A QUANTITATIVE APPROACH FOR DEMONSTRATING PLUME STABILIZATION UNDER CCS POLICY FRAMEWORKS

KEY TAKEAWAYS

Nearly two decades of Plains CO_2 Reduction (PCOR) Partnership experience evaluating carbon capture and storage (CCS) policies has led to identifying and applying a quantitative approach to demonstrate plume stabilization in the postinjection phase of a carbon dioxide (CO_2) storage operation.

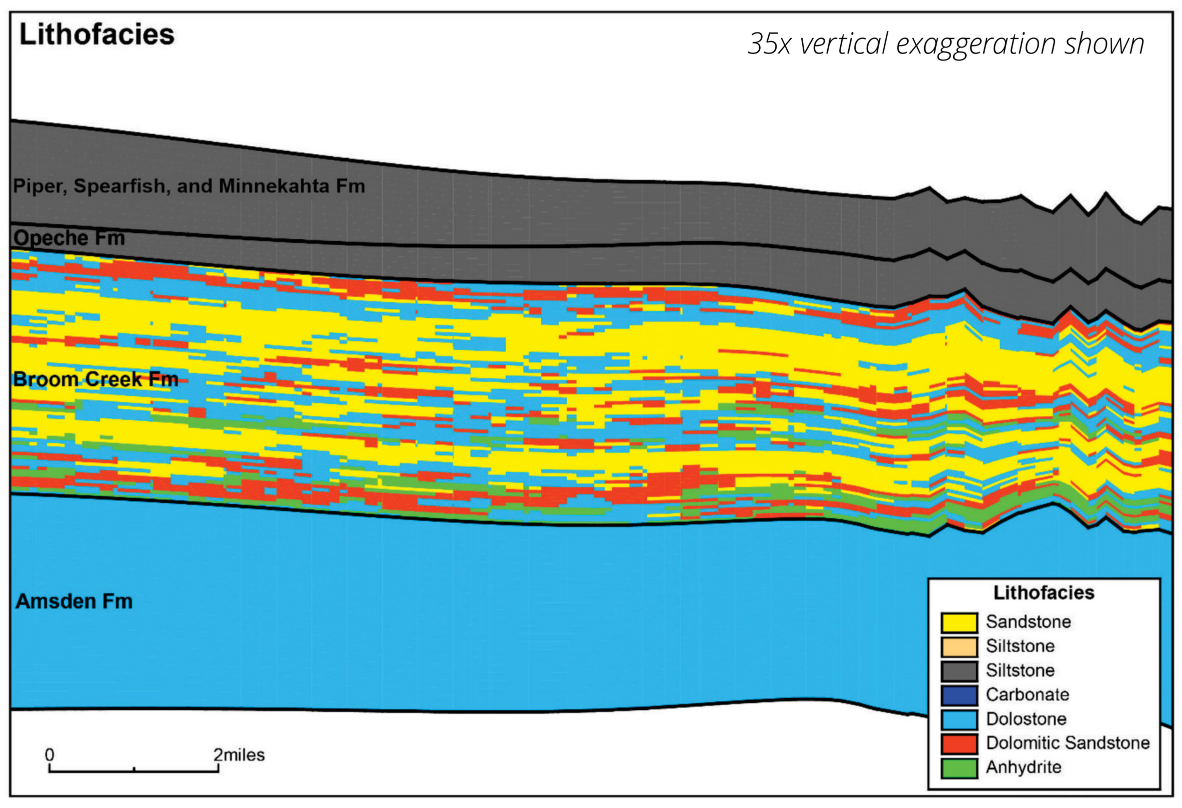
Within the United States and Canada, CCS policy requires operators to provide assurance that CO_2 is safely and permanently stored. A major component of that requirement is the demonstration of CO_2 plume stabilization in the postinjection phase. Plume stabilization means that the CO_2 plume 1) moves minimally and predictably in the storage reservoir such that it will not cross key project-defined boundaries and 2) does not threaten underground sources of drinking water, human health, or the environment.

Multiple approaches, including risk assessment, numerical simulations, and monitoring data, may be applied in combination to demonstrate plume stability. A simulation-based approach, which can be verified with monitoring data and risk assessment, is presented below using a North Dakota case study. The recommended approach uses the derivative of area with respect to time (dA/dt) metric presented in Harp and others (2019) to identify the point in time when the CO_2 plume's rate of areal expansion (dA/dt) slows significantly in the postinjection period.

GEOLOGIC MODEL USED FOR CASE STUDY

The 23x23-mile geologic model which is based on data from the eastern Williston Basin, represents a storage complex comprising the Amsden Formation as the lower confining zone (dolostone); the Broom Creek Formation as the storage reservoir (aeolian sandstone and dolostones); and the Opeche, Minnekahta, Spearfish, and Piper Formations as the upper confining zone (siltstones).

The model was generated using inputs from core measurements, well logs, and 3D seismic data. The grid cell size used was 1000 ft in both the x and y directions (with local grid refinement of 200 ft around injection wellbores), and layer thicknesses ranged between 5 and 7 ft.



RECOMMENDED APPROACH

NUMERICAL RESERVOIR SIMULATIONS | Using the detailed geologic model, injection of CO_2 was simulated with two wells injecting 77 million metric tons (tonnes) over 20 years (Years 1–20), with an additional 50 years of postinjection (Years 21–70). The distribution of gas (CO_2) saturation within the model domain at each simulated time step was used to define the CO_2 plume extent within the storage reservoir. The numerical simulation outputs include CO_2 saturation values for each grid cell, ranging between 0% (no CO_2) and 100% minus the irreducible water saturation.

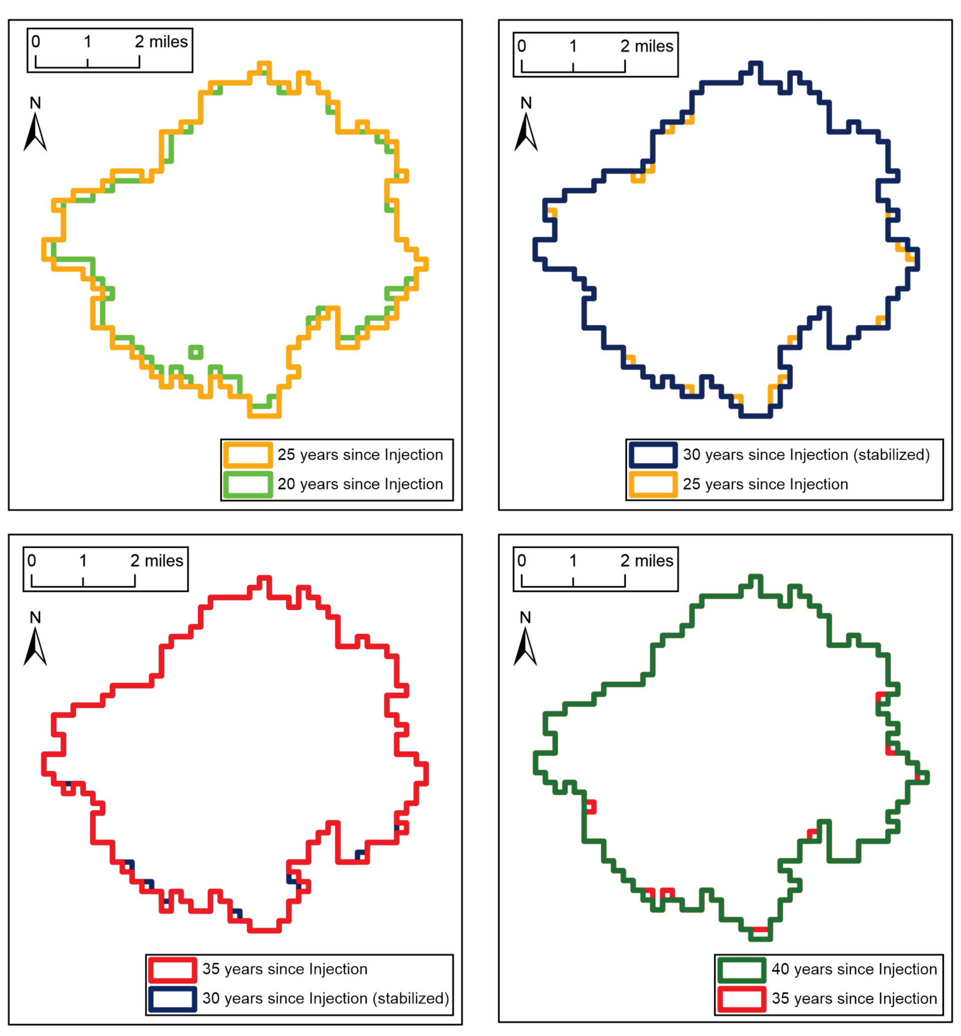
SATURATION CUTOFF | Numerical simulation solutions imply a degree of precision that is not observable in the deep subsurface, as regions of the storage reservoir with very small percentages of CO_2 saturation below the detection thresholds for wide-area monitoring methods, such as time-lapse 3D seismic. A 5% CO_2 saturation cutoff was applied to represent a reasonable detection limit of CO_2 saturations with time-lapse 3D seismic methods. This method defines the CO_2 plume extent at >5% CO_2 saturation, after the findings of Whittaker and others (2004), White and others (2014), and Roach and others (2014, 2017). Therefore, the CO_2 plume inside the boundary contains 5% or more CO_2 saturation.

PLUME METRICS | The delta, or difference, in CO_2 plume area in square miles from Year 1 through Year 70 (dA) and the growth rate per year (dA/dt) were calculated. For example, in Year 2, the CO_2 plume area was 3.3 mi^2; therefore, the change in area (dA) between Year 2 and Year 1 was 3.3 mi^2 – 1.5 mi^2, equaling 1.8 mi^2. The derivative of area with respect to time in Year 2 was the change in area, 1.8 mi^2, divided by the difference in time, 1 year.

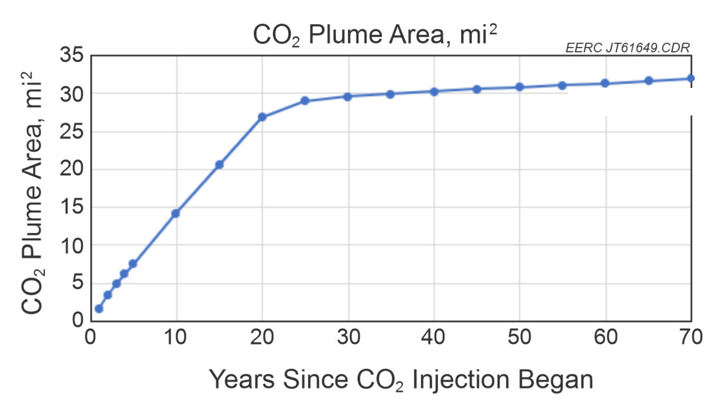
Please note, two different time steps from the simulation results are included in this example: Years 1–5 are 1-year increments, and Years 6–70 are 5-year increments.

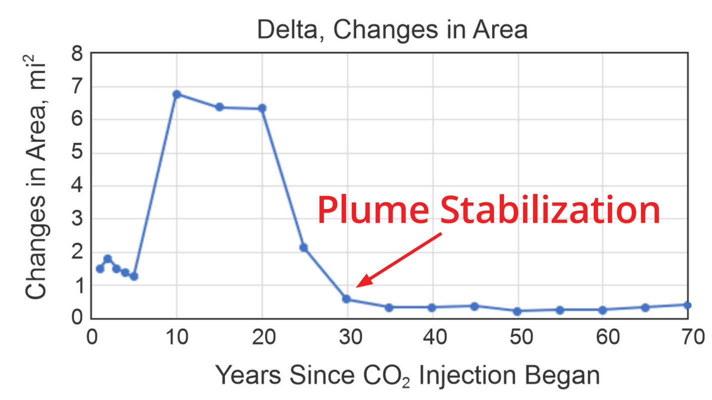
QUANTITATIVE STABILIZATION | As shown in the figures below, the CO_2 plume area expands rapidly during the operational phase (Years 1–20) from zero to approximately 26.8 mi^2. The rate of expansion then begins to slow and approach a horizontal asymptote (dA/dtcritical) after Year 20. The growth rate per year, dA/dt, provides the best metric for establishing plume stabilization. For example, at Year 30, or 10 years into the postinjection phase, dA/dtcritical is approximately 0.1 mi^2/yr and remains nearly constant for the remaining life of the simulation. In this case, at Year 30, the 5-year delta has stabilized at roughly 2% of the CO_2 plume area ([0.6mi^2/29.5 mi^2]*100% = 2%), and after Year 30, the CO_2 plume delta is always less than 2%. Therefore, the stabilized plume boundary was chosen at Year 30 based on this inflection point, tcritical. While the absolute value of the delta may be expected to vary between injection projects of different sizes, the asymptotic character of plotting dA/dt is expected to persist once the plume stabilizes. This demonstrates that as dA/dt approaches dA/dtcritical, the CO_2 plume's growth is both minimal and predictable.

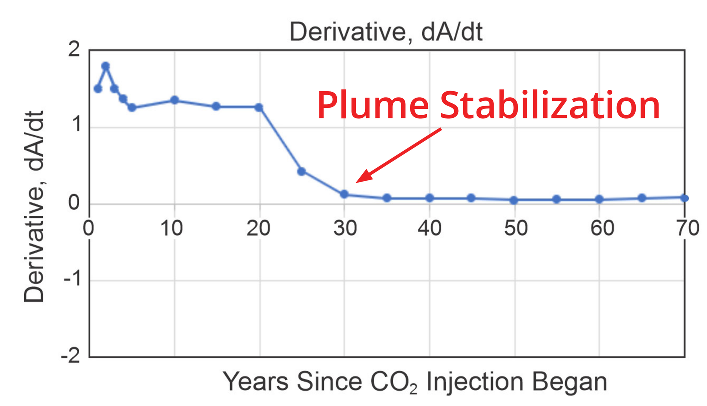
CO_2 AREAL CHANGES OVER TIME



Simulation Year	Years since Injection	CO_2 Plume Area, A (mi^2)	Delta, dA, (mi^2)	dA/dt (mi^2/yr or mi^2/5 years)
2023	1	1.5	1.5	1.5
2024	2	3.3	1.8	1.8
2025	3	4.8	1.5	1.5
2026	4	6.2	1.4	1.4
2027	5	7.4	1.3	1.3
2032	10	14.2	6.7	1.3
2037	15	20.5	6.3	1.3
2042	20	26.8	6.3	1.3
2047	25	28.9	2.1	0.4
2052	30	29.5	0.6	0.1
2057	35	29.8	0.3	0.1
2062	40	30.2	0.3	0.1
2067	45	30.5	0.4	0.1
2072	50	30.7	0.2	0.0
2077	55	31.0	0.3	0.1
2082	60	31.2	0.3	0.1
2087	65	31.6	0.3	0.1
2092	70	32.0	0.4	0.1







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