CO₂ Storage: Approaches to risk assessment and methodologies

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Quintessa
An Employee-Owned Scientific and Mathematical Consultancy
Geological Storage Options

- Different kinds of sites
- Different kinds of storage options

1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil recovery
3. Deep unused saline water-saturated reservoir rocks
4. Deep unmineable coal seams
5. Use of CO₂ in enhanced coal bed methane recovery
6. Other suggested options (e.g. basalts, oil shales, cavities)

After Cook (1999), as reproduced in IPCC Special Report on CCS (2005)
Site / project dependency of risks

- Different balance of processes influence risks in different sites / projects:
  - different balance of physical processes (rock properties, driving forces etc)
  - different balance of chemical processes (salinity, temperature, rock reactivity)

- Non-technical site / project – specific factors also influence

- Risk assessment needs to be matched to a site / project

- Can define general principles / steps

- Cannot be too prescriptive

Examples of processes to be considered
What is Risk?

‘The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment’

Risk = Probability* x Consequence

- Sometimes cannot estimate from prior knowledge
- Expert judgment needed (subjective)

- Subjective:
  - consequences of interest
  - mapping to numerical scale

- Context-dependent

Risk is not uncertainty

*Of some phenomenon, e.g. well seal failure, earthquake etc
Risk Perception

- Increasing recognition of complexity
- Increasing recognition of uncertainties
- People tend to mistake increased recognition of uncertainties for increased risk
- But risks don’t actually increase!

Solution
- recognize from start that there will be ‘unknown unknowns’
- communicate information & understanding openly, transparently
Estimating Probabilities

Risk = Probability x Consequence

Measure / observe some phenomena:
- e.g. examine lots of well seals

Determine probability distribution

Estimate future probability

Schematic:
- Likely low probability
- Older wells less well sealed
- Older wells maybe shallower

- In natural systems, often cannot measure probability distribution because
  - phenomenon very infrequent (e.g. often fault reactivation)
  - impossible / undesirable to obtain data (e.g. need to drill lots of boreholes to determine rock variability fully)
- In these cases cannot estimate future probability by numerical calculation
- Use scenario approach to explore “what if” situations
Estimating Consequences

Risk = Probability \times Consequence

• If probability of adverse event (scenario) sufficiently low, consequences may be of little concern, but
  – probability often needs to be expressed qualitatively
  – need discussion with stakeholders about what probability is acceptable
  – may need to take steps to reduce probability (e.g. planning etc)

• When probabilities cannot be estimated reliably:
  – develop hypothetical ‘what if’ scenarios for extreme events
  – model consequences
  – discuss implications of consequences with stakeholders
  – if agree consequences acceptable, then risk acceptable
  – if no agreement, take steps to reduce consequences (e.g. planning etc)
Steps in Risk Assessment

- Several slightly different approaches (e.g. DNV / CO2Qualstore, EC Directive, ISO31000)
- General themes / steps can be identified:

1. Frame the problem – context definition
2. Acquire information / data
3. Identify potential hazards
4. Identify potential receptors / sensitive domains (who / what would be affected if CO₂ leaked)
5. Assess possible impacts

- Iterations matched to milestones in project lifecycle (e.g. initially, pre-closure, pre-transfer of responsibility etc)
- But, must not be too prescriptive (allow for additional cycles)
Information to Judge Risks

Varied information needs to be considered

- **Field data, e.g.**
  - Seismic
  - Formation water analyses

- **Modelling, e.g.**
  - Short term detailed models (reservoir, geochemistry)
  - Long term performance assessment models

- **Expert judgment / reasoning, e.g.**
  - Likelihood of undesirable events
  - Likelihood of undetected features
  - Economic viability

- **Value judgments of stakeholders, e.g.**
  - ‘Not in my back yard’
  - ‘You haven’t demonstrated that it’s safe’
  - …
Tools for Risk Assessment: Models

- Wide variety of models used – helps quantify uncertainty
- Use to complement one another
- Match applications to needs of a particular:
  - site
  - project
  - stage in lifecycle

More processes, more coupling

e.g. system models

e.g. reservoir simulators

Finer discretization
Tools for Risk Assessment: Audit & Decision Making

- Databases of important issues (Features, Events, Processes)
  - audit tool
  - support discussion

- Decision-support / integration tools
  - provide audit trail
  - identify important issues
  - demonstrate relevant issues have been judged
Example: In Salah

Diagram showing the geological and production setup in In Salah, Algeria, with a focus on amine CO₂ removal. The diagram illustrates the Cretaceous sandstones/mudstones and Carboniferous mudstones layers with 5 gas wells and 3 CO₂ injectors.
Framing discussions at expert workshops
Identify issues (Features, Events, Processes) at expert workshops
Site data and reservoir models are key inputs; supplemented by systems modelling
Integration of outcomes using a decision support tool

Agree Performance Assessment Aims

Identify Aspects of the System and its Evolution that Need to be Understood to Assess Risks

Collate Information Required to Assess the Risks (Site Data, Predictive Modelling etc)

Undertake Assessment of Risks (Simple Qualitative Estimates and/or System Impacts Modelling)

Iterate if Required

Approach taken in CO2ReMoVe Project

Scenario Development: Example In Salah

After Paulley et al. 2010: GHGT10 Proceedings
**In Salah: Expected Evolution Scenario**

| CO₂ injection:    | • operations will be in line with current site operator plans;  
|                   | • will achieve a defined temperature and pressure. |
| CO₂ transport:    | • lateral extent of the CO₂ will remain within the lateral extent of the caprock;  
|                   | • 2-phase transport within storage system plus CO₂ migration into/within faults and fractures;  
|                   | • transport in faults and fractures will enhance CO₂ dissolution and diffusion into rock matrix. |
| Caprock:          | • will be tight against vertical transport, with permeability as currently estimated;  
|                   | • will behave in the same manner as for the methane reservoir;  
|                   | • will provide a measure of secondary containment following diffusion. |
| Well seals:       | • will behave ‘as designed’;  
|                   | • older wells will be re-sealed if necessary such that performance is as for ‘new’ wells;  
|                   | • will degrade, but slowly over the long term. |
| Monitoring:       | • well seals will be monitored in line with regulations, and remediated if seepage occurs;  
|                   | • monitoring of the primary and secondary geological containment systems will continue. |
| The biosphere:    | • will be as currently observed and will not evolve significantly. |

After Paulley et al. 2010: GHGT10 Proceedings
In Salah: Alternative (Unlikely) Evolution Scenarios

- **Well seal failure**
  - absence of legacy well seals, poor quality future well seals etc

- **Operational changes**
  - improvements to design/operation, *overfilling*

- **Seismic effects**
  - to show unlikely that seismic activity will disrupt the system

- **Changes to local human habits**
  - including water abstraction from shallow aquifers
Explore Consequences of Alternative (Unlikely) Evolution Scenarios – Example In Salah

- Effects of hypothetical injection for c. 10 x planned period
- Even this extreme case causes little CO₂ loss from reservoir
- Shows large safety margin for present operations
- Robust against uncertainty

Very Low Risk = Low Probability (expert judgment) x Low Impact (very small CO₂ quantities calculated to leave the reservoir even in extreme cases)

CO₂ saturation in the lower reservoir (logarithmic scale) at 200 years (left) and 1000 years (right) for the overfilling case (AES3).
Impact Simulations

- Sophisticated biosphere / impact models possible
- Models need further development, but rapid progress already
- Natural CO₂ seeps provide insights into seepage processes
- Can be used to develop / test impact models

Example: Latera, Italy

Observations

Peak CO₂ flux c. 3000 g/m²/day
After Beaubien et al. (2008), IJGCC

Modelled Impacts

Change in Modelled Biomass (%)

- Grass
- Clover

Distance From Centre of Seep (m)

After Maul et al. (2009), DECC Report R318
• Confidence-building is key
• Need to understand uncertainties – identify / address those that are significant
• Need structured framework for conversation among experts / stakeholders
• Balancing multiple kinds of evidence for and against multiple hypotheses
• Here illustrate approach using decision trees (example developed in CO2ReMoVe)
Conclusions

• Risk assessment not just numerical calculations, also
  − use qualitative and quantitative information
  − multiple lines of reasoning (never rely on one model)
  − expert judgments always important

• Risk-influencing processes are amendable to modelling

• Modelling as much to improve understanding as for prediction

• Risk and uncertainty are not the same thing

• Presenting risk judgments requires
  − clarity and traceability
  − honesty about uncertainties

• Site- and project- specific factors influence how a risk assessment
  will be done – general principles, not details can be defined

• Carry out risk assessments iteratively, link to project lifecycle