Development of Defensible CO_2 Storage Methods and Tools to Quantify Prospective Storage in Shale and Residual Oil Zone Systems

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

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Abstract

DOE NETL is working to provide defensible CO_2 storage methods and tools to quantify prospective CO_2 storage in the subsurface for the Carbon Storage Atlas, the NETL's Regional Carbon Sequestration Partnership (RCSP), and CARBONSAFE projects. Carbon storage resource estimation in subsurface formations plays a key role in establishing the scale of CCS activities for governmental policy and commercial project decision-making. DOE's Carbon Storage Atlas has quantified CO_2 storage potential for oil and natural gas reservoirs (186-232 GT), unmineable coal seams (54-113 GT), and saline formations (2,379-21,633 GT). DOE has identified hydrocarbon-bearing shale basins and residual oil zones as other geologic storage options. Currently, high-level assessments of CO_2 storage potential specific to hydrocarbon-bearing shale basins and residual oil zones at the regional and national scale are unavailable. This poster will focus on methods and tools developed to assess CO_2 storage in shale systems and residual oil zones. For storage in shale systems, numerical simulations were conducted using the FRACGEN/NFFLOW simulator to study the CO_2 injection into a depleted hydro-fractured shale reservoir and estimate storage efficiencies using a range of reservoir parameters and injection scenarios. The ranges for two efficiency factors, E_ϕ and E_S, measure the effectiveness of CO_2 stored as free and adsorbed phases, respectively. These efficiency factors were estimated to have P_{10} to P_{90} probability ranges of 0.15 to 0.36 for E_ϕ and 0.11 to 0.24 for E_S, reported after 60 years of CO_2 injection. For residual oil zone systems, we highlight the approach in terms of proposed equations and identify challenges and data gaps for estimating CO_2 storage.

Collaborators

USGS — science for a changing world

- Peter Warwick
- Emil Attanasi
- Phil Freeman
- Sean Brennan
- Ozgen Karacan
- Jacqueline Roueche

EERC — Energy & Environmental Research Center, Putting Research into Practice

- Charles Gorecki
- Wesley Peck

Illinois State Geological Survey — Prairie Research Institute

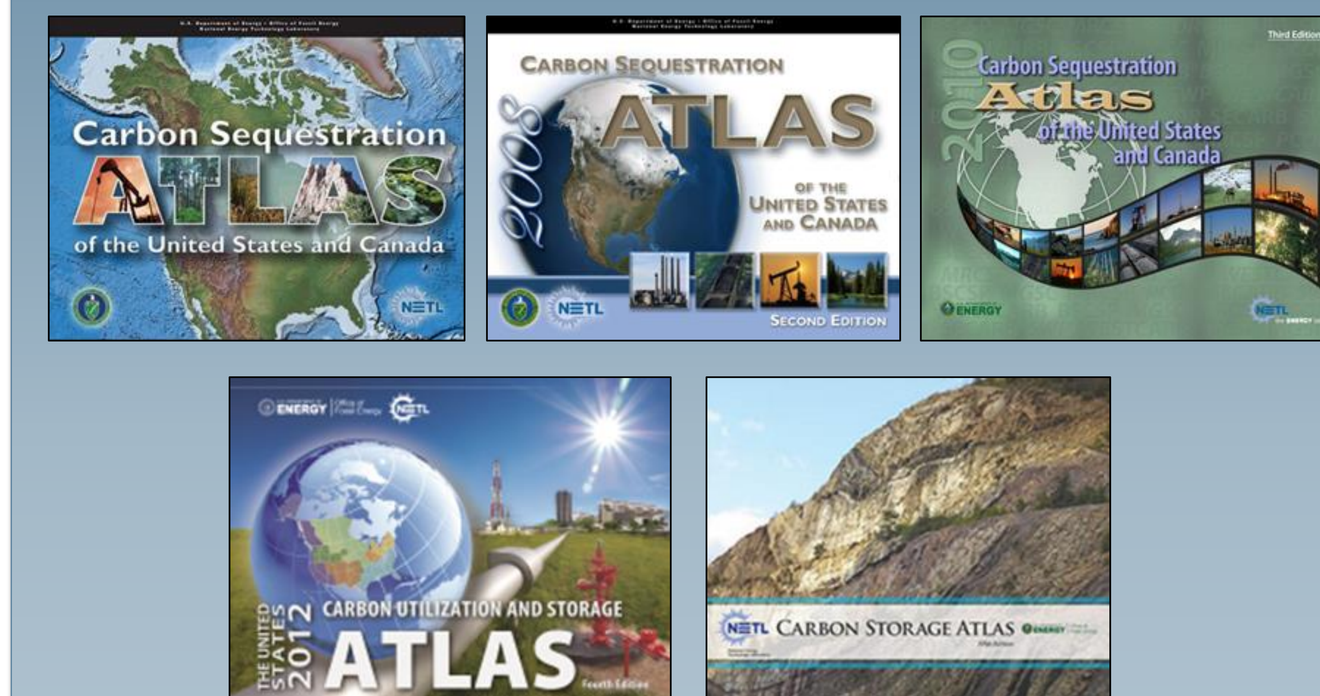
- Scott Frailey

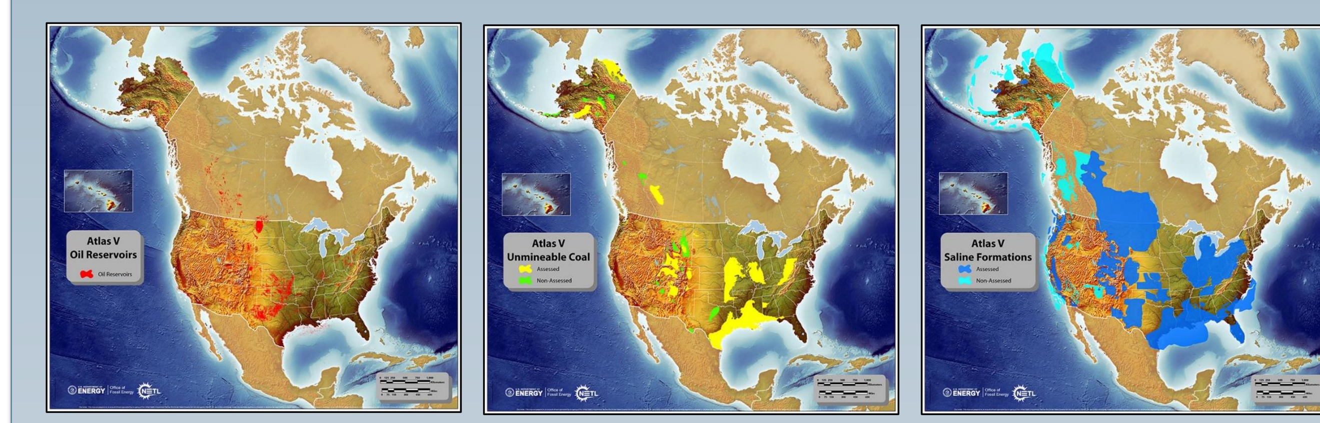
Los Alamos National Laboratory — Est. 1943

- Rajesh Pawar

Prospective CO_2 Storage Quantification

Carbon Storage Atlases



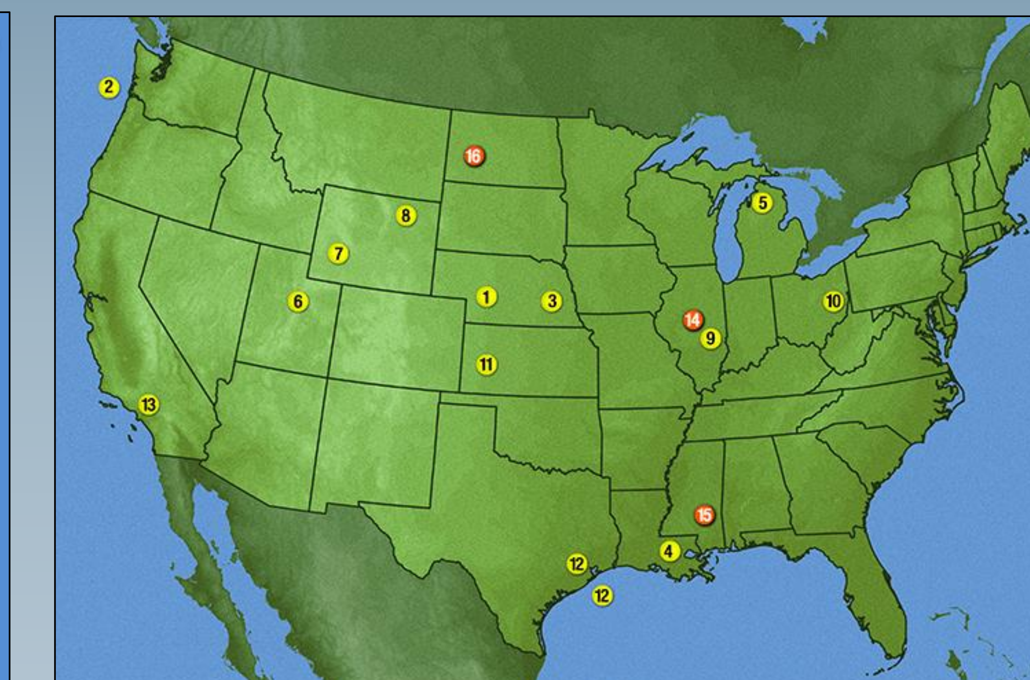


186 - 232 GT | 54 - 113 GT | 2,379 - 21,633 GT

NETL's Regional Carbon Sequestration Partnership (RCSP)

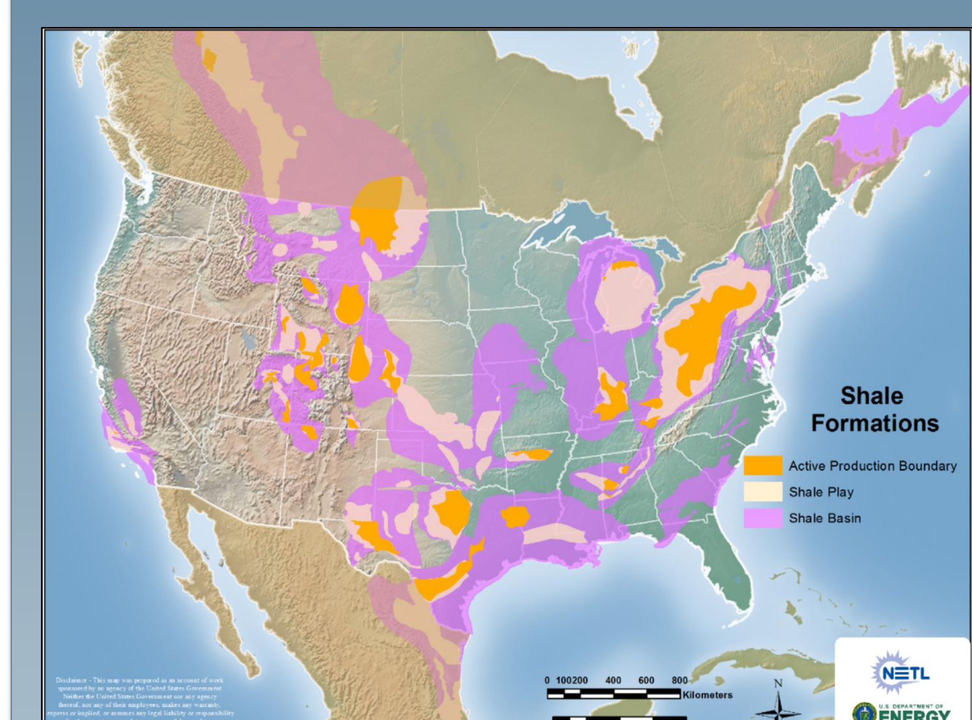
BSCSP: Big Sky Carbon Sequestration Partnership
MGSC: Midwest Geological Sequestration Consortium
MRCSP: Midwest Regional Carbon Sequestration Partnership
PCOR: The Plains CO_2 Reduction Partnership
SECARB: Southeast Regional Carbon Sequestration Partnership
SWP: Southwest Partnership on Carbon Sequestration
WESTCARB: West Coast Regional Carbon Sequestration Partnership

Carbon Storage Assurance Facility Enterprise (CarbonSAFE)



- Geologic storage of 50+ million metric tons of CO_2
- 13 Pre-feasibility projects
- 3 feasibility projects

Shale Systems



Shale formations in North America.

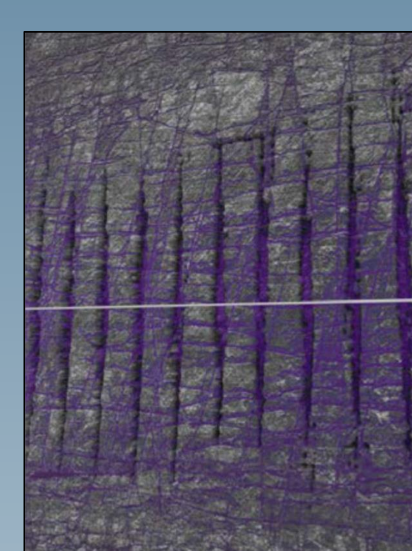


Illustration of injected CO_2 into a hydraulically fractured shale formation.

Criteria for CO_2 Storage in Shale Formations

1) In the prospective CO_2 storage shale, hydrocarbons have been or expect to be commercially produced through stimulated fracture networks.

2) The portion of the shale formation being assessed must exist at pressure and temperature conditions adequate to keep the CO_2 in a dense state, either liquid or supercritical (>800m).

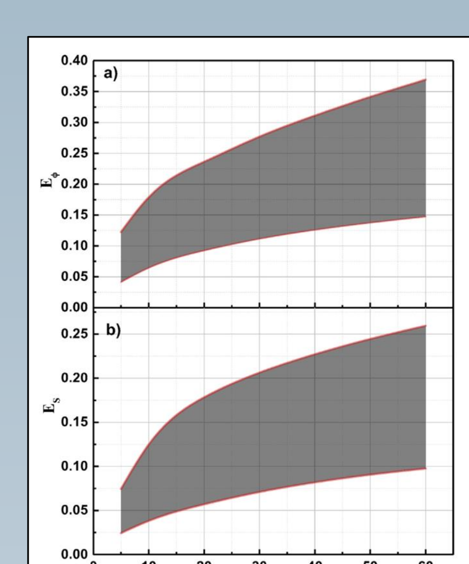
3) A suitable seal system (faults, impermeable caprocks, or liquids held under high capillary pressures) must exist in order to prevent vertical migration of CO_2 to the surface.

Shale requirements for CO_2 Storage.

E_ϕ: P_{10} to P_{90} range of 0.15 to 0.36
E_S: P_{10} to P_{90} range of 0.11 to 0.24

$$G_{CO_2} = A_t E_A h_g E_h \left[\rho_{CO_2} \phi E_\phi + \rho_{sCO_2}(1-\phi) E_S\right]$$

E_A	Fraction of formation area available for CO_2 storage
E_h	Fraction of formation thickness available for CO_2 storage
E_ϕ	Fraction of shale porosity within the net effective volume of the formation, V_e, available for CO_2 storage. This is a reservoir scale efficiency factor that is meant to address the probability that CO_2 will never reach some of the pore space due to transport heterogeneities associated with fracture networks and low matrix permeability.
E_S	Fraction of the total potential sorbed volume of CO_2 within the net effective volume of the formation, V_e, ($E_m E_{sorb}$). This is a reservoir scale efficiency factor that is meant to address both transport and sorption inefficiencies.
E_m	Fraction of the shale matrix within the effective volume of the formation, V_e, available for CO_2 storage. This is a reservoir scale efficiency factor that is meant to address the probability that CO_2 will never reach some of the shale matrix rock due to transport heterogeneities associated with fracture networks and low matrix permeability.
E_{sorb}	Fraction of ρ_{sCO_2} due to reductions in sorptive packing at reservoir pressure and temperature conditions. This is a reservoir scale efficiency factor that is meant to address the inefficiency of sorptive packing on shale matrix rock due to effective pressure and temperature conditions in the shale matrix.



Simulated efficiency factors for CO_2 storage in a) free phase and b) sorbed phase.

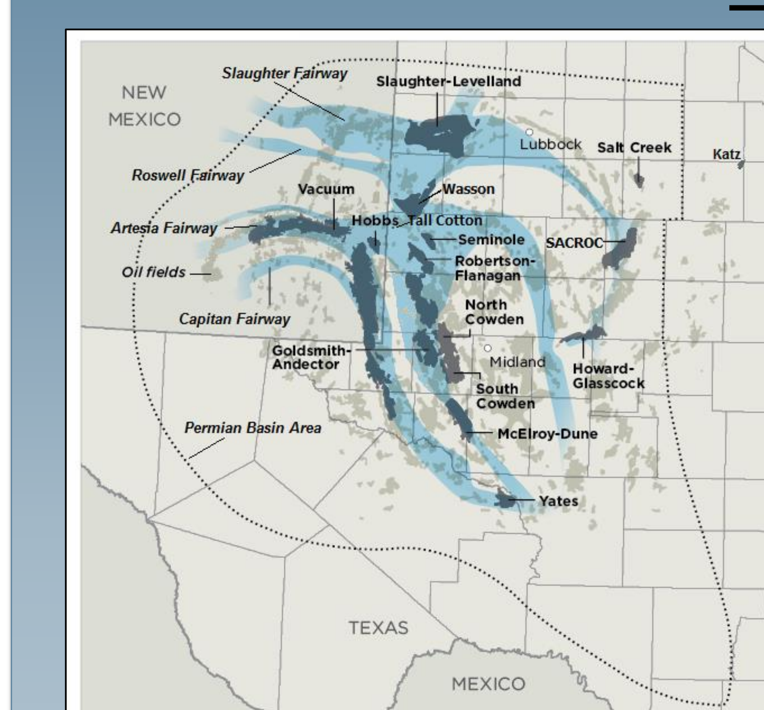
Table 3
Ranges of E_ϕ and E_S Efficiency Factor Terms for Carbon Dioxide Storage in Shales Calculated Using Method I and Method II (values in the parentheses).

Years	E_ϕ Minimum	Maximum	P_{10}	P_{90}
5	0.04 (0.17)	0.12 (0.56)	0.04 (0.25)	0.12 (0.53)
10	0.06 (0.22)	0.18 (0.59)	0.07 (0.31)	0.18 (0.57)
20	0.08 (0.27)	0.23 (0.60)	0.09 (0.34)	0.23 (0.59)
30	0.10 (0.28)	0.28 (0.60)	0.11 (0.36)	0.27 (0.58)
40	0.11 (0.28)	0.31 (0.59)	0.13 (0.37)	0.30 (0.56)
50	0.14 (0.27)	0.34 (0.58)	0.14 (0.34)	0.33 (0.55)
60	0.15 (0.26)	0.37 (0.57)	0.15 (0.34)	0.36 (0.54)

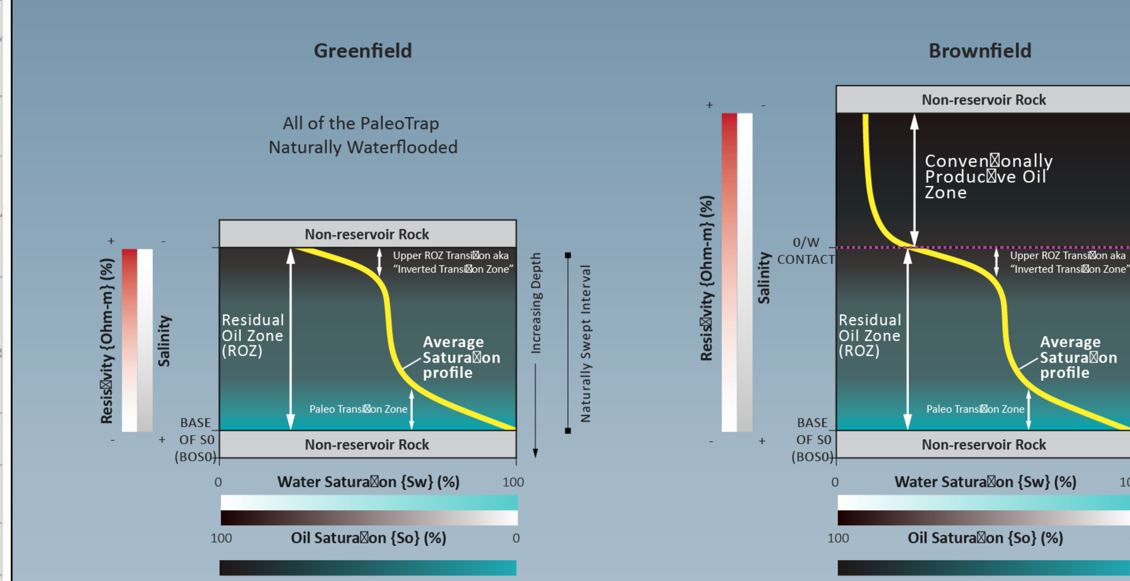
Years	E_S Minimum	Maximum	P_{10}	P_{90}
5	0.02 (0.09)	0.07 (0.36)	0.03 (0.14)	0.07 (0.34)
10	0.04 (0.13)	0.11 (0.48)	0.05 (0.16)	0.11 (0.44)
20	0.06 (0.16)	0.17 (0.57)	0.07 (0.20)	0.17 (0.53)
30	0.08 (0.15)	0.21 (0.59)	0.09 (0.20)	0.20 (0.56)
40	0.09 (0.15)	0.25 (0.58)	0.10 (0.21)	0.22 (0.57)
50	0.10 (0.15)	0.26 (0.57)	0.11 (0.20)	0.23 (0.56)
60	0.11 (0.14)	0.27 (0.55)	0.11 (0.19)	0.24 (0.55)

Ranges of efficiency factors for the free and sorbed phase storage of CO_2.

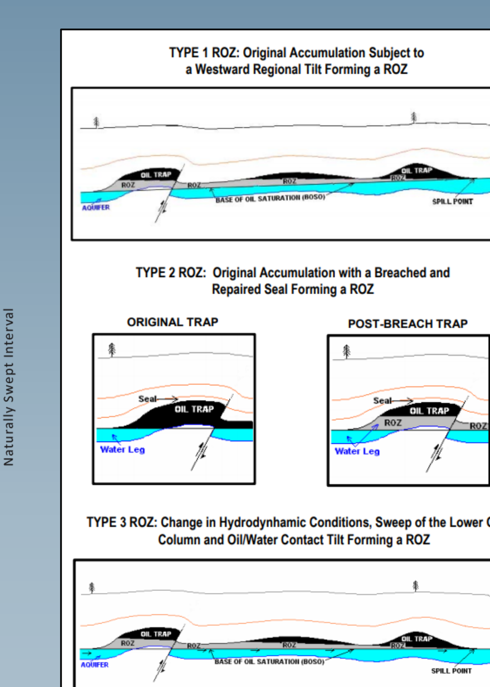
Residual Oil Zone Systems



Residual oil zone map of fairways (light blue), ROZ fields (dark blue), and oil fields (gray). (Melzer Consulting).



Greenfield and Brownfield residual oil zones showing the Upper and Lower transition zones. (Based on RPSEA study; Melzer, 2005).



Types of residual oil zones.

$$G_{CO_2} = A_t E_A h_g E_h \left[\underbrace{\phi(1-S_{wr}-S_{or})\rho_{CO_2} E_\phi}_{free\ phase} + \underbrace{\phi S_{wr}\rho_{CO_2} R_{bd} E_{bd}}_{dissolved\ in\ brine} + \underbrace{\phi S_{or}\rho_{CO_2} R_{od} E_{od}}_{dissolved\ in\ oil}\right]$$

Parameter	Description	Unit
S_{wr}	Residual water saturation	–
S_{or}	Residual oil saturation	–
ρ_{CO_2}	Density of CO_2 at reservoir conditions	kg/m^3
R_{bd}	Solubility of CO_2 in brine	$mass/mass$
R_{od}	Solubility of CO_2 in oil	$mass/mass$
E_{bd}	Efficiency factor for dissolution in brine	–
E_{od}	Efficiency factor for dissolution in oil	–
E_u	Efficiency factor for CO_2 utilization	–

References

- Goodman, A., Hakala, A., Bromhal, G., Deel, D., Rodosta, T., Frailey, S., Small, M., Allen, D., Romanov, V., Fazio, J., Huerta, N., McIntyre, D., Kutchko, B., Guthrie, G., 2011. U.S. DOE methodology for the development of geologic storage potential for carbon dioxide at the national and regional scale. Int. J. GHGC. 5, 952–965.
- Levine, J.S., Fukai, I. Soeder, D.J., Bromhal, G., Dilmore, R.M., Guthrie, G.D., Rodosta, T., Sanguinito, S., Frailey, S., Gorecki, D., Peck, W., Goodman, A.L., 2016. U.S. DOE NETL Methodology for Estimating the Prospective CO2 Storage Resource of Shales at the National and Regional Scale. Int. J. Greenh. Gas Control, v. 51, p. 81-94.
- Melzer, S., 2006, Stranded oil in the residual oil zone, Report prepared for Advanced Resources International and U.S. Department of Energy Office of Fossil Energy, p. 51.
- Melzer, S., Trenham, R.C., 2015, Recognition and exploitation of residual oil zones coming of age: Melzer Consulting, Report. p. 4.
- Myshakin, E.M., Singh, H., Sanguinito, S., Bromhal, G., Goodman, A., 2018, Numerical estimations of storage efficiency for the prospective CO2 storage resource of shales. International Journal of Greenhouse Gas Control, v. 76, p. 24-31.
- US-DOE-NETL, 2012. The United States 2012 Carbon Utilization and Storage Atlas, Fourth Edition. U.S. Deparment of Energy - National Energy Technology Laboratory - Office of Fossil Energy.
- US-DOE-NETL, 2015. Carbon Storage Atlas, fifth edition. U.S. Department of Energy—National Energy Technology Laboratory—Office of Fossil Energy.

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