THE APPLICATION OF VOLUMETRIC AND DYNAMIC CO_2 STORAGE RESOURCE ESTIMATES TO DEEP SALINE SYSTEMS

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Abstract

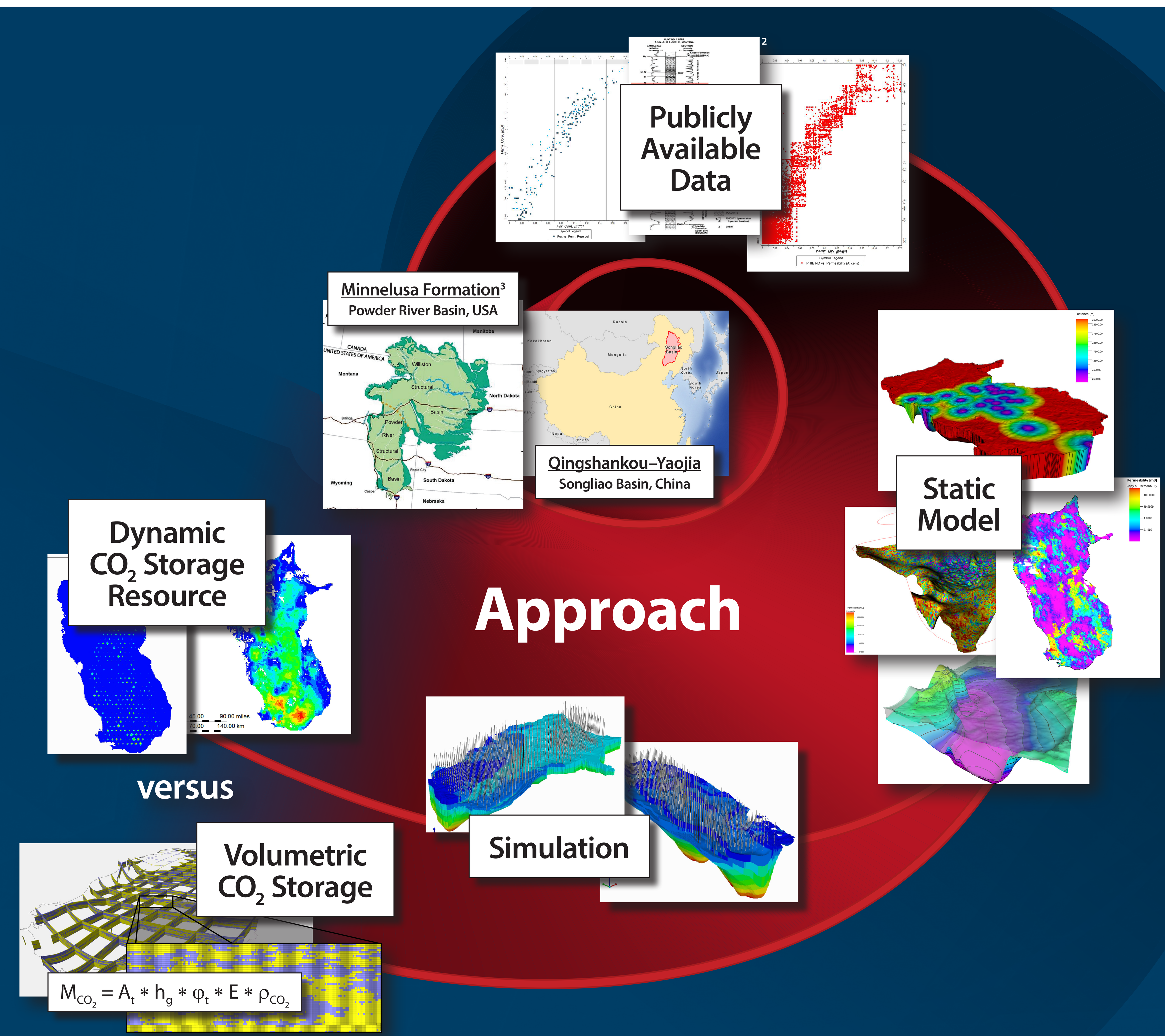
One method under consideration to reduce anthropogenic CO_2 emissions is CO_2 storage in deep saline formations (DSFs). Several methods exist to estimate the CO_2 storage resource potential of DSFs, but most are based on volumetric approaches that ignore the effect of site-specific, dynamic factors such as injection rate, injection pattern, and pressure interference. Additionally, these methods have not been validated through real-world experience or full-formation injection simulations. As a result, they may over- or underestimate the effective storage resource potential. The Energy & Environmental Research Center (EERC), in collaboration with the IEA Greenhouse Gas R&D Programme (IEAGHG) and the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), has conducted an investigation comparing volumetric and dynamic storage resource estimates for two deep saline systems: the Minnelusa Formation in the Powder River Basin, USA, and the Qingshankou and Yaojia Formations in the Songliao Basin, China.

For each system, volumetric and dynamic effective storage resource estimates were determined. First, a three-dimensional geocellular model was built using publicly available data. Second, the models were upscaled, and an effective volumetric CO_2 storage resource estimate was calculated. Third, 12 CO_2 injection scenarios were developed and conducted for each system. Finally, the simulation results, representing the dynamic storage resource estimate, were analyzed and compared to the volumetric estimate.

The results show that a volumetric approach can be used to reasonably estimate a formation's CO_2 storage resource potential, provided that the appropriate methodology and storage efficiency terms are used and that the length of CO_2 injection is considered. Additionally, factors such as geologic heterogeneity, water extraction, and pressure buildup can significantly impact storage efficiency.

Goals and Objectives

- Evaluate site-specific dynamic effects (e.g., injection rate, injection pattern and strategy, timing of injection, boundary conditions, and pressure interference between injection locations) on the estimation of the CO_2 storage resource in deep saline formations.
- Using publicly available data, build two basin-scale models of deep saline formations that are suitable targets for CO_2 storage.
- Create base case and high-, mid-, and low-case scenarios of reservoir properties.
- Calculate the static CO_2 storage resource for each formation using the volumetric method developed by IEAGHG.[1]
- Perform CO_2 injection simulations for both models, taking into account site-specific characteristics and operational parameters.
- Estimate the dynamic CO_2 storage resource.
- Compare the static and dynamic CO_2 storage resource estimates for each formation.



Open-System Effective Storage Efficiency Factors and Resulting Effective Storage Resource for the P10, P50, and P90 Upper Minnelusa Models

Parameter	Symbol	Unit	P10	P50	P90
Total Pore Volume	V_{PV}	km^3	153	174	212
Effective-to-Total Pore Volume Ratio	E_{geol}		40%	45%	47%
Volumetric Displacement Efficiency	E_D		7.4%	14%	24%
Effective Storage Efficiency Factor	E_E		2.9%	6.3%	11%
Effective Storage Volume	E_{vol}	km^3	4.48	11	23.7
Average CO_2 Density	ρ_{CO2}	kg/m^3	773*	773*	773*
Effective CO_2 Storage Mass	$M_{CO_2, E}$	Mt**	3466	8519	18,282

* CO_2 density was calculated at average reservoir properties of 33.6 MPa and 81°C.
** Million tonnes.

$$M_{CO_2} = A_t * h_g * \varphi_t * E * \rho_{CO_2}$$

Open System

$$E_E = E_{geol} * E_D$$
$$E_{geol} = E_{An/At} * E_{hn/hg} * E_{\varphi eff/\varphi tot}$$
$$E_D = E_{vol} * E_d$$

Closed System

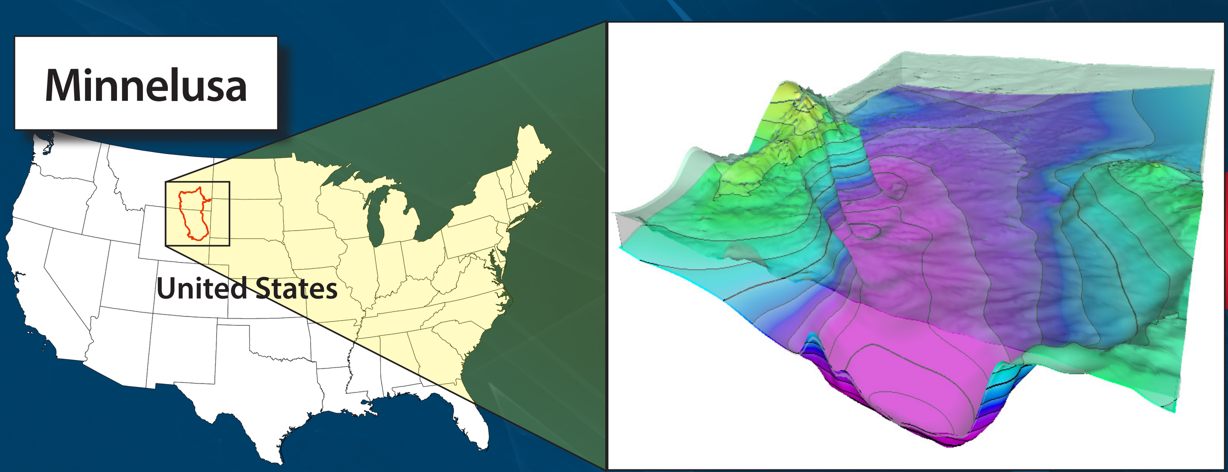
$$E_{comp} = \Delta P * (c_w + c_f)$$

Closed-System Compressibility Storage Efficiency Factors and Resulting Compressibility Storage Resource for the P10, P50, and P90 Qingshankou–Yaojia System Models

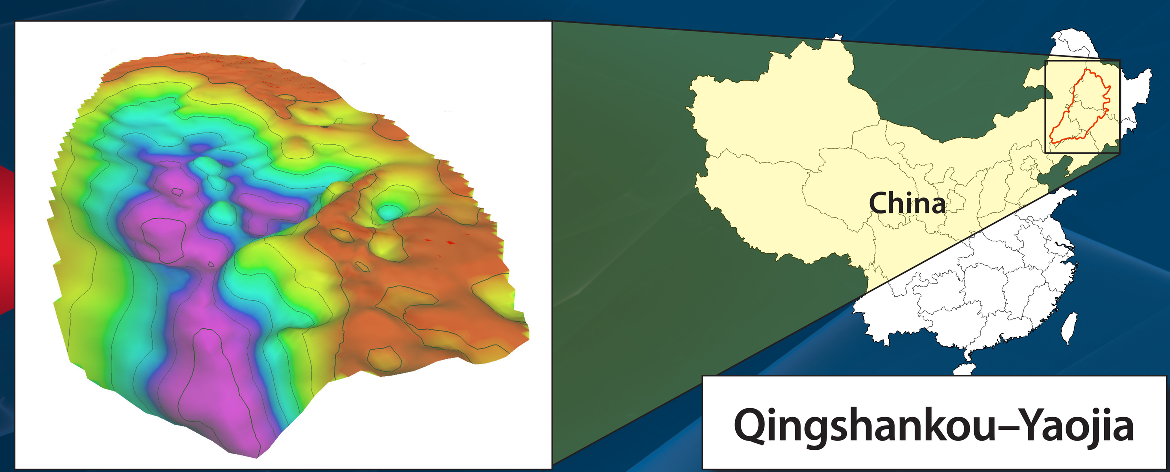
Parameter	Symbol	Unit	P10	P50	P90
Total Pore Volume	V_{PV}	km^3	742	1290	1810
Water Compressibility*	c_w	1/kPa	3.93E-07	3.93E-07	3.93E-07
Pore Compressibility*	c_p	1/kPa	4.50E-07	4.50E-07	4.50E-07
Initial Pressure	P_0	kPa	12,542	12,542	12,542
Maximum Pressure**	P_{max}	kPa	15,051	15,051	15,051
Percent Pore Volume from Compressibility	E_{comp}		0.21%	0.21%	0.21%
Compressible Reservoir CO_2 Storage Volume	$V_{CO_2, comp}$	km^3	1.57	2.73	3.82
Average CO_2 Density Max	ρ_{max}	kg/m^3	680	680	680
Compressible Reservoir CO_2 Storage Mass	$M_{CO_2, comp}$	Mt	1067	1852	2597

* Obtained from Zhao and others (2012), Esken and others (2012), and Zhang and others (2005).
** Maximum allowable injection pressure was determined by adding 20% to the initial pressure.

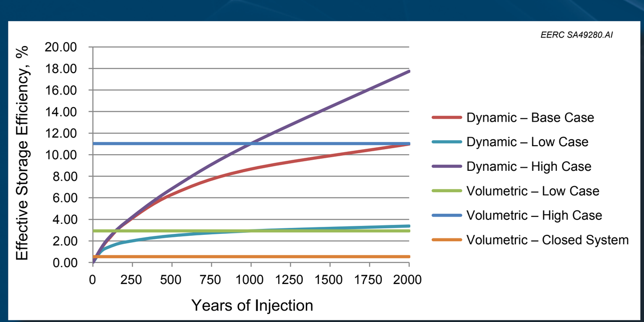
Volumetric Storage Resource

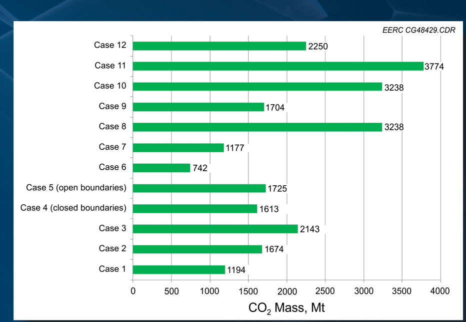


Results



Dynamic Storage Resource

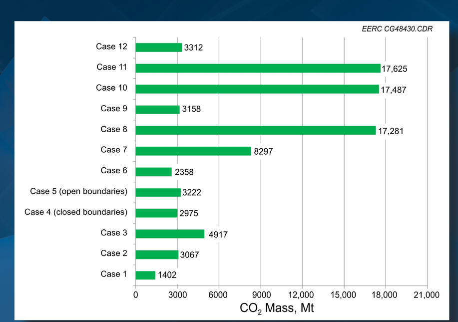


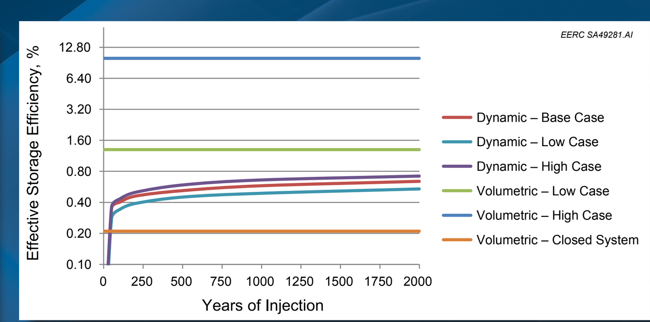


Simulation Cases and Simulation Notes

Simulation Cases	Injection Wells	Extraction Wells
1 – P10 Semiclosed Boundaries	462	NA
2 – P50 Semiclosed Boundaries	475	NA
3 – P90 Semiclosed Boundaries	492	NA
4 – P50 Closed Boundaries	475	NA
5 – P50 Open Boundaries	475	NA
6 – P50 Half the Number of Vertical Injectors	238	NA
7 – P50 Half the Number of Vertical Injectors and Extractors	238	237
8 – P50 Vertical Injection and Extractors	475	345
9 – P50 Horizontal Injectors	475*	NA
10 – P50 Horizontal Injectors and Vertical Extractors	475*	345
11 – P50 Horizontal Injectors and Extractors	475*	345*
12 – P50 Double the Number of Vertical Injectors	820	NA

* Indicates horizontal wells.
Unless otherwise indicated, boundary conditions are semiclosed.





Minnelusa System Effective CO_2 Storage Efficiency

	Low	High
Volumetric Efficiency – Closed System	0.54%	0.54%
Volumetric Efficiency – Open System	2.9%	11%
Dynamic Efficiency – 50 years of Injection	0.55%	1.7%
Dynamic Efficiency – 200 years of Injection	1.9%	4.3%
Dynamic Efficiency – 500 years of Injection	2.5%	7.9%
Dynamic Efficiency – 2000 years of Injection	3.4%	18%

Qingshankou–Yaojia System Effective CO_2 Storage Efficiency

	Low	High
Volumetric Efficiency – Closed System	0.21%	0.21%
Volumetric Efficiency – Open System	1.3%	10%
Dynamic Efficiency – 50 years of Injection	0.28%	0.40%
Dynamic Efficiency – 200 years of Injection	0.39%	0.52%
Dynamic Efficiency – 500 years of Injection	0.45%	0.60%
Dynamic Efficiency – 2000 years of Injection	0.62%	0.72%

Conclusions

- For open systems, the dynamic CO_2 storage resource potential is time-dependent, asymptotically approaching the volumetric CO_2 storage resource potential over very long periods of time.
- For closed systems, the maximum efficiency is reached much more quickly, and the results are roughly equivalent to the volumetric results calculated using a closed-system storage efficiency term.
- Within the first 50 years of injection, both systems had dynamic storage efficiency values that were close to the closed-system efficiency or were approaching the P10 volumetric efficiency.
- Volumetric methodologies are applicable as long as:
  - The boundary conditions are known (i.e., open, closed, or semiclosed) and the appropriate efficiency terms are used.
  - Enough time is given.
  - Enough wells are used.
  - The full usable extent of the formation is considered.
- Optimization methods can be used in closed systems to achieve open-system volumetric results.

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References

1. IEA Greenhouse Gas R&D Programme, 2009, Development of storage coefficients for CO_2 storage in deep saline formations: 2009/12, October 2009.
2. Modified from George, G., 1984, Cyclic sedimentation and depositional environments of the Upper Minnelusa Formation, Central Campbell County, Wyoming, in The Permian and Pennsylvanian geology of Wyoming: 35th Annual Field Conference Guidebook, p. 75–95.
3. North American Lambert Conformal Conic Projection, North America Datum 1983.

This report will be available from IEAGHG. Please contact James Craig at james.craig@ieaghg.org with inquiries.