◆ ACN CCUS Technical Workshop Day 2: Wed, October 6◆

Overview of CO_2 Storage Technologies

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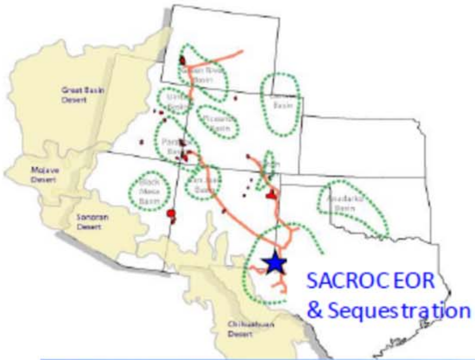
RITE
Research Institute of Innovative Technology for the Earth

1. Before Looking Ahead, Let's Review the Journey so far

CO_2-EOR / Geological CO_2 Storage (GCS)



Enhanced Oil Recovery - US ***(DOE, 2020)***

- First US patent for CO_2 EOR issued in 1952
- First field test in 1964
- First commercial project (SACROC) in 1972

Sleipner Project- Norway **1Mt / year**

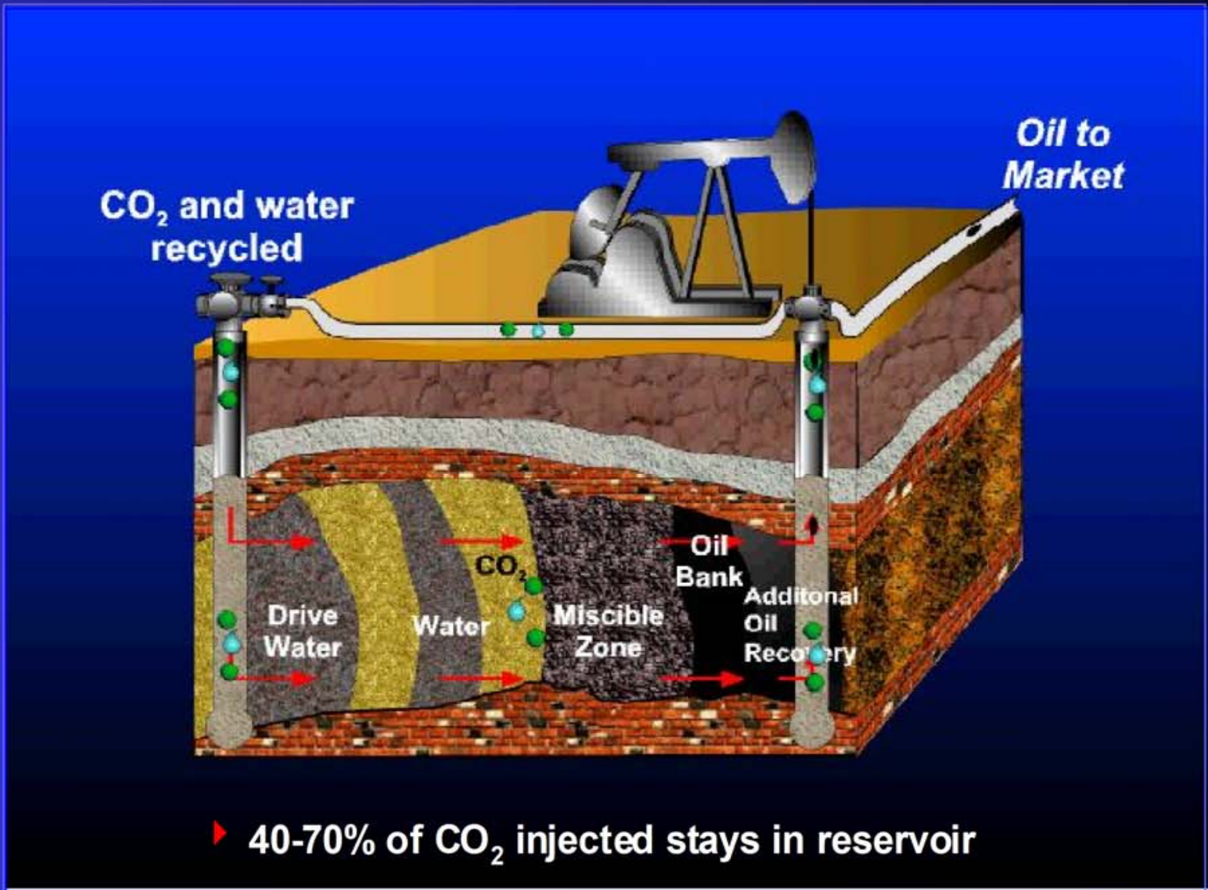
- CO_2 removed from natural gas produced on production platform in North Sea
- Injection into saline reservoir under sea
- Started 1996

Weyburn – Saskatchewan **3Mt / year**

- EOR project with 50 wells
- Uses CO_2 from coal gasification plant
- Started 2000

Weyburn CO_2 Miscible Flood Project

CCUS (Enhanced Oil Recovery) *from PTRC, Canada*

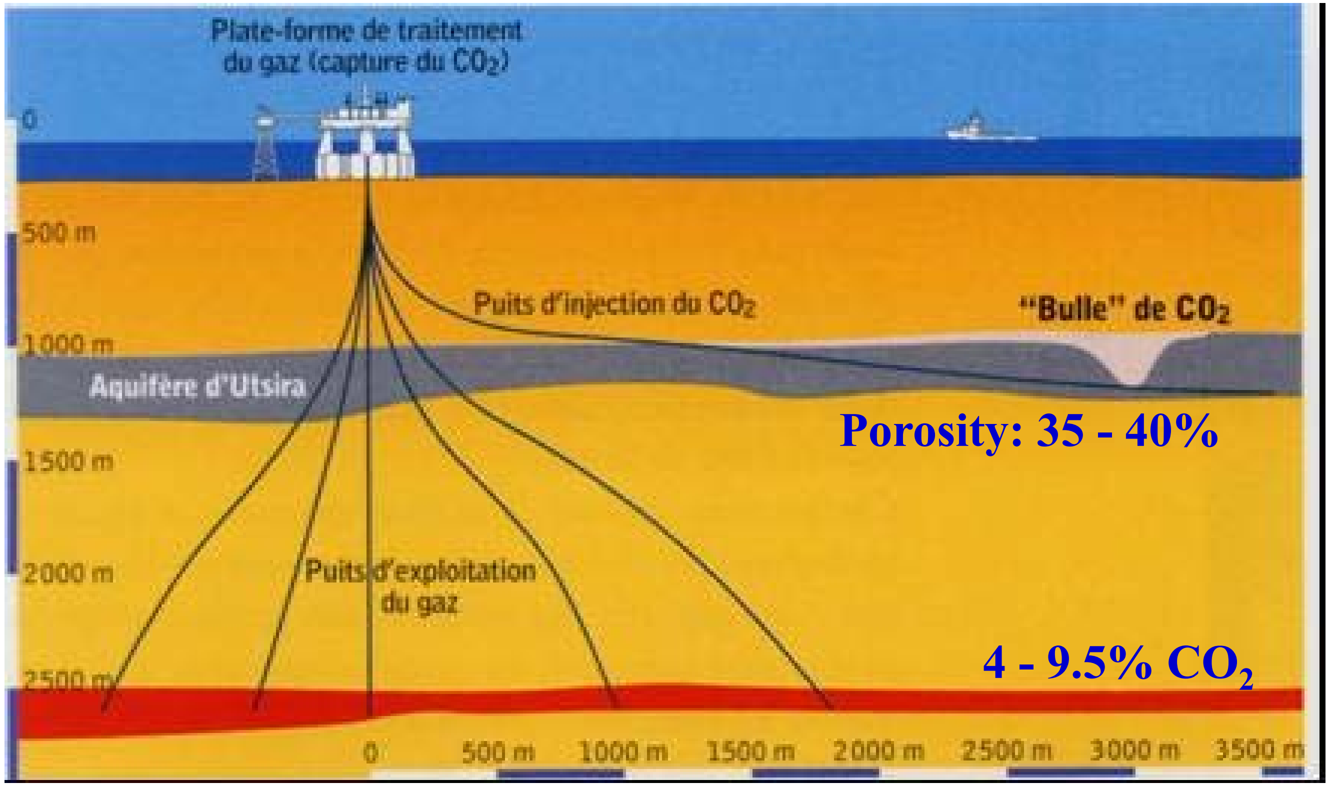


- CO_2 from Dakota Gasification Co., North Dakota
- Pipeline, 325 km, delivers 5000 t/d of CO_2

3 million ton/y
(CO_2 injection)

SACS (Saline Aquifer CO_2 Storage)

North Sea, Norway (Statoil), Sleipner



Porous Sand
(Net sand:80-100%)

High Permeability
(1 - 3 darcy)

Temp: 37 °C
Pressure: 8 - 11MPa

1 million ton/year
(3% of Norway)

The introduction of a tax on CO_2 emissions in 1991, seeking to more than triple its tax on carbon dioxide by 2030 from €60 to €200.

GCS: part of gas field development, started in 1996, **25 years** assurance monitoring

Much Progress on Carbon Storage, But Uncertainties Remain

Source: US DOE

	Then CCS Program Initiated (1997)	**Now** Progress to Date	**Future** CCS Broad Commercial Deployment
Storage R&D	• Little known	• Knowledge gained and **tools** being developed and tested	• "Commercial **toolbox**" developed
Infrastructure/Field Tests	• Little known; Sleipner project initiated	• Increased visibility; Knowledge gained and lessons learned	• Potential realized; Frameworks in place for market deployment

➢ **If cost issues lie with capture, risk issues lie with storage**

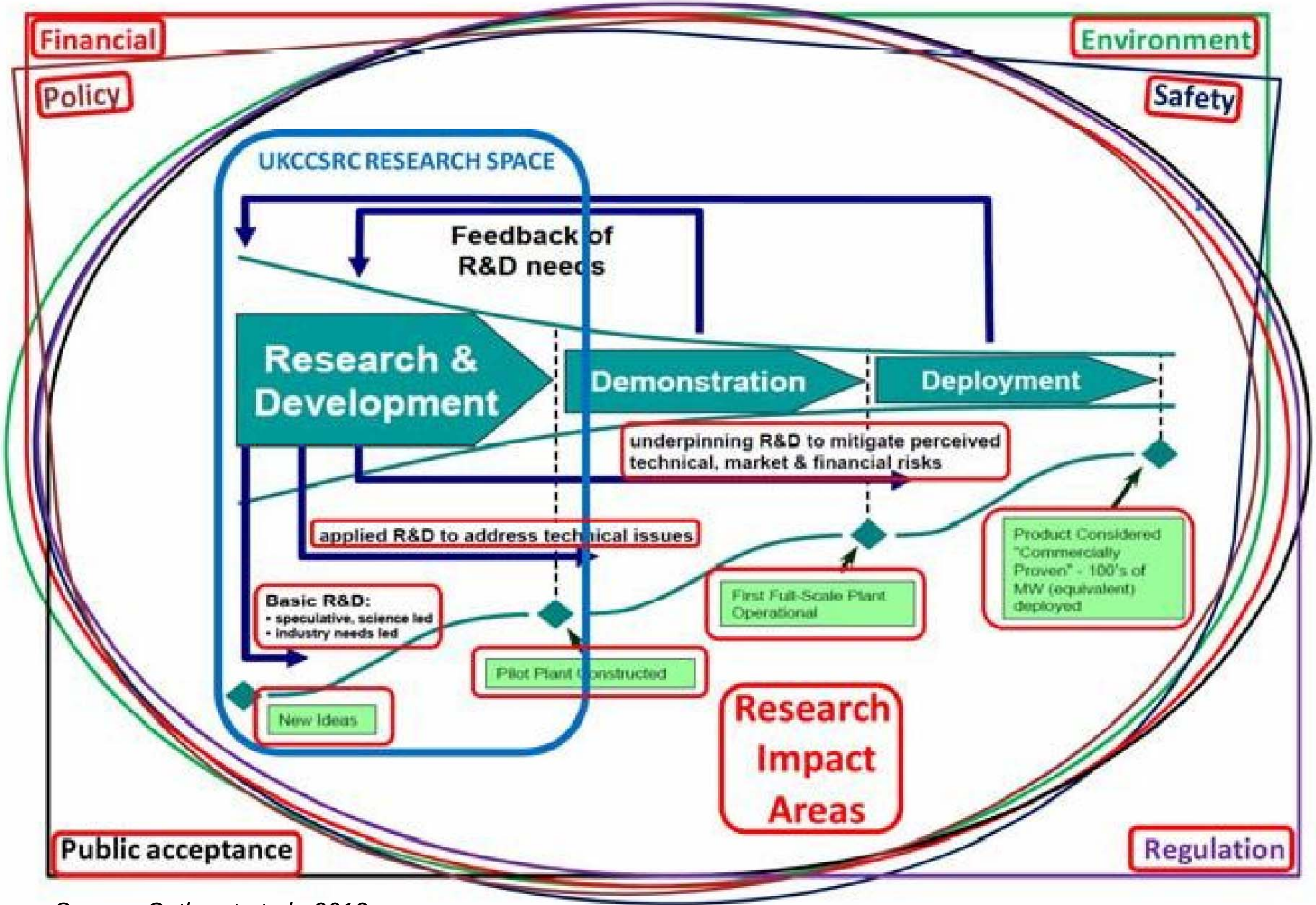
- **Questions about scale up, liability, performance**

▪***R&D focused on: Cost (Capture) and Confidence (Storage),***

▪***Demonstrations: Integration and Learning***

(improve storage efficiency, advanced monitoring)

Can We Achieve Commercial CO_2 Storage?



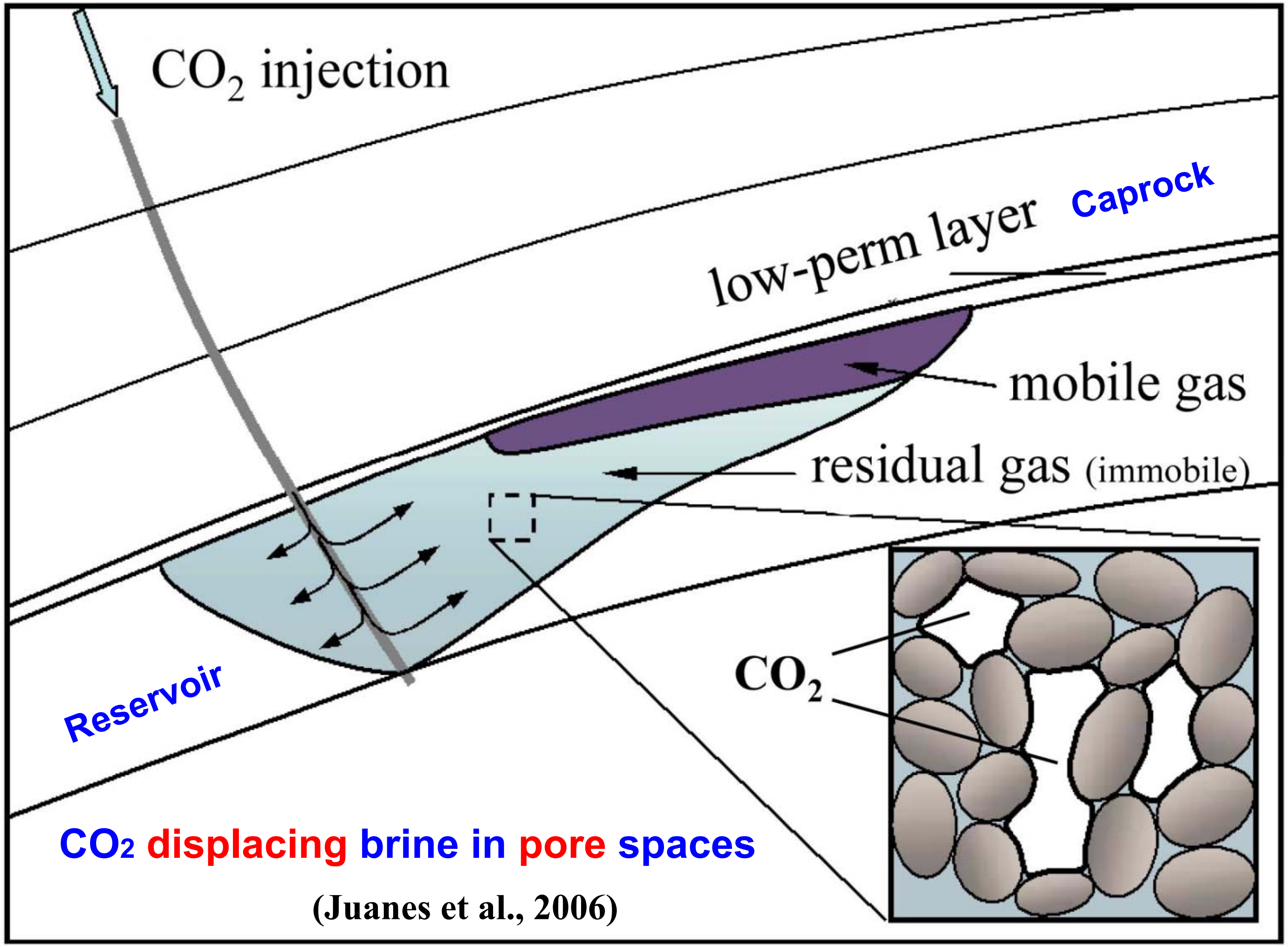
Source: Cathcart et al., 2013

2. Permanently Storing CO_2 in Subsurface

- Mobile phase trapped by seal
- Dissolution in water
- Precipitation as a mineral
- Immobile phase as residual, nonwetting saturation

CO_2 Trapping Mechanisms: long term security
(how long is enough long?)

What happens when injecting CO_2 into reservoirs?



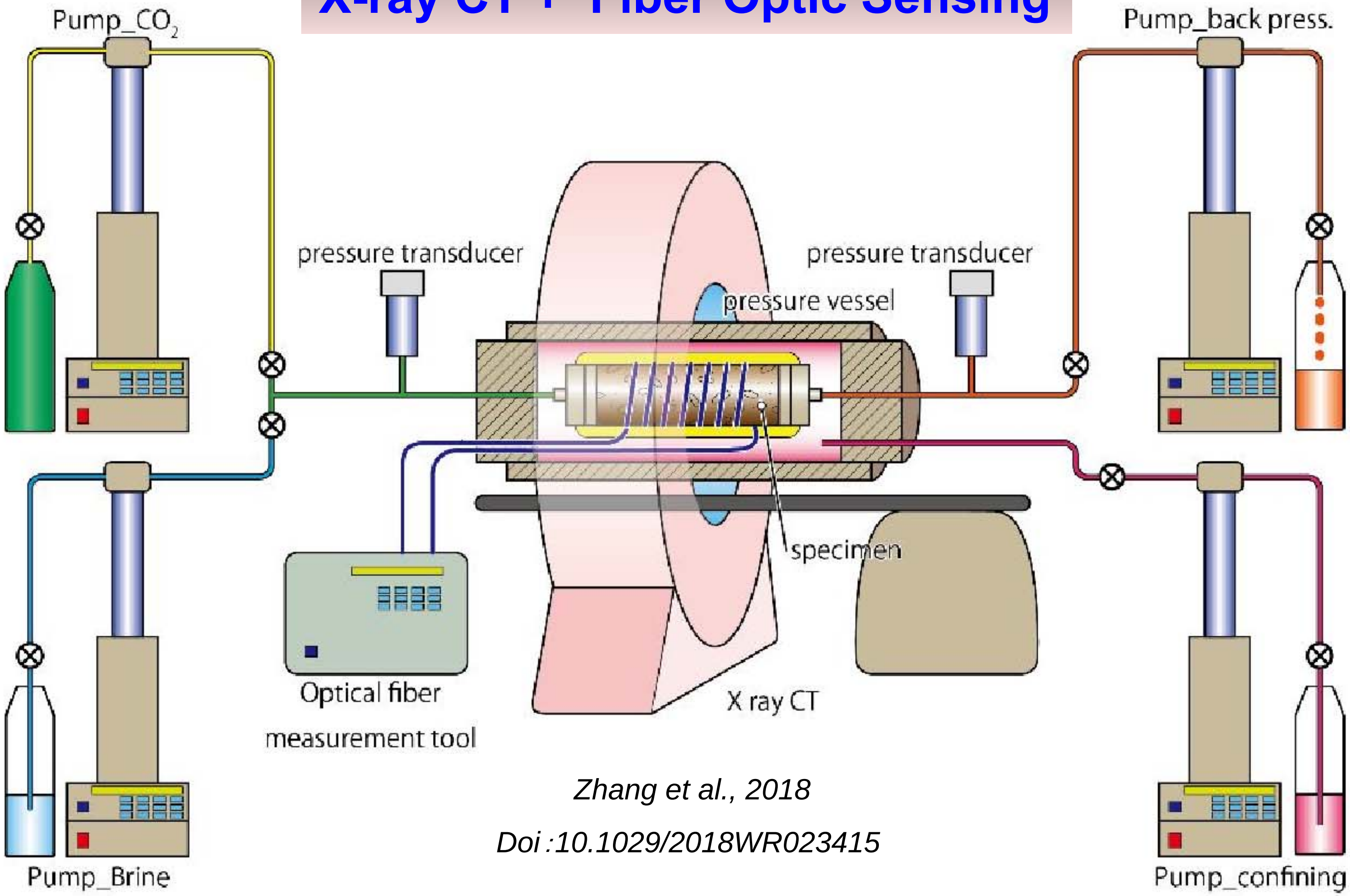
CO2 displacing brine in pore spaces

(Juanes et al., 2006)

-- *Insights from our lab experiment –*

mobile phase (supercritical CO_2) trapped by seal

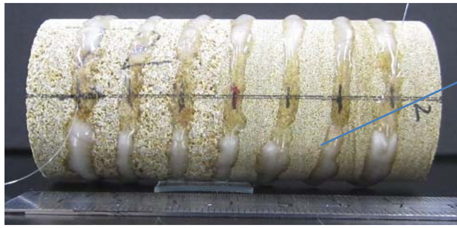
X-ray CT + Fiber Optic Sensing



Zhang et al., 2018

Doi :10.1029/2018WR023415

Visualization of the CO_2 plume and pressure fronts

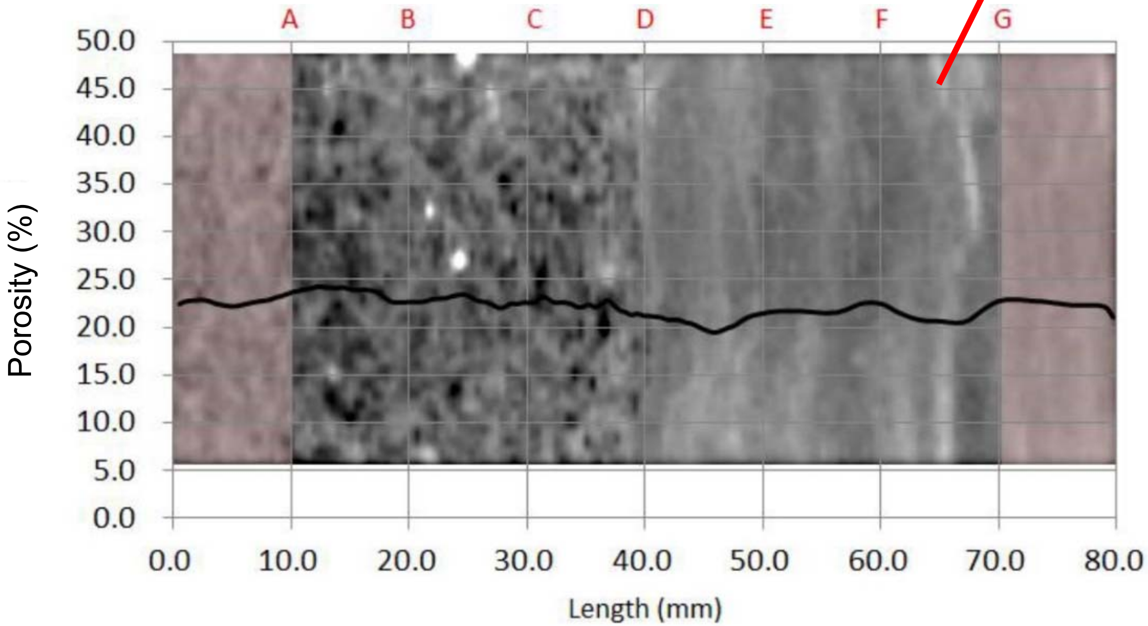


optic fiber cemented on the rock sample

Caprock (fine grain)

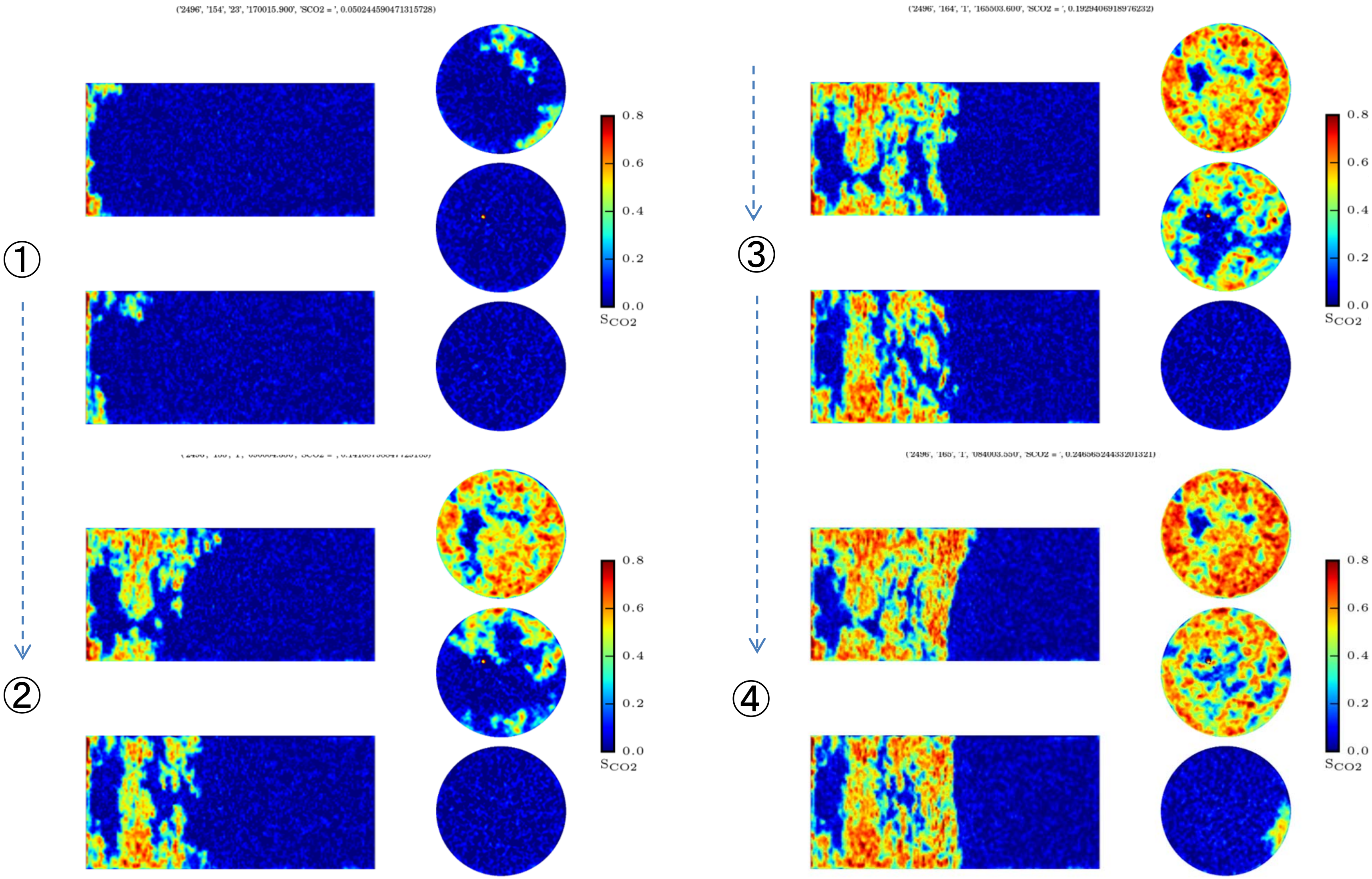
Reservoir (coarse grain)

X-CT image

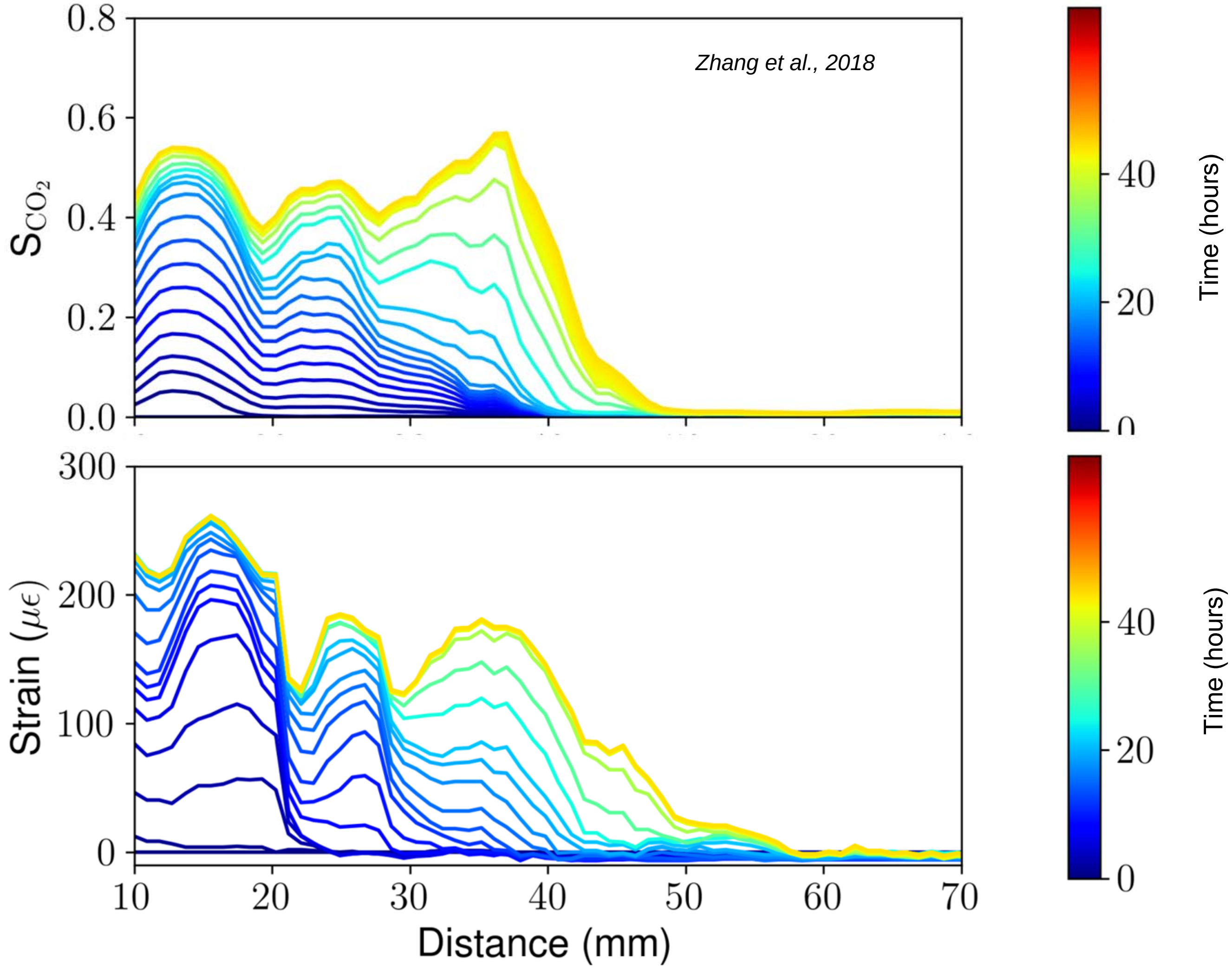


How optic fiber will response to CO2 penetration from "reservoir" to "caprock" ?

CO_2 accumulation in reservoir (coarse grain)



CO_2 saturation profile vs strain profile along the sample length



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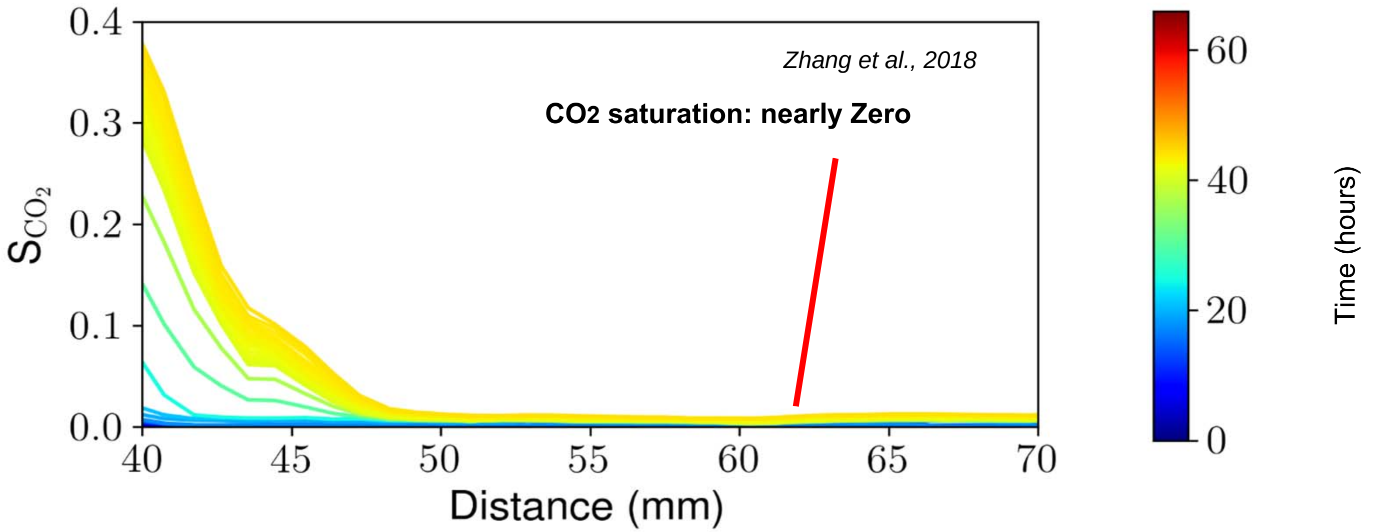
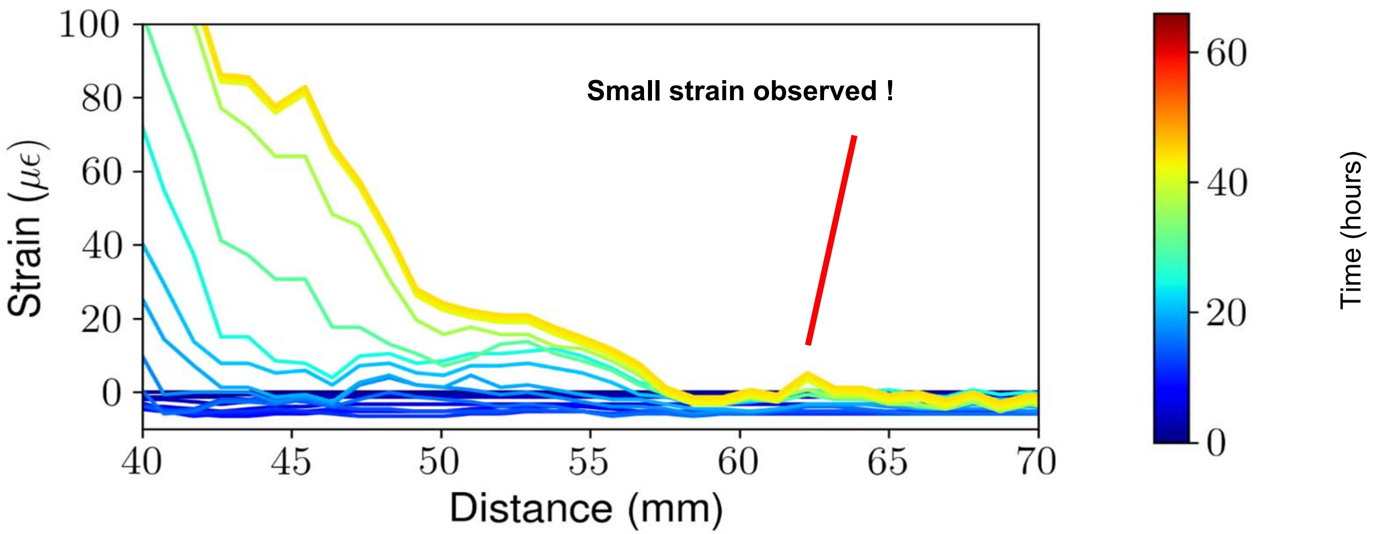
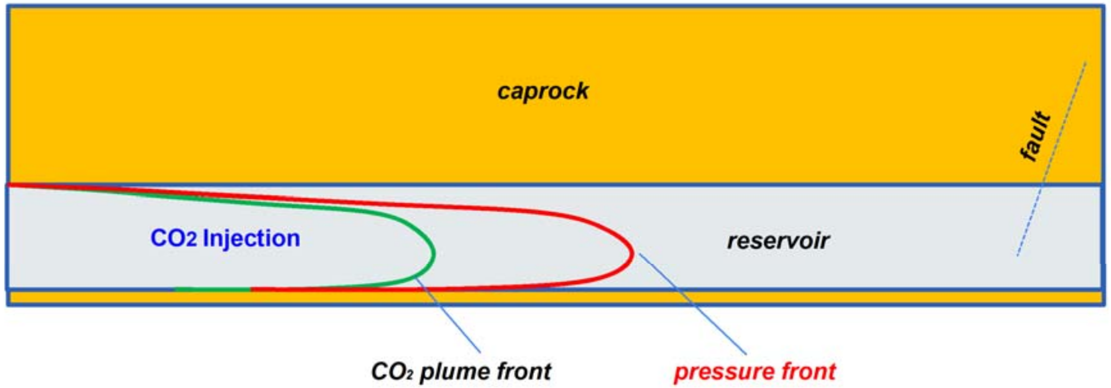
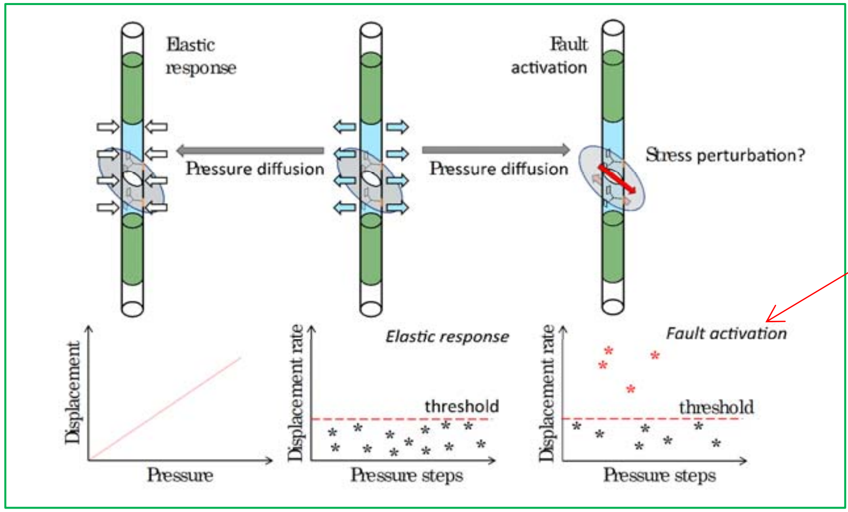




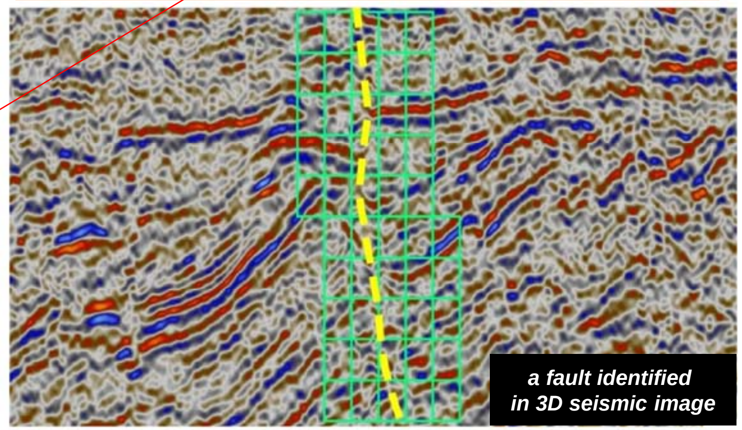
Fault Integrity Monitoring (reactivation, leakage) with Fiber Optic Sensing



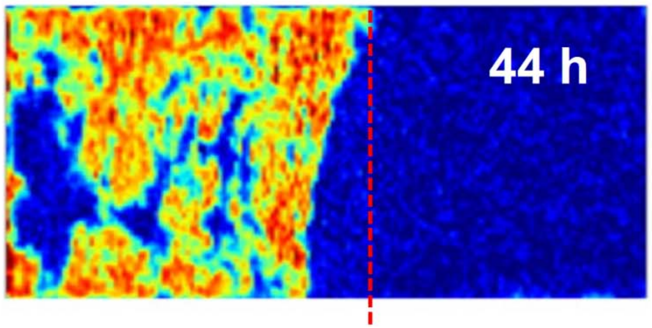


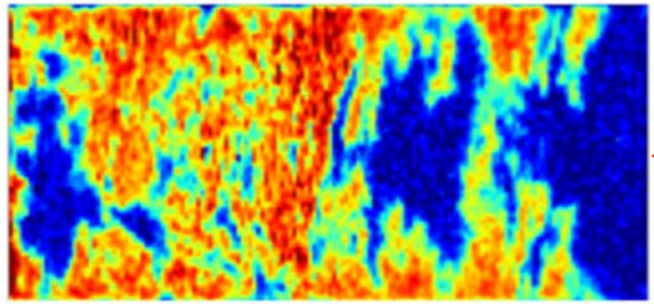
Kakurina et al, 2020

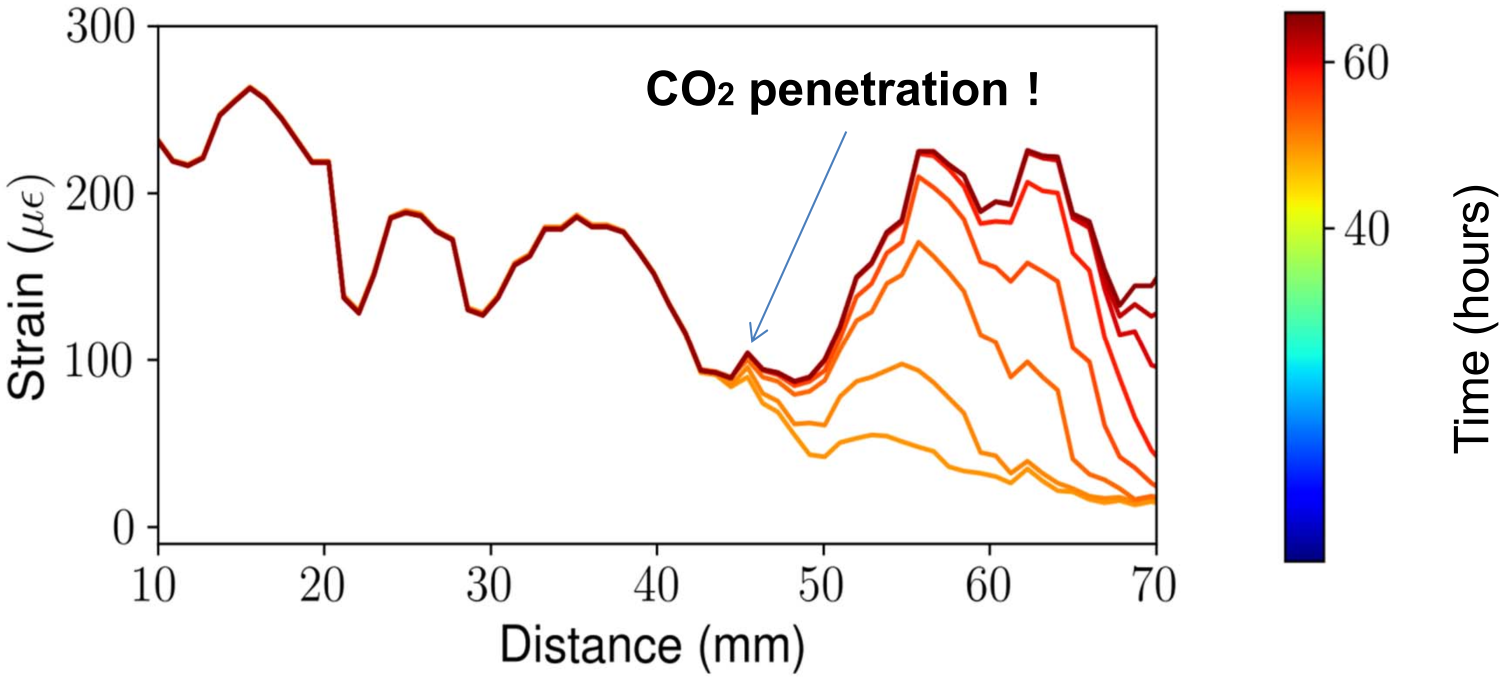
Installing fiber optic cables behind casing of monitoring wells for Distributed Strain, Temperature and Acoustic sensing



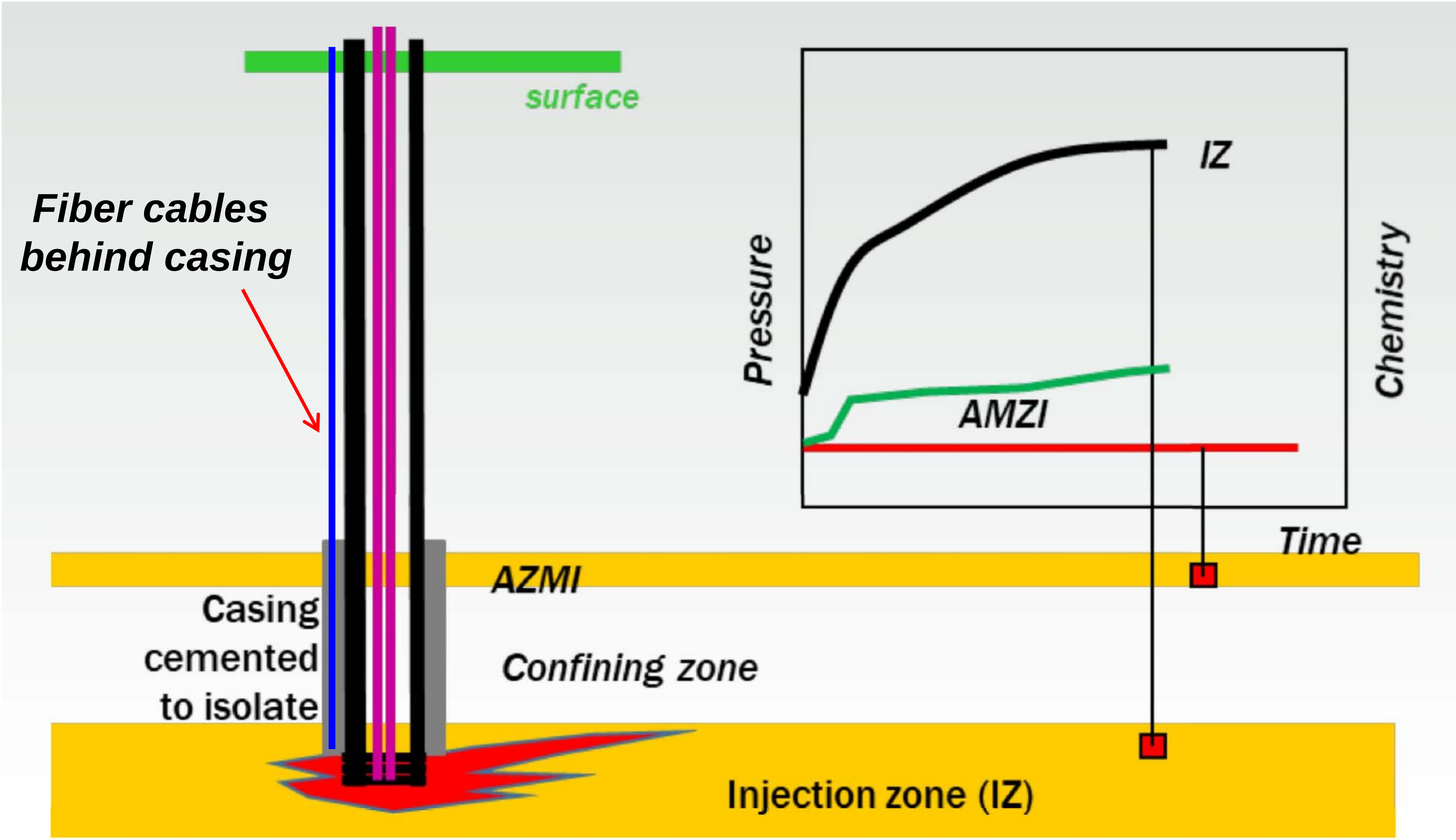
Strain response to CO_2 penetrating into the fine grain part







Application #1 for well integrity monitoring, combined with AZMI (Above-Zone Monitoring Interval) pressure monitoring



Hovorka et al, 2018

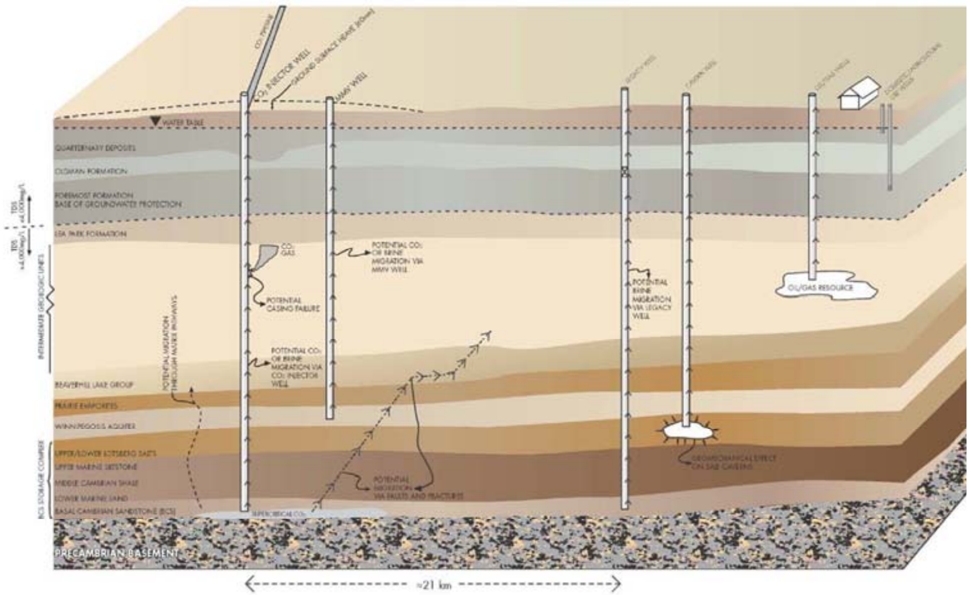
3. CO_2 Monitoring for Permanence & Safety

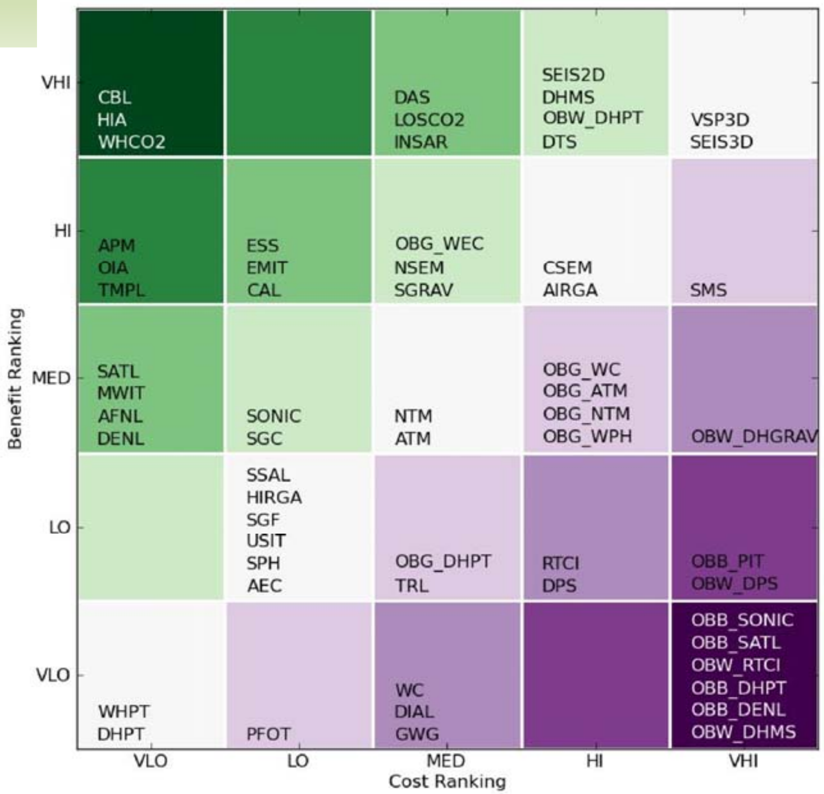
- To track the movement of CO_2 and assure permanence for geologic storage.
- To decrease the cost and uncertainty in measurements and satisfy regulations.
- To provide measurements and reservoir conditions for decision making and process optimization, calibrating and improving geological model for predication of long-term behavior of injected CO_2 in the subsurface.
- To develop skills on risk communication and public acceptance on geological storage.

Design a monitoring program to monitor a CO_2 storage project during all stages from site characterization through to post - injection.

Shell QUEST Report (2010)

Quest Carbon Capture and Storage Project Measurement, Monitoring and Verification Plan

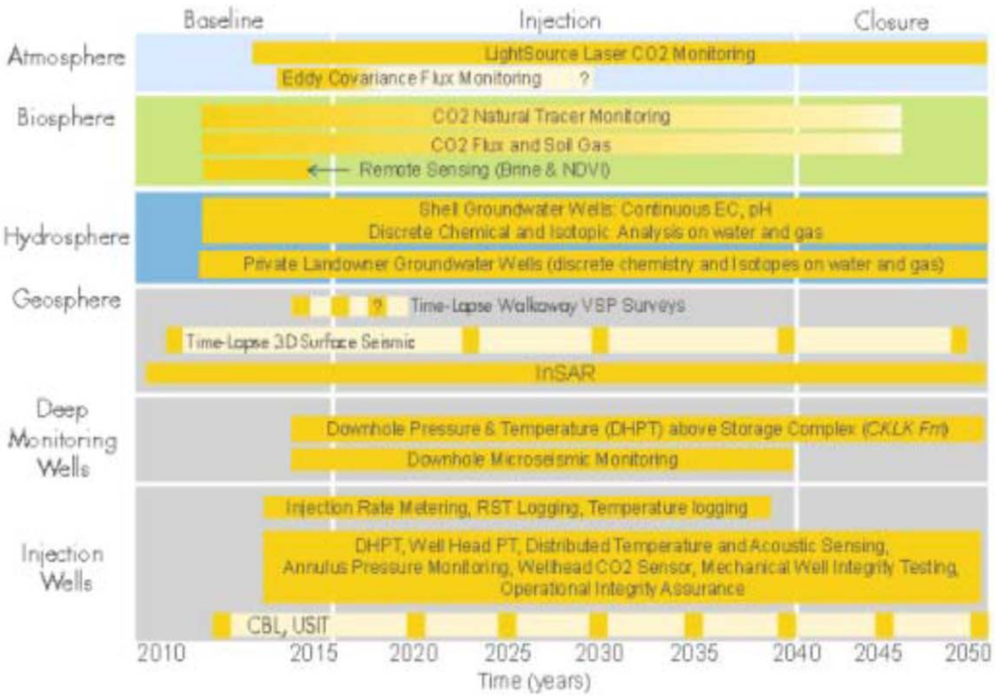




A risk-based approach for Measurement Monitoring and Verification (MMV) activities, providing early warning of any breach of containment, reducing risk and ensuring the remaining risk is insignificant compared to everyday risks broadly accepted by society

Creating Value from Monitoring for Cost Reduction

Quest MMV Plan 2015

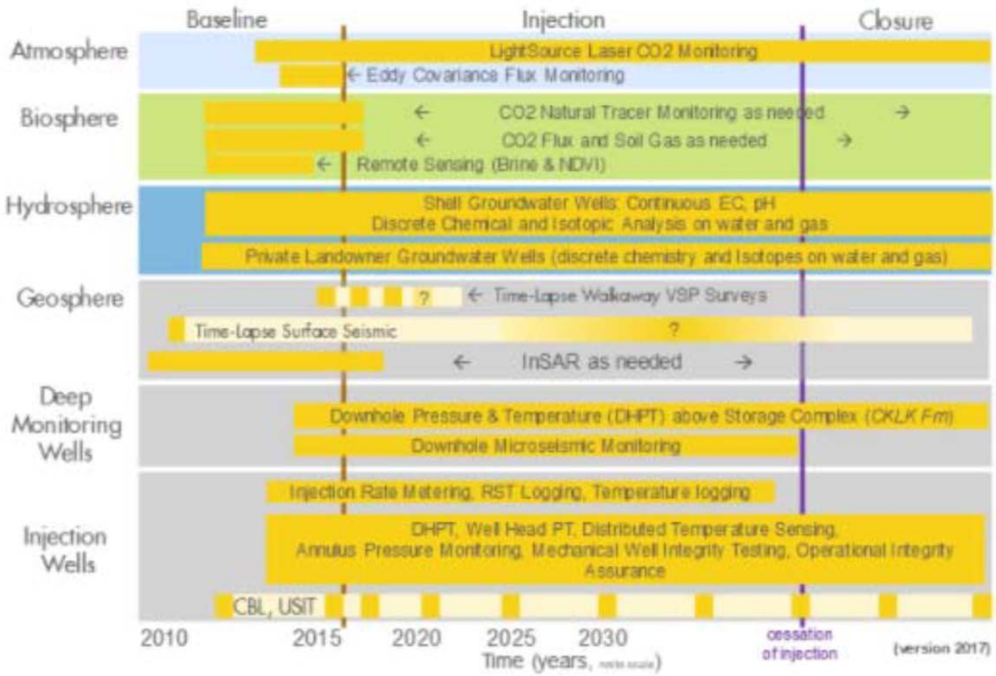


- First of a kind – conservative approach
- Comprehensive: from atmosphere to geosphere
- Risk-based
- Site-specific
- Independently reviewed
- Combination of new and traditional technologies
- Baseline data collected before start-up
- Adaptive – updated every 3 years

MMV: Measurement, Monitoring and Verification Plan

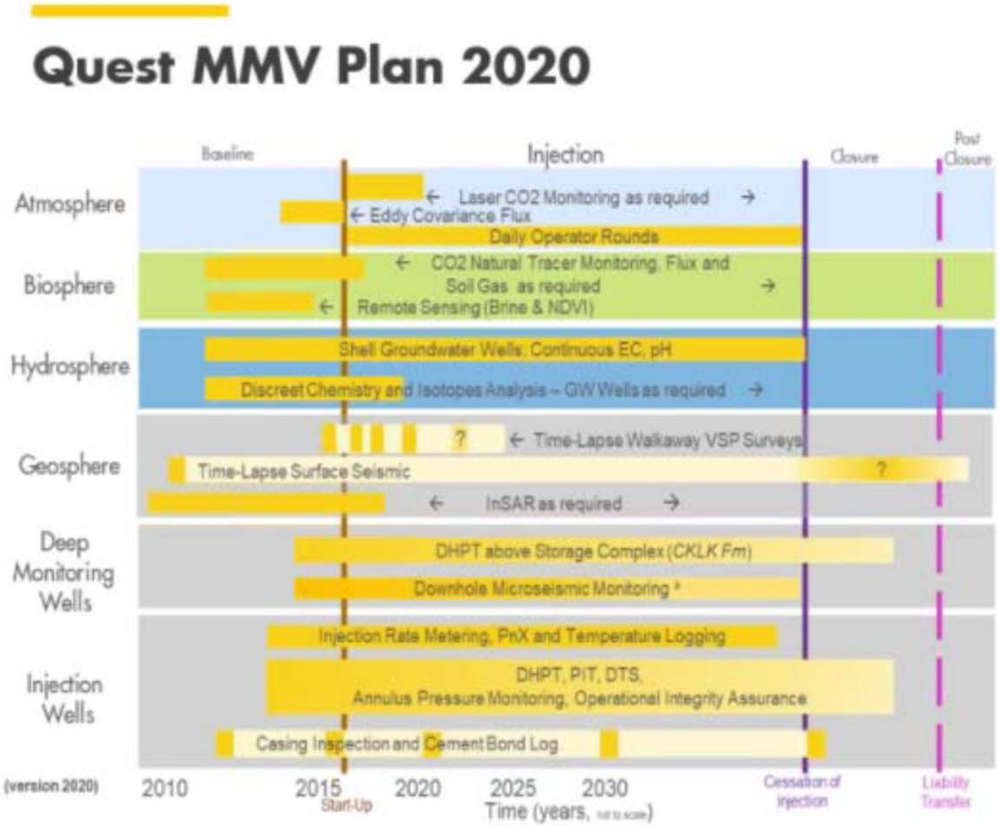
Creating Value from Monitoring for Cost Reduction

Quest MMV Plan 2017



- Focus on addressing key risks: drive towards ALARP
- Reduce or eliminate those technologies that do not drive decisions
- Tiered approach – much of the data analysis is on as needed basis:
  - Tier 1: early warning system
  - Tier 2/3: supporting data
- More emphasis on downhole technologies
- Seismic planning redesigned based on plume expectations

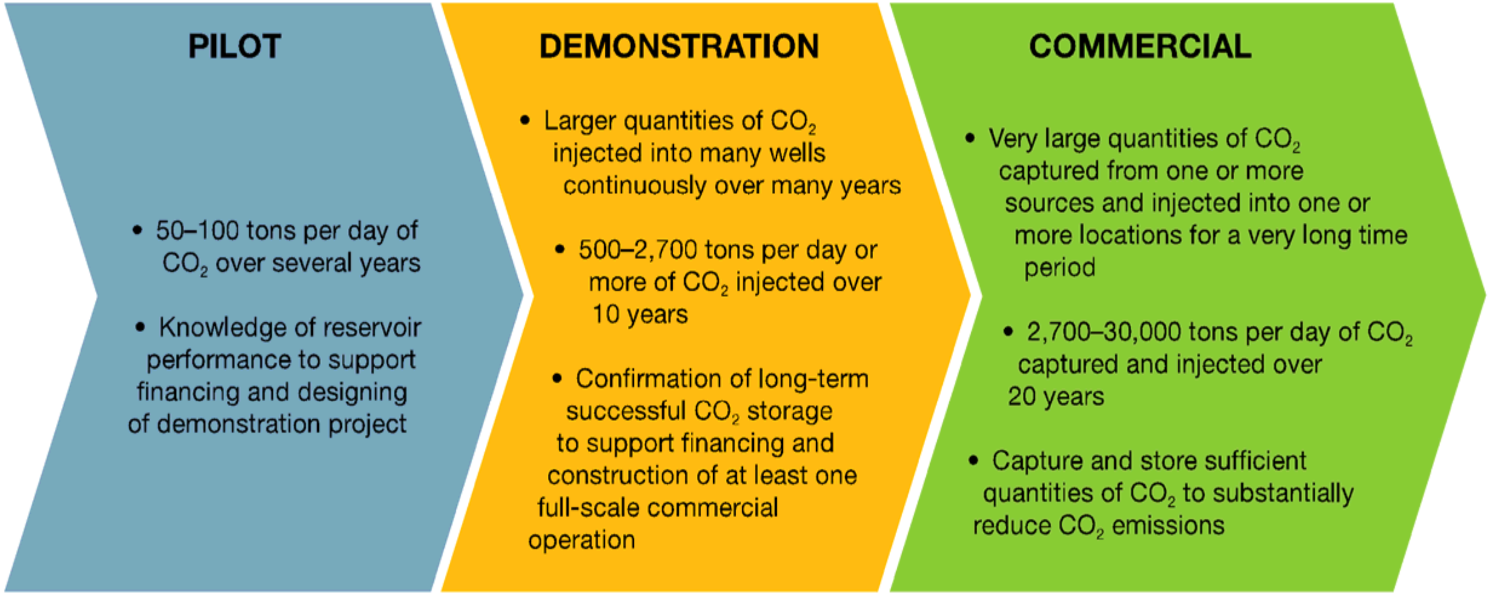
Creating Value from Monitoring for Cost Reduction



- Approved by the Alberta Energy Regulator and Government of Alberta
- Focused on updated risk profile
- Further clarification of Tiered approach
- Incorporate operational activities and well integrity processes
- Continues to drive down costs, optimize monitoring frequency

4. Stages of Carbon Capture and Storage Development

Source: ADB, 2013



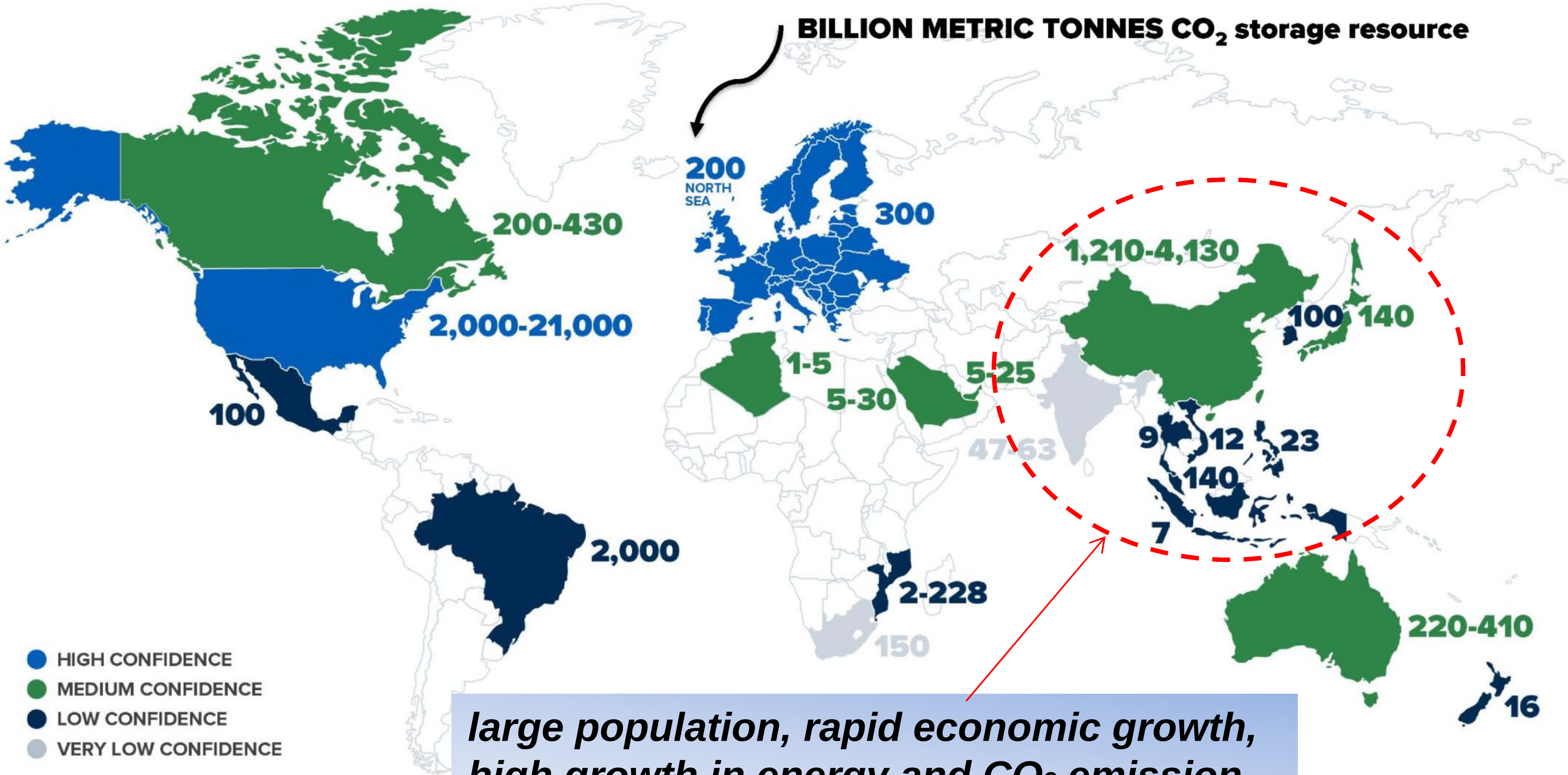
LEARNING by DOING !

Most CCS/CCUS projects operating in United States, Canada and Norway and main operators are major oil and gas companies.

Some projects in East Asian countries (China, Japan), Australia and Middle East, but less in Southeast Asian countries (Malaysia, Indonesia).

GLOBAL STORAGE RESOURCES

Source: GCCSI



large population, rapid economic growth, high growth in energy and CO_2 emission

Norwegian/US CCS collaboration opportunities

"...realise a cost-effective solution for full-scale CCS in Norway, provided that this incite technology development in an international perspective".

- Characterization - new methods for cost-effective site selection decisions
- Monitoring Verification and Accounting - making it smarted and more cost-effective
- Wellbore construction, materials, integrity - smart wells, re-use of old wells, P&A technologies

- Focus on reduction of uncertainties and pressure management
- Real storage domains have complex geologies and pressure barriers

- Where to find the best sands?

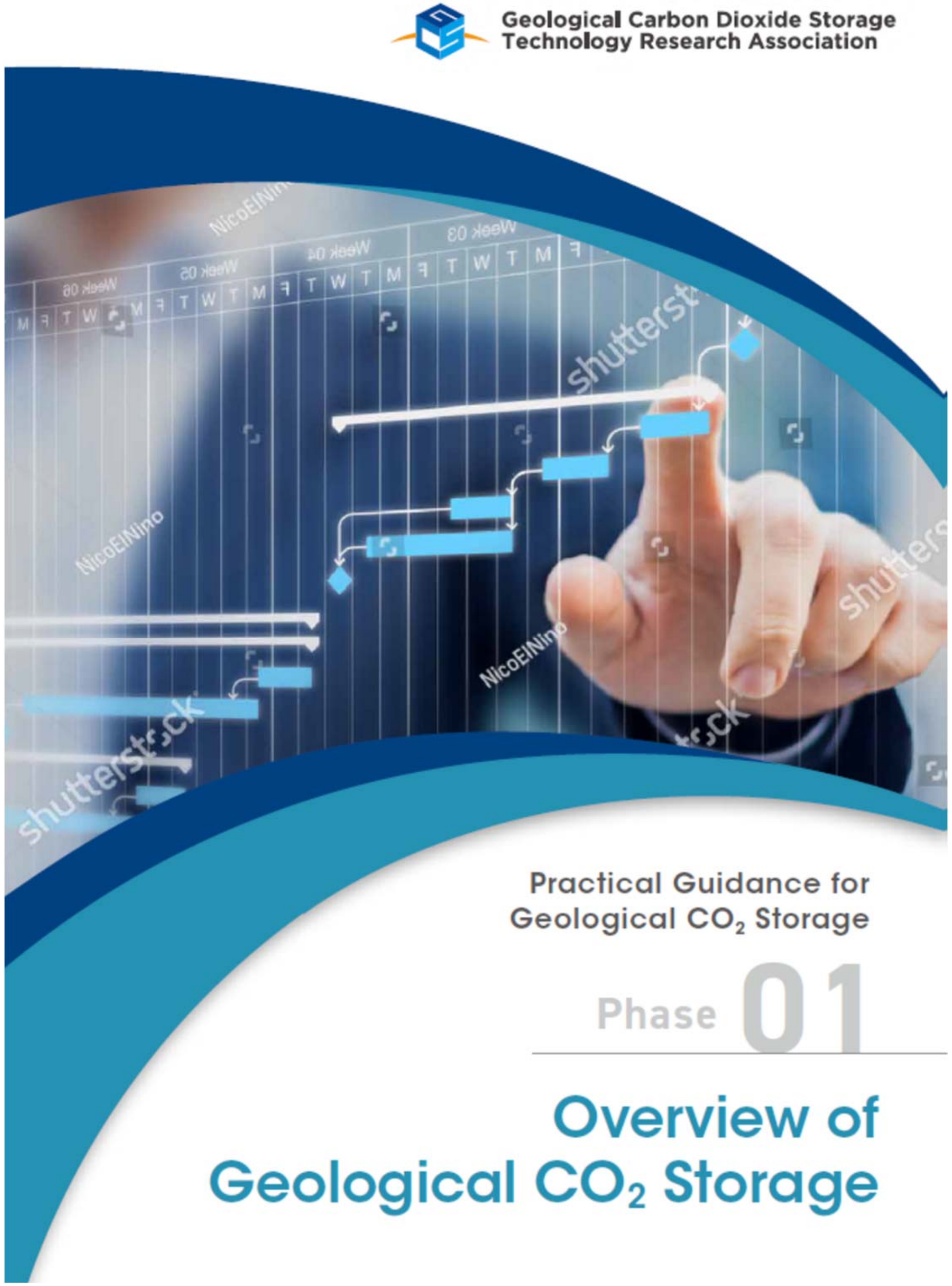
- There are some faults in the area, can they cause any migration challenges?

➢ A plan for monitoring of pressure and potential leakage

➢ RITE has collaborations with United States (fiber optic sensing for CO_2 storage monitoring), Australia (fault characterization and integrity monitoring).

➢ RITE and Tokyo Gas Co. licensed microbubble CO_2 patent to a Chinese oil service company for enhanced oil recovery in China.

Potential collaboration with Southeast countries on CCUS R&D and deployment



Publication Schedule

Phase 01 : Oct. 2021
Phase 02 : Mar. 2022
Phases 03-04: FY2022
Phases 05-08: FY2023

Acknowledgment

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