Optimizing Deep Subsurface Monitoring Methods: Principles

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GCCC Experience Base

- Frio I and II saline tests 2004-2009
- SWP monitoring of long running SACROC CO_2 EOR
- SECARB monitoring Cranfield saline and CO_2 EOR
- * Monitoring design for Air Products CO_2 to Hastings Field for EOR
- * Monitoring design for NRG-Petra-Nova CO_2 to West Ranch Field for EOR
- Reviewing for numerous projects
- ISO standards Working Group 6, IEAGHG network etc.

* Some elements confidential

Major points

- Matching monitoring to risk via forward modeling - variant using an ALPMI* process

Assessment of Low Probability Material Impact (ALPMI)

  - Part 1: Describing *material impact** quantitatively
  - Part 2: Sensitivity of monitoring strategy to *material impact**
  - Examples of optimizing leakage detection
- Implications of matching monitoring to risks: site specific parameters
  - CO_2 EOR not same risk profile as saline
  - CO_2-EOR specific risks and monitoring approaches
- If time, attaining confidence prior to closure

* Defined next slides

ALPMI part 1: Quantify possible unacceptable outcomes “Material Impacts”

- Increase recognition of project success and lower cost of monitoring by describing material impact in quantitative terms
  - “Material impact” specifies what is considered “failure” or “unacceptable” to key stakeholders
  - Replace generalities such as “safe” “effective”
  - Specify magnitude, frequency or duration and probability of material impact.

Material impact examples (random)

- Loss of CO_2 at a rate greater than 10,000 tones per year for a period of more than 10 years @ 80% confidence
- >5% probability of earthquake > magnitude 4 within 100 years
- Pressure trend that will exceed calculation mechanical stability prior to project completion
- Plume migration such that location of saturation of >5% pore volume CO_2 at stabilization is within a footprint (shown on a map)

Note: I recommend that rules call for such definitions but is premature to specify them apriori

Notes about material impact

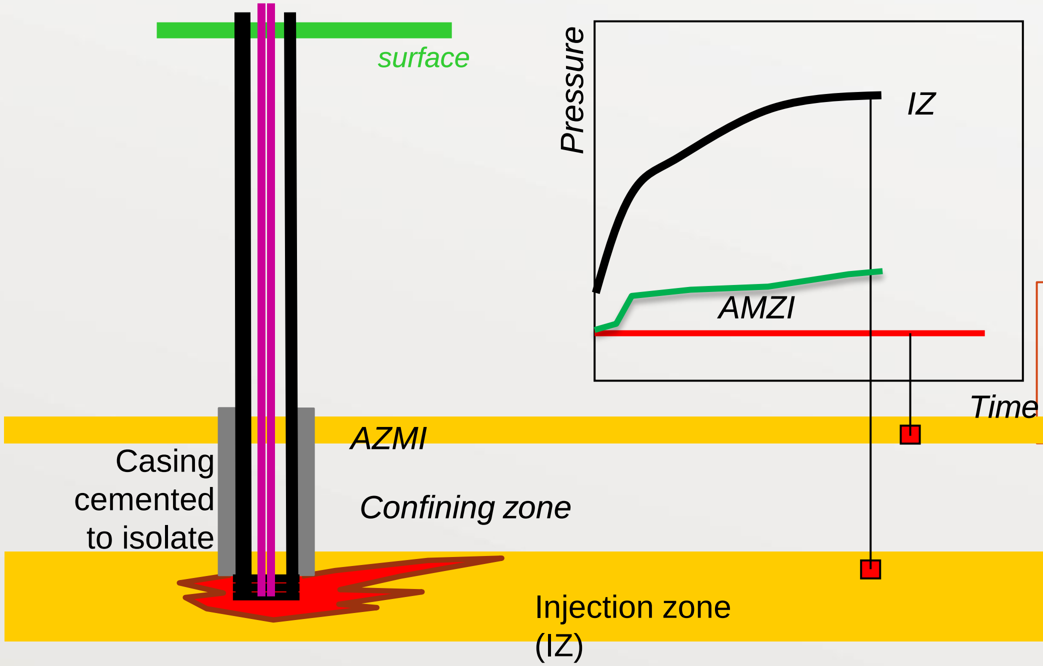
- “Low probability” occurrences: events with frequency of occurrence so low that statistical approaches are ineffective
  - Small experience with CCS and relatively high intrinsic safety of subsurface and limit a probability × severity approach.
  - Do not expend energy on calculating risk – if material because of stakeholder concern, jump to mitigation via monitoring
- Avoid calculations as percent stored
  - Create perverse outcome of higher performance standard for small injection volumes

ALPMI part 2: Assess sensitivity of monitoring strategy to material impact

- Essential to forward model impact
  1. Create material impact scenarios

     e.g. for CO_2 leakage or change in pore pressure that would increase seismic risk
  2. Evaluate sensitivity of instruments, spacing, frequency of data collection, other statistical measures against scenarios.

Example of optimizing leakage detection: above zone monitoring for leakage detection



Above-Zone pressure monitoring – Assume leakage

Above-Zone pressure monitoring – no leakage

Simple model of leakage response: Input parameters

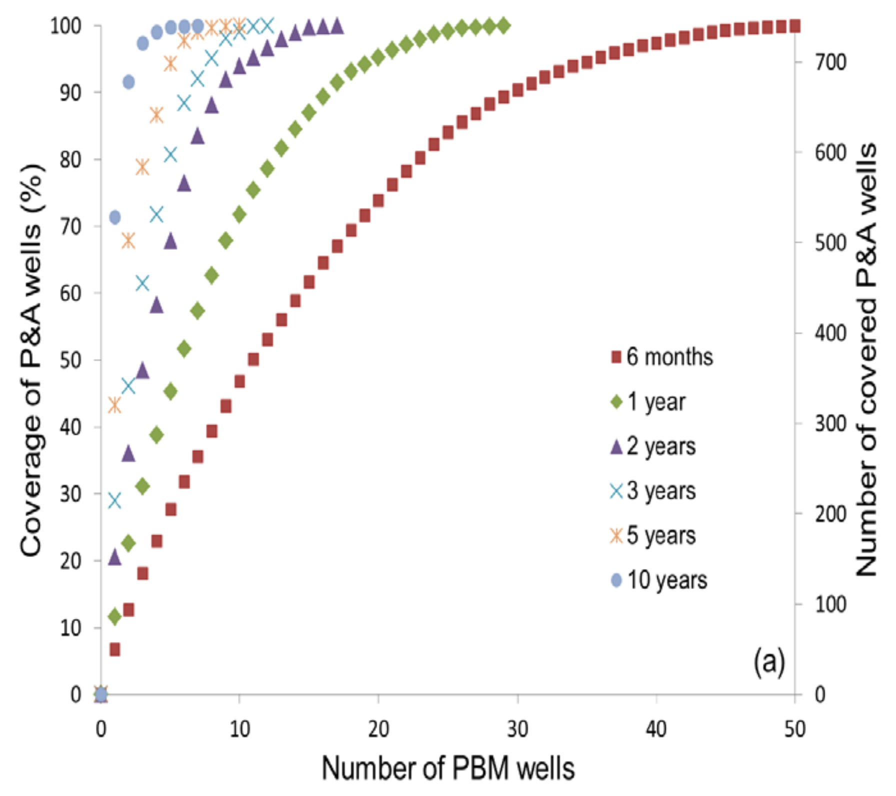
Pressure-based Model Parameter	Value	Unit
Permeability	9.87e-13	(m^2)
Porosity of monitoring reservoir	0.25	-
Leakage rate at reservoir condition	0.0001	(m^3/s)
Total compressibility	1E-9	(Pa^{-1})
Temperature	47.78	°C
Pressure	9,652,660	(Pa)
Thickness of monitoring reservoir	25	(m)
Monitoring detection time	365	(day)
Radius of leaky well	0.05	(m)
Viscosity	0.000578	(Pa.s)
CO$_2$ viscosity	0.0000302	(Pa.s)
CO$_2$ density	401	(kg/m^3)
Pressure gauge detection threshold	10000	(Pa)

Geochemical-based Model Parameter	Value	Unit
Dispersion coefficient	400	dm
Hydraulic gradient	0.05	-
Cpi1 (CO$_2$ initial concentration)	0.71552e-3	mol/day
Cpi2 (H$^+$ initial concentration)	0.61843e-7	mol/day
Cpi3 (HCOE$^-$ initial concentration)	0.47522e-2	mol/day
Cpi4 (CO3^{-2} initial concentration)	0.30728e-5	mol/day
Cpi5 (OH$^-$ initial concentration)	0.15091e-6	mol/day
Cpi6 (Ca^{+2} initial concentration)	0.77923e-3	mol/day
Leakage detection limit	10*cpi	mol/day

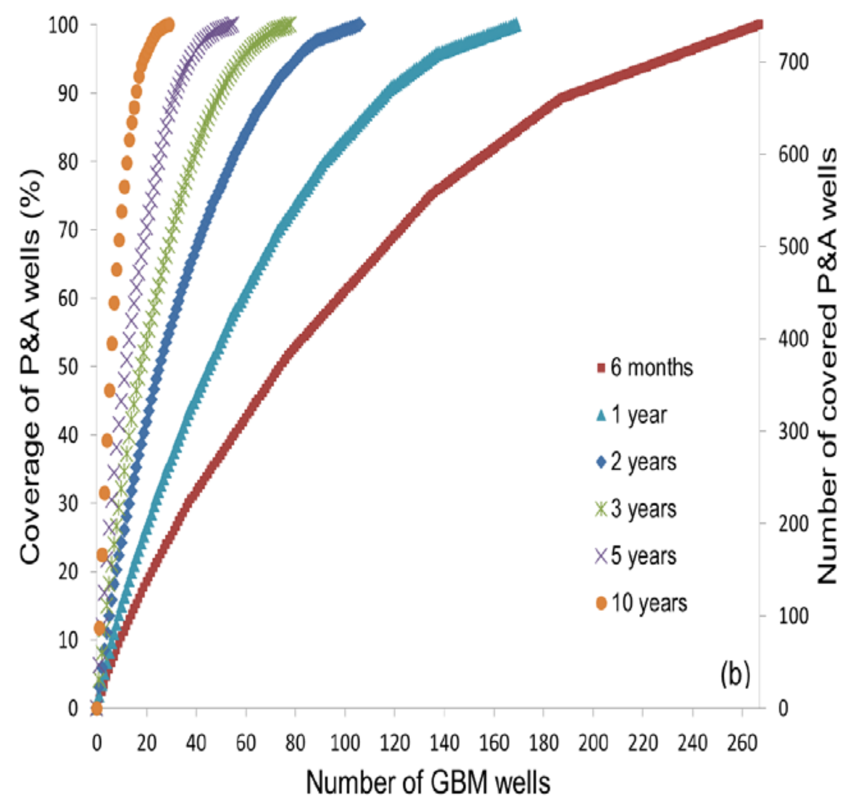
Behni Bollhassani, UT MS thesis

Sensitivity analysis for leakage detection time in models

Detecting pressure signal



Detecting geochemical signal



Behni Bollhassani, UT MS thesis

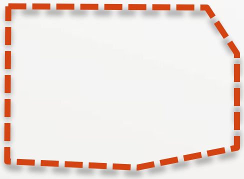
Example of APMI approach to plume migration

Predicted plume footprint year 5 of >5% CO_2 saturation in zone

Measured plume s footprint year 5 of >5% CO_2 saturation in zone

Match to model OK or not OK?

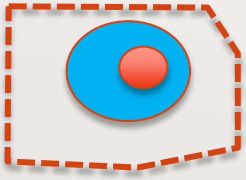
Example of APMI approach to plume migration



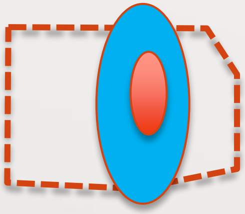
1) Stakeholder – defined boundary between acceptable and unacceptable extent of >5% saturation plume at stabilization

2) Modeled plume evolution by ALPMI process

● 5 year plume ● Stabilized plume

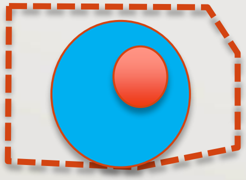


Planned

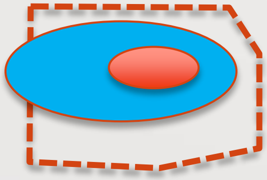


N-S preferred flow

Match to model shows not OK



Faster than expected migration



E-W preferred flow ← 5yr

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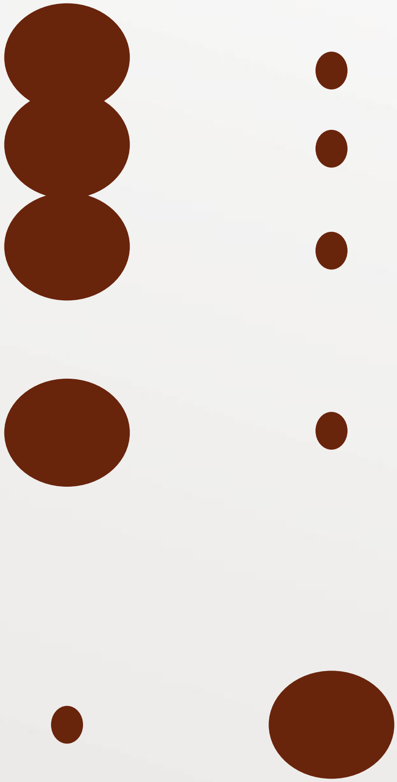
Implications of matching monitoring to risks: site specific parameters

- Widely accepted principle: mitigate risk by monitoring for trend toward material impact
- Corollary: Major differences between monitoring and CO_2 EOR because of different initial risk profiles
- Perfect monitoring for saline storage will be ineffective for CO_2 EOR

Comparing *generalized* risk at saline and CO_2 EOR storage sites



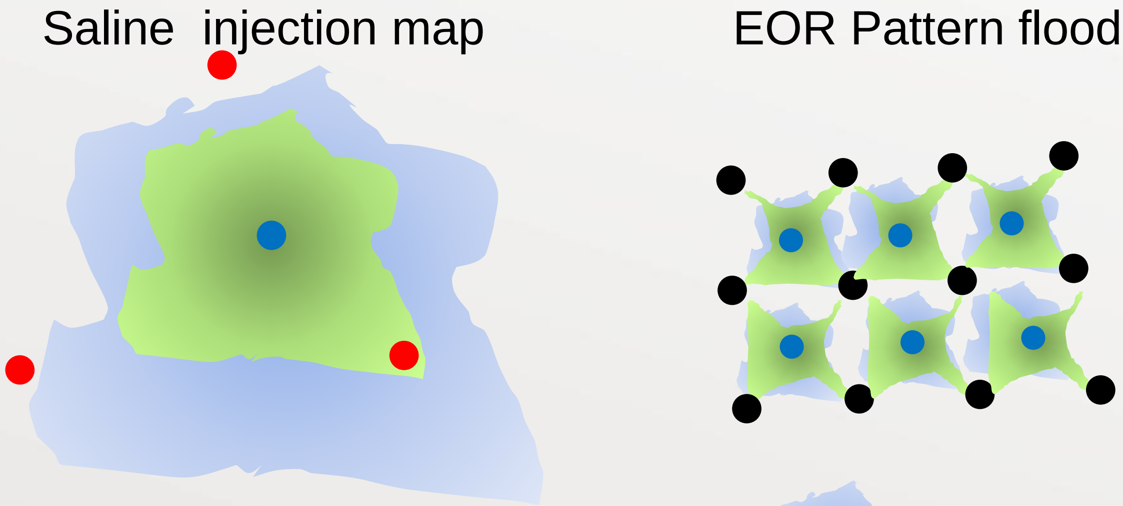
Material Impact	Saline Risk	**CO_2 EOR Risk**	**CO_2 EOR Risk Mitigation**
Inadequate storage capacity	●	•	Production history
Excessive lateral migration	●	•	Well-defined structure
Excessive pressure increase	●	•	Active pressure management
Inadequate confinement (seal)	●	•	Geologic history of trapping fluids
Inadequate well performance	•	●	Number of wells

Dot size proportional to probability

Examples of unique issues at CO_2 EOR site

- Active control of AoR parameters by patterns of injection and withdrawal wells
  - – Magnitude of elevated pressure
  - – Area of elevated pressure
  - – Areas occupied by CO_2
- Assess and monitor quality of active control

Comparing saline injection to CO_2 EOR pattern flood - value of active control



Saline injection map

EOR Pattern flood map

- 🔵 Injection well
- ● Production well
- 🔴 Monitoring well
- 🟩 CO_2 plume
- 🟦 Elevated pressure

Examples of unique issues at CO_2 EOR site

- Strong impact of past practices
  - Perturbed pressure prior to and during CO_2 EOR
  - Complex and perturbed fluid chemistries
    - E.g. impact of methane in system on geophysical detection of CO_2.
- Limit options and generate opportunity
  - E.g. connectivity of zones that have been energized can be assessed prior to injection
  - Fluids produced from shallower zone may be ideal and low cost monitoring option

A plea not to plan prolonged closure monitoring

- Discovering flaws in system during closure are too late
  - Mitigation of large volumes stored is very difficult: back production would produce water and impurities such as methane
- Effort to reduce uncertainties early in the project would be much more valuable
  - E.g. test migration/stabilization process at appropriate (smallish scale) to create a highly reliable model: case study at Frio test

More Information: www.gulfcoastcarbon.org

Thank you!

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