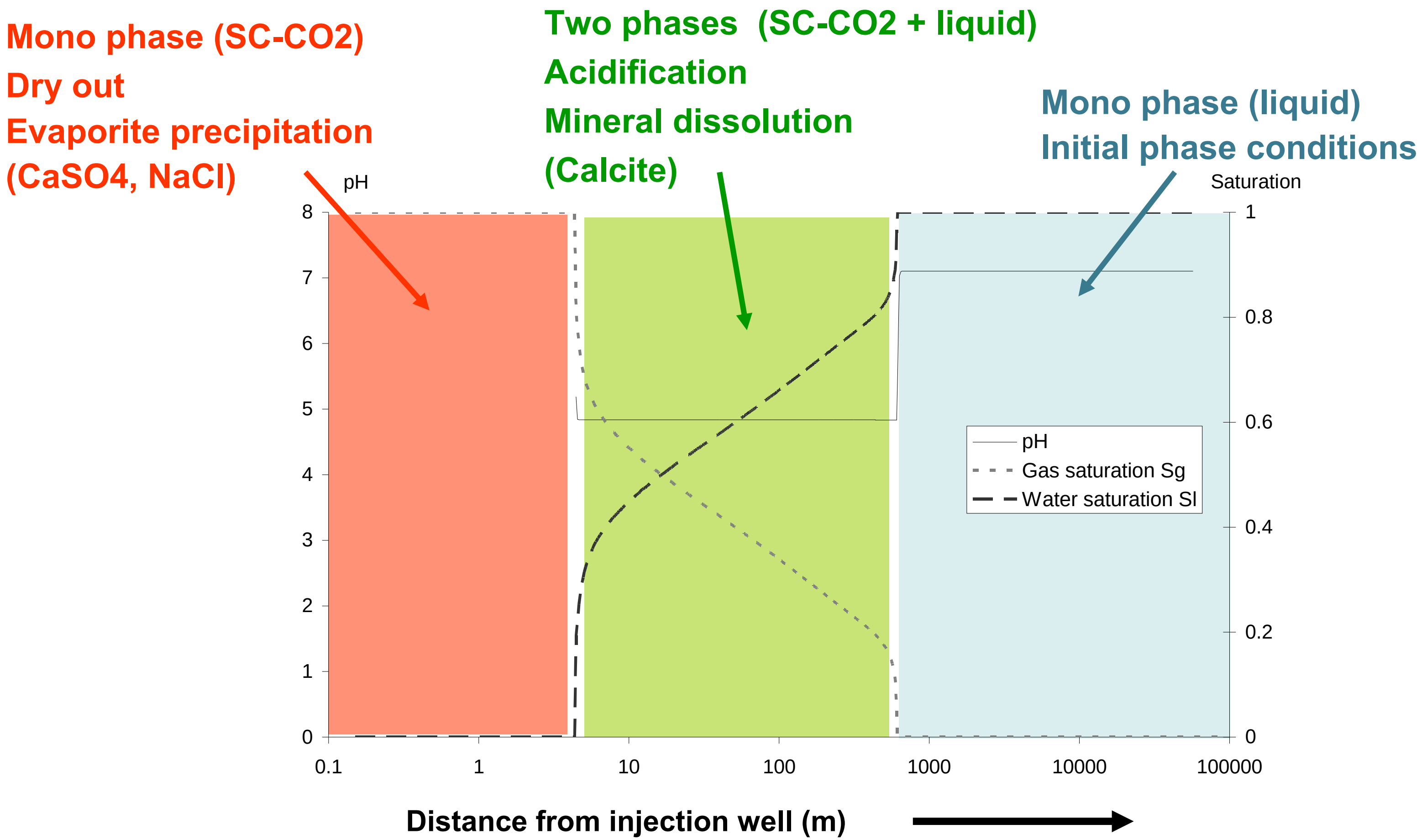
Chemical changes function of distance from the injection well after 10 years of injection (CO_2 injection rate: 10 kg/s = 0.3 Mt/y)



Dry-out zone a few meters around the injection well

Various mineral precipitation and dissolution processes that impact on injectivity

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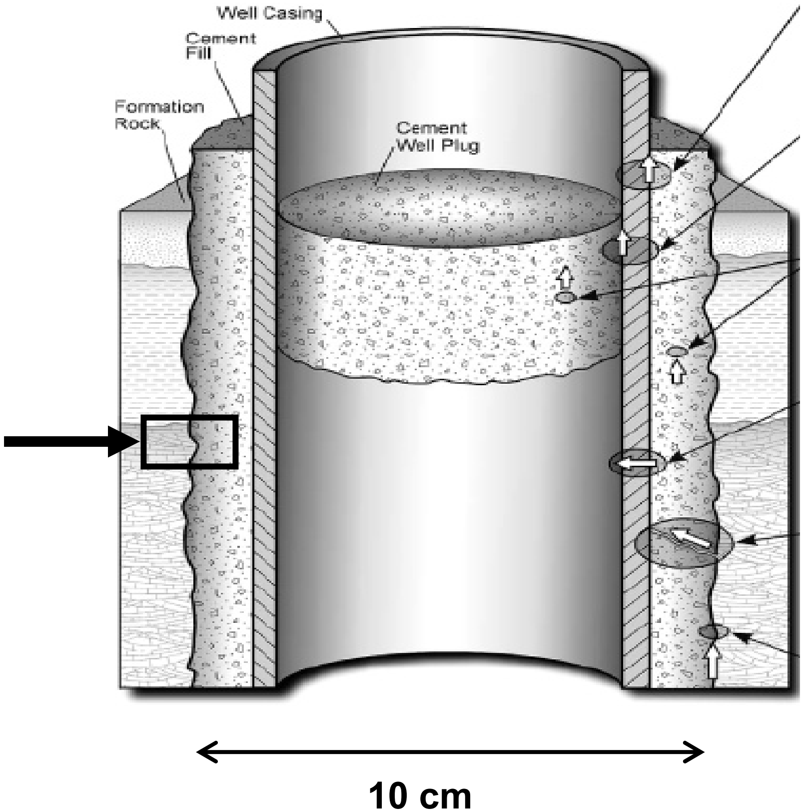
Modelling CO_2 reactivity with well cements
(Jacquemet 2007)

> **New research domain**

> **Example:**

1D diffusion of dissolved CO_2 into the cement at 500 bar and 150°C and induced geochemical reactions

> **Further developments under progress**



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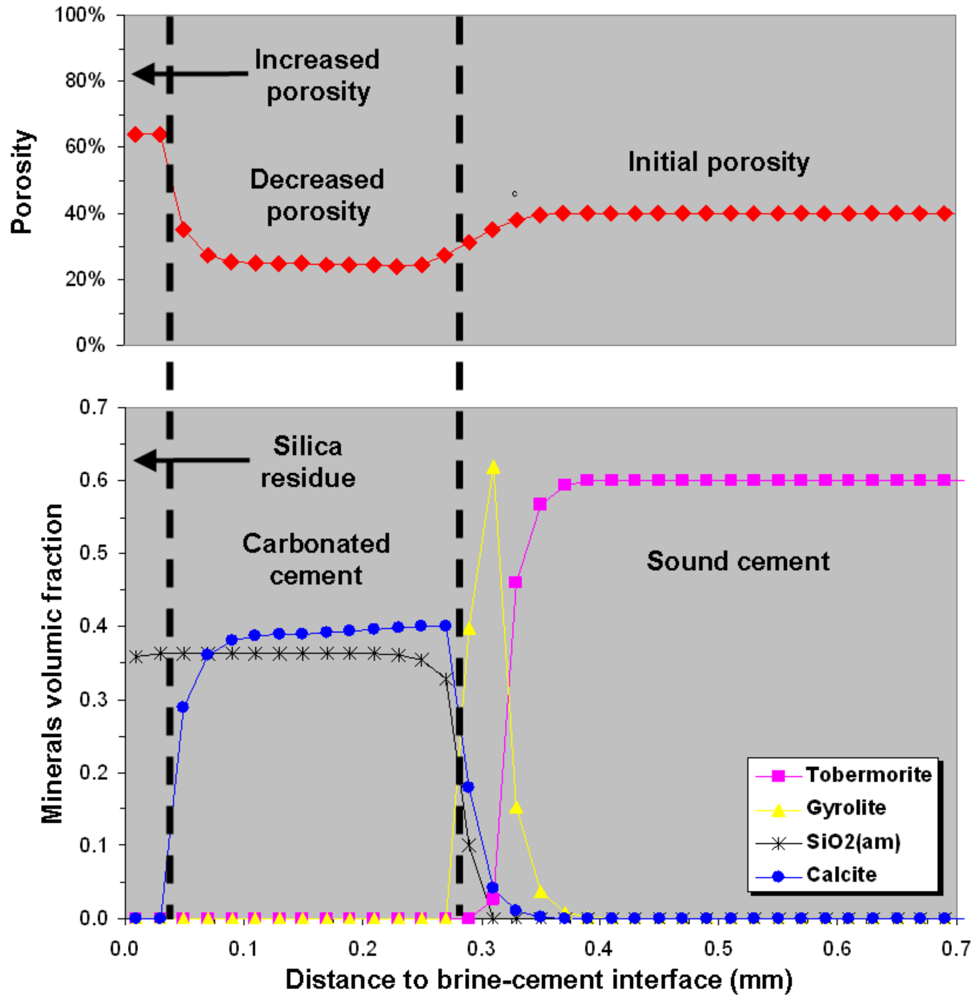
Mineralogical & porosity changes after 2 months of cement alteration



> **Perspectives:**

- Coupling with mechanics
- Chemistry feedback on diffusivity

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Conclusions on the modelling of chemical reactivity

> **Multiple modelling approaches are needed to assess the chemical impact of CO_2 storage**

> **During the last 15 years, geochemical and coupled geochemical and flow modelling have made large progress**

> **Still large uncertainties due to:**

- the complexity of the various processes involved
- insufficient site-specific geochemical data acquisition (rock and fluid samples for precise mineralogy, salinity, detailed fluid chemistry, etc.),
- insufficient site-specific hydrodynamic data acquisition (porosity, permeability, dispersivity, laws Kr-Pc relative permeability - capillary pressure, etc.)
- heterogeneities

> **New research areas:**

- Impact of impurities co-injected with CO_2 (e.g. O_2, N_2, NO, SO_2, H_2S)
- Links geochemistry-geomechanics
- Pore scale modelling to simulate wormhole formation

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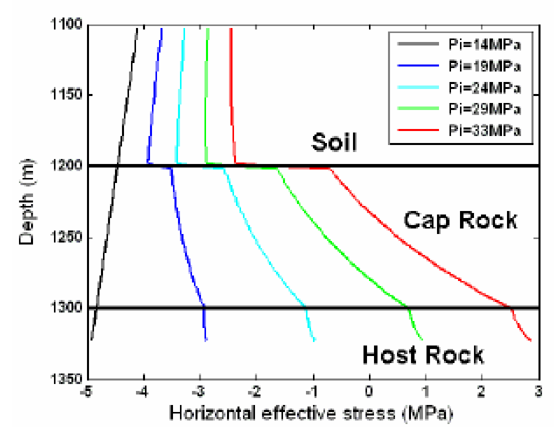
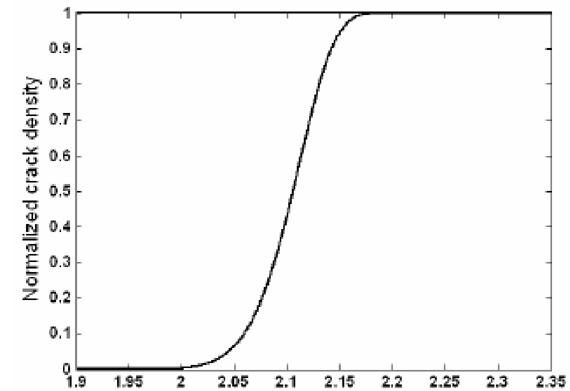
Geomechanical modelling

- Determination of the maximum injection pressure, in order to preserve the integrity of the caprock while optimising the CO_2 injection rate
- Modelling of fault reactivation and induced leakage or ground movement
- Assessment of the Impact of a seismic event on a storage site (application to Total pilot at Lacq)

Evolution of the effective stress with injection pressure



Crack density fonction of injection pressure



Pression d'injection normée

Injection pressure:
15 MPa during 30 years

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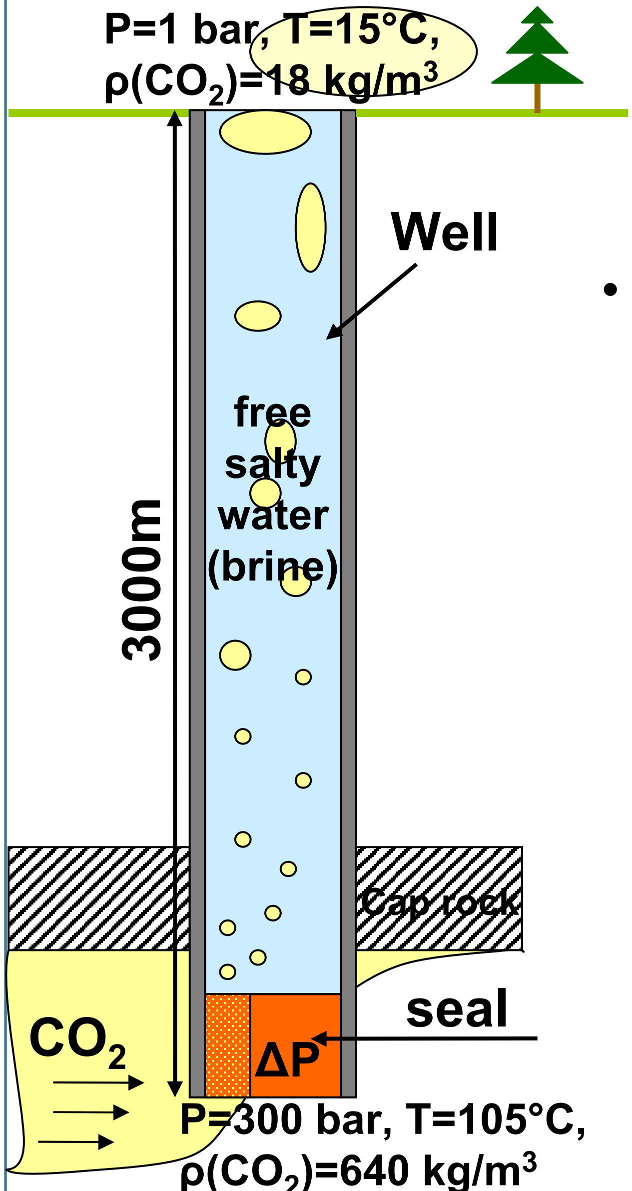
CO2 leakage scenario through a well (Wertz, 2008)



CO2 in a free water column

1-D analytical Model

- **Assumptions:**
  - **Static and Stationary flow**
  - **CO_2 thermally balanced by water**
  - **Geothermal gradient 3°C/100m, 10bar/100m**
  - **Darcy Flow in the seal due to overpressure**
  - **Bubble and slug flow models in the well**
  - **Velocity $V(CO_2)$ depends on:**
    - **density $\rho_{CO2}(P,T)$**
    - **interfacial tension $\sigma_{CO2/brine}(P,T)$,**
    - **gas volume fraction x**

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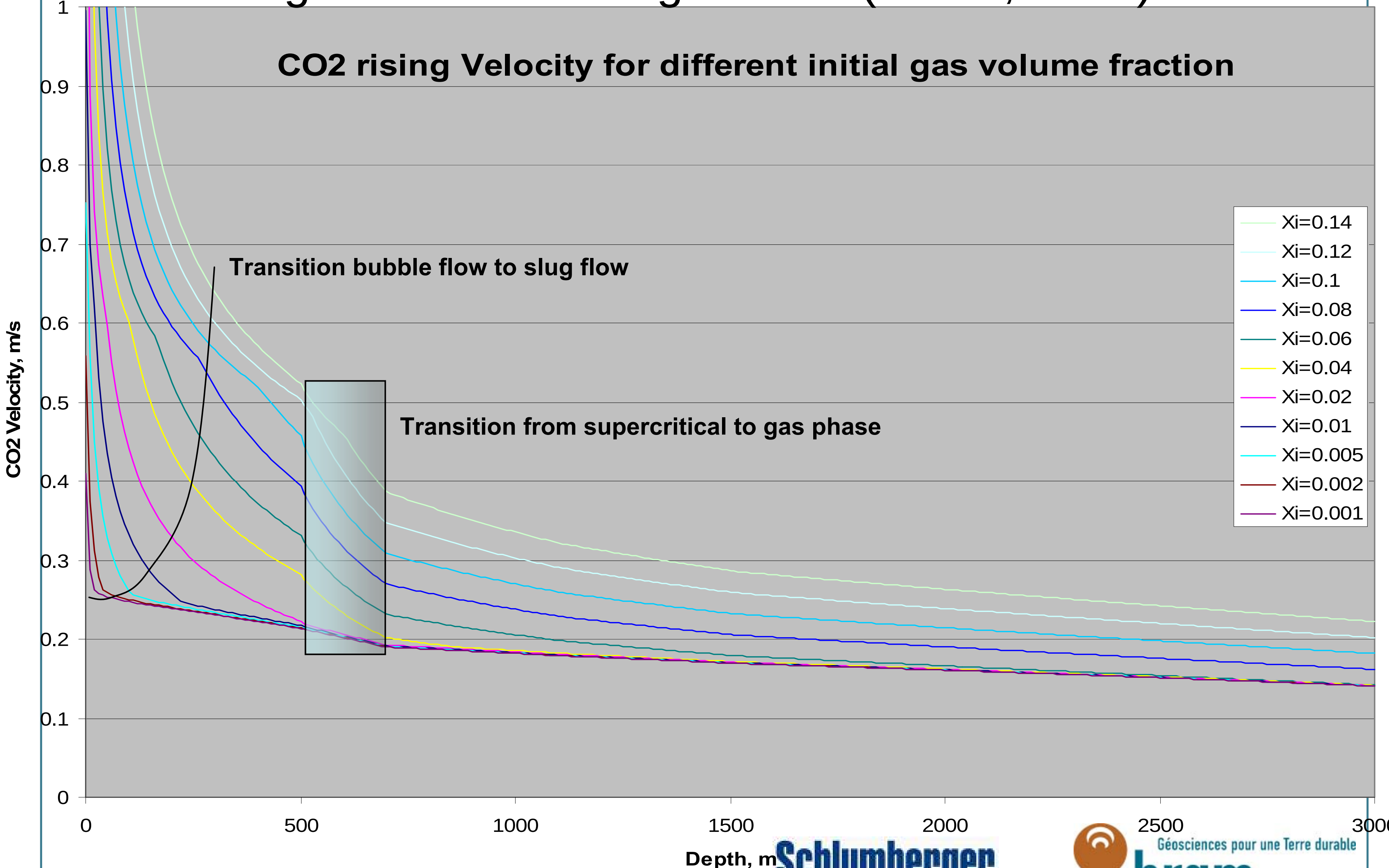
CO2 leakage scenario through a well (Wertz, 2008)



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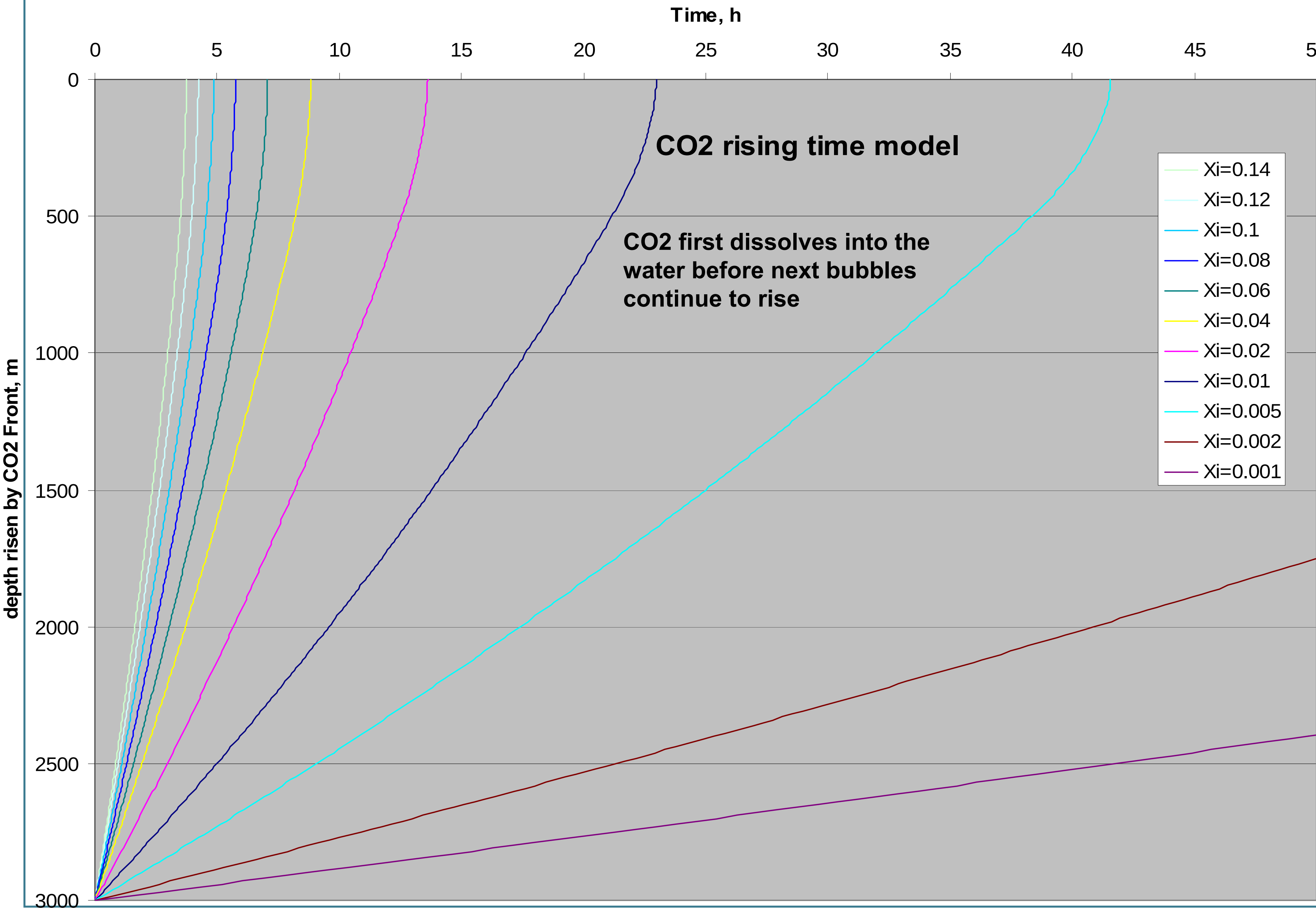
CO2 leakage scenario through a well (Wertz, 2008)



CO2 leakage scenario through a well (Wertz, 2008)

Conclusions:

- **Analytical model is faster, and physically easy to describe**
- **Analytical and numerical models are complementary:**
  - **while some codes can fail at the phase transition, analytical models can foresee it and find a workaround**
  - **making analytical and numerical models converge to a similar solution strengthens the confidence in the solution.**

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4- Previous initiatives of code comparison

- 2002 Workshop at LBNL, Berkeley, USA: Inter-comparison of numerical simulation codes for geologic disposal of CO2 report (reported in Pruess et al. 2004)

  "Code intercomparison builds confidence in numerical simulation models for geologic disposal of CO2"

  Energy 29 (2004) 1431–1444

- 2008 Workshop at University of Stuttgart, Germany: Numerical Models for Carbon Dioxide Storage in Geological Formations (report to be issued)

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LBNL code intercomparison exercise (2002)

- Participants:

Research Institute	Code(s)
LBNL, USA	TOUGH2 Family
University of Stuttgart, Germany	MUFTE_UG
CSIRO Petroleum, Australia	TOUGH2/ECO2
IFP, France	SIMUSCOPP
University of Stanford, USA	NON BAPTISE
Alberta Research Council (ARC), Canada	GEM
LANL, USA	FLOTRAN, ECLIPSE 300
LLNL, USA	NUFT
Industrial Research Limited (IRL), NZ	CHEM-TOUGH
PNNL, USA	STOMP

- 8 very simplified exercises (1D, 2D radial, schematic & homogeneous media) that probed advective and diffusive mass transport in multiphase conditions, with partitioning of CO2 between gas and aqueous phases; two problems also involved solid minerals and oil phases.
- broad agreement in most areas; bugs corrected, some unexpl. discrepancies
- also points out sensitivities to fluid properties and discretization approaches that need further study.
- It is hoped that future code intercomparisons will address coupled processes in fully 3D heterogeneous media, constrained by actual field observations.

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Univ. of Stuttgart code intercomparison exercise (2008)

> Participants:

Research Institute	Code(s)
University of Bergen/Princeton, Norvège/USA University of Texas/Austin, USA IFP Rueil Malmaison, France University of Stuttgart, Germany RWTH Aachen, Germany BGR Hannover, Germany LANL, USA	Semi-analytical solutions IPARS-CO2 COORES MUFTE TOUGHREACT ROCKFLOW FEHM
University of Stuttgart, Germany	DuMux
BRGM Orléans, France	RTAFF2
HW Edinburgh, UK	ECLIPSE 300
Schlumberger Carbon Services, Paris	ECLIPSE 300
University of Stanford, UK	GPRS

> 3 exercises: focused on fluid flow and numerical aspects, 3D geometries

> some big discrepancies that need to be further analysed (discretization, numerical algorithm, etc.)

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5- Additional efforts needed

> Needs expressed by IEA GHG Wellbore Integrity Network

- Numerical models of wellbore geochemistry and geomechanics need additional development for providing long-term predictions
- Numerical models incorporating realistic permeability distributions for wells are needed to evaluate the leakage potential of fields with multiple wells
- Integrated geomechanical and geochemical experiments/numerical models are needed to capture full range of wellbore behavior
- Long-term numerical modeling grounded in enhanced field and experimental data

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5- Additional efforts needed

> Needs expressed by IEA GHG Monitoring Network

- Recognizes the importance of modelling in the various phases of CO_2 storage (site investigation, drilling & well testing, storage operation, site closure)
- “The monitoring measurements should be history matched against the predictive flow modelling”
- “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 CO_2 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”.

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5- Additional efforts needed

> Needs expressed by IEA GHG Risk Network

- How confident are we in modelling results?
- Need for modelling physical/chemical/mechanical phenomena in a way that can be useful for risk assessment

> Needs expressed by ZEP - the European Technology Platform for Zero Emissions Fossil Fuel Power Plant:

- R&D area: Long-term modelling of CO_2 storage in deep saline aquifers: “Modelling is used to characterise both short-term and long-term storage performance in terms of injectivity, capacity, containment, and quantitative estimation of potential leakage. A dedicated project is needed to develop and demonstrate the capacity of models to adequately predict the storage behaviour and CO_2 fate. This will increase confidence in the safe implementation of storage sites and will be useful for optimising the injection operations and the short/long term monitoring strategies”.

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6- Towards a IEA GHG modelling network?
– Feedback from questionnaire (18 received, 16 with opinion)

> FOR (13), e.g.:

- YES. Modelling is a key component of all CCS projects and thus determining best practises in this area would be very useful.
- YES, it is important to create a place where this community can meet, especially to perform benchmarking
- YES - Definitely. Modelling needs to be performed at several levels, which transcends the scope of the individual networks at present. Our confidence in our ability to model both the small scale and large scale phenomena in the system will be greatly enhanced if we focus effort on this problem and share information that is currently within the domain of the individual network groups.

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6- Towards a IEA GHG modelling network?
– Feedback from questionnaire (18 received, 16 with opinion)

> FOR (13), e.g.:

- YES. I think the results of work done in the other networks can feed the modelling to develop better models, but that this topic is a stand alone issue.
- Simulation and modelling is very important for CCS. So, new network should deal with modelling and simulation
- 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.

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6- Towards a IEA GHG modelling network?
– Feedback from questionnaire (18 received, 16 with opinion)

> AGAINST (2):

- 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).
- NO. Modeling is a crosscutting activity that pertains to all the existing networks.

> MAY BE (1):

- Maybe to some extent

6- Towards a IEA GHG modelling network?

Conclusion is best summarised by one of the answers to the questionnaire:

> "**YES**, I believe there would be a lot of benefit from a modelling network. Significant components of the practice of CO2 injection and geologic storage can be described only by modelling (e.g., estimated injectivity, injection field design and injection rates, total storage capacity, plume fate and tracking, etc.). Modelling of these technical components will be important in preparing carbon storage permits, and convincing regulators and the public of storage safety and viability. Therefore, a modelling network would contribute to more directly integrating modelling developments with developments in WI, M, and RA, and would also promote accurate, dependable, and practical modelling as applied to permitting and monitoring CO2 geologic storage".

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Breakout Session 2
Modelling in Risk Assessment Network

- Agreement that the RA network has done little work on the specifics of process modelling to date
- Two opposing viewpoints expressed:
  - 1: Modelling of processes in geosphere merits separate network
  - 2: Difficult to justify modelling network because modelling is such an integral part of risk assessment. Separate network may have detrimental effect on RA network – may be more appropriate to have a ‘sub group’

2

- Agreement that any new network needs clear focus: risk network must inform new modelling network of requirements, i.e. Modelling needs to be focussed on potential regulatory requirements and level of sophistication
- General acceptance that detailed process modelling is vital, though counter point also made asking if site screening can avoid need for detailed modelling

Modelling in the Monitoring Network

- Modelling requirements of the Monitoring Network
- Where are modelling issues best addressed (current networks, new network?)
- What will this network offer that is not or could not be covered in monitoring

Modelling Network

- Modelling of CCS is a specialized area and a modelling network would be good for sharing these challenges
- Goal of network: Work flows associated with modelling
  - “Process” of modelling
- In modelling there is always issues with inversion – monitoring (of the “right” parameters) is key to this inversion. Also a recognition that no model can do everything...
- Modelling is has used (and is using) tools from the oil and gas industry that were not designed for CO2 storage – modelling network continue GS specific model development
- Modelling could help identify appropriate, generic levels of simplicity to allow design of monitoring, area of influence, etc
- Could look at how to communicate complex simulation results to the public

Modelling Network

- 4 Areas of modelling
  - Bench Marking (can be independent)
    - Code validation
    - Analytical
    - Code comparison
  - Calibration (can be independent)
    - lab scale, small scale comparisons
    - Some inversion
  - **Validation (Needs to be integrated with monitoring)**
    - **this occurs through monitoring**
  - Long-term predictions (1,000's of years - potentially independent)

Monitoring and Modelling

- Modelling can give monitoring the questions that they need to answer
- Monitoring has traditionally not focused on modelling
- Historically there has been a lack of “projects” to demonstrate monitoring and modelling but things are changing
- Interaction between the modelling and monitoring helps define the limitation between areas

Monitoring and Modelling

- The monitoring people have to work very closely with the modellers in order to calibrate the models
  - Monitoring can help reduce the uncertainty in the models
- Integration of data is required between the monitoring and the modelling
- Monitoring and modelling are dependant
  - History matching and forward modelling
  - But issues of underlying physics, process coding, etc are specific to modelling
- Integration could be handled by planned joint meetings
- Monitoring Day 1, Mon./Mod. Day 2 and Mod. Day 3

Conclusions

- Regardless of whether the modelling network is created, the monitoring network needs increased focus on modelling and monitoring issues of CCS

Breakout Session 3

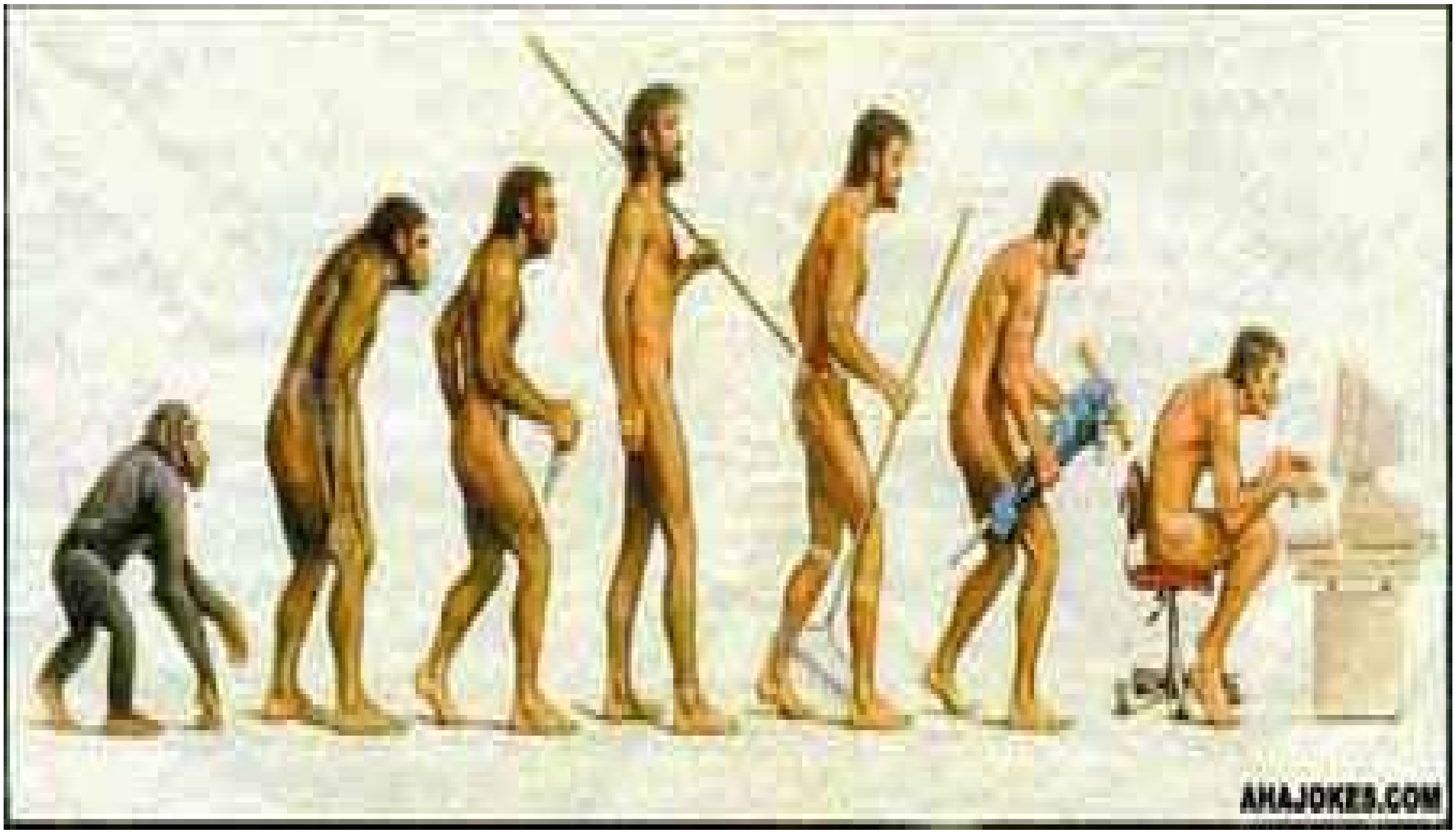
Regulatory Efforts in the US

- Experimental Well Guidance (March 2007)
- Regulatory Development for Commercial Projects
  - Announcement: Oct. 2007
  - Proposal: Summer 2008
  - Final: TBD
- Some Challenges
  - New technical and legal issues
  - Multi-jurisdictional implementation
  - Limited experience w/ permitting CO_2 (at Fed level)
  - No commercial scale projects in the US (yet)
  - Data availability and access

Life Before the Announcement

Reaction to the Announcement

Evolution to a More Enlightened State



Breakout Session 3 CCS Phases Group 1: Site selection and Characterisation

- CO2CRC slides provided introduction
- Some highlighted issues:
  - Characterise injectate chemistry
  - Old and future wells
  - Onshore versus offshore considerations
  - No such thing as a perfect site

2

Some assumptions made:

- Selection process – this is best site
- Due diligence has been done
- EIA not required
- Access rights granted
- *Regulatory requirements known*
- *Liability issues resolved*

3

- CAPACITY
- INJECTIVITY
- CONTAINMENT
- Risks – leakage
  - Wells ***
  - Seals
  - Faults
- Plans to monitor (baseline), verify, remediate
- Longer timescale considerations

4

- Uncertainties to resolve:
- Geochem reactions (injectivity and capacity effects)
- Methods to resolve uncertainties:
- Lab tests and/or pilots

5

- Data needs:
- Characterisation of adjacent strata (above/below)
- Receptors e.g. Potable aquifers
- Oil field production and exploration data
- Potable aquifers
- Well data

6

- Key source of risk: containment issues
- Main risk scenario involves 100 existing wells
- Existing records?
- Location, integrity, remediation?
- Well liability issues resolution
- Re-entry of wells may be required

7

- Knowledge gap: how to handle old wells
- What do we think standards should be for treatment of old wells
- Avoid interaction with old wells where possible
- Performance standards for regulations

8

- Key messages for main scenario:
  - Capacity, injectivity, containment issues
  - Risks – seals and faults easier to resolve
  - Wells more difficult
  - Monitoring and verification, remediation plan
  - Uncertainties – geochemical effects
  - Data needs

9 – New Scenarios

Saline aquifer:

- Much more effort needed for characterisation – lack of data and costs of acquisition
- Larger study volume of rock
- Capacity calculations
- Containment integrity and methods of appraisal
- Trapping mechanisms
- Geochemical data and effects

10

For alternative saline aquifer scenario: issues (networks) other than wellbore become of increasing relative importance

IEA Greenhouse Gas R&D Programme

IEA Greenhouse Gas R&D Programme
1st Joint Network Meeting

New York – 11-13 June 2008

BG2 – Operation at 1MtCO2

Focus on gaps

- Differences in actual behaviour vs Simulation
  - Regulators expectations – can Networks inform
- Limitations of monitoring – how can we track plumes? seismic ? Other techniques?
  - Qualitative
  - Quantitative – level of accuracy ?
- Well population – do we have sufficient info on abandonment conditions ?
- Triggers for remediation or action – can networks provide criteria
  - Impacts of leaks
- How does regulator know if monitoring plans adequate
  - More observation wells means more risk of leakage
  - Regulator expectations on monitoring plans – not R&D level
  - Regulators will need to draw on expertise – eg 3rd party verification of mon plans – role for networks
  - Need to be able to respond quickly, and anticipate needs
- Are all potential risks covered - oil field so low risks, well population cause the risk

Purity

- Compromises at CCS deployment scale-up, more impurities creates more uncertainty, Technol and industry specific

BG2 – Operation at larger scale

More CO2

- Need more injection wells

EOR

- Moving from EOR to storage changes lots of things
- Retrospective site characterisation? Or stay as oil producer
- Differences between EOR and storage sites
- Can you get credits?

Populated areas

- Storage – more public concerns – more assurance monitoring, more remediation plans
- Transport
- Use of natural analogues, or not?
- Ground water impacts driving regulation
- Impacts on other underground activities?

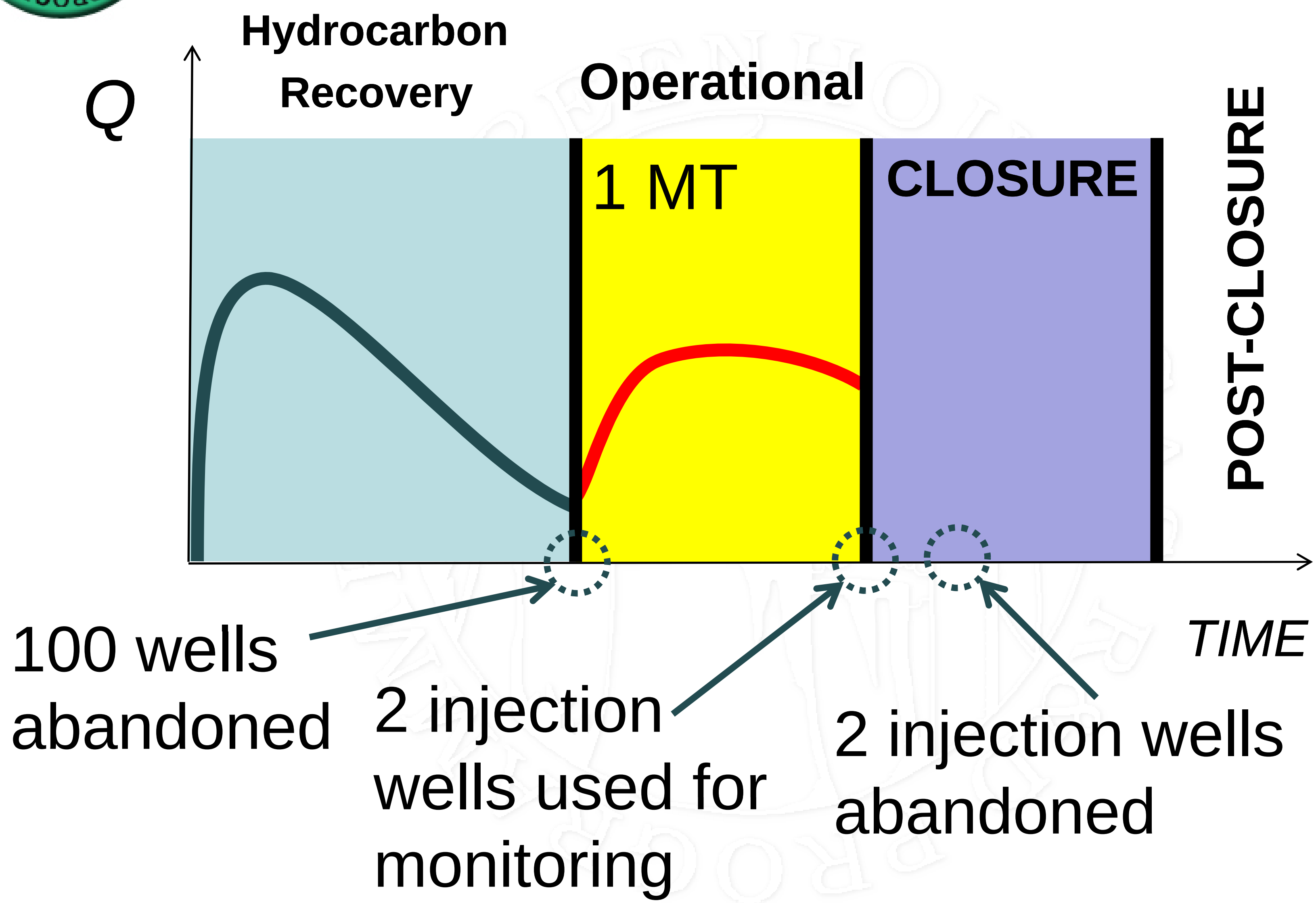
Saline aquifers

- Additional information is needed – under site characterisation
- How to monitor? Need more modelling and monitoring to be assured of storage security

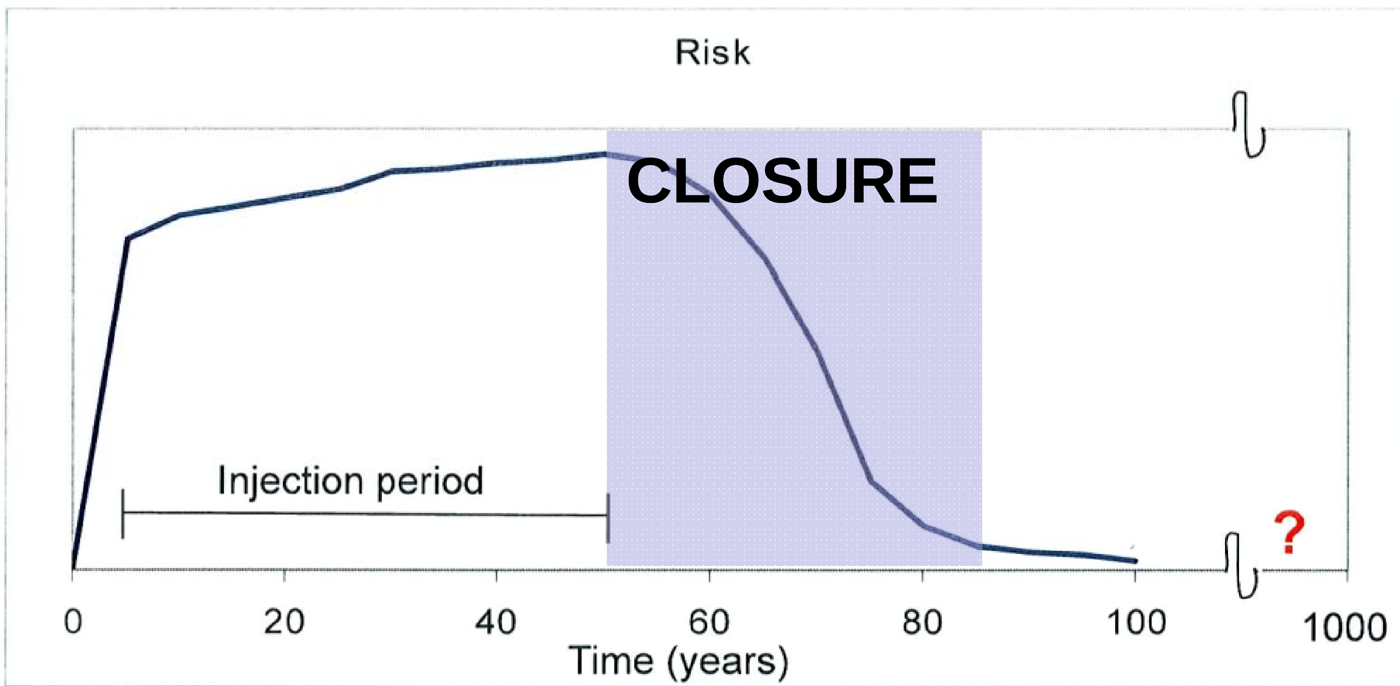
Breakout 3 – Closure

- Definition of closure:
  - Injection ends & up to abandonment and handover

- Aim of closure:
  - Provide sufficient information to the regulator to allow hand over
  - Demonstrate that the risk is within acceptable limits
    - Pressure stability
    - Plume stability (not moving or moving predictably)
    - Leaking or not leaking (if it does leak we will see it)


Hydrocarbon Recovery
Operational
Q
1 MT
CLOSURE
POST-CLOSURE
TIME
100 wells abandoned
2 injection wells used for monitoring
2 injection wells abandoned

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



Scenario assumptions

- 2 operational wells to be abandoned
- 100 abandoned wells (of various ages)
- Reservoir model has been updated during the operational phase
- The operational model is large enough for long-term migration modelling and risk assessment
- A thorough monitoring programme was implemented during operation
- Abandoned wells have been approved for CO_2 storage

Data

- Pressure distribution at the end of CO_2 injection
- Evolving pressure during transient reductions
- Update operational dynamic model as transient response disappears
- Partitioning between the CO_2 and oil
- Demonstrate area of influence estimates for post-closure time period
- Review the performance records of the 100 abandoned wells
  - At the onset of closure – post closure, do we need to reassess well integrity. Well integrity issues at closure are controversial. Some believe that pressure in the abandoned wells should be monitored during operation and closure. Some believe that you will get your abandoned wells signed off before operation begins therefore no more monitoring is required.
- Demonstrate that the CO_2 is not leaking through the cap rock

Data acquisition

- Use injection wells to monitor pressure falloff
  - There was discussion about handover and whether or not the well will be abandoned
- Sufficient monitoring during the closure period to ensure that the modelled plume behaviour in confirmed
- Simulation/monitoring to ensure storage complex is below “regulated” risk thresholds
- The risk assessment must be updated to establish the monitoring schedule and the duration of the closure period
  - This would initially use the monitoring data from the operation and will be updated with monitoring data from the closure period
- Risk reduction measures may be necessary if closure monitoring identifies risk exposure
  - This may mean additional wells or intervention to bring the risk back with in the accepted threshold

Data acquisition

- Risk reduction measures may be necessary if closure monitoring identifies risk exposure
  - This may mean additional wells or intervention to bring the risk back with in the accepted threshold

Conclusions

- Closure success is completely dependent on the operational phase
- You cannot recover in the closure period from failures to collect data in the operational period
- The more you inject and the longer you inject, the more reliant you are on a good model and good validation

Network Gaps

- Integration of modelling is not addressed in networks
- We could have designated modelling individuals embedded within the other networks
- There needs to be a better discussion of operational risk vs. long-term risk
- Well integrity network needs to better understand what will be required, if anything, during closure to validate well integrity
- Well integrity network need to address the uncertainty associated with well integrity
- Someone needs to look at the monitoring of abandoned wells
- Which network should look at the impacts of fracturing the caprock

Network Gaps continues

- What details are required to feed into the geochemical model
- We need far improved communication between all the networks
- The monitoring network needs to look more at closure monitoring and how to prove security before handover when the sensitivity of the tools decreases
- The risk assessment needs to establish criteria for the duration of the closure period
- The networks should get more specific on issues as we go forward and improve our knowledge
- The monitoring and risk assessment networks need to look more at history matching and what we mean by it and what we want from it

Breakout Session 3
Post Closure Group

- Define closure,
- Define post closure – at what point does activity move into this stage?
  - Plume stabilisation?
  - Reduced or diminished risks?
  - No further monitoring needed?
  - Transfer of liability to government body?
  - Occasional surface or USDW surveys needed, but no more?
  - 1Mt storage = minimal risks anyway!

Breakout Session 3
Post Closure Group

- Post closure probably area we know least about,
- Transfer of liability to governmental body, and fund for remediation / mitigation if required,
- When post closure phase is reached, models are in existence to cover monitoring requirements, plume migration and risk assessment, and these models will have been validated / moderated to some degree,
- Possible two time scenarios—short and long

Breakout Session 3
Post Closure Group

- Legacy monitoring – learn from models and monitor those areas identified as higher risk,
- Likely that all wells would be plugged at this point, with no access, making re-entry difficult and costly if needed,
- Possible that risk increases post closure if migrating plume begins to interact with more abandoned wells, but depending on classification of post closure phase, stabilisation = no further plume migration,

Breakout Session 3
Post Closure Group

- Different scenarios:
- Larger volumes of CO_2
  - Larger plume,
  - Increased leakage risk,
  - Associated with more wells,
  - Issues associated with scale,
  - Stability takes longer to occur,
  - Increased chance of future human activity (residential development etc. taking place in the vicinity,

Breakout Session 3
Post Closure Group

- Offshore storage:
  - Intervention is much harder,
  - Monitoring more difficult,
  - Species affected altered,
  - Migration / leakage may not be vertical – increased area for monitoring,
  - Access to wells more difficult – and more expensive,
  - Use of ROV to monitor sea bed (Sleipner experience),
  - Fewer wells,

Breakout Session 3
Post Closure Group

- Saline Aquifer storage:
  - Fewer wells,
  - Lack of structural trapping,
  - Less predictable lateral migration,
  - Aquifer flow leading to monitoring over wider area,
  - Increased timescale involved due to trapping mechanisms prolonging plume migration activity, necessitating monitoring during post closure or delay of post closure phase,
  - Higher risk of leak due to over-pressure of reservoir,

Breakout Session 3
Post Closure Group

- EOR Activity:
  - Potentially looking at an increased number of wells,
  - Little difference to post closure phase,
- Heavily populated area:
  - Regular water testing,
  - Basement monitors for CO_2,

Breakout Session 3
Post Closure Group

CO2CRC COOPERATIVE RESEARCH CENTRE FOR GREENHOUSE GAS TECHNOLOGIES

Reducing greenhouse gas emissions to the atmosphere

Otway Demonstration Quantitative Risk Assessment Case Study

Eris O'Brien - Risk Discipline Leader

Adapted from: Watson, M. 2007. Risk associated with the proposed Otway Basin Pilot Project (CO2CRC Otway Project): Quantitative risk assessment with newly acquired data and updated interpretation, CRC for Greenhouse Gas Technologies, Canberra. CO2CRC ID Number RPT07-787

IEA GHG R&D Programme Joint Networks Meeting
New York, USA
11th – 13th June 2008

CRC

Supporting participants: Australian Gov Departments | Australian National University | LBNL I ARC | CANSYD | Meiji University | The Process Group | University of Queensland | Newcastle University | USDoE

Established & supported under the Australian Government's Cooperative Research Centres Programme

CO2CRC Otway Project, Victoria

Description – Australia's only operational storage project, involving demonstration of geological storage of CO_2 and monitoring and verification of the behaviour of the stored CO_2.

Storage – Depleted gas field at 2000m depth

- ***Storage Commence*** – April 2, 2008
- ***Storage Rate* –** 100,000 tonnes total over 1-2 years (Stage 1)

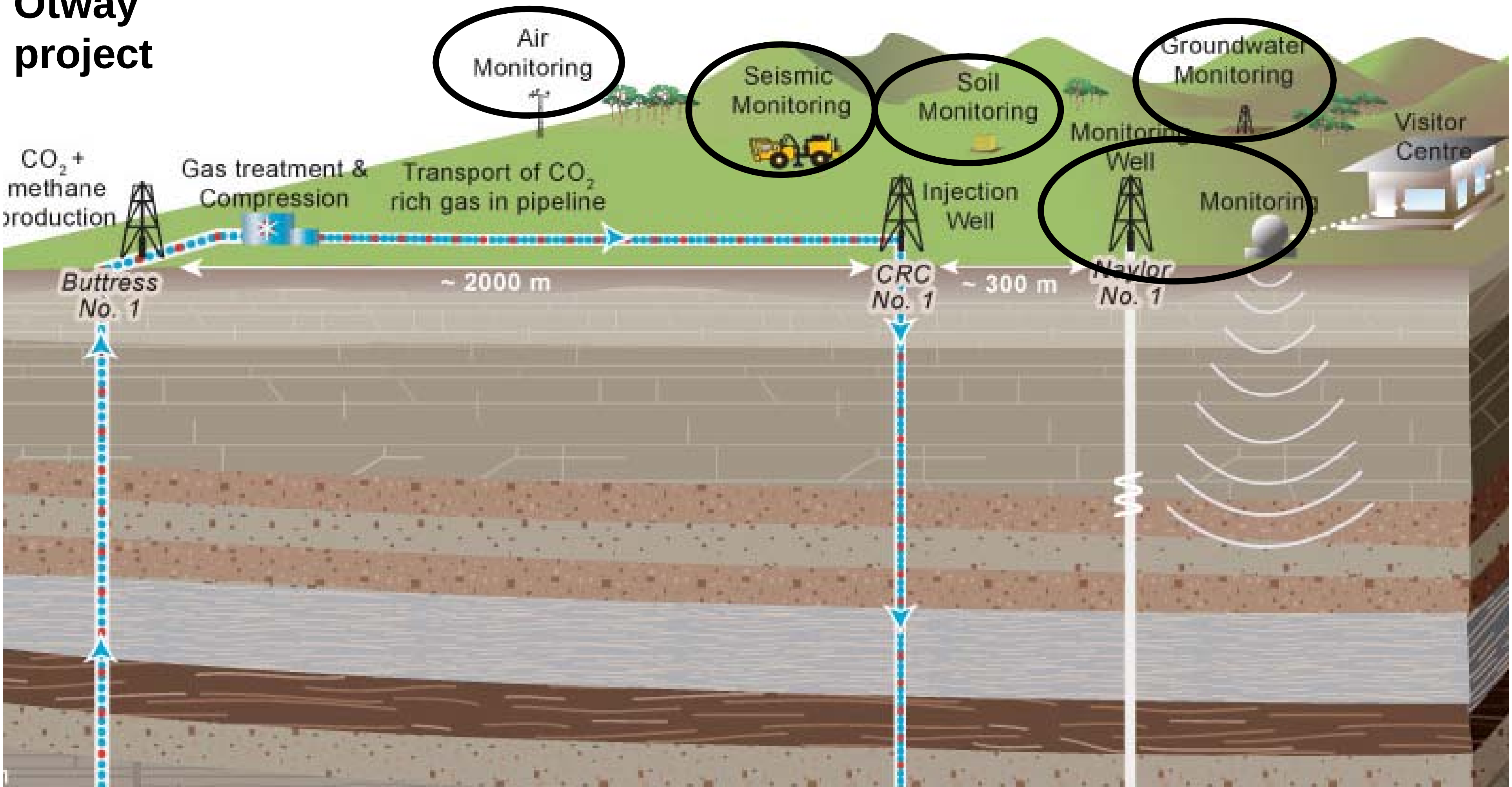
Cost – $A 40M plus

Partners – CO2CRC, Industry, Government and Researchers (Universities, CSIRO, GA, LBNL, ARC, GNS, KIGAM),

Participating countries Australia, New Zealand, USA, Korea, Canada

Operating Company

Monitoring and verification: key components of the Otway project



Otway QRA Risk Methodology

- URS's trademark RISQUE methodology in conjunction with CO2CRC expertise to come up with a quantified risk assessment.
- Risk process was a structured 2 day workshop (July 2007).
- An expert panel was used and regulators were in attendance for learnings, which aided project approvals.
- Expert panel considered the data gathered since the 2005 initial risk assessment and updated the risk assessment for the pilot project.
- Concentrated on containment in (and leakage from) intended storage site and not leakage into overlying formations or surface

CO2CRC Otway Project has provide important learnings on Regulatory issues

Onshore activities are regulated in Australia by the State authorities, but there is currently no CCS legislation in place. Therefore to enable the Otway Project to proceed, CO2CRC has worked with the Victorian State regulators, to meet statutory environmental, health and safety standards relevant to a CCS project, using existing legislation including:

- ***Petroleum legislation***
- ***Water legislation***
- ***RD&D provisions of the EPA***
- ***Planning scheme exemptions***
- ***Compulsory land acquisition***
- ***Health and safety***
- ***Biodiversity legislation (EPBC)***

RISQUE Method* Explained

*(Risk Identification and Strategy using Quantitative Evaluation)

- Quantitative: Risk = Probability x Cost (measured in some common currency)
- Use Expert Panel: eg. Geology, Geophysics, Geomechanics, Geochemistry, Simulations, Hydrogeology, RA Technology
- Panel identifies:
- risk events, their likelihood, and costs
- options, their costs and benefits
- Assess each potential alternative:
- Estimate risk quotient
- Estimate risk cost (reasonable cost due to risk event)
- Determine benefit – cost
- Use outputs to formulate strategy

*Described in book: Triple Line Risk Management

The Risk Register (1)

Permeable zones in seals	Risk of leakage through the pore space of the seals.
Faults through seals	Based on known faults in seals and fault types (compressive regime or opposite). 3-D seismic used to identify evidence of this.
Injection and monitoring wells	The primary source of leakage for sequestration projects – leakage up the casing of wells – may get above seals into other aquifers, or worst case may get to surface.
Regional scale over pressurisation	The potential reactivation of faults and fractures as a result of injection of CO2 and overpressurisation that could occur during injection.

The Risk Register (2)

Local scale over pressurisation	Development of near well bore fractures that would allow loss of CO_2 as a result of CO_2 injection.
Exceeding the spill point of the storage site	The risk that the identified structure has less capacity than thought and the spill point is exceeded.
Earthquake induced fractures	Earthquake causes fault apertures to open leading to short term high leakage rates and long term low leakage rates.
Incorrectly predicting the migration direction	The chance that the CO_2 plume moves in a direction other than predicted and leaks.

Results

At a planning confidence level of 80% it was seen that:

- **No single risk event exceeded acceptable risk quotient.**
- **Total risk events quotient less than acceptable target (1% leakage over 1000 years) (LOW RISK)**

Major risk events are:

- **Leakage from existing faults**
- **Leakage from wells – in particular damage to cement.**

Consequence Analysis

Final step – analyse the consequence of leakage from primary containment.

- Leakage into secondary containment would have negligible impact to human health, safety, the environment or to any natural resources in the area.
- Risk of leakage from secondary containment considered almost impossible*.
- Risk of leakage into freshwater aquifers or to surface considered almost impossible.
- Migration of heavy metals out of primary containment considered almost impossible.

* Almost impossible – 1 in 10^{-6}

Acknowledgements

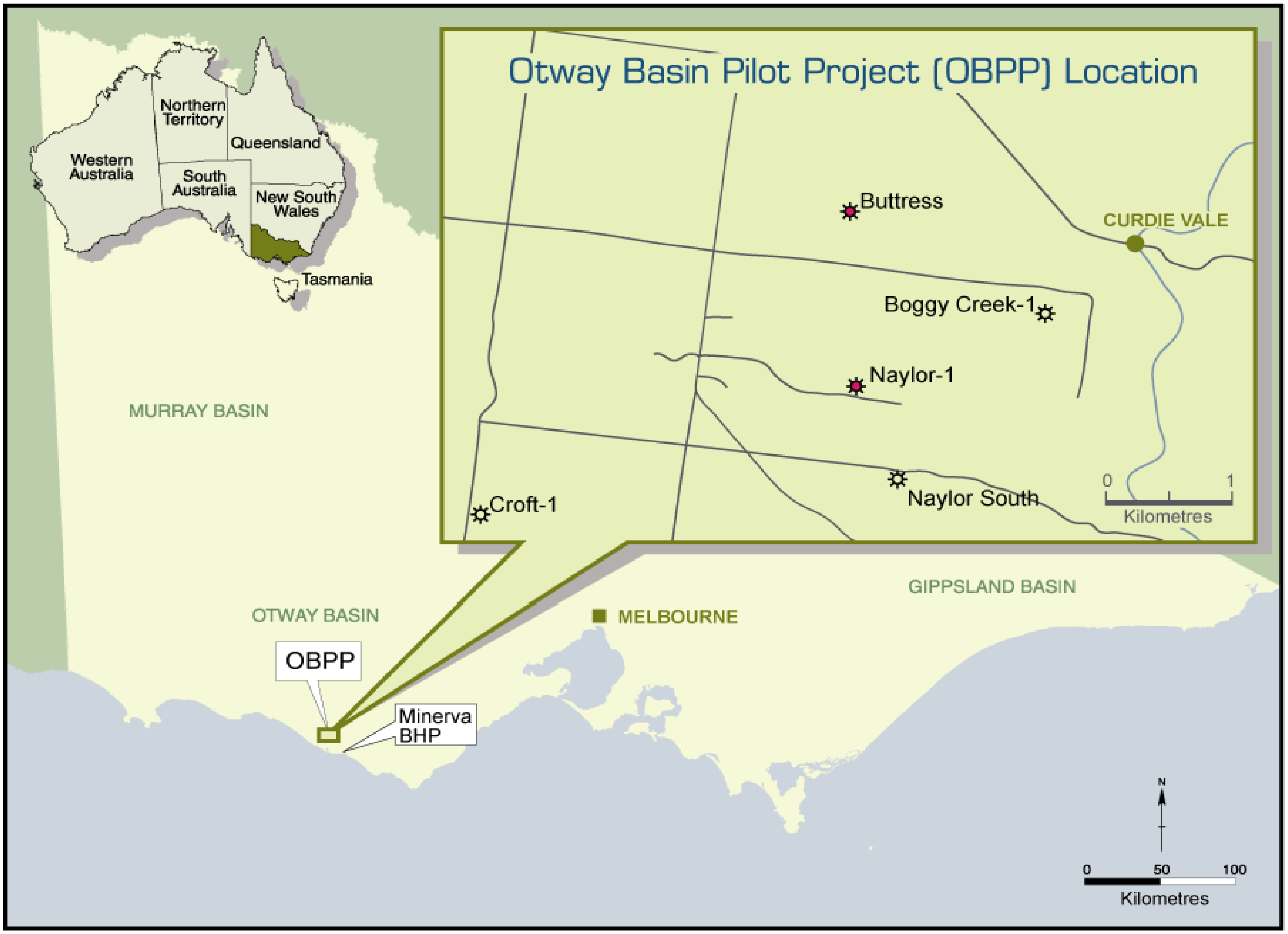
- **CO2CRC Study team – Max Watson, Andy Rigg, the Expert Panel & Adrian Bowden (URS)**
- **CO2CRC Sponsors and Research Collaborators:**

Context

Otway Basin Pilot Project

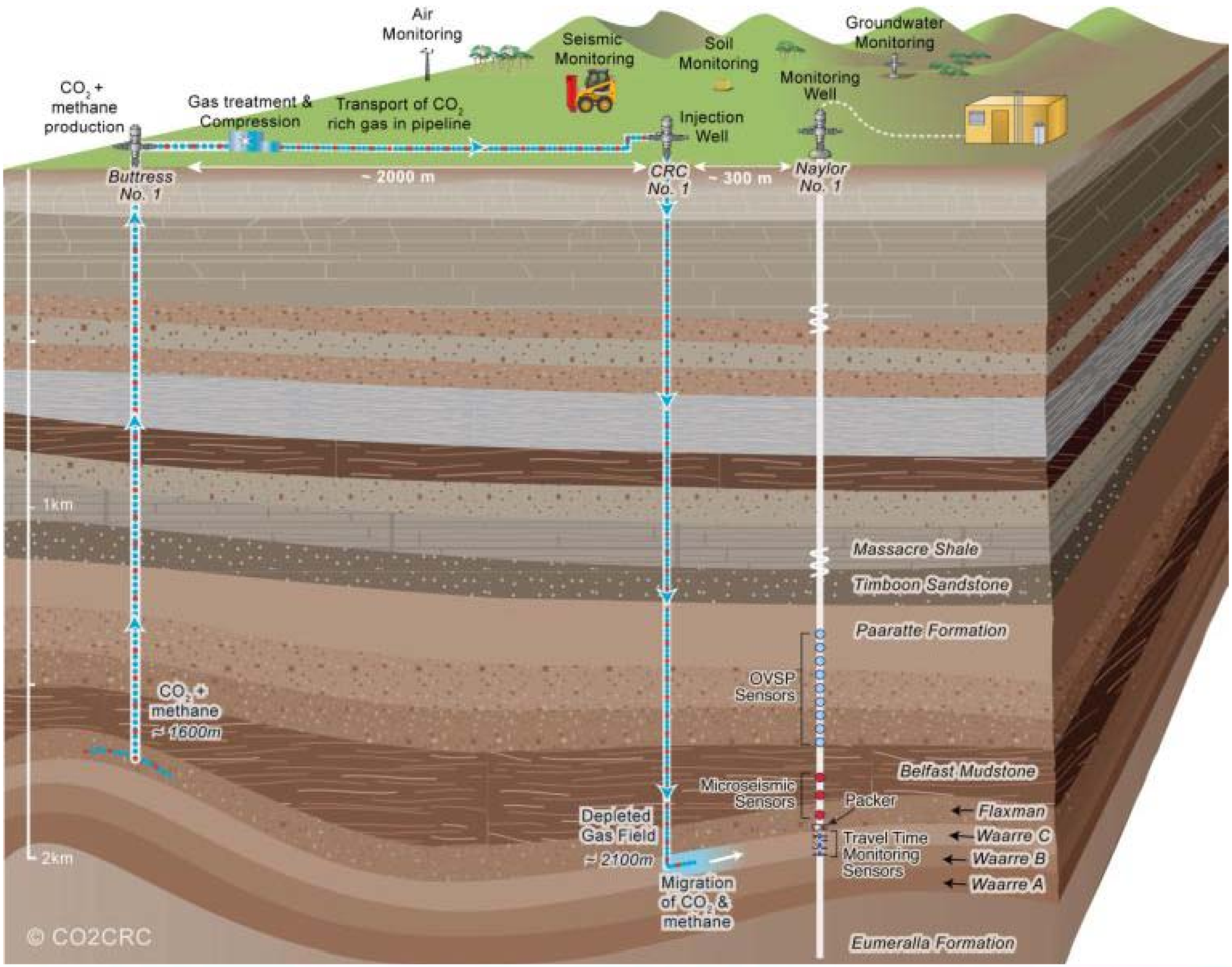
- **CO_2 sourced from a nearby CO_2-rich gas field (Buttress) and transported via pipeline to the injection site (CRC-1) located to the east of and downdip from a depleted gas field (Naylor) in the Port Campbell region of the onshore Otway Basin.**
- **The injection volume is fixed at 3 MMscf/d for a period of 2 years for a total of 100,000t stored.**
- **The single well used as the injector is the CRC-1 well, located ~300m from the crest of the structure. The existing Naylor-1 well is the monitoring well. Both wells to be in contact with the CO_2 plume throughout the 'risked' 1000 year period.**

CO2CRC



Otway Basin Pilot Project (OBPP) Location
Buttress
CURDIE VALE
Boggy Creek-1
Naylor-1
Naylor South
Croft-1
0
1
Kilometres
Northern Territory
Queensland
Western Australia
South Australia
New South Wales
Tasmania
MURRAY BASIN
OTWAY BASIN
MELBOURNE
GIPPSLAND BASIN
OBPP
Minerva BHP
N
0
50
100
Kilometres

CO2CRC


Air Monitoring
Seismic Monitoring
Soil Monitoring
Groundwater Monitoring
CO_2 + methane production
Gas treatment & Compression
Transport of CO_2 rich gas in pipeline
Injection Well
Monitoring Well
Buttress No. 1
~ 2000 m
CRC No. 1
~ 300 m
Naylor No. 1
1km
2km
Massacre Shale
Timboon Sandstone
Paaratte Formation
OVSP Sensors
CO_2 + methane ~ 1600m
Belfast Mudstone
Microseismic Sensors
Packer
Flaxman
Depleted Gas Field ~ 2100m
Travel Time Monitoring Sensors
Waarre C
Waarre B
Waarre A
Migration of CO_2 & methane
Eumeralla Formation
© CO2CRC

CO2CRC

Breakout Session 4
The Future

- Next meeting to be held in May 2009 in Calgary, hosted by Stefan Bachu, ERCB,
- Suggestion to look at differing formats – less presentations, more discussion?

Breakout Session 4
The Future

- New regulatory data to be released “soon”, look towards this being presented,
  - Next meeting to include review of changes in regulatory systems in different areas / states / countries,
- Get greater input from regulators
- Develop an IEA GHG-style report on the state-of-the-art

Breakout Session 4
The Future

- Abandonment practices?
- What kind of demonstration of well performance is necessary?
- Inclusion of class 1 well operators in meeting – different experience? Suggestions?
- Take questions from Monitoring and RA,
- DNV presentations
  - API on SCP risk,
  - Sub sea well-head penetration risk and benefit,
  - StatoilHydro commissioned study by DNV of CO_2 leakage in geological storage,

Breakout Session 4
The Future

- Salt Creek EOR field experience - Anadarko
- CCP2 on 3rd well autopsy work,
- What is the range/type of wells which should be studied in detail?
- Inclusion of numerical studies of well leakage: Oxand, Wertz (2008) and Schlumberger,
- Steel performance; abandonment, milling,
- Use of chemical sealant to stop formation leaks of CO_2

Breakout Session 4
The Future

- Performance of barite as a seal,
- Numerical model of well kill,
- History match well performance,
- Geomechanical model of well history:
  - Weyburn,
  - Size of interfaces that can be sustained,
- StatoilHydro to talk about Snøvhit, including well design?
- Steel pipe and cement liners – corrosion in transport pipes,
- Impact of impurities in gas stream and well integrity,
  - AEP mountaineer experiences,

Breakout Session 4
The Future

- Transportation of CO_2 and impurities, presentation:
  - KinderMorgan?
- Input for RA network – details of well logs from Nagoaka project before and after earthquake events showing continual well integrity,
- Input from Monitoring on monitoring methods and requirements?

Breakout Session 4
Risk Assessment Network

- Review of aims/objectives on brochure
- Some changes proposed for wording of aims
- Consensus that network has been working towards achieving aims
- Focus on identifying technical and network gaps

Technical Gaps

- Identification of regulators for project
- Leakage through wellbore – statistics, classification, causes
- Impacts of leakage in shallow marine environments and potable aquifers
- Quantification of impacts
- Modelling: for RA needs versus front end process modelling
- Application of process models for RA needs

Technical gaps (2)

- Benchmarking of existing projects
- Incorporation of M&V into RA process (+vice versa)
- Linkage of public confidence to RA
- Engagement of insurers, regulators and NGO's
- Risk screening for site selection
- Risks associated with co-contaminants

Ranking

- Above technical gaps not ranked – but should be!

Network Gaps

- Risk and monitoring networks: not sufficiently integrated
- Possible solutions include communication (meetings, newsletter, webcast etc)
- Lack of info to identify other groups/individuals in this field
- Communication with new IEA regulator network

6

Monitoring Wrap-up

- What the attendees get from network
- What we saw as important
- Role of network in information exchange
- Planning of meeting
- Interplay of networks/ joint meetings and hence goals...where should we be in 3 yrs
- Reservoir characterization ?

What people get from the meeting

- The current brochures don't necessarily reflect what has happened in the network yet
- There are other people who do not attend the networks who would be interested in getting the information
- The size of the meetings is good and lends itself to discussion
- The discussion is the most valuable part of the meetings

Like to see - 1

- Include a review session at the START of each meeting (global view)
- A cross-network registration and email invitation list
- Need better links to regional work (RCSP)
- Better information could be provided before the network so the meetings hit the ground running
- Issue focused or specific goal focused meetings with key issues to be addressed rather than more general presentations
  - Eg. Ground water protection, emissions credits
- Training type sessions associated with network meetings (tutorials)
- Field data supported activities
- Review communications
  - Currently web-based
- Review Projects

Like to see - 2

- Linkages with projects that have budget to explore the issues we discuss (CCP3)
  - Network cant fund but could facilitate or support the “platform” of technology
- The Network contribute to ongoing “transfer of knowledge” to regulators
  - “Clue-in” tutorial process in the UK
- Cherry-picking the most interesting parts of projects
- More modellers need to be attracted to the network process

Other points

- We are not an exclusive club, we can invite expertise in from outside the network
- Do not abandon the technical nature of the meetings
- There is mixed opinion about the open inclusion of regulators into the network
  - Planned integration of regulators in meetings
  - Regulators need to be informed by the network but the method is unclear (possible webinars for regulators once a year)
- Does the reporting of the networks stop a lot of people from sharing their information about projects
- How do you get the network to help scope the meetings
- The networks are best scoped by the questions they are trying to answer
- Workflow type interaction in flow of data between areas? (Networks?)
- “Inform” industry or be “informed by” industry?

Network integration

- The chairs of the networks could discuss their upcoming programmes
- Maybe an annual joint network webcast in additions to the specific networks
- More joint network meetings (3 years?)
  - Where would we want to be by then
- More web based meetings
- The monitoring network will always focus on tools unless there is integration of risk
  - Risk has to be a formal part of the monitoring agenda
  - Risk assessment was discussed at the end of the monitoring network in Edmonton
- Representatives from one network representing at others
- How long to monitor for is a risk/monitoring issue

Network integration

- Which network does site characterization fit in the networks?
  - Does it warrant a network or focus in current networks?
  - Is site characterization just the front end of performance/risk assessment?

Topics to address

- Monitoring for fault activation, pore pressure
  - Issues surrounding CO_2 moving through a fault (how, why, when)
- Dissolved CO_2 in-situ
- How to plan a monitoring programme
  - The process of identifying the things to do with monitoring
  - Should involved people from the Risk Assessment network
- Innovative emerging monitoring technologies
- How modelling fits into monitoring

Japan – 2009

- Key issues to address
  - Time for cross-network discussion and timing (closure, post closure, etc)
    - Risk
    - What does risk assessment really need to know from monitoring and can monitoring provide it? (thresholds, triggers, etc)
  - Emphasis on projects
    - Planning
    - Systems approach
  - Innovative/emerging technologies
    - Sensitivities, application
  - Monitoring for DETAILED processes in geological container (faults, fault reactivation, etc)
  - How are modelling and monitoring linked/integrated

Monitoring network in 3 years

- More learning from projects more projects
  - RCSP will have 20 small scale injections underway/complete
  - Ketsin, Otway, Snhovit, Lacq, Weyburn+3, In Salah+3, Sleipner+3
  - Better understanding of what regulators (globally) have asked of monitoring programmes
  - Review of tools, what has been applied, what has worked or not, what was applicable
- Quantitative discussion on performance limits for monitoring
- How to plan a monitoring programme based on risk assessment
- Improved understanding of how risk/performance assessment processes guide development of a monitoring programme

Monitoring network in 3 years

- Improved understanding how best to integrate modelling and monitoring to demonstrate CCS performance

A Systems Approach to Monitoring

1. What/why
   - Goal – project performance, environment (groundwater, ecosystems, etc)
   - Tools
   - Timeframes
2. Spatial distributions/frequency
   - Based on site characterisation & data needs
     - How do we get a useful data set
3. Thresholds/Detection limits
   - Informed by Risk Assessment and/or Regulation
   - Do tools have capabilities
4. Actions taken when
   - What do we do?
   - What are the tools?

IEA Greenhouse Gas R&D Programme

1st Joint Network Meeting

Co-organisers and sponsors: EPA
Sponsors: EPRI and OXAND

New York – 11-13 June 2008

Joint Network Meeting

Aims

- Review networks
- Enhance links between networks
- Identify any gaps, and duplication
- Consider role of modelling in networks
- Leverage cross-network expertise
- Refine future focus and priorities of networks

Gaps

- Well monitoring
- Monitoring for other substances
- Quantification of CO_2 - leakage and stored
- Risk assessment scaling up from few wells to 1,000s
- Need more learning from projects, shared learning to other projects (need more projects)
- Monitoring for other stakeholders than regulators
- Monitoring for leakage to well intermediate zones
- Risk Network to interface with Insurance industry
- Closer involvement with regulators – and with those who advise regulators
- Include costs
- ....and others
- Little duplication, other than terminology

How to address these and by which group ?

Session 4.
Network Summary and Future work

- Breakouts by Network. Same chairs and rooms.
- To discuss and agree future focus, priorities, activities.
- Presentations back.

- 11:00 Presentations
- 12:30 Lunch
- 13:30 Session 5. Conclusions and next steps
- 15:30 End

Breakout Groups

- For the three Network Specific Breakout groups the chairs and IEA GHG staff representatives will be as follows:
  - **Wellbore Integrity** – Bill Carey (Chair), Craig Gardner (co-chair), Toby Aiken (IEA GHG Staff)
  - **Risk Assessment** – John Kaldi (Chair), Claudia Vivalda (co-chair), Neil Wildgust (IEA GHG Staff)
  - **Monitoring** – Kevin Dodds (Chair), Rick Chalaturnyk (co-chair), Brendan Beck (IEA GHG Staff)

Session 5: Joint Network Meeting

Aims

- Review networks
- Enhance links between networks
- Identify any gaps, and duplication
- Consider role of modelling in networks
- Leverage cross-network expertise
- Refine future focus and priorities of networks

R&D Networks

- Bring together international key groups of experts to share knowledge and experience
- Identify and address knowledge gaps
- Act as informed bodies, eg for regulators
- CO_2 geological storage – assessing and managing risks
- Started in 2004/5
  - Monitoring Research Network
  - Risk Assessment Research Network
  - Wellbore Integrity Research Network

- Benefit experts and wider stakeholders
- but - depend on experts' time and inputs – valuable and widely appreciated

Networks – future focus and priorities

- Good exercise, useful, for forward thinking
- Key points for IEAGHG and Networks to act on
- Good that they're thinking of other Networks, modelling etc
- Steering coms to prioritise identified gaps for agendas for next meetings
- Interfaces are key (intra and inter-network)

Role of modelling in networks

- Need for Modelling 'activity', ie 'prediction of CO_2 fate and effects'
- IEAGHG will reflect on the discussions
  - Initial meeting (2008/9?) and study
  - Focus on reservoir and cap-rock, other applications can be covered in networks
  - Review of modelling tools
  - Inherent and close links into other networks
  - Source of advice to .... Regulators, others
  - Scope out study

Future Network Options

Create new networks ?

- Need for additional Modelling ‘activity’
- CO_2 infrastructure safety/risk – IEAGHG Study - reflect after study
- Site characterisation – single meeting ? To scope out. IEAGHG DNV study to input on this. Use networks to peer review DNV.

Cross-network working groups –

- Linked meetings – overlap two network meetings by a common day

Future Network Options - cont

Future Joint Network Meetings ?

- Feedback on this meeting
- JN every three years ?

Future Network Options - cont

Proposals:-

- Annual co-ordination of steering committees . Information sharing. Set questions/objectives for each others meeting
- Network orientated report from each network meeting on 'Learning points' for other networks
- Coordinate closer with those network members who interface with regulators – identify and anticipate key issues for networks to address
- 'Expert judgements' - Networks to support/include experts being used by regulators
- Networks to input to IEA CCS Regulators Network

http://www.iea.org/Textbase/subjectqueries/ccs_network.asp

Future Network Options - cont

IEAGHG will

- Pick up the actions mentioned
- Reflect and act on modelling discussions
- Summary report from this JN meeting summarising ideas and future plans, and ppts onto web site
- Revise Network brochures – comments by 4 July to Toby
- Coordinate steering committees
- Combine storage networks mailings

Future Network Meetings

- Risk – Melbourne, 16-17 Apr 2009
- Monitoring – Tokyo, May-June 2009 tbc
- Wellbore – Calgary, May 2009 date tbc

Nicholas Stern says:

- *"We badly underestimated the degree of damages and the risks of climate change ……we need to get better at carbon capture and sequestration very quickly"*

From the Independent 17 April 2008

THANK YOU !

Sponsors

- EPA, with EPRI and OXAND
- Chairs and co-chairs
- Organising committee
- Everyone – we can't do anything without you !

IEA Greenhouse Gas R&D Programme

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