Progress and challenges in risk management at CCS sites: US perspective

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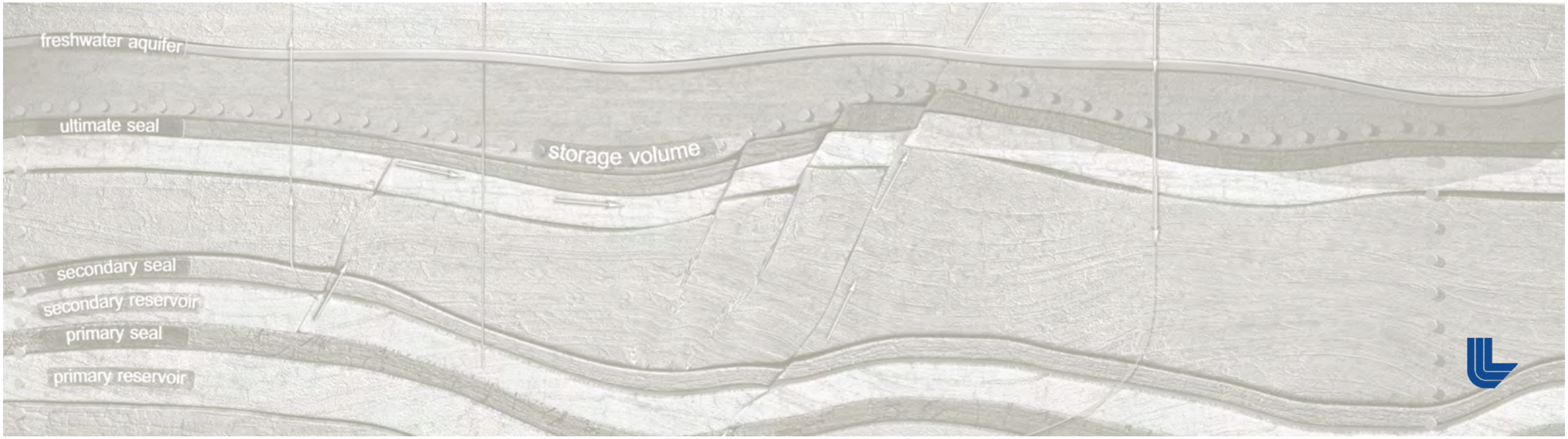

The U.S. Department of Energy National Laboratory System

Mission:
Scientific innovation for challenges of national importance

Goals for today …

1) Discuss current regulatory and policy landscape in the USA

2) Describe field experience with Risk Management at CCS projects

3) Identify a few key needs to accelerate the deployment of CCS

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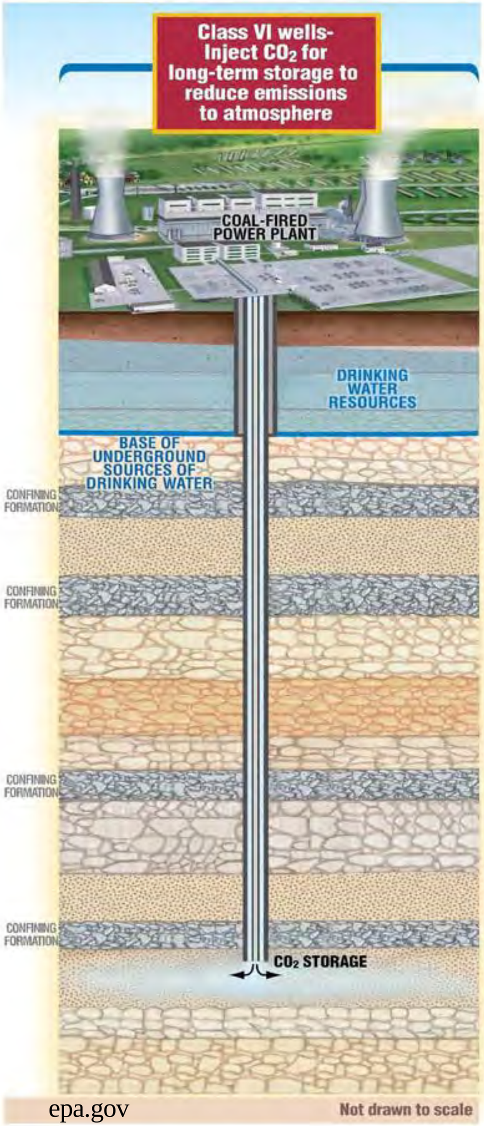
Environmental Protection Agency (EPA)

Safe Water Drinking Act

Underground Injection Control Program (UIC)



Class-II Injection Wells

- Wastewater disposal
- CO_2-enhanced oil recovery

Class-VI Injection Wells

- Long-term CO_2 storage

Estimated and Measured First-of-a-Kind Costs for CCS Applied to Different Plants

Source: Adapted from the Global CCS Institute, 2017. EFI, 2018.

45-Q

Tax Credit Value Available for Different Sources and Uses of CO_2

	Minimum Size of Eligible Carbon Capture Plant by Type ($ktCO_2/yr$)			Relevant Level of Tax Credit in a Given Operational Year ($USD/$tCO_2$)									
Type of CO_2 Storage/Use	Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	2025	2026	Beyond 2026
Dedicated Geological Storage	500	100	100	28	31	34	36	39	42	45	47	50	Indexed to Inflation
Storage via EOR	500	100	100	17	19	22	24	26	28	31	33	35	
Other Utilization Processes[1]	25	25	25	17[2]	19	22	24	26	28	31	33	35	

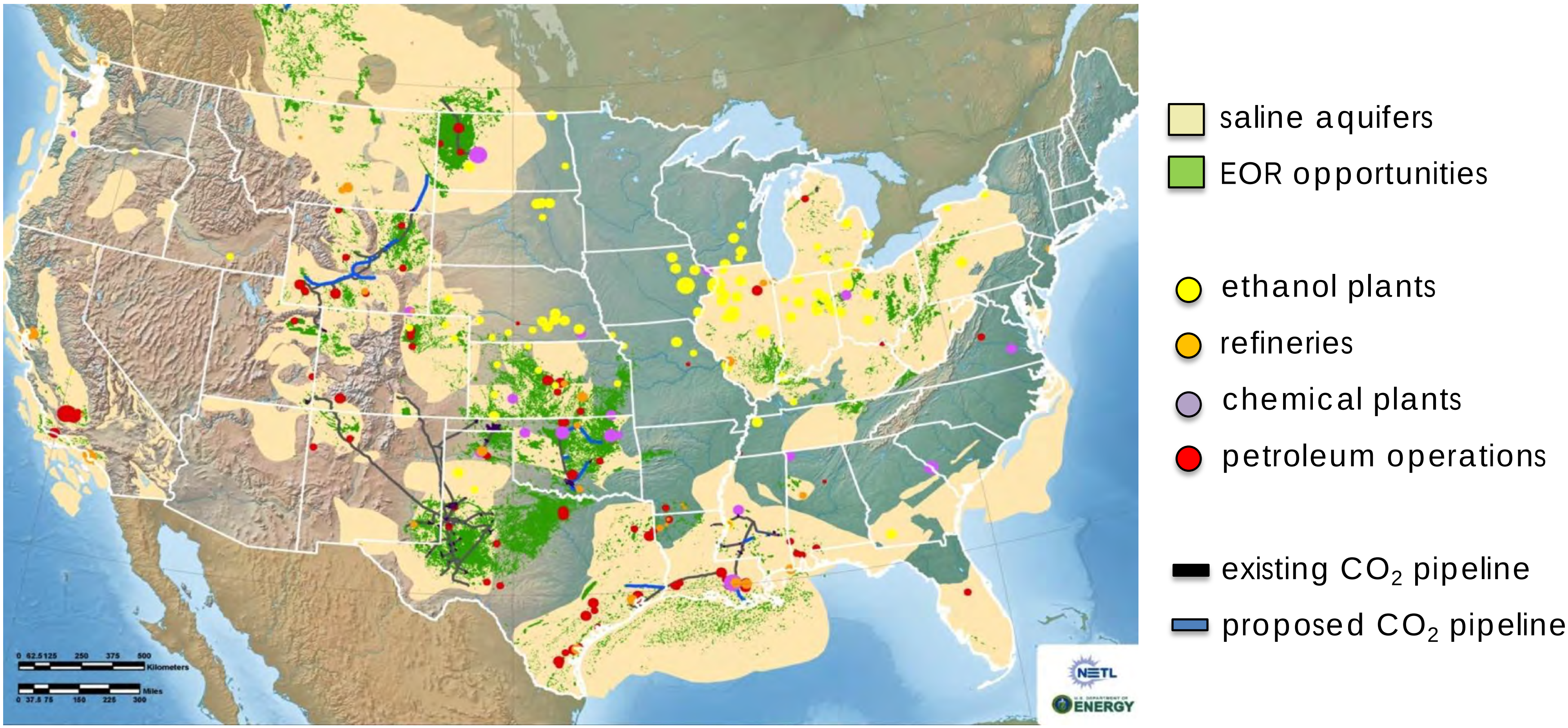
[1] Each CO_2 source cannot be greater than 500 $ktCO_2/yr$

[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions

ENERGY FUTURES INITIATIVE

Source: Closely adapted from Simon Bennett and Tristan Stanley, Commentary: US budget bill may help carbon capture get back on track, International Energy Agency.

Opportunities for carbon management in the industrial sector



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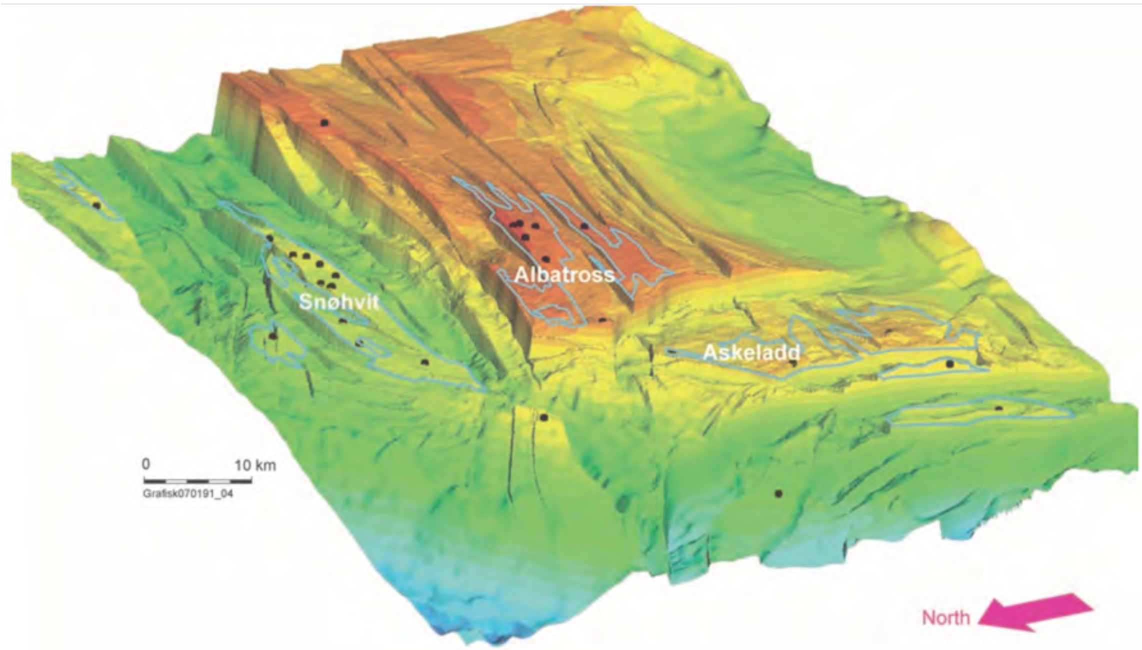
Storage projects are designed around two competing goals:

1) Storage volume
2) Storage security



Key hazards considered in design and operations:

1) Wellbore leakage
2) Fault leakage
3) Hydraulic fracturing

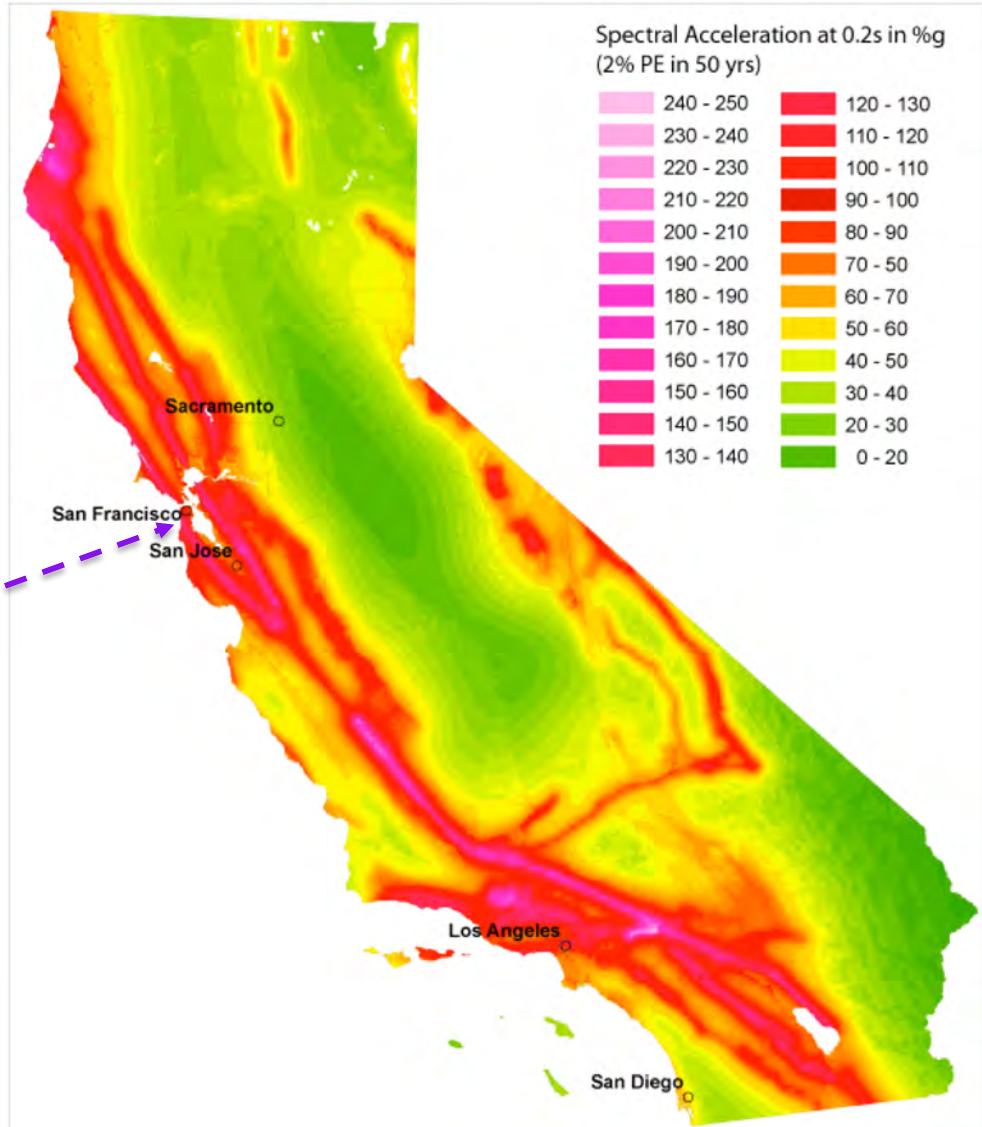
Pathways for brine and/or CO_2 to escape storage zone

4) Induced seismicity

Earthquake nuisance potential

Components of risk ....

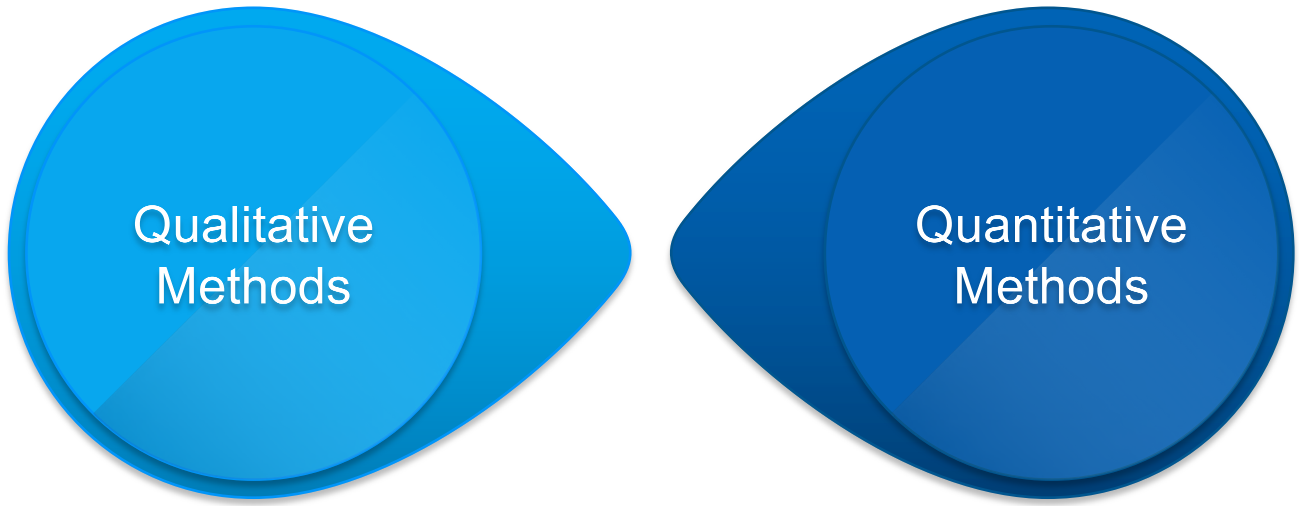
1) One or more scenarios of concern
2) The probability of the scenario occurring (hazard)
3) The probability of resulting damage (vulnerability)


Spectral Acceleration at 0.2s in %g
(2% PE in 50 yrs)
240 - 250
230 - 240
220 - 230
210 - 220
200 - 210
190 - 200
180 - 190
170 - 180
160 - 170
150 - 160
140 - 150
130 - 140
120 - 130
110 - 120
100 - 110
90 - 100
80 - 90
70 - 50
60 - 70
50 - 60
40 - 50
30 - 40
20 - 30
0 - 20
Sacramento
San Francisco
San Jose
Los Angeles
San Diego

Context …

- It is important to talk about the things that can go wrong with CCS.
- Like any industrial activity, CCS involves some risk.
- We pursue CCS to avoid the much larger risk of global climate change.
- Empirical experience across many projects demonstrates that it can be deployed safely and responsibly.

How do we assess (and manage) risk for a CCS project?



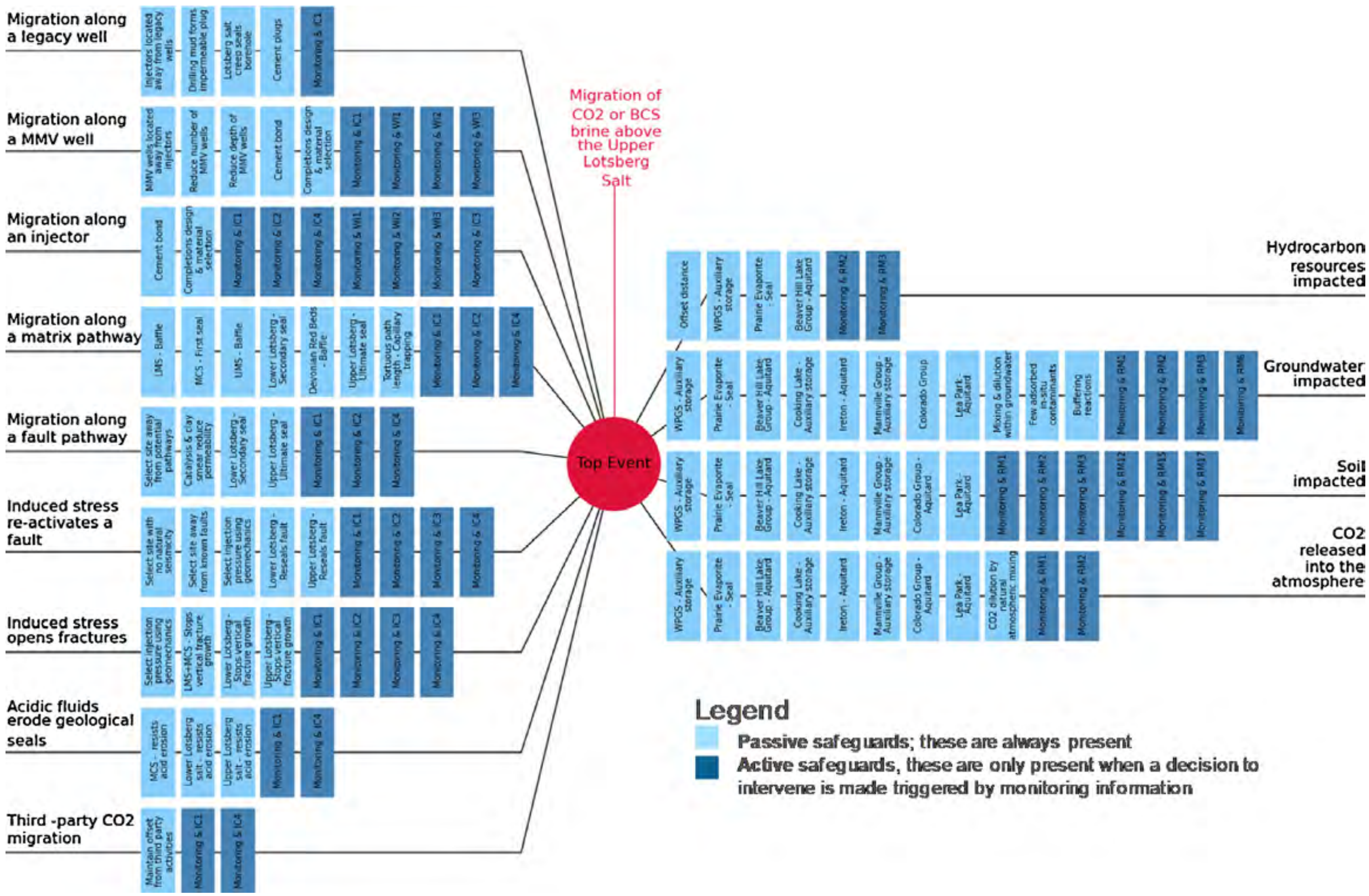
Qualitative Methods

- Structured Expert Solicitation
- Widely used in industry
- Well-suited to complex systems
- Open to bias

Quantitative Methods

- Probabilistic Methods
- Objective
- Garbage in, garbage out
- Little utility for “black-swan” events

Quest Project - Bowtie Diagram



[Bourne et al. 2014, Pawar et al. 2015]

Key Risks for CCS Projects – US Perspective

Market Risk

- Financing and liability
- CO_2 Source Availability

Technical Risk

- Wellbore leakage in legacy wells
- Unexpected capacity and injectivity limits
- Induced seismicity
- Long-term monitoring costs / obligations

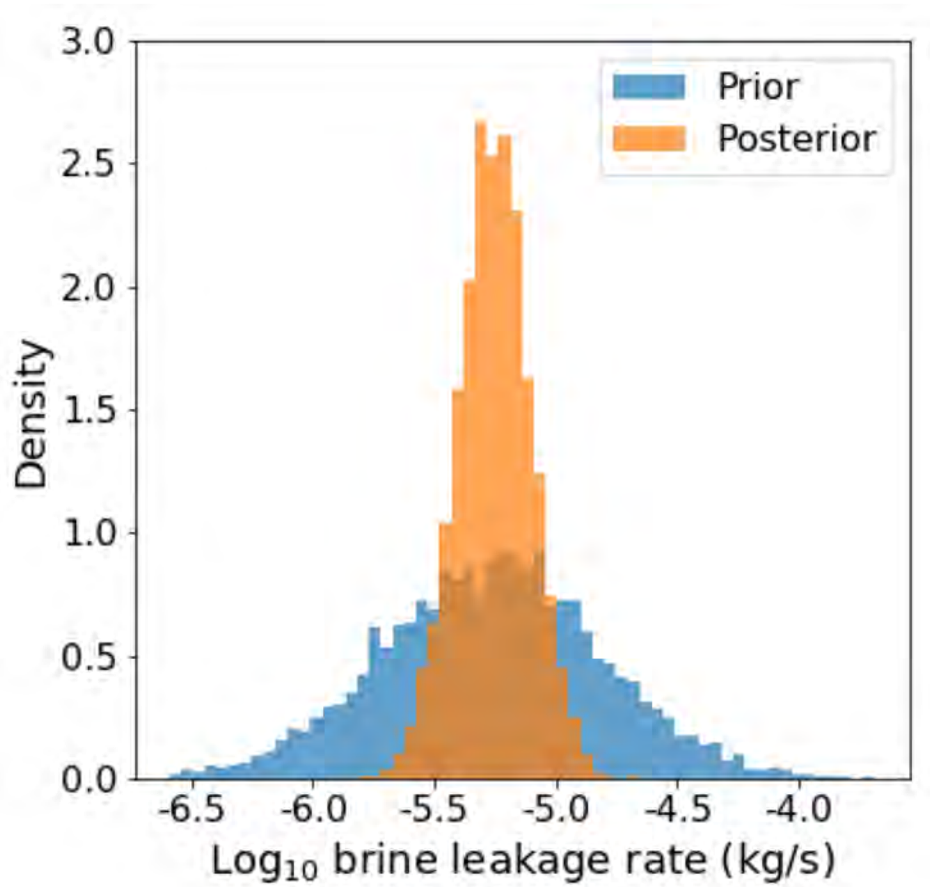
Technical Risk 1: Wellbore Leakage

Legacy Wellbore Leakage – Salt Creek CO_2-EOR Case Study

Helicopter-based magnetic survey [Hendricks 2009, NRDC 2017]

Legacy Wellbore Leakage – Salt Creek CO_2-EOR Case Study

Legacy Wellbore Leakage – Probabilistic Risk Assessment



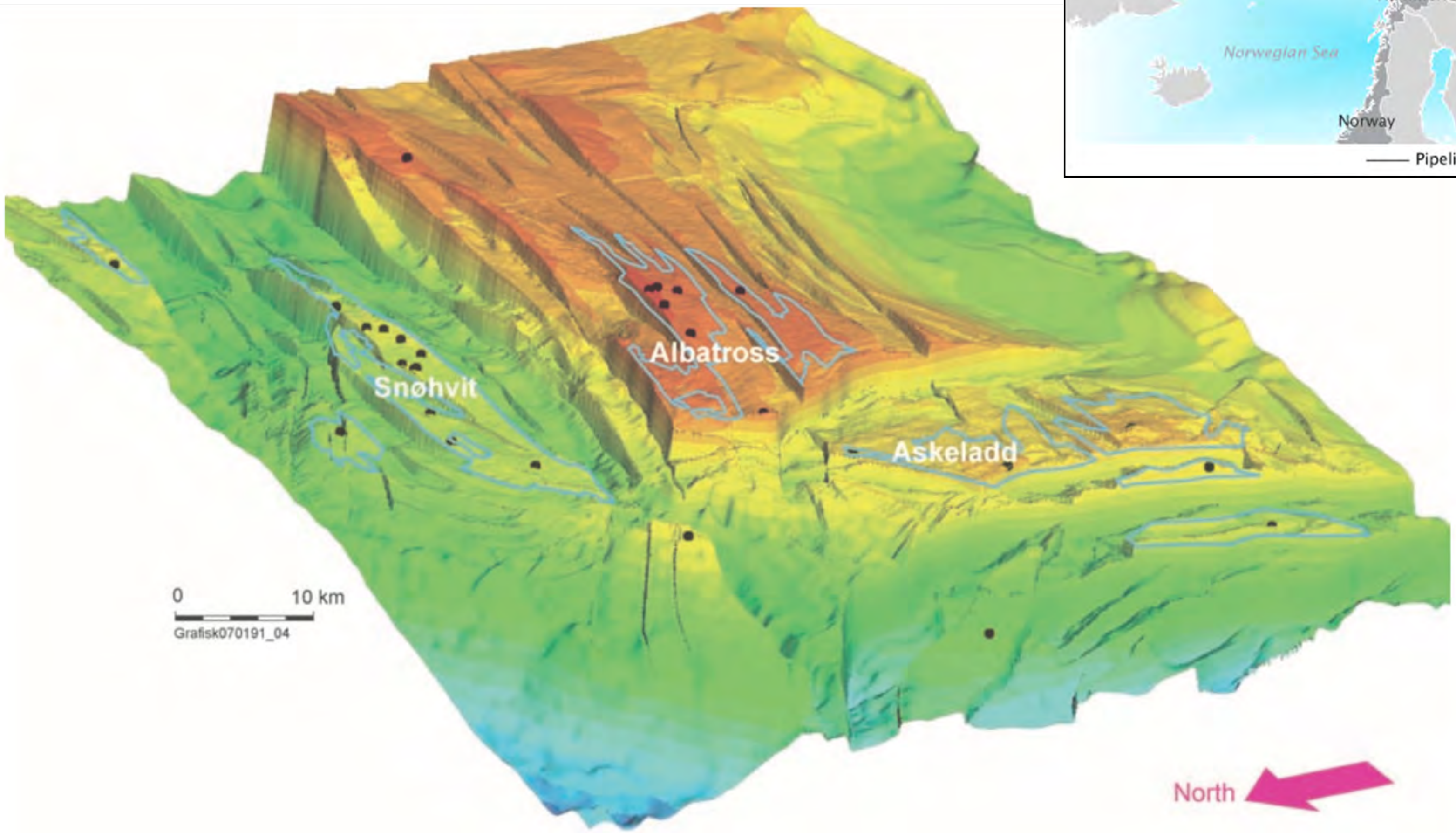
NRAP Integrated Assessment Model, 2018

Recommendations:

- Maintain a common database of well schematics, repair logs, and monitoring observations.
- Use probabilistic methods to quantify risk and update constantly with new information.
- Use results to inform inspection frequency and similar decisions.
- Avoid sensitive receptors and deploy multiple leak barrier strategies.
- Research community should invest in novel leak detection sensing.

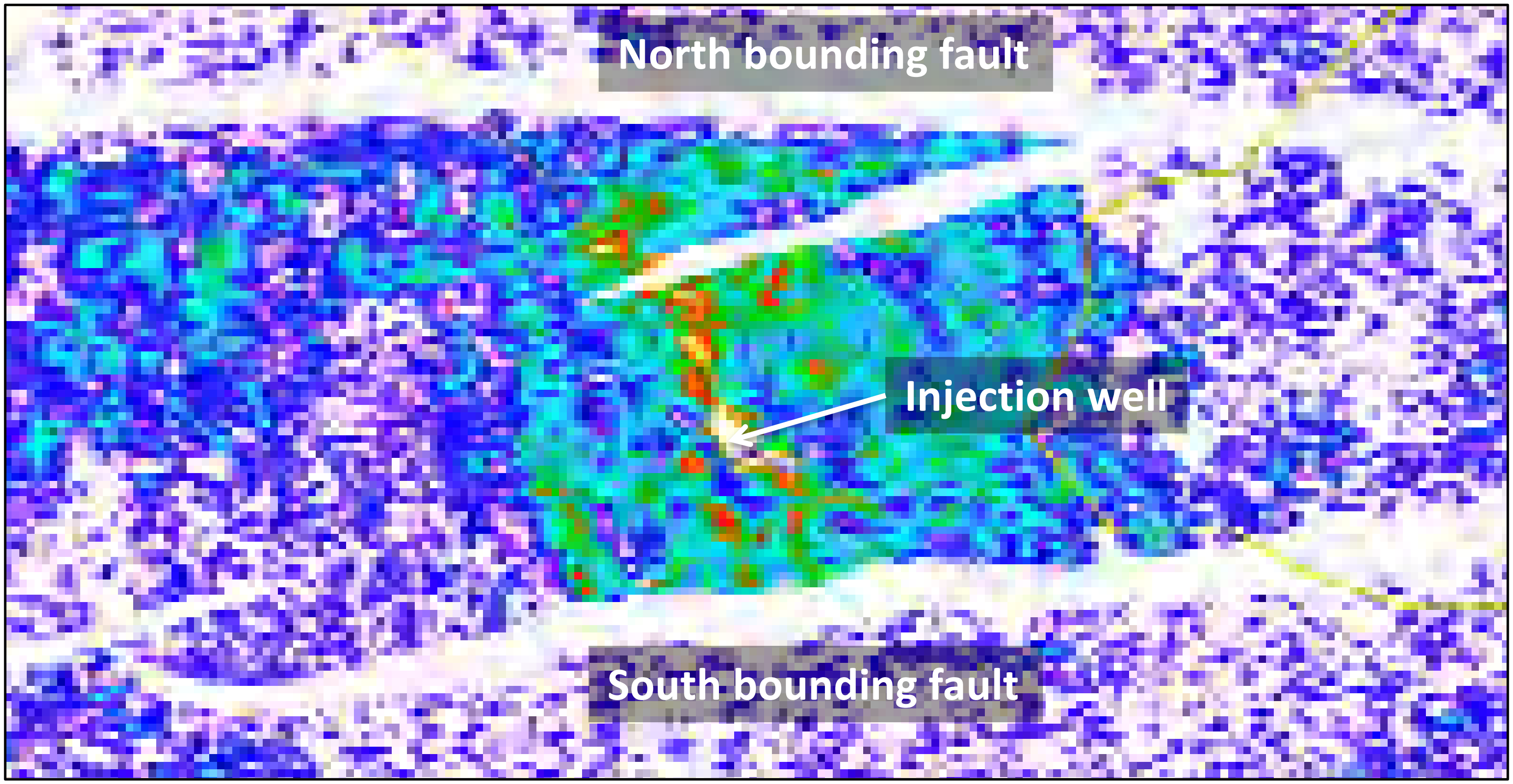
Technical Risk 2: Capacity and Injectivity Limits

Snøhvit CCS Project



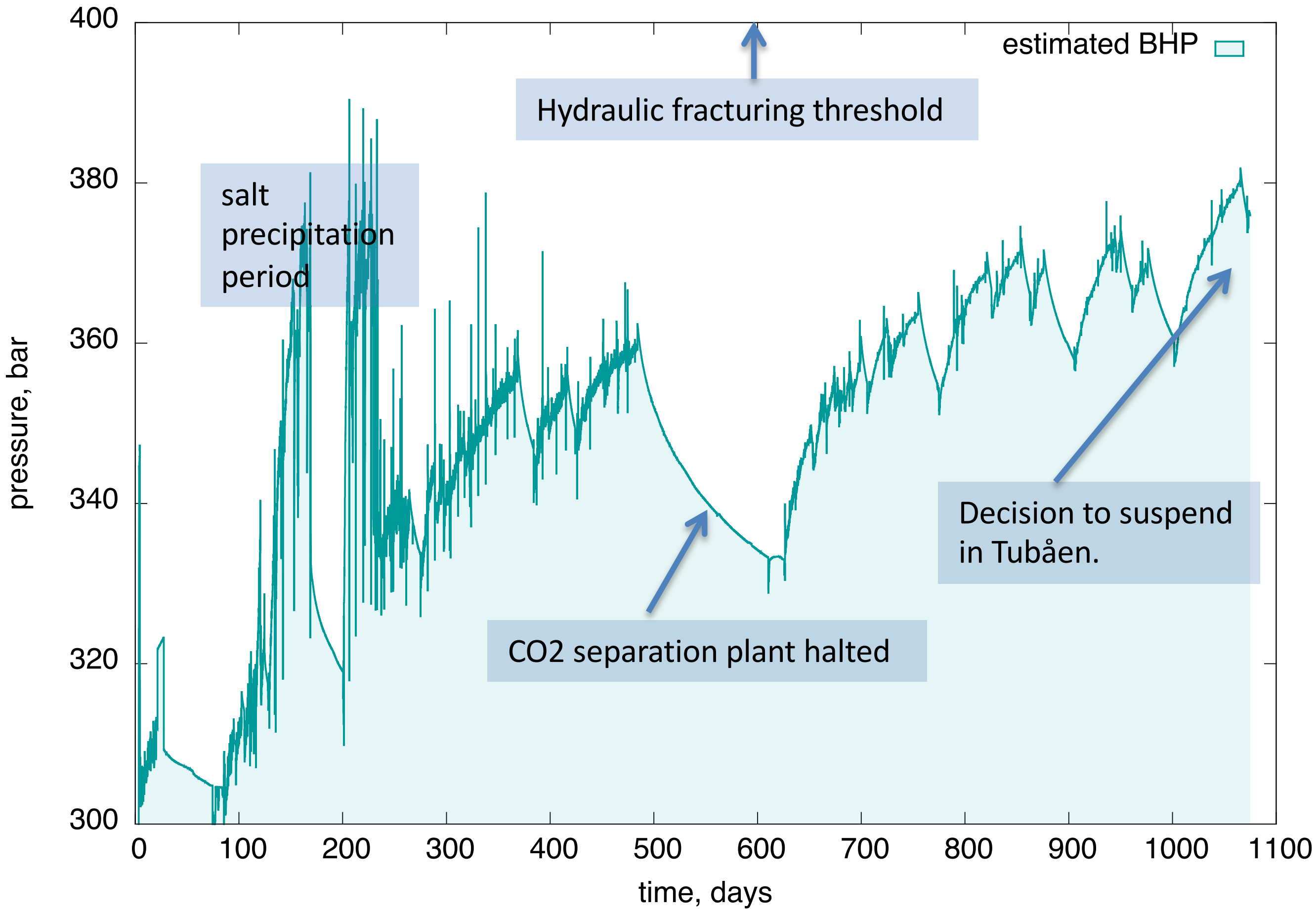
[Spencer et al. 2008, Chiaramonte et al. 2014]

Snøhvit CCS Project



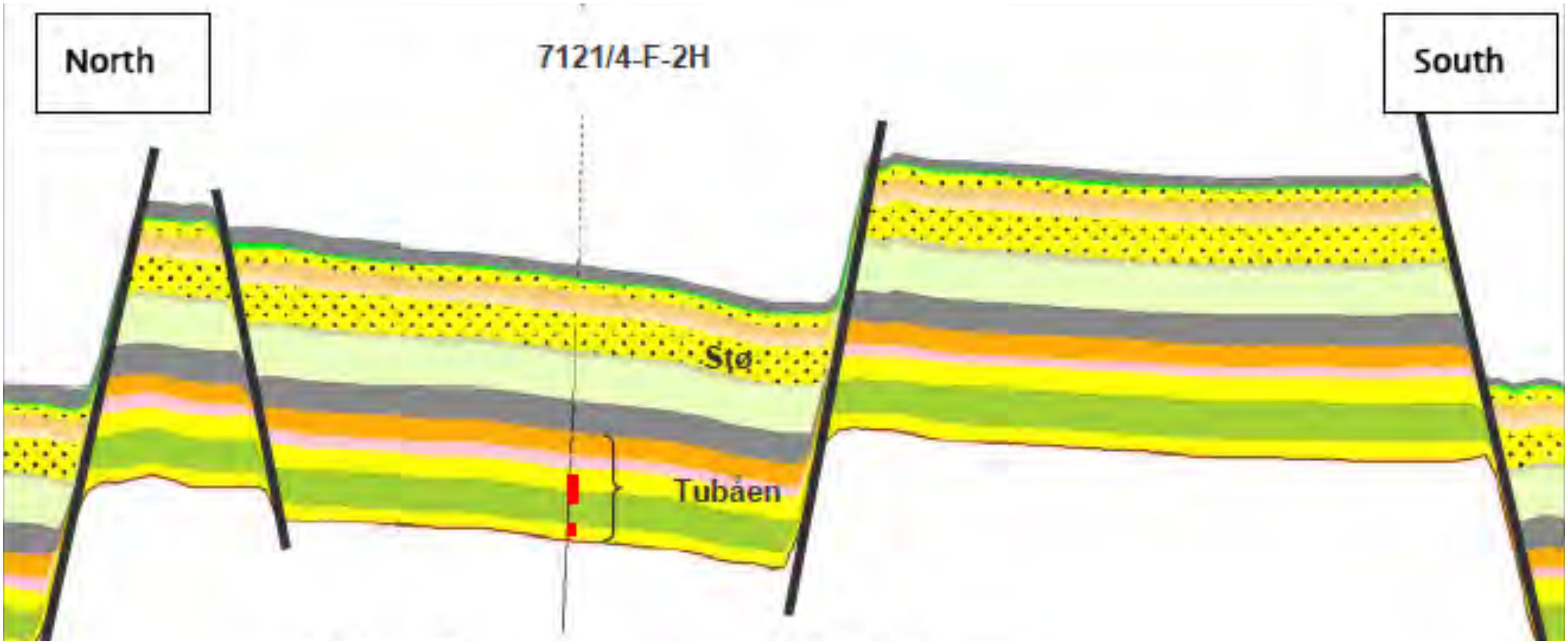
4D Seismic Difference Amplitude Map [Hansen et al. 2012]

Snøhvit CCS Project – Tubåen Injection



[Statoil]

Snøhvit CCS Project



N-S vertical cross section showing Tubåen and Stø formations, providing multiple injection targets

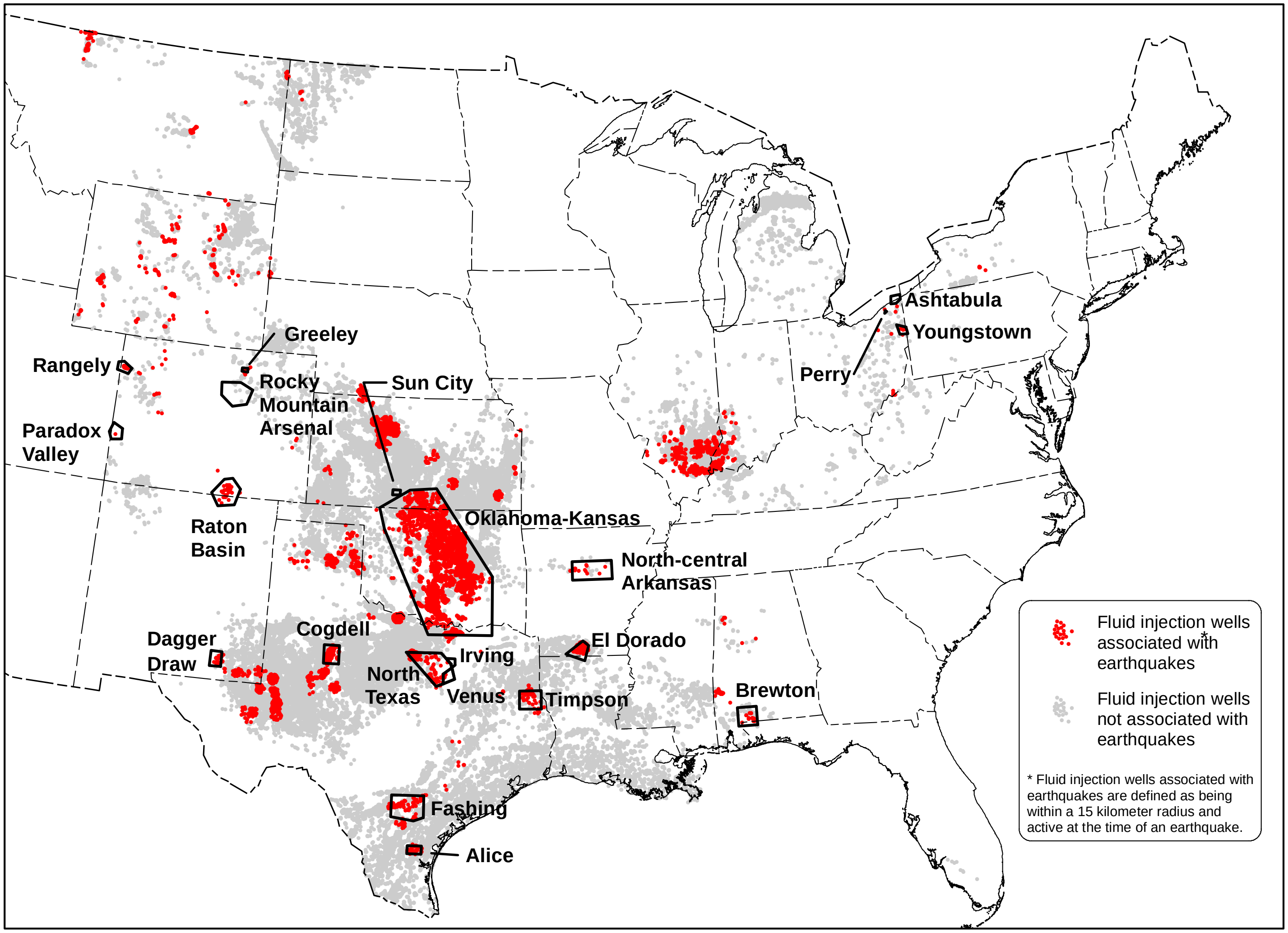
Capacity and Injectivity

Recommendations:

- Have a backup plan—i.e. wells with multiple injection horizons available
- Focus on a hub model of CCS deployment, using previous success to place new wells
- Research community should invest in site characterization and monitoring methods, as well as well design and permeability-stimulation methods.

Technical Risk 3: Induced Seismicity

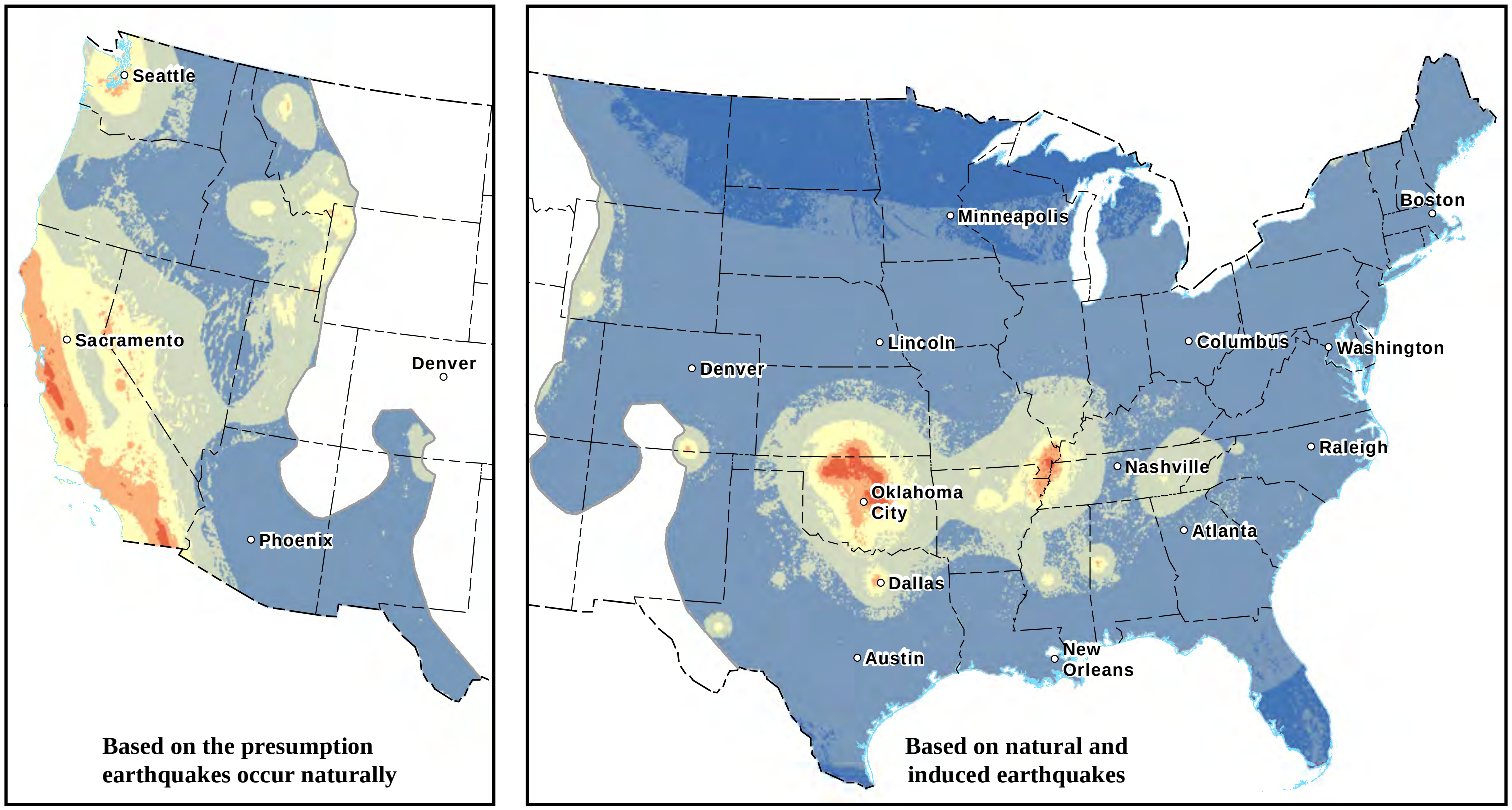
USGS Map of 21 Areas Impacted by Induced Earthquakes



USGS map displaying 21 areas impacted by induced earthquakes as well as the location of fluid injection wells that have and have not been associated with earthquakes.

[USGS 2016]

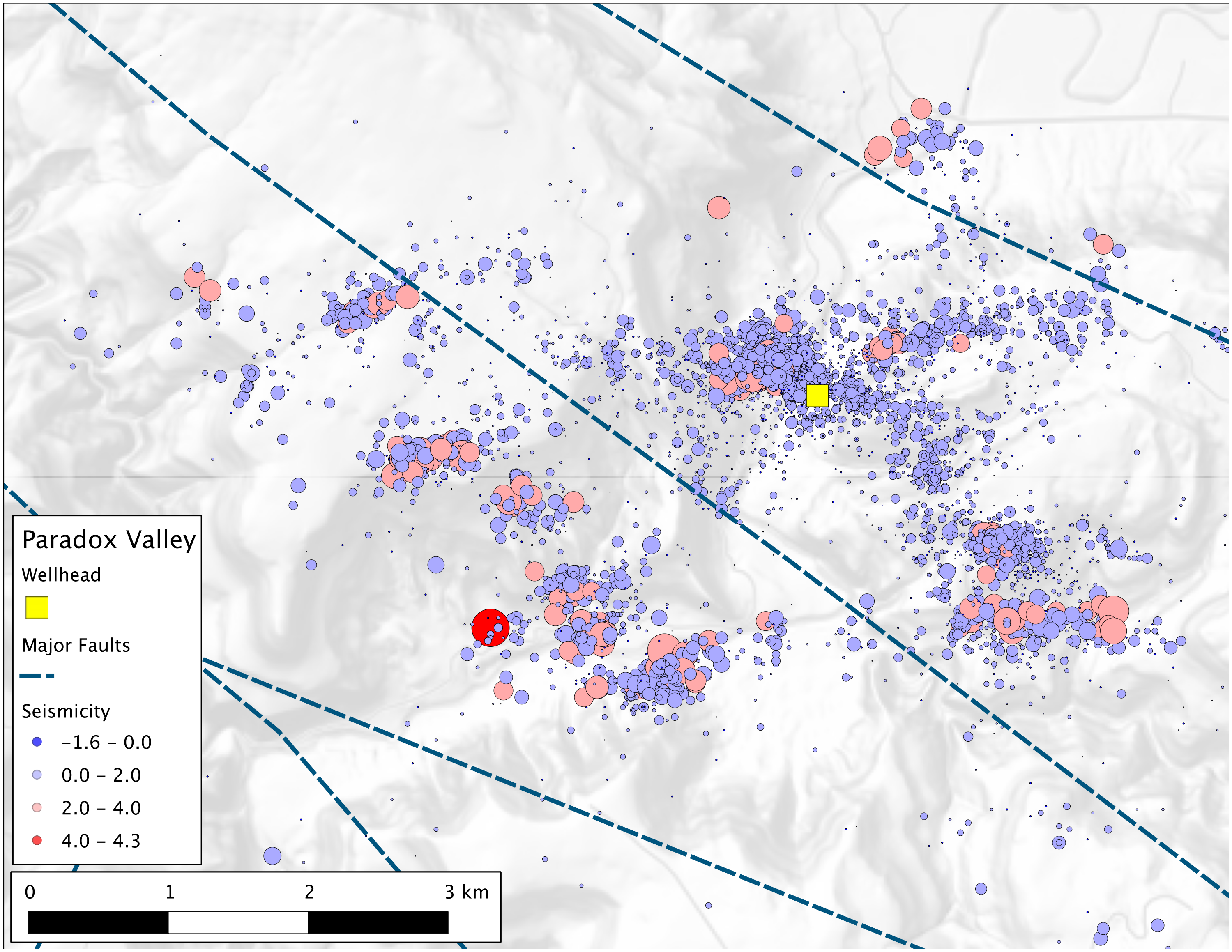
USGS Forecast for Ground Shaking Intensity from Natural and Induced Earthquakes in 2016



Modified Mercalli Intensity

VIII+	Shaking severe, heavier damage
VII	Shaking very strong, moderate damage
VI	Shaking strong, felt by all, minor damage
V	Shaking moderate, felt indoors by most, outdoors by many
IV	Shaking light, felt indoors by many, outdoors by few
III	Shaking weak, felt indoors by several

[USGS 2016]



Induced seismicity

Paradox Valley Brine Disposal Unit

Colorado, USA

[Data: Bureau of Reclamation]

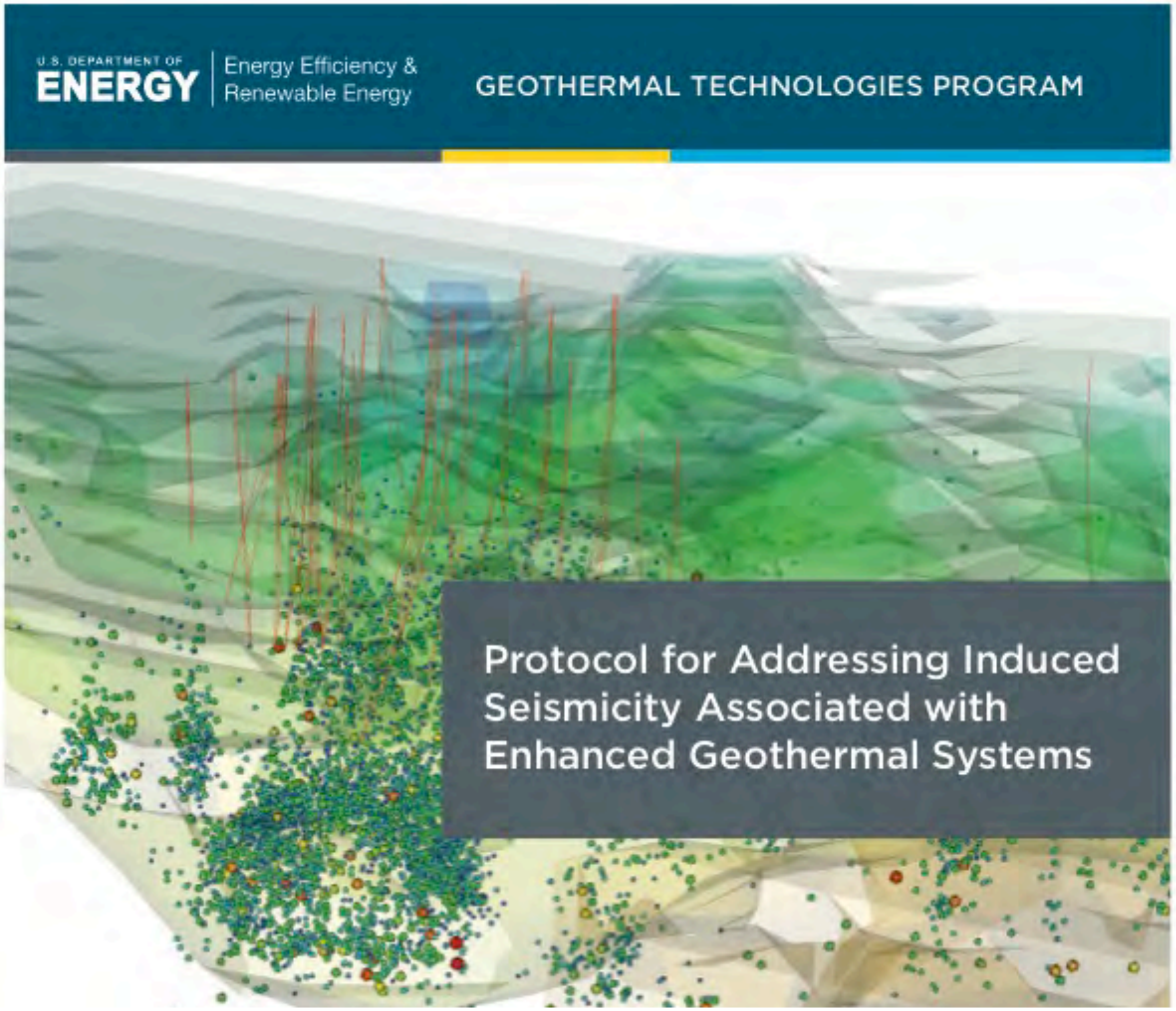
Seismicity observed at CO_2 injection operations

Operation	Category	Max Observed Magnitude	Seismicity Type
Aneth USA	CO2-EOR	M 0.8	Type II
Cogdell USA	CO2-EOR	M 4.4	Type I
Weyburn Canada	CO2-EOR	M -1	Type II
Decatur USA	Dedicated Storage	M 1	Type I
In Salah Algeria	Dedicated Storage	M 1	Type I & II

Type I = Seismicity concentrated within overpressured zone.
Type II = Seismicity outside overpressured zone.

Aneth: Rutledge 2010, Zhou et al. 2010, Soma & Rutledge 2013. **Cogdell**: Gan and Frohlich 2013, Davis and Pennington 1989. **Weyburn**: Whittaker et al. 2011, White et al. 2011, Verdon et al. 2010 & 2011. **Decatur**: Will et al. 2014, Couëslan et al. 2014, Kaven et al. 2014 & 2015. **In Salah:** Oye et al. 2013, Goertz-Allman et al. 2014, Verdon et al. 2015.

Carbon Storage Seismicity Protocol: Ongoing Effort



- Starting Point: GTO Geothermal Seismicity Protocol (2012).
- Goal: Develop best-practices guidelines relevant for US carbon storage
- See also: Many relevant reports completed / underway by other countries and organizations

Reference: E. Majer et al (2012).

GTO Seismicity Protocol: Key Steps

Step 1	Perform a preliminary screening evaluation.
Step 2	Implement an outreach and communication program.
Step 3	Review and select criteria for ground vibration and noise.
Step 4	Establish seismic monitoring.
★ Step 5	Quantify the hazard from natural and induced seismic events.
Step 6	Characterize the risk of induced seismic events.
Step 7	Develop risk-based mitigation plan.

Reference: E. Majer et al (2012).

Induced Seismicity

Recommendations:

- Avoid pressure communication with brittle basement units
- All projects should deploy passive seismic monitoring
- All projects need a comprehensive seismic risk management plan
- Focus on a hub model of CCS deployment, using previous success to place new wells
- Research investments: novel passive seismic monitoring techniques, real-time hazard forecasting methods, and US-offshore CCS targets.

[White et al. 2016]

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Key hurdles hindering storage project deployment include:

1. Policy commitment to mitigating climate change
2. Accelerating project permitting timelines
3. Public perception and risk communication issues

Technical risks exist, but many successful projects demonstrate that they can be managed.

Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage

Report of the Mission Innovation Carbon Capture, Utilization, and Storage Experts' Workshop

Mission Innovation
September 2017

Questions ?

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