Numerical Simulation of Commercial-Scale CO_2 Storage in a Saline Formation Evaluating Basin-Scale Pressure Interference and CO_2 Plume Commingling

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Management Project Review Meeting
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Outline

– Project Overview.

– Accomplishments to Date:

- Modeling suite.
- Modeling descriptions.
- Simulation results.
- Publications.

– Lessons Learned.

Why Basin-Scale Modeling Is Critical

Decarbonization Goals

Executive Order 14008

- 50% emission reduction by 2030.
- CO_2 emission-free (carbon pollution-free) power sector by 2035.
- Overall net-zero emission economy by no later than 2050.

Rapid Carbon Capture and Storage (CCS) Growth Needed

CarbonSAFE Targets

- By 2025 Validation Phase: 5 Mt/year injectivity and 250 Mt capacity.
- By 2030 Activation Phase: 65 Mt/year injectivity and 2,000 Mt capacity.
- By 2035 Expansion Phase: 250 Mt/year injectivity and 7,500 Mt capacity.
- By 2040 At-Scale Phase: 450 Mt/year injectivity and 13,500 Mt capacity.
- By 2050 Midcentury: >1,000 Mt/year and >30,000 Mt capacity.

Bipartisan Infrastructure Law

a.k.a. Infrastructure Investment and Jobs Act

Investment Area:

- Carbon Capture Demonstration Projects and Large-Scale Pilots: $3.5B
- Low-Interest Loans to Large CO_2 Pipeline Projects: $2.1B
- Large-Scale Carbon Storage Projects: $2.5B
- Four Regional Direct Air Capture Hubs: $3.5B

45Q Incentives and Potential Enhancement

Build Back Better Act

- Expanded and revised several times since initially established in 2008.
- Carbon Capture Utilization and Storage Tax Credit Amendments Act, introduced in March 2021, to increase the 45Q credit values.

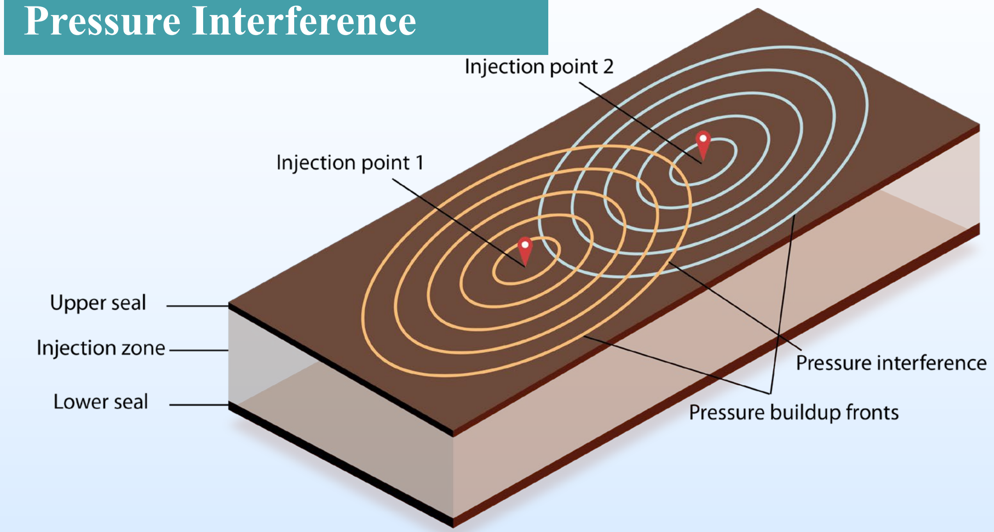
Basin-Scale Analysis and Modeling

*Mt = million metric tons

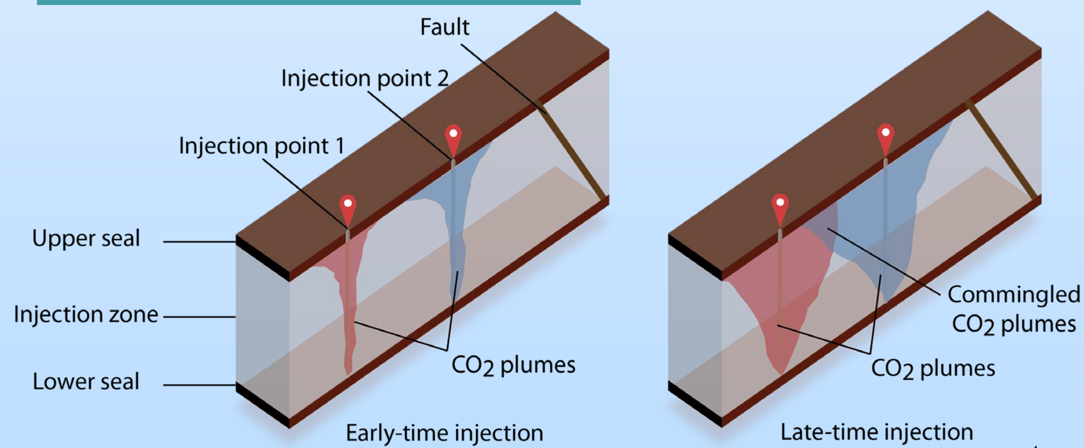
CO_2 Storage at Basin Scale

- Pressure interference between adjacent commercial-scale CO_2 injection into saline formations in a shared sedimentary basin may occur, potentially increasing subsurface risks associated with:
  - Wellbore leakage.
  - Fault leakage.
  - Induced seismicity.
- Pressure buildup could also increase the cost of geologic CO_2 storage by:
  - Limiting CO_2 injection rates, requiring more injection wells.
  - Constraining dynamic storage capacities to be below estimated based on accessible pore volume.
  - Requiring adaptive pressure management measures (i.e., brine extraction).
- CO_2 plume commingling could raise concerns over CO_2 accounting and liability guidelines in performing corrective actions in case of potential CO_2 leakage risks.

Pressure Interference



CO_2 Plume Commingling



Objectives

Basin-Scale Modeling

CO_2 Plume Extent

Pressure Buildup Aerial Extent

Pressure Buildup Magnitude

Pressure Interference

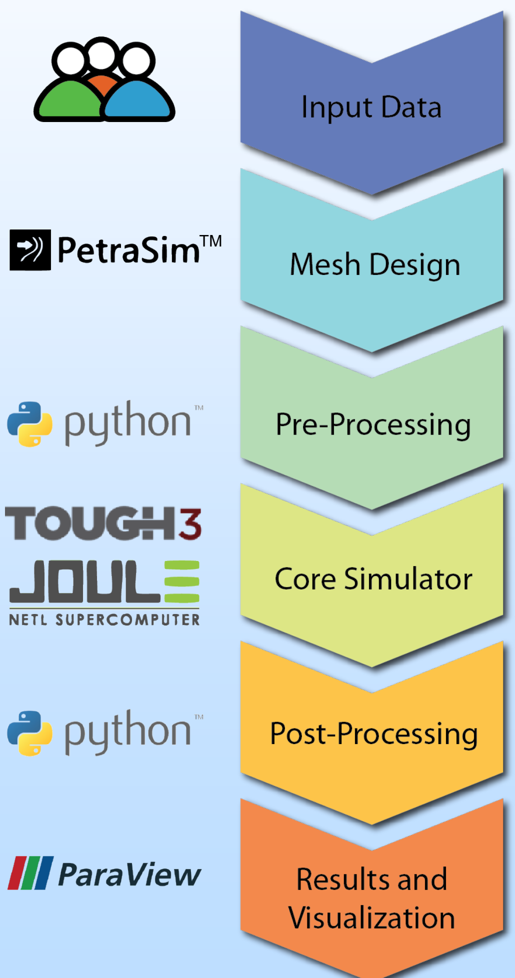
Assess factors that influence the Area of Review per Class VI regulations, such as CO_2 plume front and pressure buildup front.

Provide support of site screening and selection and injection design considerations.

Demonstrate importance of interproject coordination.

Accomplishments to Date

Demonstration of TOUGH3-ECO2M reservoir simulator and development of full-cycle reservoir simulation methodology

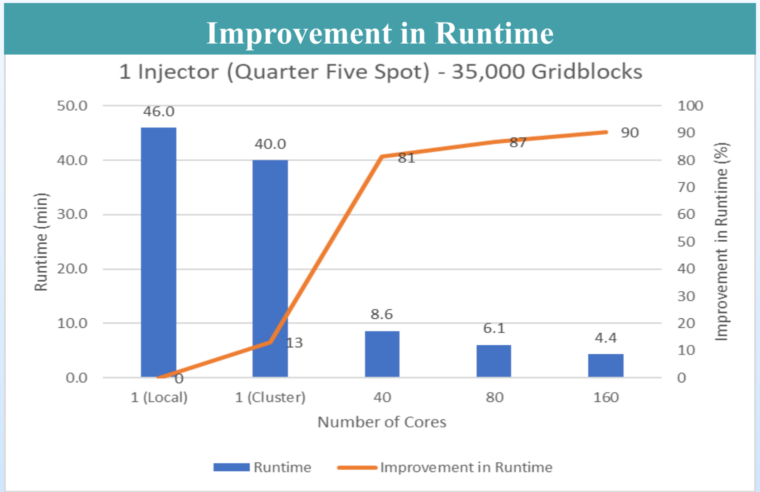


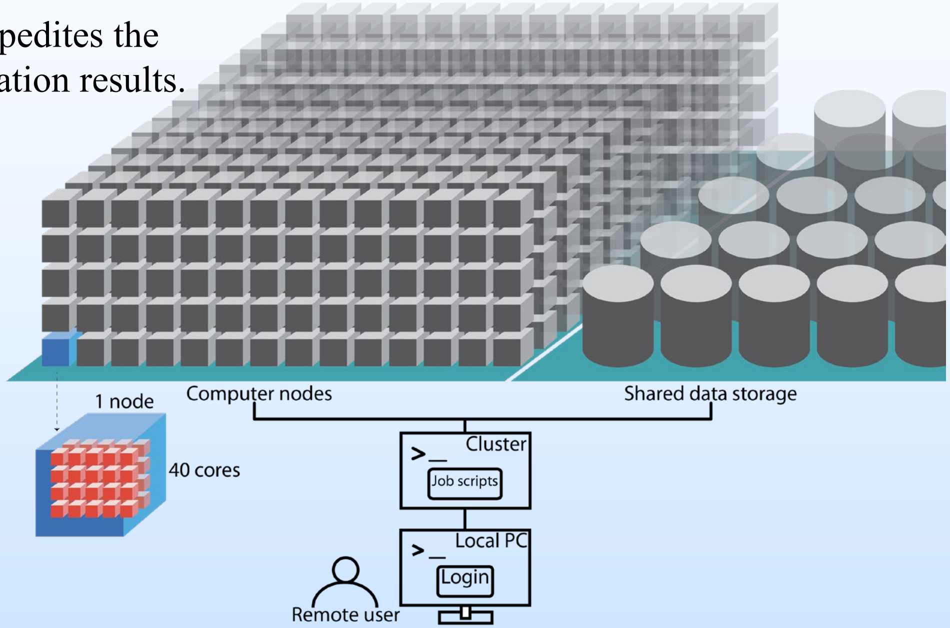
- TOUGH3 is a multi-component, multi-phase, non-isothermal flow simulator with parallelization supported.
- ECO2M is an EOS module that allows partitioning of water and CO_2 between phases; dissolution/precipitation of salt; and phase change between liquid-rich and gaseous-rich CO_2.
- NETL supercomputer Joule 2.0 is among the most powerful in the world (24th in the U.S. and 70th in the world) according to a 2020 ranking by TOP500.
- ParaView is an open-source tool for advanced visualizations and results analytics and automated workflow.
- Python-based pre- and post-processing tools were developed in-house to prepare PetraSim™ input data files to be compatible with Joule as well as to parse output data files compatible with ParaView.
- This suite of tools allows a full-cycle reservoir simulation methodology for geologic CO_2 storage and, potentially, other subsurface research domains.

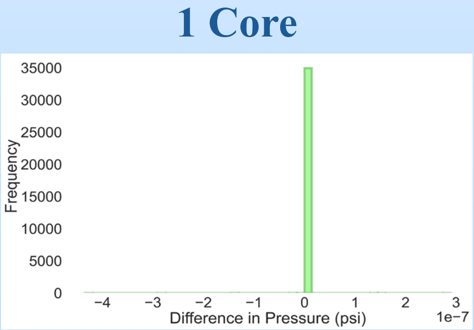
Accomplishments to Date

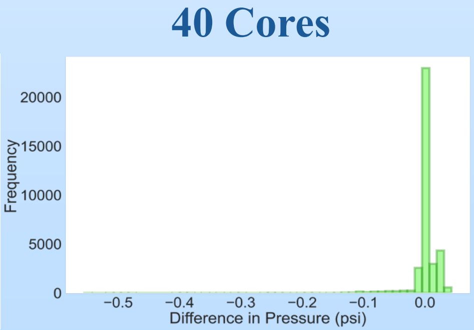
Leveraging NETL supercomputer Joule 2.0 for fast parallel simulation runs

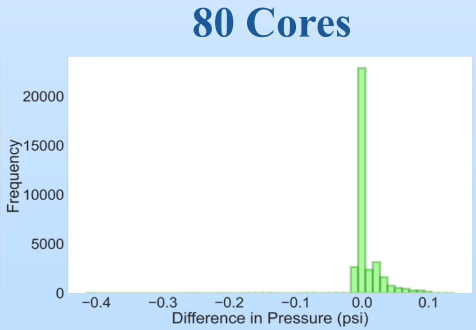
Running 3-D models on the supercomputer significantly expedites the runtime while maintaining the numerical accuracy of simulation results.

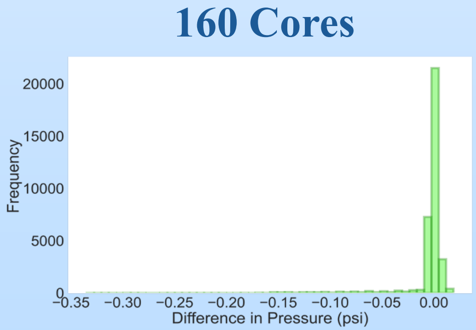










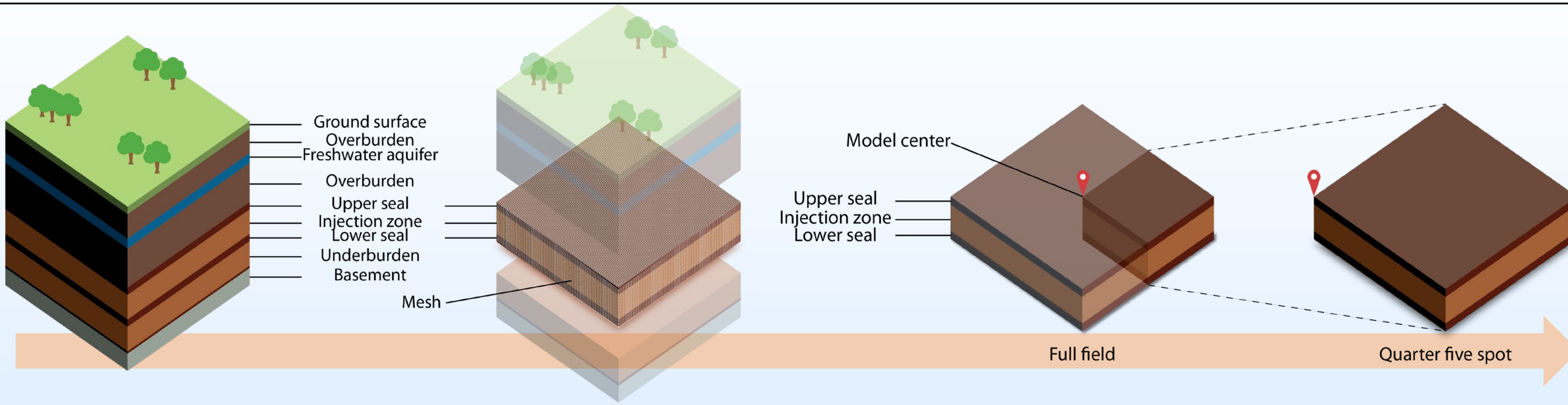


Model Descriptions

Reservoir Parameter Assumptions				
Parameter	**Unit**	**Upper Seal**	**Injection Zone**	**Lower Seal**
Thickness	m	60	200	20
Porosity	%	5	10	5
Permeability (k_h)	mD	$1x10^{-3}$	50	$1x10^{-4}$
k_v/k_h	-	0.3	0.3	0.3
Top depth	m	940	1000	1200
Pore compressibility	Pa^{-1}	$1x10^{-10}$	$1x10^{-10}$	$1x10^{-10}$
Lateral boundary	-	Closed	Closed	Closed
Vertical (top) boundary	-	Closed	-	-
Vertical (bottom) boundary	-	-	-	Closed

- Conceptual basin-scale model (homogeneous saline formations).
- CO_2 injection rate = 1 Mt/yr/well.
- Injection duration = 30 years.
- Post Injection Site Care (PISC) duration = 50 years.

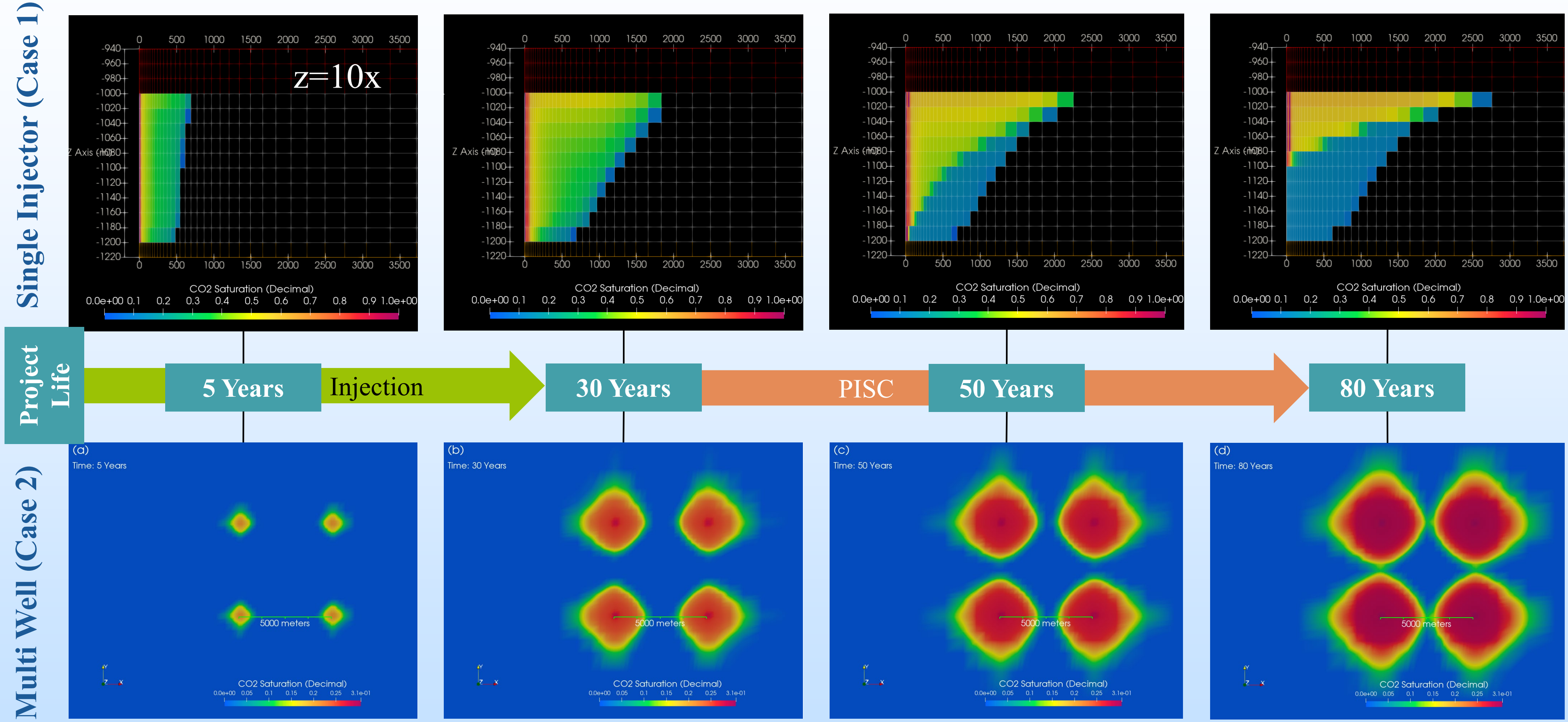
Modeling Workflow



Modeling Cases

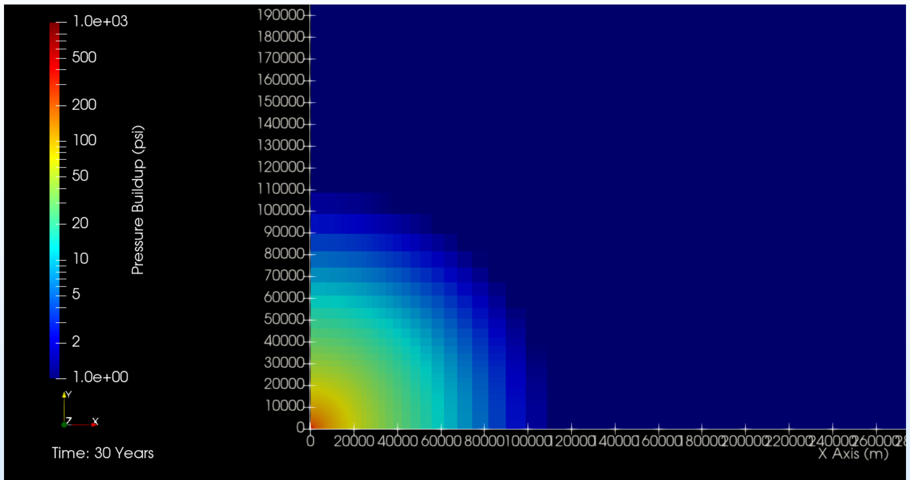
Case	Number of Injectors	Model Segmentation	Model Lateral Extent (km x km)	Total Injection Rate Into the Model (Mt/yr)	Well Spacing (km)
1	1 (Single-injector)	Quarter five-spot	500 x 500	0.25	None
2	4 (Multi-well)	None (full field)	1000 x 1000	4	5
3					10
4					20
5					40
6					80
7					125

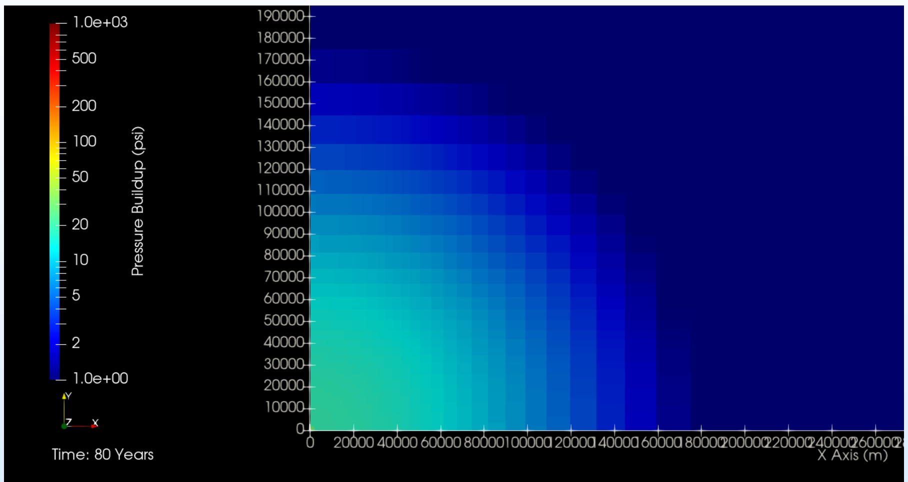
CO_2 Plume



- Radius of CO_2 plume: ~2 km at the end of injection and ~2.5 km at the end of PISC.
- CO_2 plumes from different injection wells are shown to start interfering with one another in Case 2 (5 km well spacing) by the end of PISC.
- The radius of the CO_2 plume does not significantly change during PISC. However, CO_2 vertical migration takes place during PISC, which increases the plume radius during PISC.

Pressure Buildup (Single Injector)



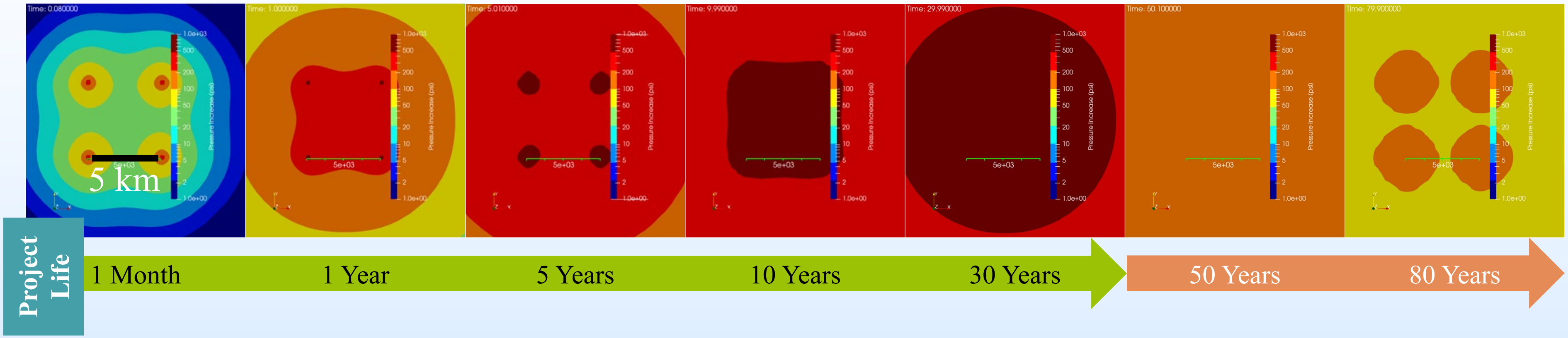


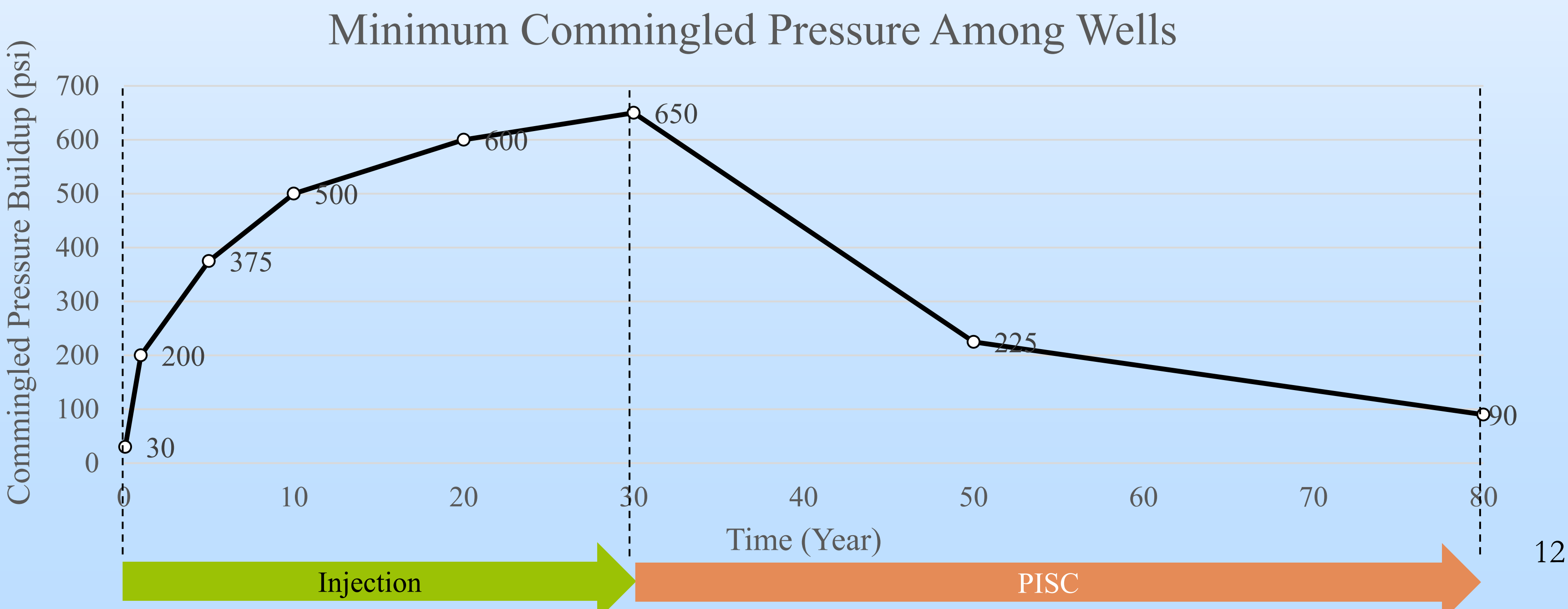
- Pressure buildup here is defined as the difference between the pressure at time of interest and the initial pressure at a particular grid block.
- Radius of pressure buildup is summarized in the table.
- Radius of pressure buildup is consistently larger than the radius of the CO_2 plume.

Pressure Buildup (psi)	Maximum Radius (km) of Pressure Buildup	
	End of Injection	End of PISC
1	112	178
10	64	78
100	12	None (max of 40-psi at 1 km)

Pressure Interference (Multi Well)

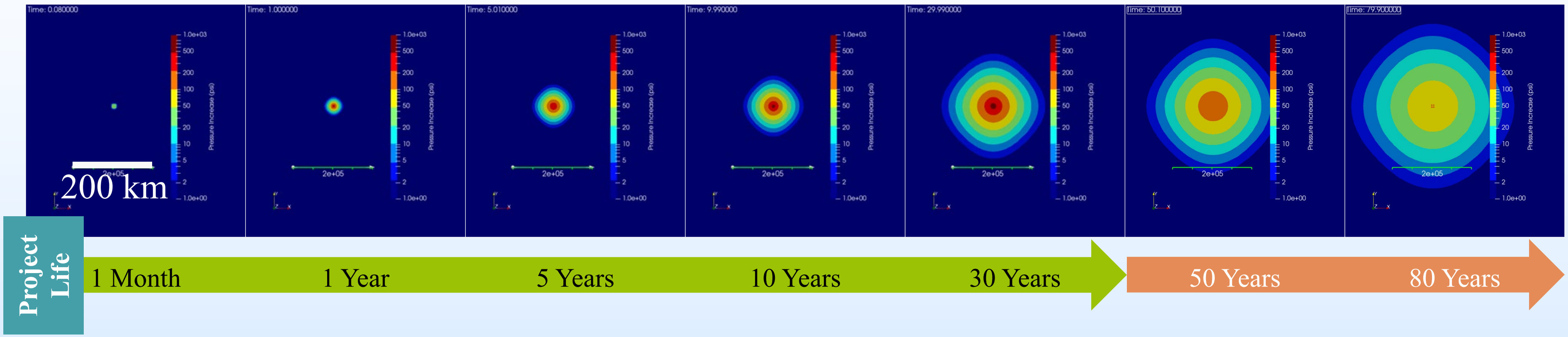
Near Injection Site

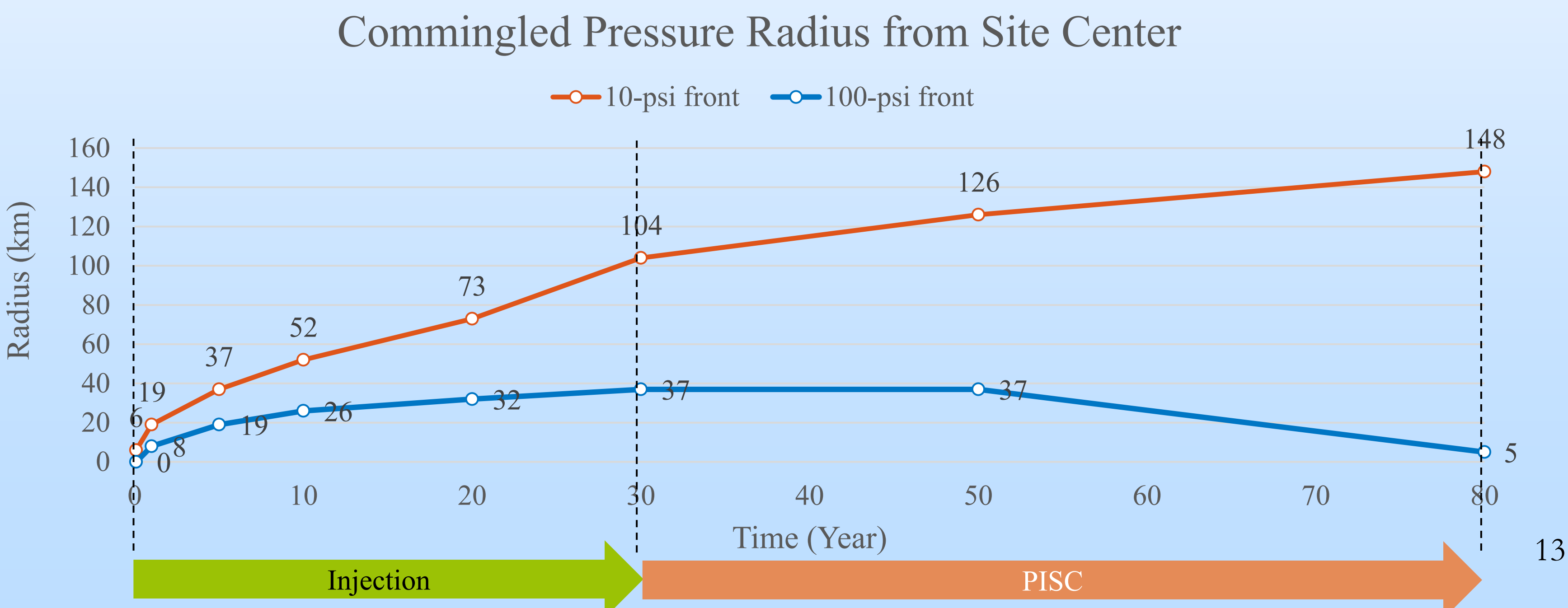




Pressure Interference (Multi Well)

At Basin Scale

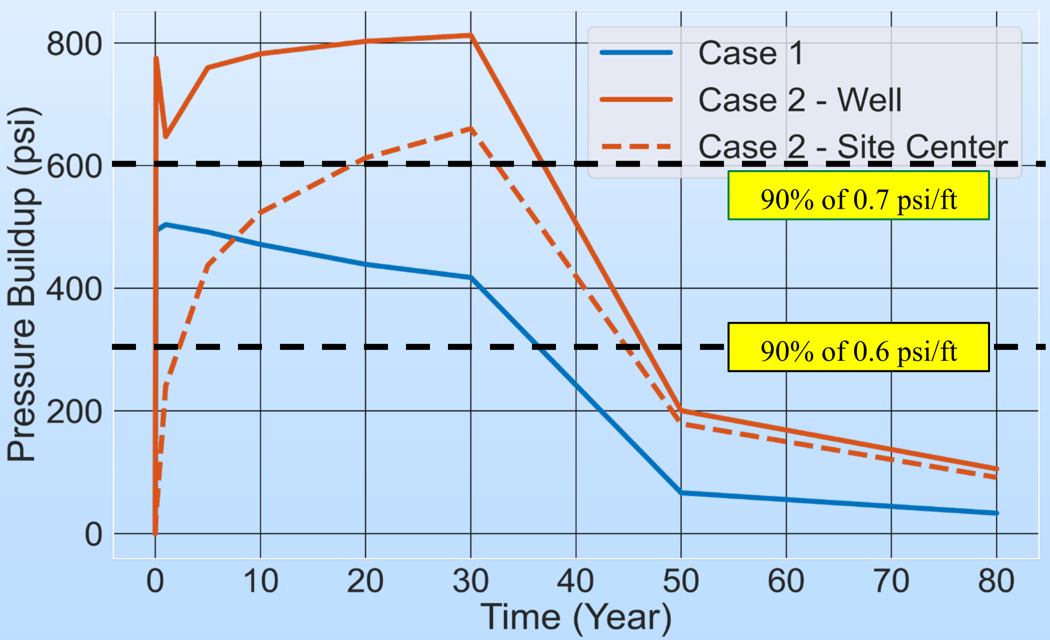




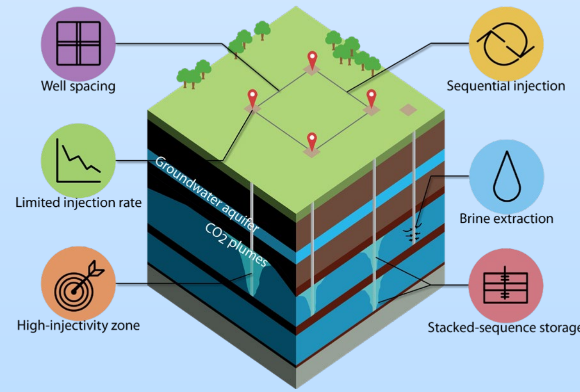
Fracture Pressure Thresholds

At Injector

Fracture Gradient (psi/ft)	Initial Ambient Pressure at Top of Perforation (psi)	Fracture Pressure at Top of Perforation (psi)	Fracture Pressure Threshold (psi)	Maximum Allowable Pressure Buildup (psi)	Single Injector (Case 1)	Multi Well (Case 2)
0.6	1,487	1,988	1,789	302	Strategy needed	Strategy needed
0.7	1,487	2,319	2,087	600	Safe	Strategy needed
0.8	1,487	2,650	2,385	898	Safe	Safe

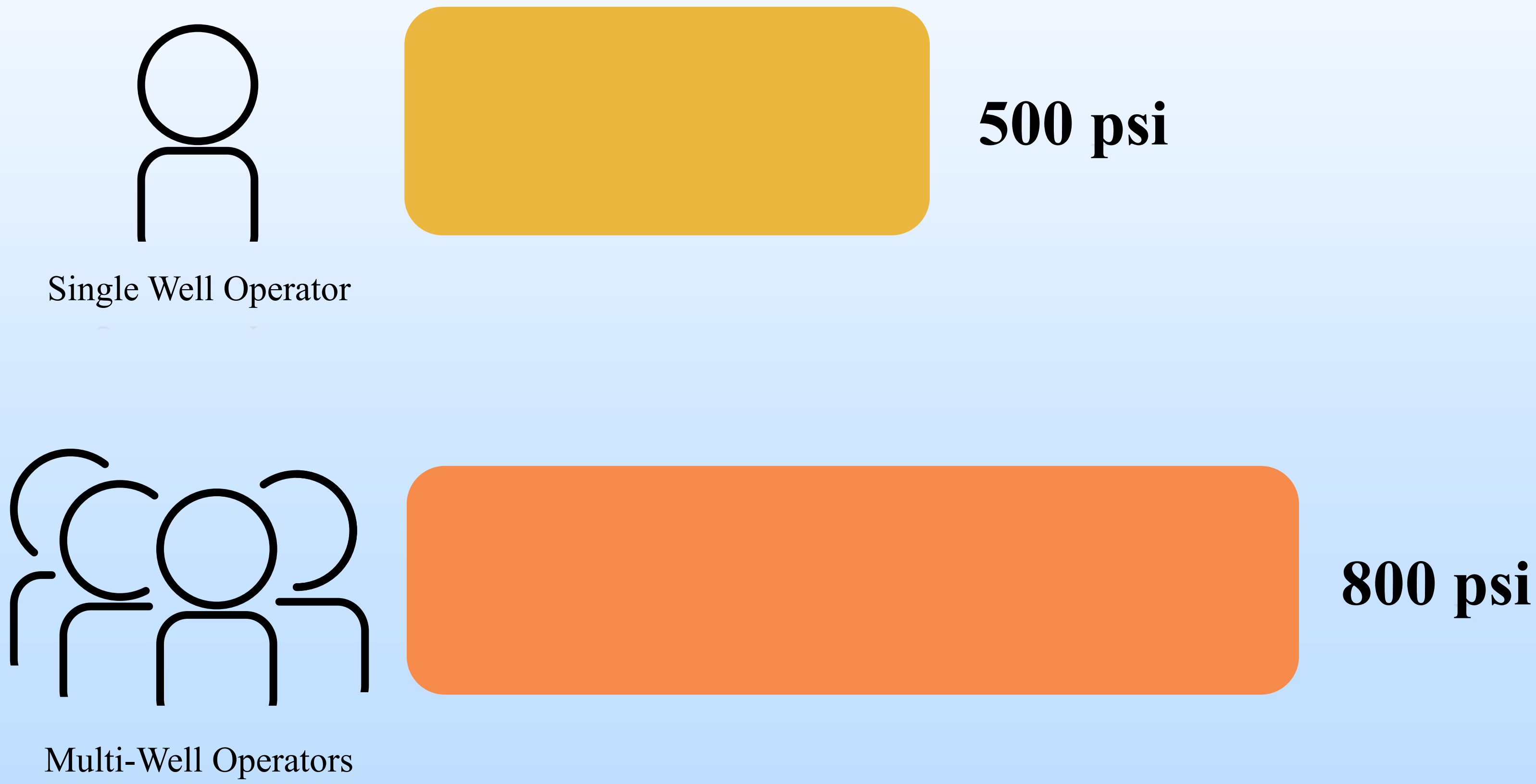


- Multi-well commercial-scale project (Case 2) would require that operational strategies be implemented to manage the pressure buildup if the assumed site has a fracture gradient **lower than 0.8 psi/ft**.



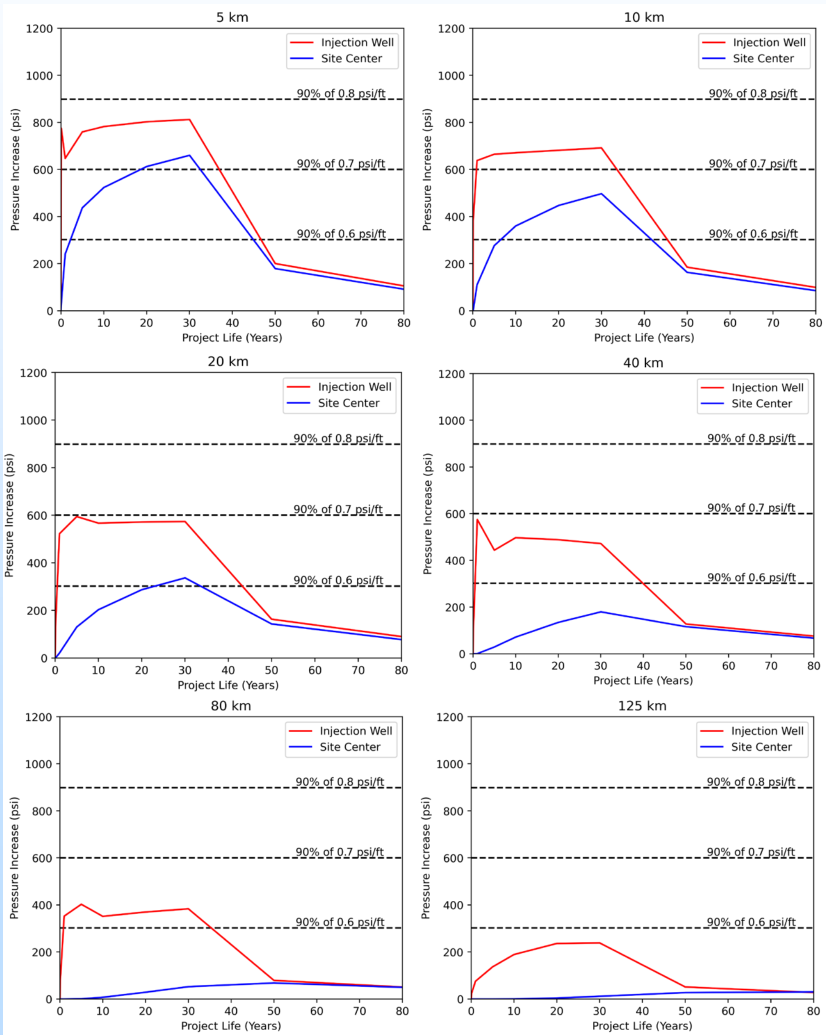
Pressure Interference

Effect of Pressure Interference on Peak of Pressure Buildup Near Injection Site



Well Spacing

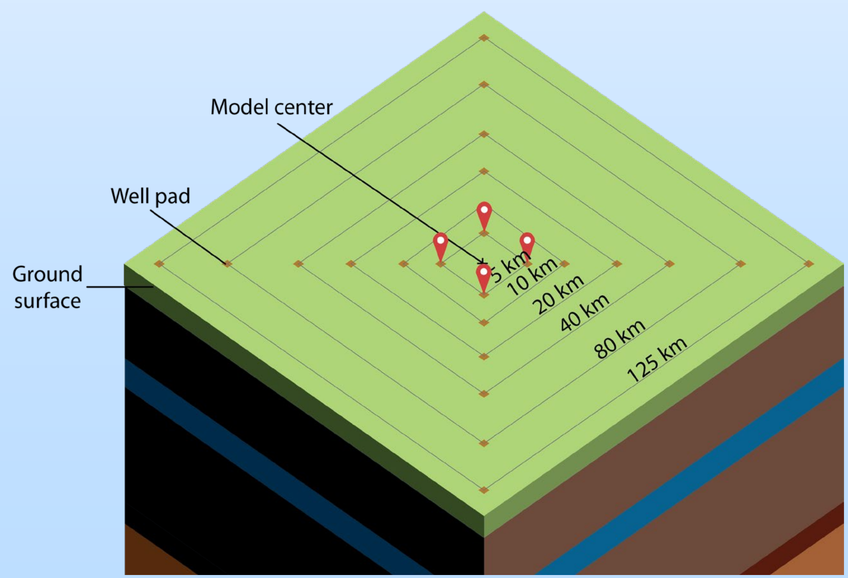
At Injector and Site Center



- The risk of exceeding the fracture pressure threshold provides a context to place the injection wells farther apart.

Fracture Gradient (psi/ft)	Minimum Well Spacing (km)
0.8	5
0.7	20
0.6	80-125

- The combination of well spacing with other strategies (e.g., brine production, storage in a stacked sequence of formation) could decrease the minimum well spacing shown.



Accomplishments to Date

Publications/Data

Conference Presentation at SPE Western Regional Meeting 2022 in Bakersfield, CA

Conference Paper Published at SPE Western Regional Meeting 2022

SPE-209283-MS

Basin Management of Geologic CO_2 Storage: Effect of Well Spacing on CO_2 Plume and Pressure Interference

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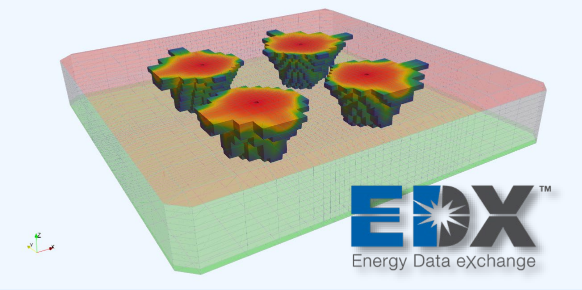
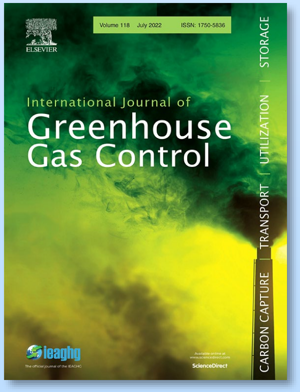
Abstract

Large-scale deployment of carbon capture and storage (CCS) is a key decarbonization approach to achieve drastic reductions in greenhouse gas emission levels. The United States Department of Energy's National Energy Technology Laboratory, through the Carbon Storage Assurance Facility Enterprise Initiative projects, defines a commercial-scale CO_2 saline storage project as one in which at least 50 million tonnes of CO_2 are injected over the course of 20 to 30 years. Large-scale decarbonization through CCS may likely involve many commercial-scale CO_2 storage projects located in close proximity. Nearby injection operations may result in CO_2 plume commingling and create pressure buildup over time, which could cause pressure interference and may require preventative strategies to avoid exceedance of fracture pressure threshold. This study employs numerical modeling to analyze the evolution of the extent of CO_2 and pressure plumes in which the commercial-scale CO_2 storage projects inject simultaneously into a common storage formation from multiple projects located in proximity. Injection operations target an extensive saline formation with formation top of 1 km below ground surface, thickness of 200 m, horizontal and vertical permeabilities of 50 and 15 mD, porosity of 10%, and all external boundaries closed to fluid flow (i.e., top, bottom and all sides). The injection occurs at 1 million tonnes/year per well for 30 years, followed by a 50-year post-injection period (PISC). The effect of well spacing and resulting pressure buildup and CO_2 plume migration is explicitly evaluated. For the circumstances modeled, our analysis indicates that the radius of the CO_2 plume extends 2-4 km from the CO_2 injection well(s). Under the multi-project injections, CO_2 plume commingling does not occur during injection; however, during PISC and pressure equilibration, CO_2 plumes commingle under certain well spacings. However, the radius of the pressure-buildup plume is in the range of tens or a few hundreds of kilometers, depending on the amount of pressure increase used to define the plume edge. These findings indicate that a degree of pressure interference can occur between storage projects located near each other, particularly during the early stages of the project. Additionally, our analysis of pressure interference shows that required well spacing needed to avoid approaching or exceeding fracture pressure thresholds can be extensive for formations with low fracture gradients (i.e., in the range of 80–125 km for formations with a pressure gradient of 0.6 psi/ft), but significantly smaller for formations with higher fracture gradients (i.e., 5 km for 0.8 psi/ft). Given the potential pressure interference which may occur

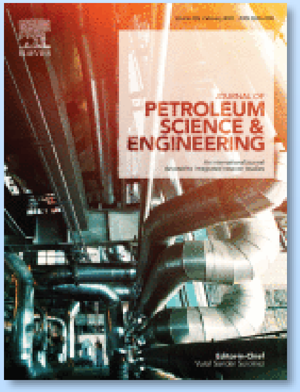
Reservoir Model Posted on NETL's EDX (*pending posting*)



Peer-Reviewed Journal Manuscript for Single-Formation Storage Prepared for *International Journal of Greenhouse Gas Control*
(*under internal review*)



Peer-Reviewed Journal Manuscript for Stacked-Sequence Storage Prepared for *Journal of Petroleum Science and Engineering*
(*under internal review*)



NETL Report (Aggregate)
(*in process*)

Lessons Learned

CCS is an important technology to reduce greenhouse gas emissions while providing affordable and reliable energy, but several technical aspects must be considered when deployed.

The radius of pressure buildup ranges on the order of tens to a few hundreds of kilometers, depending on the magnitude of pressure buildup that defines the front.

Pressure interference among injection wells can force wells to be spaced farther apart or reduce their injection rates.

Because this study analyzes a very specific geologic situation, well configuration, CO_2 injection rate, and model boundary conditions, this exploratory study bears further investigation across other geologic situations.

Proper awareness, planning, and coordination amongst storage projects and stakeholders are critical to enable CO_2 storage deployment upscaling.

Thank you!

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Appendix

- These slides will not be discussed during the presentation but are mandatory.