PRE-ACT
- SAFE AND COST-EFFICIENT CO₂ STORAGE

Peder Eliasson, SINTEF
4th ACT Knowledge Sharing Workshop
Divani Palace Acropolis Hotel, Athens, 6 November 2019
Pre-ACT background

• Response to first ACT call 2016
• Wanted to identify and address main storage-related challenges for accelerated deployment of CCS in collaboration with industry.
• Focus on crucial storage challenges: capacity, confidence, and cost
• Least common denominator: pressure

Pressure control and conformance management for safe and efficient CO$_2$ storage - Accelerating CCS Technologies (Acronym: Pre-ACT)

www.sintef.no/pre-act
Pre-ACT approach

- Answering to industry needs
- Learning from demonstration, pilot, and field lab data
- Deliverables with focus on industry uptake
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Pre-ACT impact

- Methodologies and recommendations for **cost-efficient monitoring, reliable conformance assessment and decision making** (Pre-ACT Protocols)
- North Sea case studies:
  - Smeaheia (SINTEF, Equinor, ++)
  - P18-4 (TNO, TAQA, ++)
  - Endurance (BGS, Shell, ++)
- Workshops with industry, stakeholders, researchers
- First Svelvik CO₂ Field Lab campaign
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WP1: Pre-injection modelling

- WP leader: Jim White (BGS)
- Study optimal injection planning via effective pressure control
- Focus on understanding propagation and control of pressure increases following injection through a program of modelling and laboratory work
Fault heterogeneity

- Study of the effect of uncertain fault characterisation
- Varying sealing properties in fault relay zones has a major impact on pressure propagation

Lothe et al. (2019)

Lothe et al. (2018)
Heterogentities in reservoir

- Study effect of facies related heterogeneities (400x400 m grid block) using 27 layers.
- The base case is a stochastic model with clay layers and localized zones of high permeability.
- $\text{CO}_2$ injection rate is constant at 3 Mt/yr for 50 yrs
- Injected $\text{CO}_2$ migrates rapidly toward east, here with sealing faults
- Tighter clay layers result in more dissolved gas

From Lothe et al. (2019)
Pressure control

- Effect of geological heterogeneities on pressure studied
- Four different production well locations compared
- Various orientation and degree of heterogeneity (case D shown here)
- Impact of hypersaline discharge also modelled

Winner of 2018 Video Prize Archer Award
(UK National Supercomputing Service)

The tides move the hypersaline water back and forth

https://youtu.be/EmQv4qk0kUo
Geomechanical lab studies

- Acoustic Emission tests on-going at NGI
  - First results available
- Thermal stress tests on-going at SINTEF
  - Modelling at TNO
WP2: Novel monitoring concepts

- WP leader: Conny Schmidt-Hattenberger (GFZ)
- Minimize cost and get sufficient information by using passive-active monitoring strategy
- Novel concepts for quantification of pore pressure and saturation
- Methods applied to Svelvik CO₂ field lab
Passive-active monitoring workflow

• Sparse, semi-continuous monitoring, with complementary detailed measurements
• Potentially all geophysical methods are suitable
• Investigation of different passive seismic data types
  • Ambient noise
  • Teleseismic, regional earthquakes, micro-seismicity
Ambient Noise Seismic Interferometry

• Velocity (\(v_p\)) models for low containment case

\[\text{\(v_p\) at d\_0}\]

\[\text{\(v_p\) at d\_15}\]
Ambient Noise Seismic Interferometry

• Retrieved auto-correlations (fmax=70)

\[(d_{15} - d_0) \times 2\] with random noise
Rock physics inversion

• An integrated methodology for **quantitative CO₂ monitoring** using a Bayesian formulation (accounting for uncertainty) has been developed

• Multiple data sets used to quantify e.g. pressure and saturation

adding measurement error
Rock physics inversion

- An integrated methodology for **quant** Bayesian formulation (accounting for uncertainty)
- Multiple data sets used to quantify e.

Dupuy et al. (presentation at Petroleum Geostatistics 2019)
Svelvik CO\textsubscript{2} Field Lab

- Unique laboratory for development and testing of technologies for quantitative monitoring of CO\textsubscript{2} storage
- 1 Injection well, 4 observation wells
- Cross-hole seismic and ERT, in-situ pressure measurements, DAS, DTS, DSS
- Pre-ACT data for pressure-saturation discrimination and quantification
  - First brine injection for pressure change alone
  - Then CO\textsubscript{2} injection for combined saturation and pressure change
WP3: Conformance verification

• WP leader: Stefan Carpentier (TNO)
• Construct a workflow integrating multiple data types and uncertainties for assessing industrial scale CO₂ storage site conformance
• Definition of ‘conformance’, confidence levels
• Optimal workflow and monitoring plan for determining conformance and making decisions
CO2 migration can be accurately imaged with geophysical data.

Flow simulations, based on the best estimates of reservoir parameters, allow prediction to be made.

But results do not always match!
Conformance and value-of-information

- Injected CO2 must remain within regulatory/safety bounds
  - Quantity of interest: conformance verification at the end of injection period \( (t = T) \)

- Monitoring alternatives:
  - Time-lapse survey during interval \( t = [0,T] \)
  - How to design the configuration of such a survey?
  - Which configuration is most useful for conformance verification at \( t = T \)?

Value of information
Survey considerations

- Varying time of acquisition
Value-of-information

- **Expected gain** (in conformance units) and **deployment costs** ($) associated with each configuration in the search of the best **trade-off**

- **Impact on CCS industry:** More cost-effective monitoring surveys through 1) lower survey effort and 2) faster turnaround leads to 3) earlier decision making and 4) more grip on uncertainties
Value-of-information

- **Expected gain** (in conformance units) and **deployment costs** ($) associated with each configuration in the search of the best **trade-off**

- **Impact on CCS industry:** 80% result for 20% effort (enough for well-informed decisions)
WP4: Decision making

• WP leader: Alv-Arne Grimstad (SINTEF)
• Investigate and describe procedures that should be set in motion if a conformance test has failed
• Enable knowledge-based decision-making
• Explore consequences of possible actions
WP4 context

• What does a failed conformance test signify?
• Monitoring data indicates that the storage site behaviour cannot with sufficient certainty be said to be consistent with predictions
• Predictions of future storage site behaviour should show safe containment (by "definition")
• A failed conformance test therefore means that we are not sure that the site develops in a manner that ensures containment of injected CO2

Development of shut-in pressure at Snøhvit Tubåen. Predicted exceed of estimated fracture reactivation pressure (390 bar) led to change of injection plan. From Hermanrud et al, 2013; Figure 6.
WP5: Workflow demonstration

• WP leader: Ane Lothe (SINTEF)
• Demonstrate value of project results through **application of the methodology developed in WP1–WP4** to storage scenarios at realistic sites
• **Communicate the results to stakeholders:** authorities, regulators, policy and decision makers, politicians, etc.
Workflow demonstration

• **Smeaheia case** (SINTEF, Equinor)
  - Effect of gas Troll production on regional pressure depletion
  - Base injection plans to account for uncertainties
  - Develop a monitoring plan addressing changing baseline

• **P18-4** (*TNO, TAQA*)
  - Base-line injection plans will be tested and optimised
  - A monitor plan will be designed

• **Endurance** (BGS, Shell)
  - Case study based on pressure linked injection operations
  - Focus on water extraction and boundary limits to control injection and extraction rates

• **Snøhvit** (SINTEF, Total)
  - Extra case being discussed
Dissemination (organized workshops)

• Pre-ACT kick-off days at Sem Gård, Norway, 7-9 November 2017.
  • Open workshop about and a field trip to the ECCSEL Svelvik CO2 Field Lab. Participation from Pre-ACT, NFR, Gassnova, NPD, UiO, Uppsala University, Aker Solutions, smaller vendors and several research institutes.
  • Pre-ACT kick-off meeting
  • Pre-ACT WP4 workshop on decision-making
Dissemination (organized workshops)

- WP2/WP3 meeting with public workshop on "Quantitative measures of site conformance" (20-21 February 2018, Utrecht). External participation from EBN (NL) and NPD (NO).

- Pre-ACT Annual Meeting (19-20 November 2018, Utrecht)
  - Annual meeting
  - **CO2 monitoring/conformance workshop** (semi-public). Common lunch with the ACT ECObASE project. Participants from other ACT projects (Elegancy and DETECT) and projects such as ENOS, the Field Research Station (FRS), and ICO2P.
Dissemination (other workshops)

- CO2 GeoNet poster (May 2018)
- Otway Stage 3 Peer Review panel participation
- Invitation to meet US federal- and state-government delegation
- Input and poster at Accelerating CCUS Intl. Conference (Edinburgh, Nov 2018)
- Presentation at "NCCS workshop on fault derisking" (Feb 2019)
- Presentations at two ACT Knowledge Sharing Workshops (Oct 2017, Nov 2018)
- Presentations at two EERA-CCS steering committe meetings (Dec 2017, Dec 2018)
- Presentation at "EU CCS Storage Research Projects Science-Policy Showcase" (Sept -19)
- Presentation CSLF Annual Technical Group Technical Meeting (Nov 2019)
Dissemination (conference presentations)

• 1 poster at EAGE Conference and Exhibition (Copenhagen, 2018)

• 1 poster at SEG annual meeting (Anaheim, 2018)

• 1 poster at European Meeting of Environmental and Engineering Geophysics

• 3 presentations/posters at GHGT-14 (Melbourne, 2018)

• 6 presentations/posters at 5th Geological Storage Workshop (Utrecht, 2018)

• 1 presentation at EAGE ws Practical Reservoir Monitoring (Amsterdam, 2019)

• Presentations at SEG and Petroleum Geostatistics
Dissemination (publications)

- 16 publications, proceedings papers, and extended abstracts (until midterm)
- Links on Pre-ACT website

Stakeholder workshops

- 1st meeting in Trondheim, 10 April 2019
  - "First government exploitation permit for CO₂ storage at the Norwegian Continental Shelf"

- 2nd meeting in Brussels, 10 October 2019
  - "Mission: Safe and cost-efficient CO₂ storage for European industry"

- 3rd meeting in "Oslo", 14 November 2019
  - Svelvik official opening
  - Open for anybody to participate

- 4th meeting (TBD, February 2020)

www.sintef.no/projectweb/svelvik-co2-field-lab
Acknowledgements

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