Mission Innovation workshop
Trondheim, June 19-20

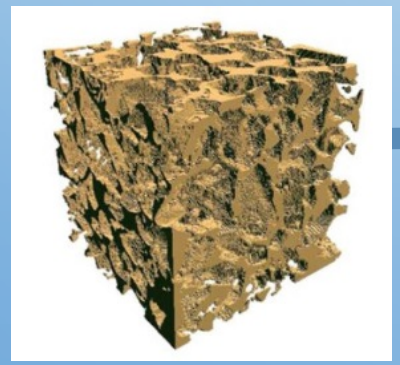
Session 3 – Storage and CO_2 networks

Introduction – Philip Ringrose, Equinor & NTNU

What we focused on in the 2017 MI Workshop

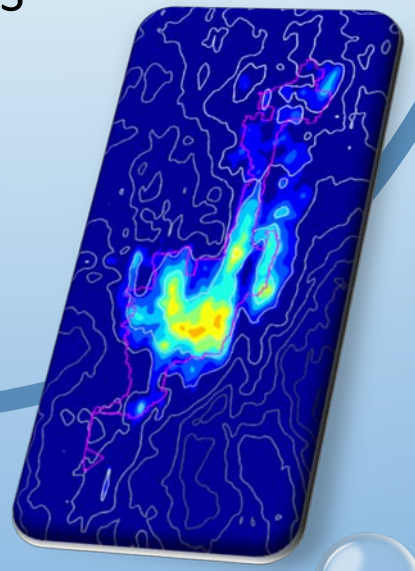
- Sequestration has to get to gigatonne (Gt) per year scale to meet global CO_2 emissions reductions targets.
- We know how to do 1Mt per year projects (e.g. Sleipner)
- We have sufficient capacity for Gt storage (in theory)
- BUT …
  - Many technical challenges need to be addressed
  - The world's nations must want to do CCS

Vison and road-map for scale-up from Mission Innovation CCUS



Pore scale:
nano to dm scale

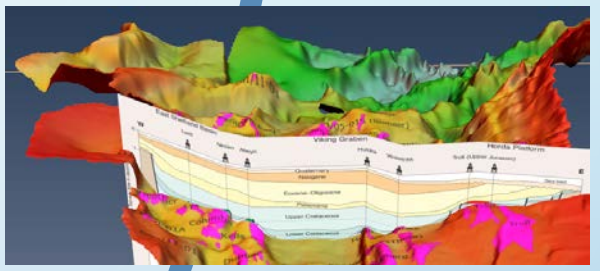
HPC:
10^{7-9} voxel models
Highly parallelized



Field scale:
dm to km scale

HPC:
10^{7-8} cell models
100's-1000's CPUs
Uncertainty handling via multiple realizations

Basin scale:
10s – 100s km

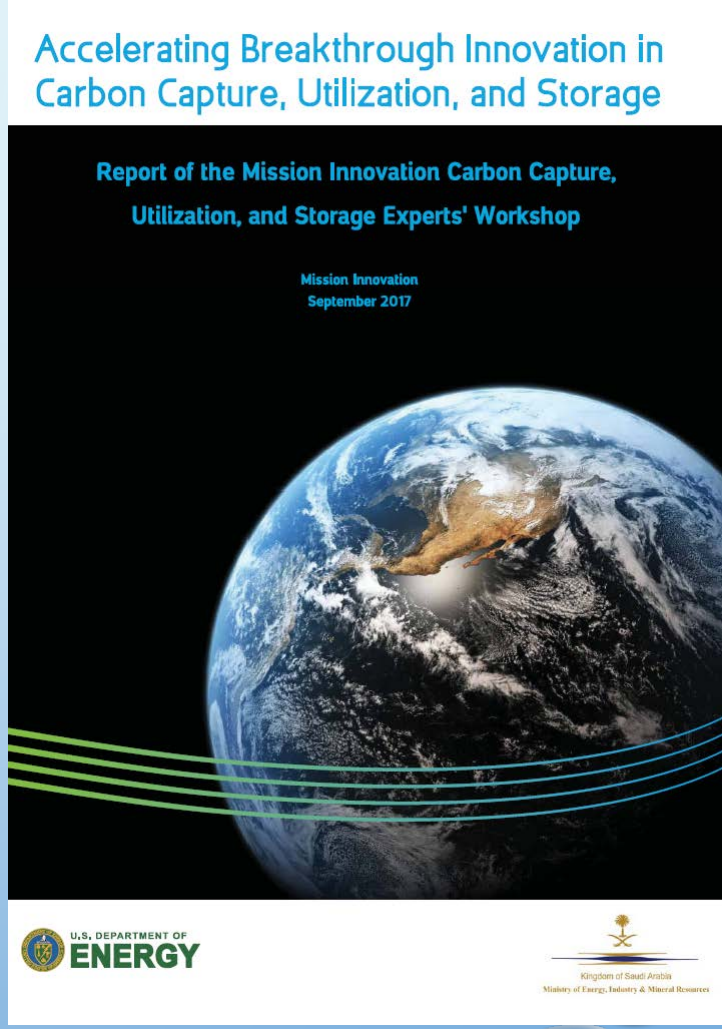


HPC:
10^{8-10} voxels
Multi-models/datasets
Parallelized

Topics covered in the 2017 MI Workshop

Focus Area 3: CO_2 storage - Co-Chair Don DePaolo (USA)

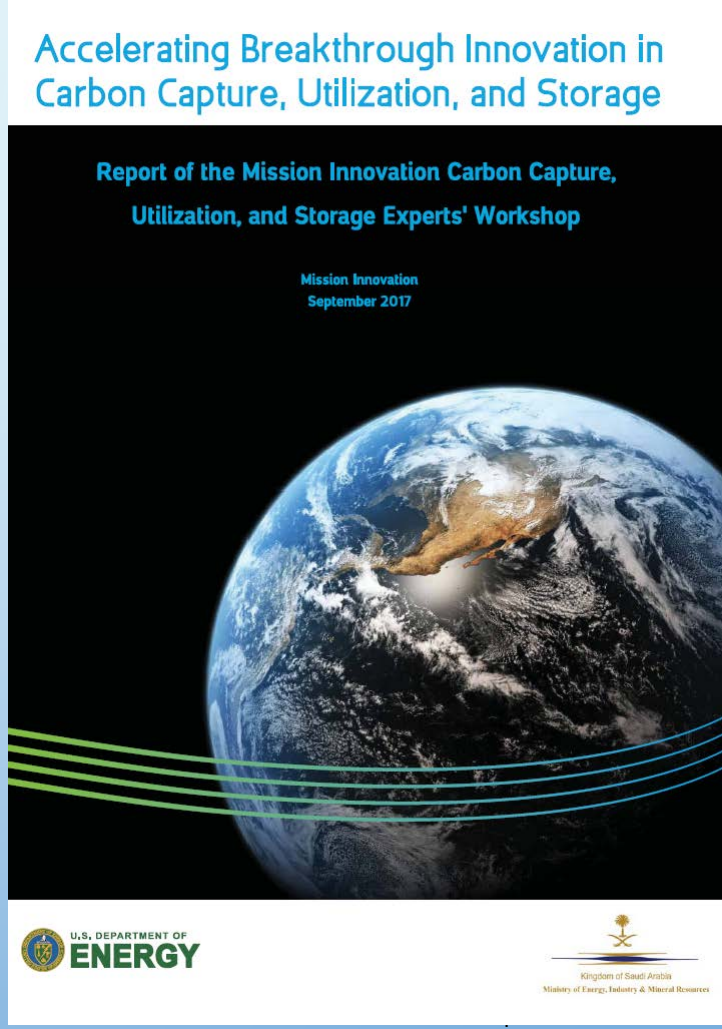
- **Panel S1: Injectivity and Capacity**
  Panel Leads: Philip Ringrose (NOR) and Curt Oldenburg (USA)
- **Panel S2: Monitoring, Verification and Performance Metrics**
  Panel Leads: Ziqiui Xue (JPN) and Jonathan Pearce (UK)
- **Panel S3: Forecasting and Managing Induced Seismicity**
  Panel Leads: Hideo Aochi (FRA) and David Eaton (CAN)
- **Panel S4: Well Diagnostics**
  Panel Leads: Franz May (GER) and Rick Chalaturnyk (CAN)



PRDs identified for CO_2 storage

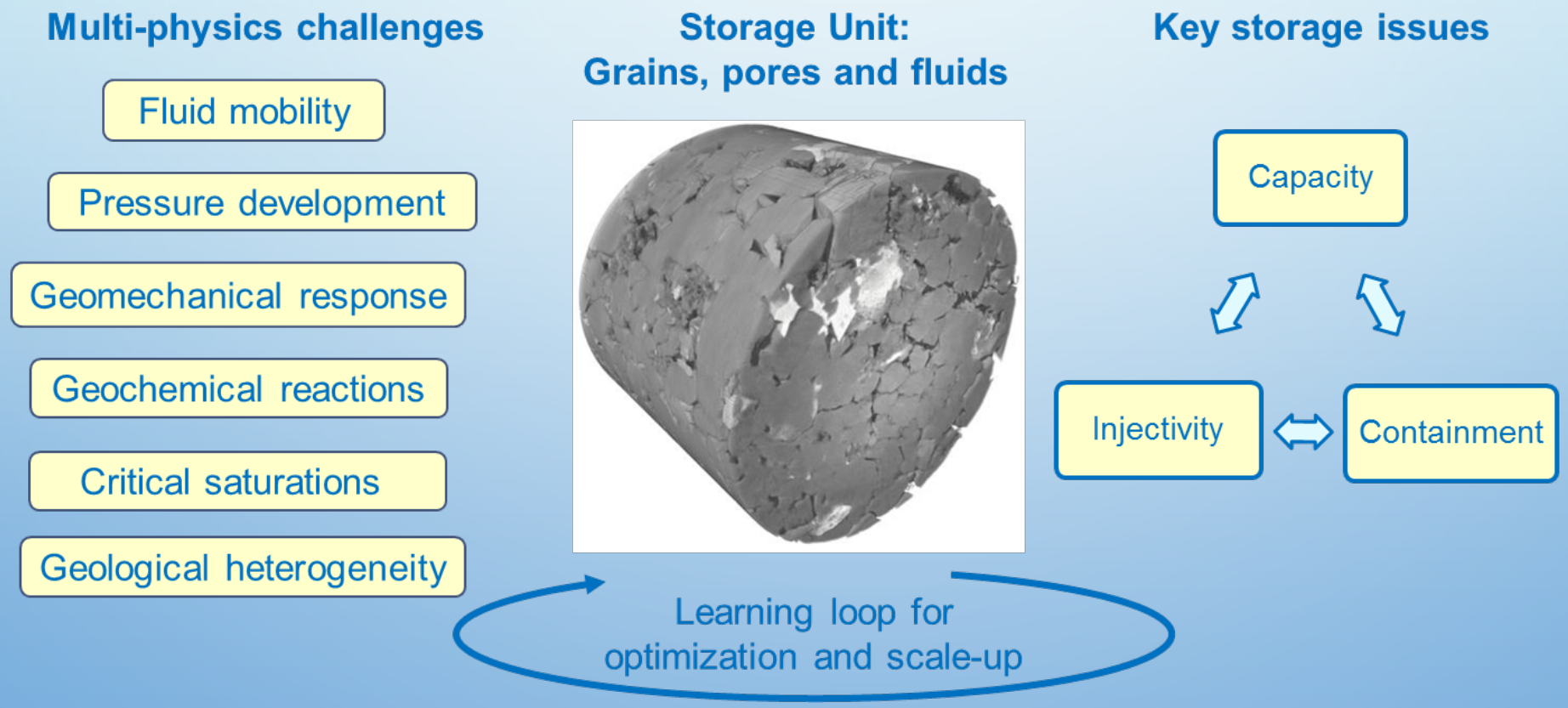
Nine ‘Principle Research Directions’ (PRDs) were identified

1. Advancing multiphysics and **multiscale fluid flow** to achieve gigatonne/year capacity
2. Understanding **dynamic pressure limits** for gigatonne-scale CO2 injection
3. Optimizing injection of CO_2 by **control of the near-well environment**
4. Developing **smart convergence monitoring** to demonstrate containment and enable storage site closure
5. Realizing smart monitoring to **assess anomalies** and provide assurance
6. Improving characterization of **fault and fracture systems**
7. Achieving next-generation **seismic risk** forecasting
8. Locating, evaluating, and remediating existing and **abandoned wells**
9. Establishing, demonstrating and forecasting **well integrity**



Some reflections on technology for maturing Gt storage - 1

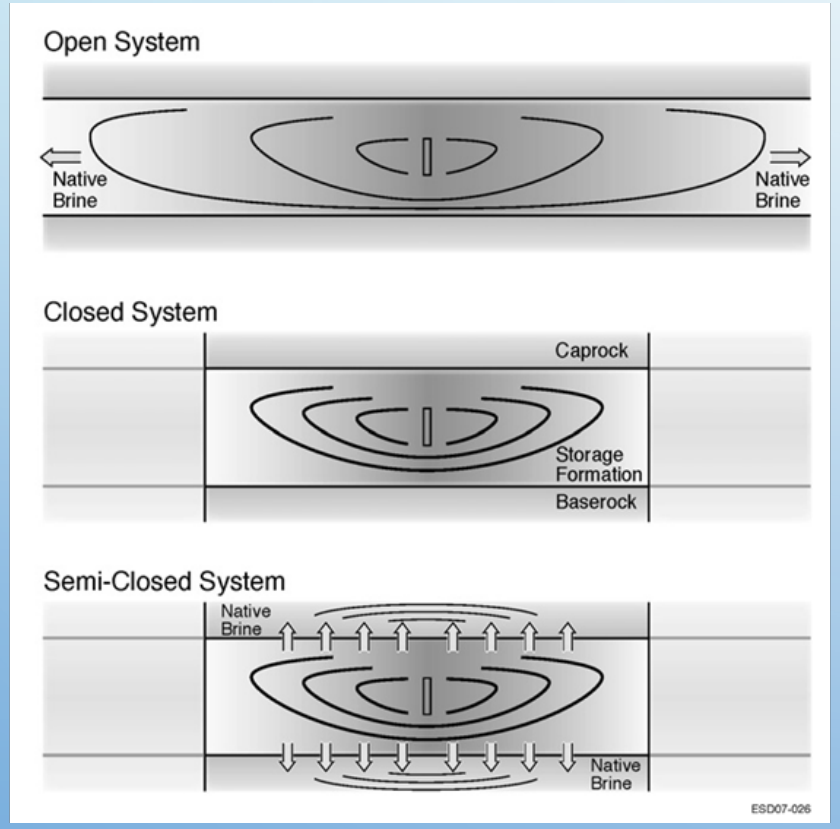
- Many ongoing R&D projects on CO2-brine flow properties, geomechanics and pressure modelling
- But **how do we transfer these learnings to emerging storage project developments**?

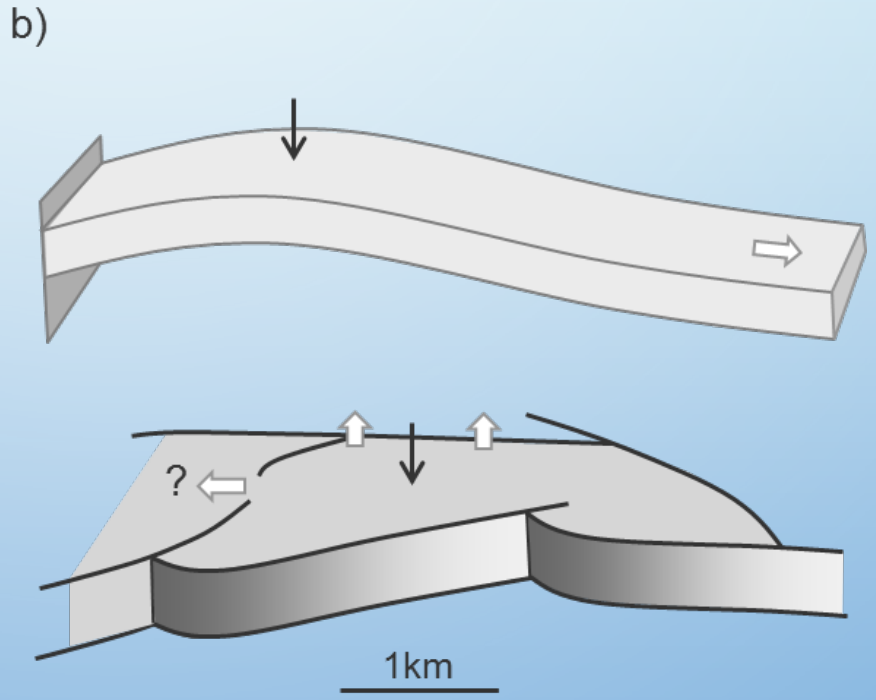


Overview of CO2 storage challenges (Core image courtesy of Sam Krevor, Imperial College London; Lai et al., 2015).

Some reflections on technology for maturing Gt storage - 2

- Much discussion and speculation on practical limits to capacity – especially pressure limits
- But **how do we turn concerns into carefully evaluated capacity estimates for projects**?



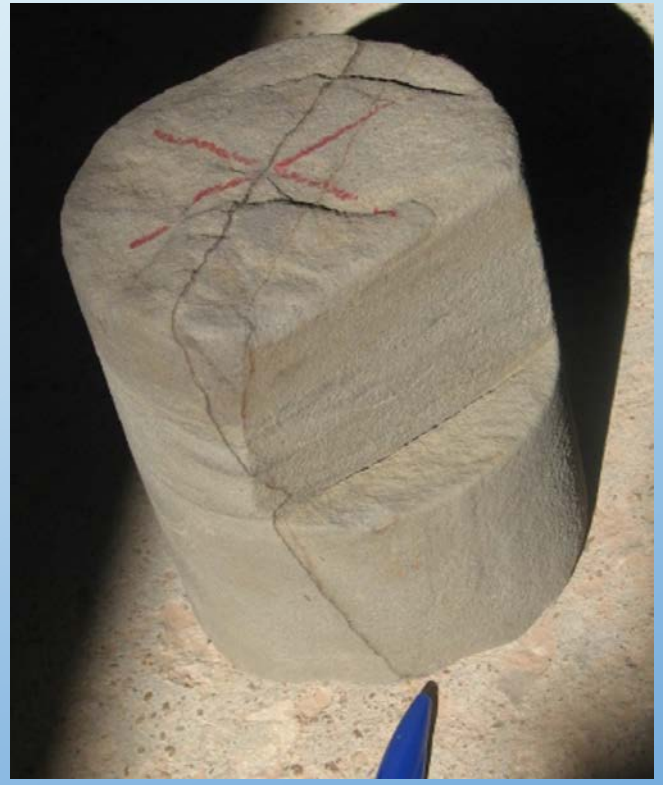


(a) Open, closed, or semi-closed systems [Image from Zhou et al. 2008] (b) Typical 3D geometries of semi-open and semi-closed geologic storage systems.

Some reflections on technology for maturing Gt storage - 3

- Many ongoing R&D projects on monitoring systems, geomechanics/seismicity, well integrity
- But **how do we turn concerns into acceptable risks for managed projects**?

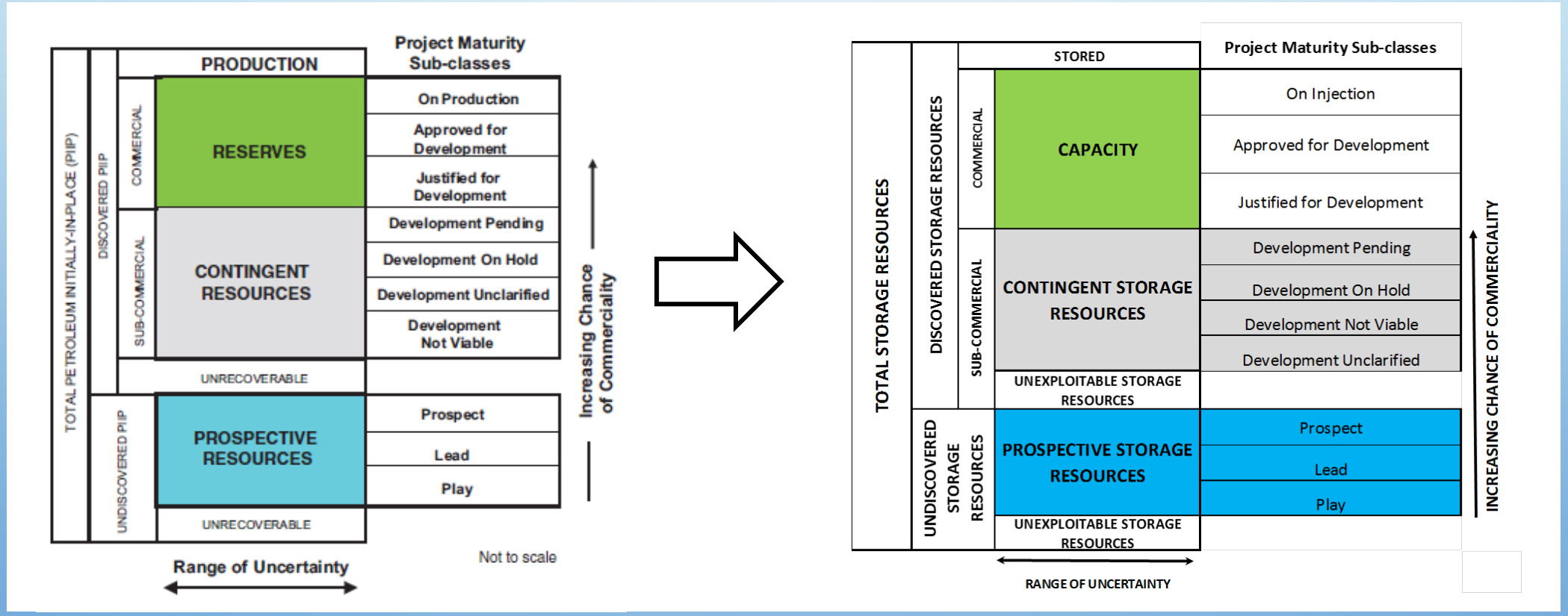
Sub-sea injection monitoring systems (Image from Equinor)



Core analysis

Finding a system for maturing storage resources

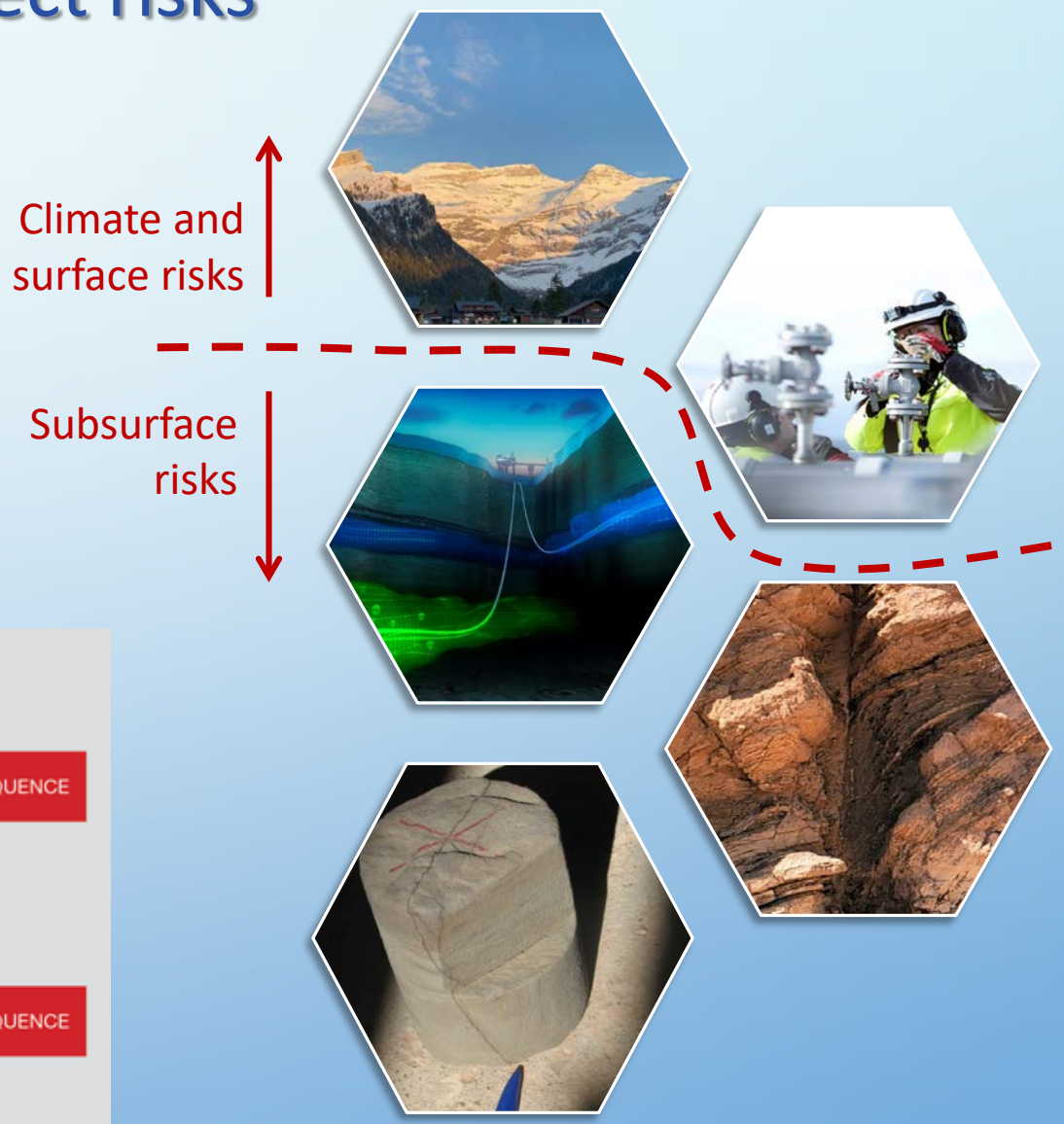
- SRMS (storage resource management system) is a framework for resource reporting derived from long established Petroleum Resources system (SPE)
- ALIGN CCUS project has proposed a practical approach to maturing CO_2 Storage Readiness Levels (SRLs)



Finding ways to manage storage project risks

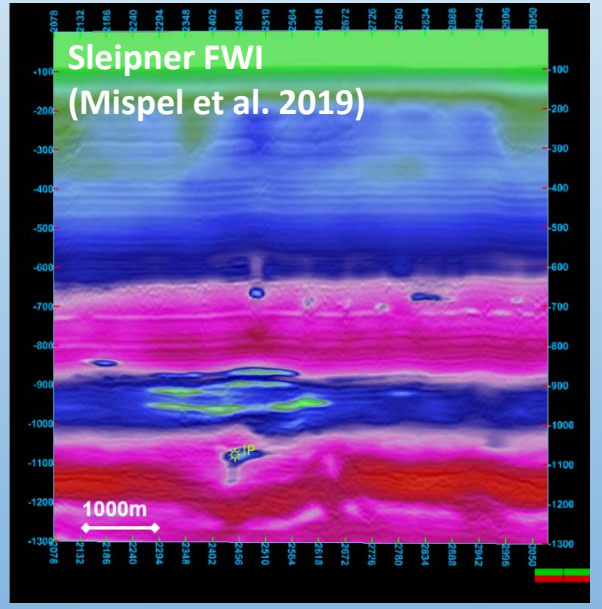
1. Public perception risks
   - Needs effective communication strategy
2. Market failure risks
   - Significant and hard to handle
3. Site performance risks
   - Good track record, technically manageable

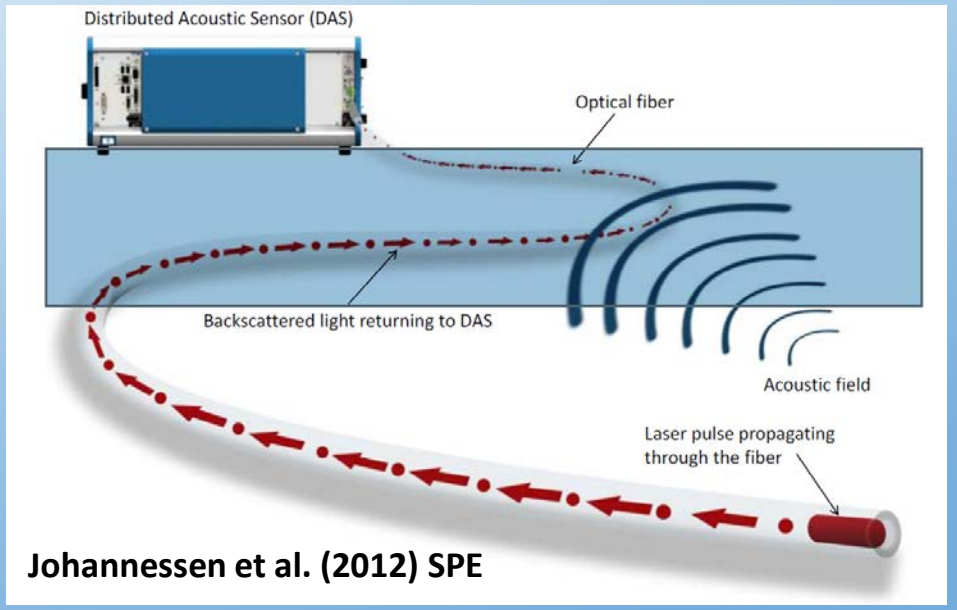
Bow-tie risk assessment methodology is applied to most projects now



Using digitization to build confidence?

1. Continuous monitoring of injection wells and injection sites using fiber-optic sensing
2. Monitoring the overburden and the reservoir using advanced seismic imaging (FWI, FO-VSP, passive sensing)
3. Cost effective environmental surveys
4. ‘Can-do’ attitudes
5. Using HPC power





Johannessen et al. (2012) SPE

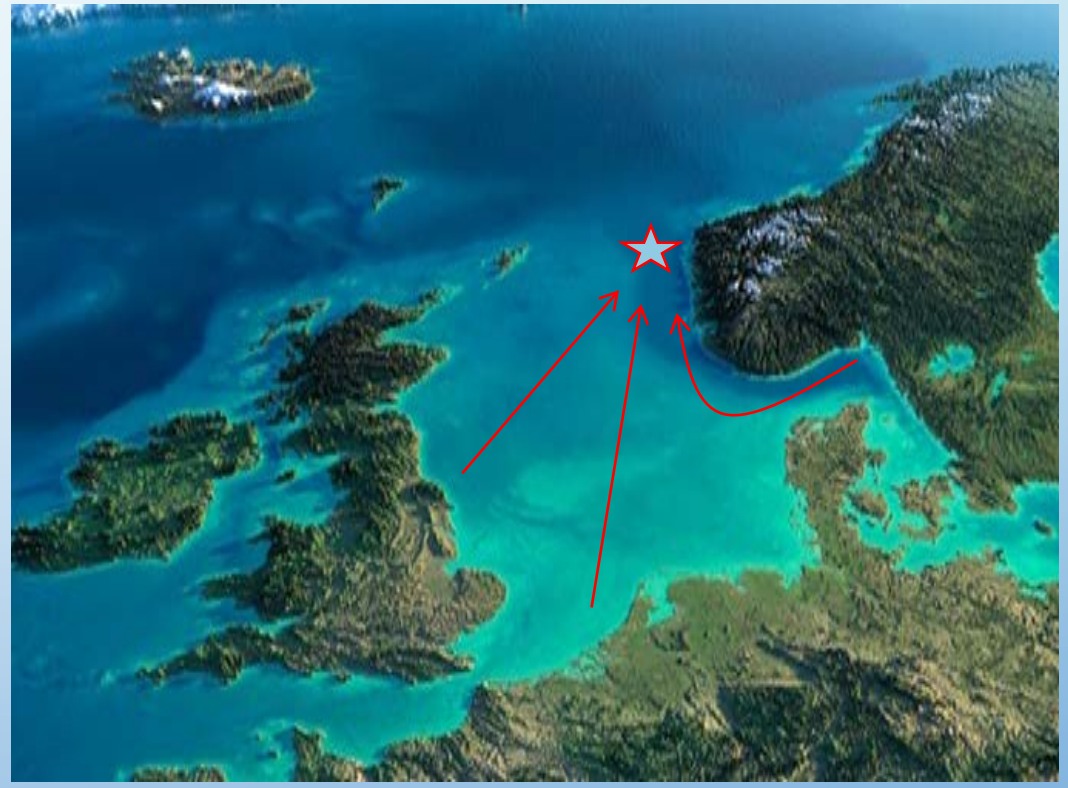
CCS hubs – strength from collaboration

- Northern Lights 'open-source storage' has already been an effective catalyst for CCS in Europe
- But we need more efforts on working together on integrated common solutions for CCS

CO2 storage hubs:

- Reduces risk and threshold for others
- Enables additional CO_2 storage

- Allows stepwise development of CCS from more regional hubs



- Norway CCS hub:
  Catalyst for roll-out of CCS in Europe?

Summary of challenges

1. How do we **transfer learnings** from ‘R&D in the lab’ to emerging storage project developments?
2. How do we turn **concerns about capacity** into carefully evaluated estimates for projects?
3. How do we turn **concerns about storage risks** into acceptable project management plans?
4. How do we **use the digital revolution** to build confidence in CO_2 storage as a public good / climate mitigation action?
5. How do we use **CCS hubs** to accelerate storage?