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Quantifying and Enhancing CO_2 Storage Capacity

Storage in Saline Formations R&D Workshop
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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

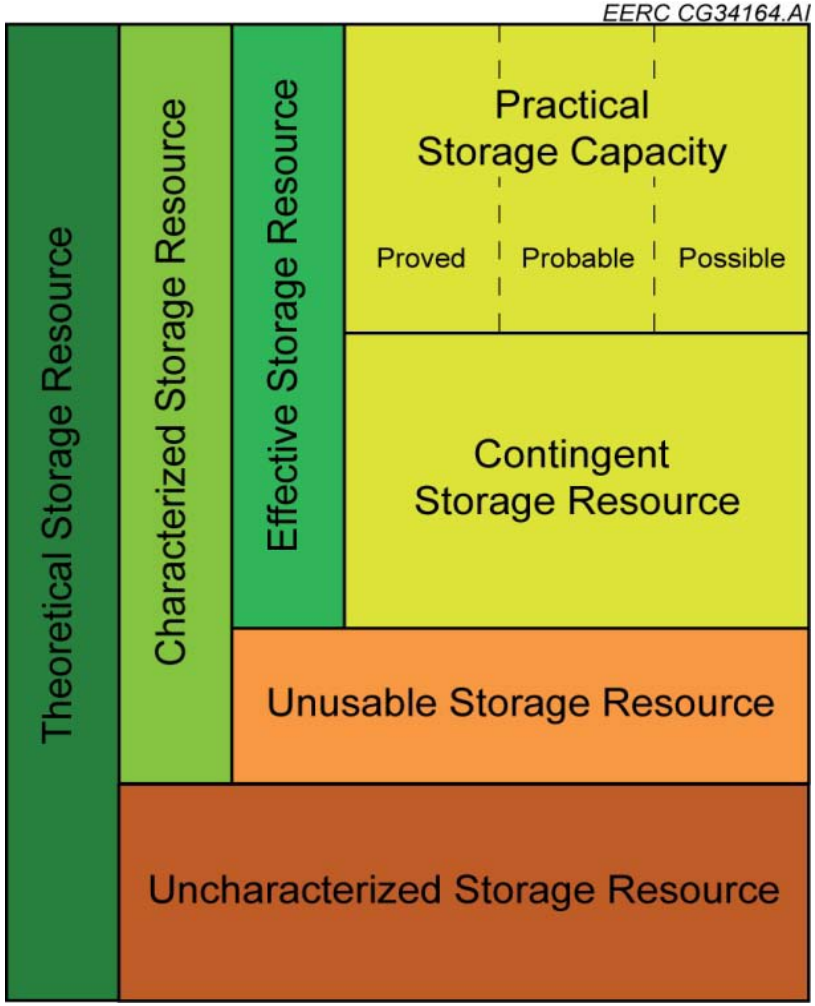
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

PCO2R Partnership

Resource vs. Capacity

- **Carbon Dioxide (CO_2) Storage Resource Estimates:** Represents the fraction of the pore volume of a sedimentary rock formation available for CO_2 storage and accessible to injected CO_2. Economic and regulatory constraints are not considered when estimating CO_2 storage resource assessments (U.S. Department of Energy [DOE], 2010).
- **CO_2 Storage Capacity Estimates:** Represents the fraction of the pore volume of a sedimentary rock formation available for CO_2 storage when the current economic and regulatory considerations are included (DOE, 2010).

Terminology

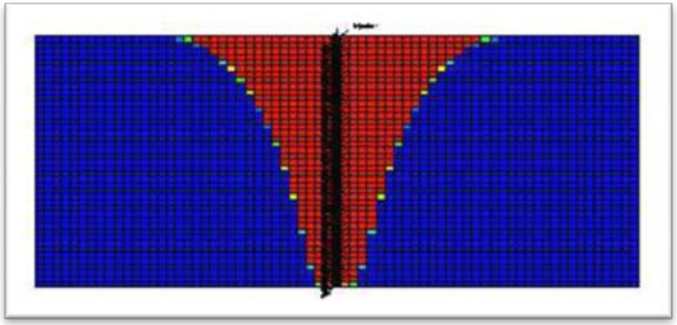


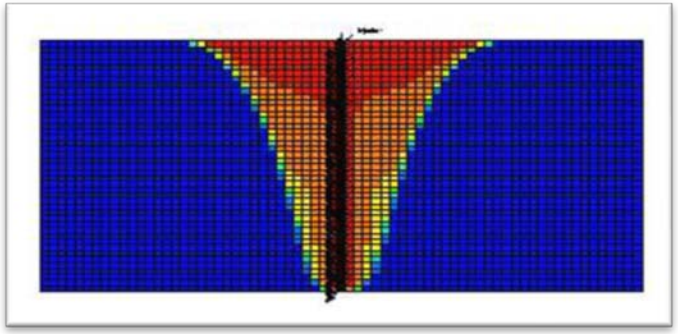
Gorecki et al., 2009.

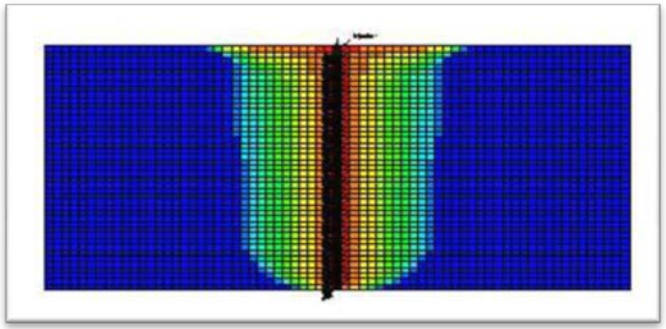
- **<u>Effective Storage Resource</u>:** Represents the fraction of the pore volume of a sedimentary rock formation available for CO_2 storage after technical constraints have been applied (Gorecki et al., 2009).

- **<u>Practical Storage Capacity</u>:** The storage capacity can be estimated by applying economic and regulatory constraints to the effective storage resource. Practical storage capacity may be further broken down similarly to petroleum industry standards (Gorecki et al., 2009).

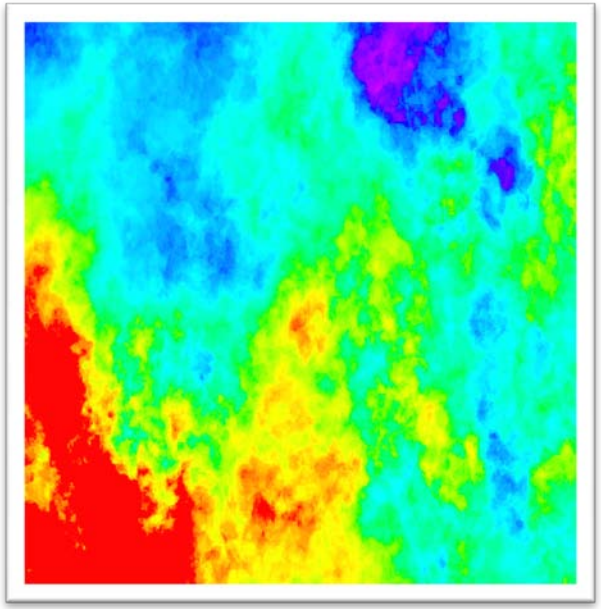
Storage Efficiency and Storage Efficiency Factors

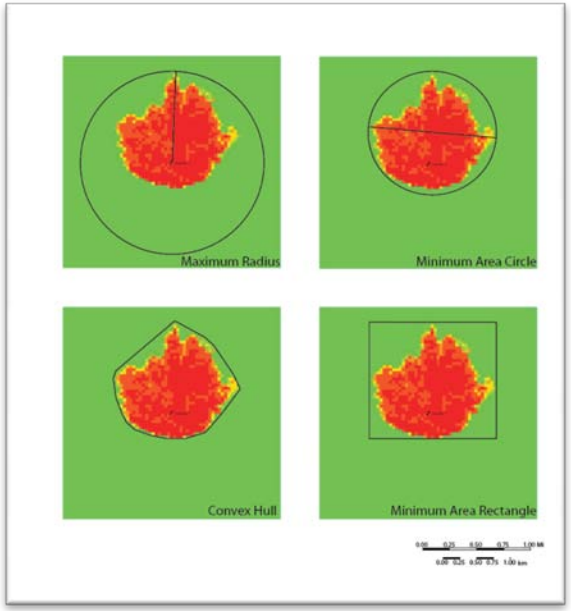




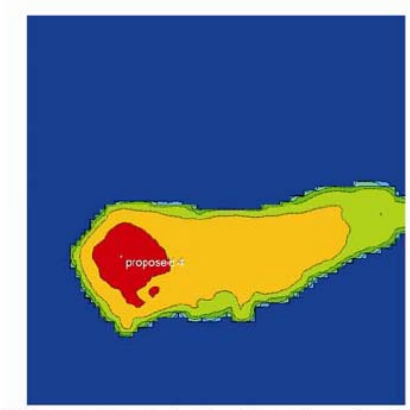


Gorecki et al., 2009

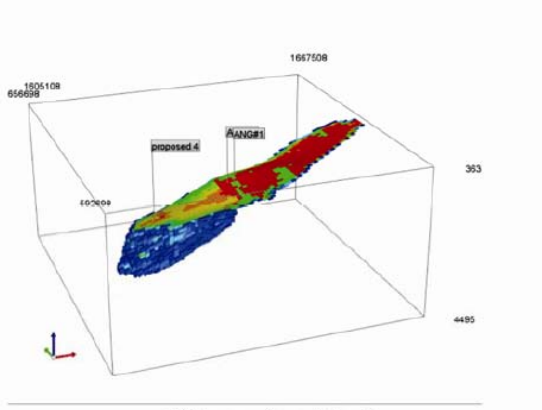




Gorecki et al., 2009

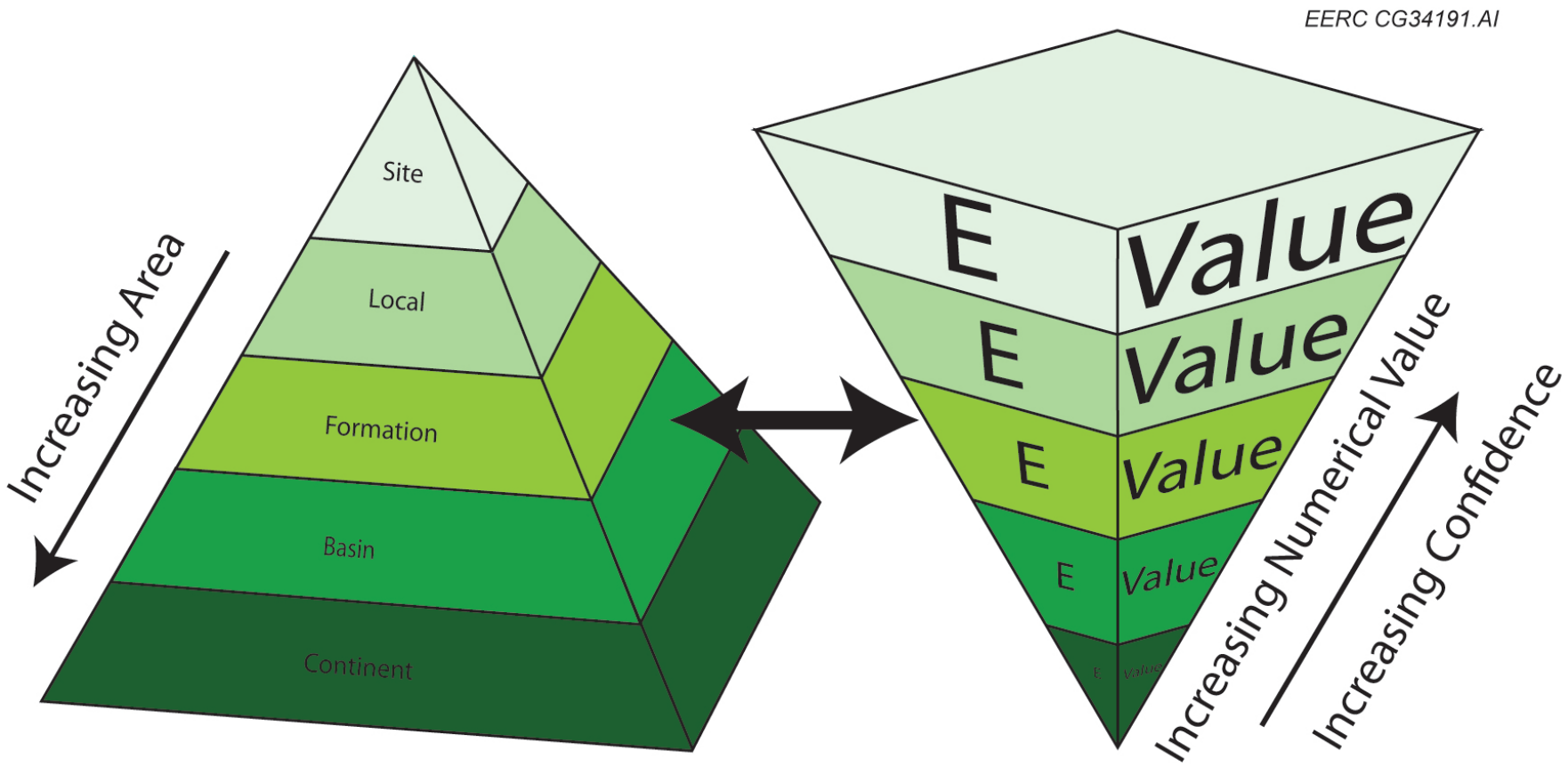


300 years from Injection Start. Spread to 27.14 mi^2



300 years from Injection

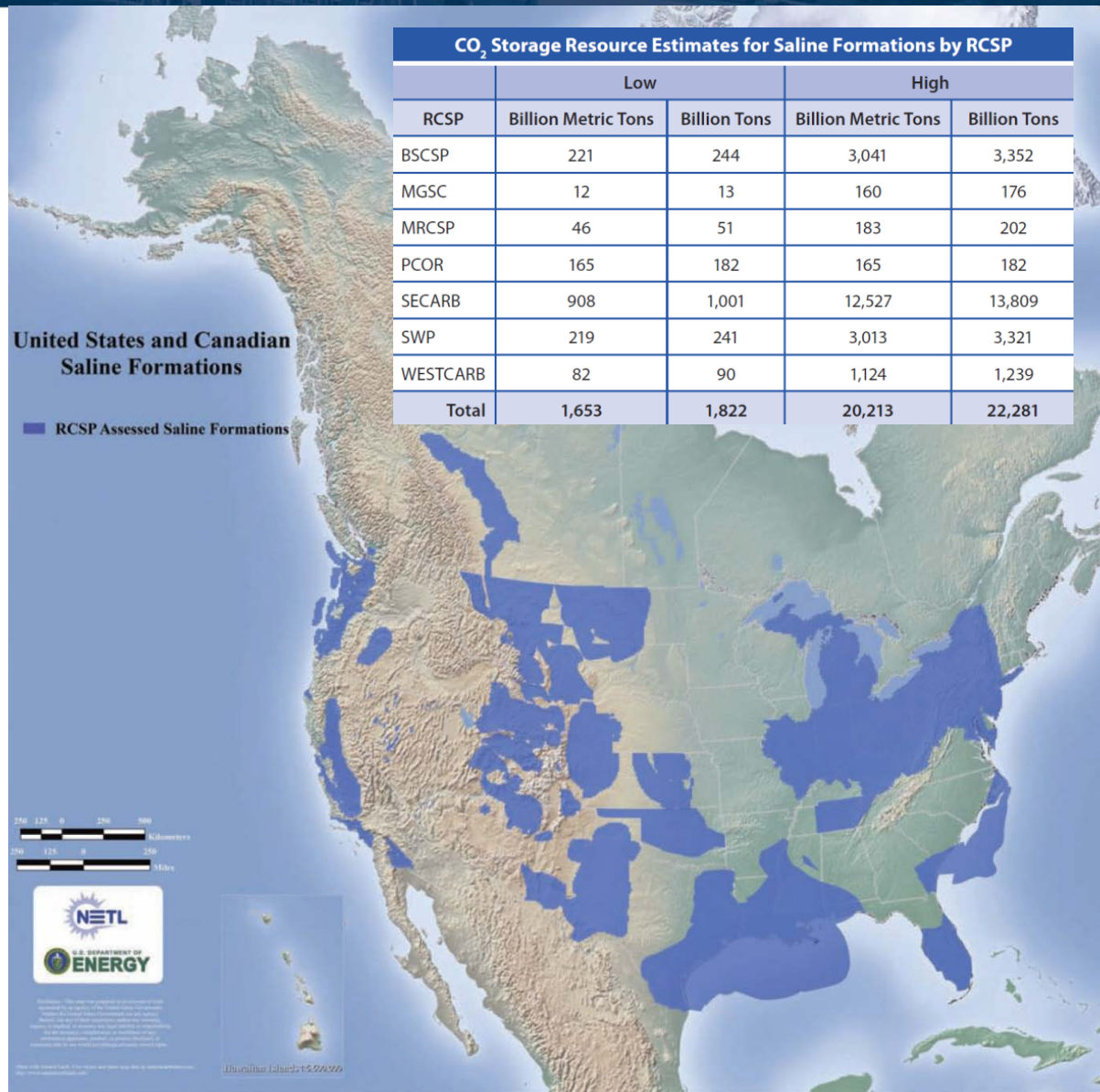
Storage Efficiency Factors at Different Scales



Gorecki et al., 2009

Quantifying CO_2 Storage Resource

- How much CO_2 can be stored in deep brine-filled formations (saline formations or saline aquifers)?



CO_2 Storage Resource Estimates for Saline Formations by RCSP

	Low		High	
RCSP	Billion Metric Tons	Billion Tons	Billion Metric Tons	Billion Tons
BSCSP	221	244	3,041	3,352
MGSC	12	13	160	176
MRCSP	46	51	183	202
PCOR	165	182	165	182
SECARB	908	1,001	12,527	13,809
SWP	219	241	3,013	3,321
WESTCARB	82	90	1,124	1,239
Total	1,653	1,822	20,213	22,281

CO_2 Storage Resource/Capacity Methodologies

- Static CO_2 storage resource/capacity methodologies:
  - DOE, Carbon Sequestration Leadership Forum (CSLF), and IEAGHG methodology
  - U.S. Geological Survey (USGS) methodology
  - Closed system, compressibility methodology
- Dynamic CO_2 storage resource/capacity methodologies
  - Concerned with pressure, injectivity, timing of injection projects, etc.
  - Based largely on detailed CO_2 injection simulations on the site.

Comparison of Open-System Methodologies

- Fundamentally, the methods presented by CSLF (2007) and DOE (2007, 2008, 2010) are the same method (CSLF, 2008).
- Any storage volume estimated with one method can be compared to the other, as long as the assumptions made are the same (Gorecki et al., 2009).

Effective Storage Resource

$$V_{CO_2,DOE_E} = A * h * \phi * E_E$$

$$V_{CO_2,CSLF_E} = A * h * \phi * (1 - S_{wirr}) * C_C$$

$$E_E = C_C * (1 - S_{wirr})$$

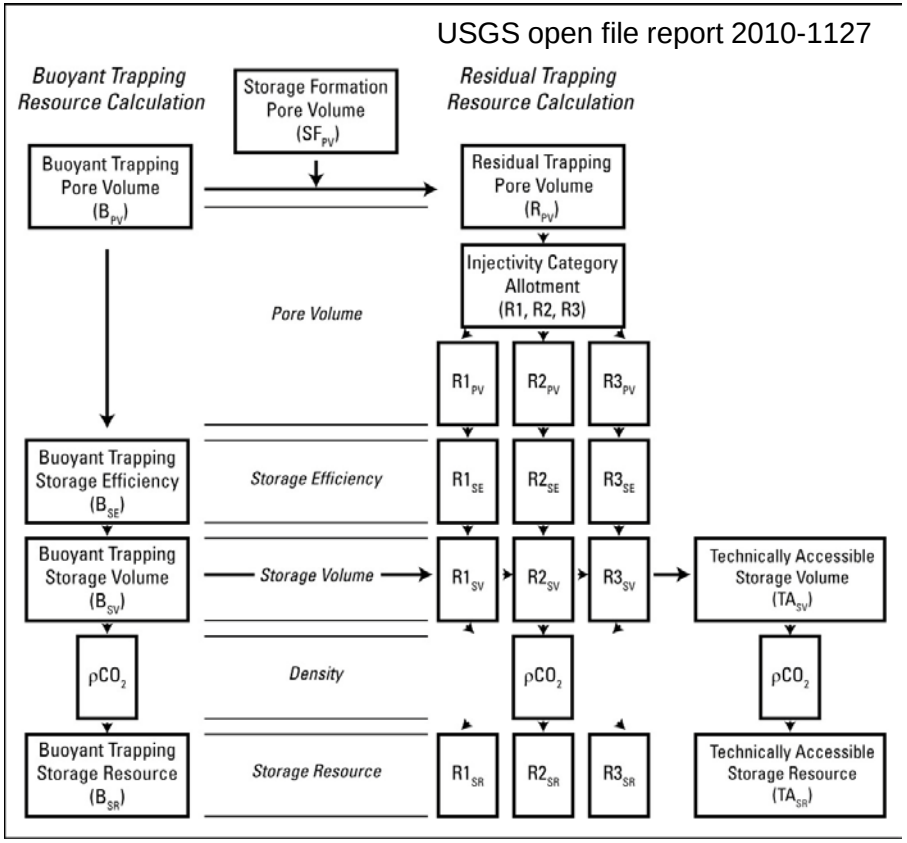
$$V_{CO_2,DOE_E} = V_{CO_2,CSLF_E}$$

Comparison of Open-System Methodologies

- The USGS methodology uses the same volumetric equation as the CSLF and DOE methodologies except that storage resource is divided into buoyant and residual trapping with classes based on permeability

$$SF_{PV,\ USGS} = A_{SF} * T_{PI} * \phi_{PI}$$

Buoyant Trapping + Residual Trapping



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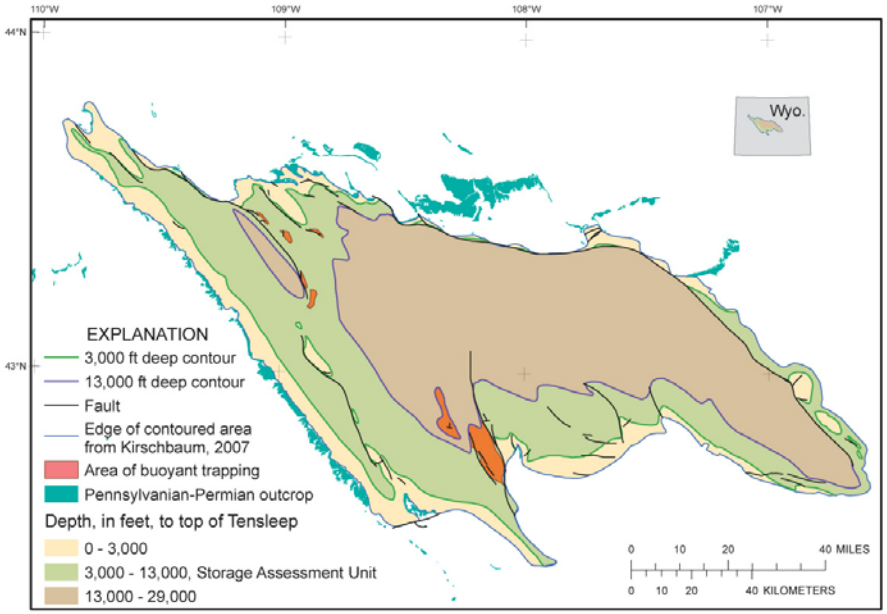
Comparison of Open-System Methodologies

Tensleep Sandstone of the Wind River Basin, Wyoming

DATA Input from USGS open file report 2010-1127				
Porous Volume	**Units**	**Min**	**Mode**	**Max**
1) Total Area of Assessment Unit	Acres	1300000	1400000	1500000
2) Net Porous Interal	Feet	80	100	120
3) Porosity	%	10	15	20
Buoyant Trapping				
4) Net Pore Volume	MMbbl	190	205	4100
5) Trapping Efficiency	%	10	30	60
6) CO2 Density	kg/m3	675	700	725
Residual Trapping				
8) CO2 Density	kg/m3	675	700	725
Class 1 (5%) Trapping Efficiency	%	1	5	7
Class 2 (90%) Trapping Efficiency	%	1	7	15
Class 3 (5%) Trapping Efficiency	%	0	0	7



CO2 Storage Resource			
	P5	P50	P95
Methodology	Mt	Mt	Mt
USGS*	466	1134	1928
CSLF*	527	1335	2416
DOE*	527	1335	2416

*DATA Input from USGS open file report 2010-1127

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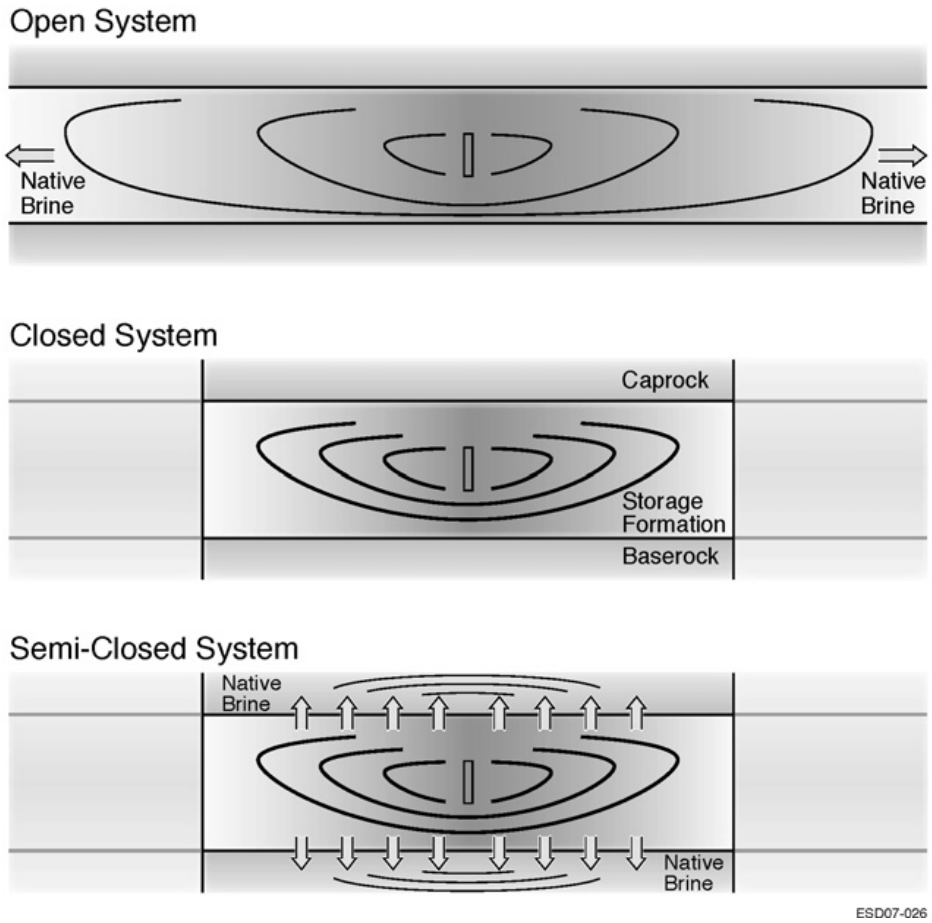
Open and Closed Systems



- Large, continuous, permeable, little to no pressure feedback
- Compartmentalized, large pressure feedback
- Most realistic, some combination of the two

Zhou et al., 2008

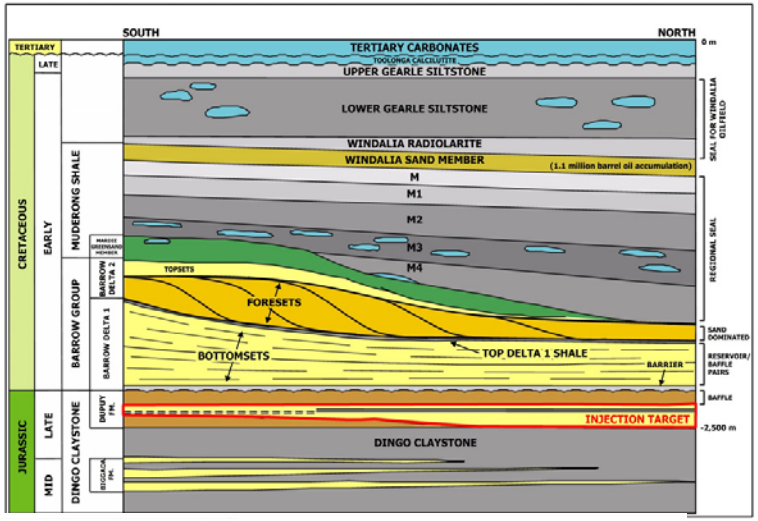
Open Systems

- Open systems are governed by **displacement.**

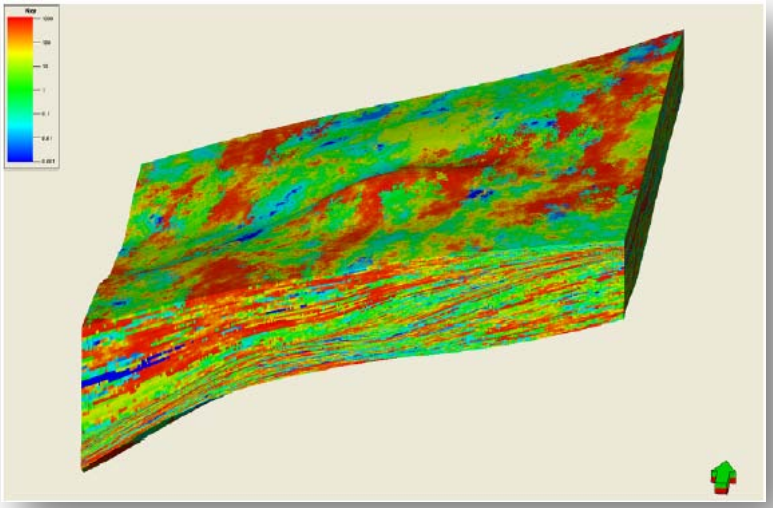
$$G_{CO_2} = A * h * \phi * \rho_{CO_2} * E$$ (DOE, 2008, 2010)

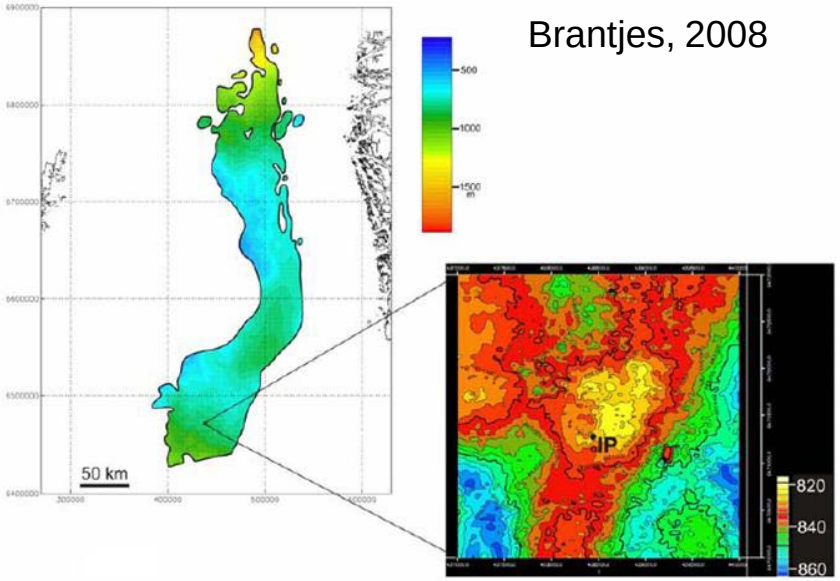
$$E = E_{geol} * E_V * E_d$$

$$E_{geol} = A_n / A_t * h_n / h_g * \phi_V / \phi_d$$ (Gorecki et al., 2009)



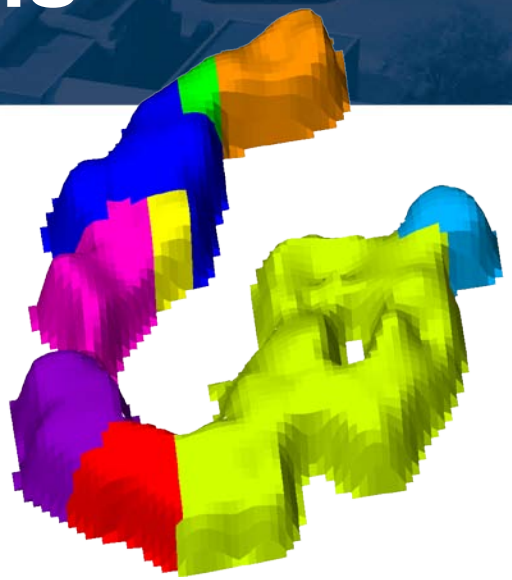
Brantjes, 2008

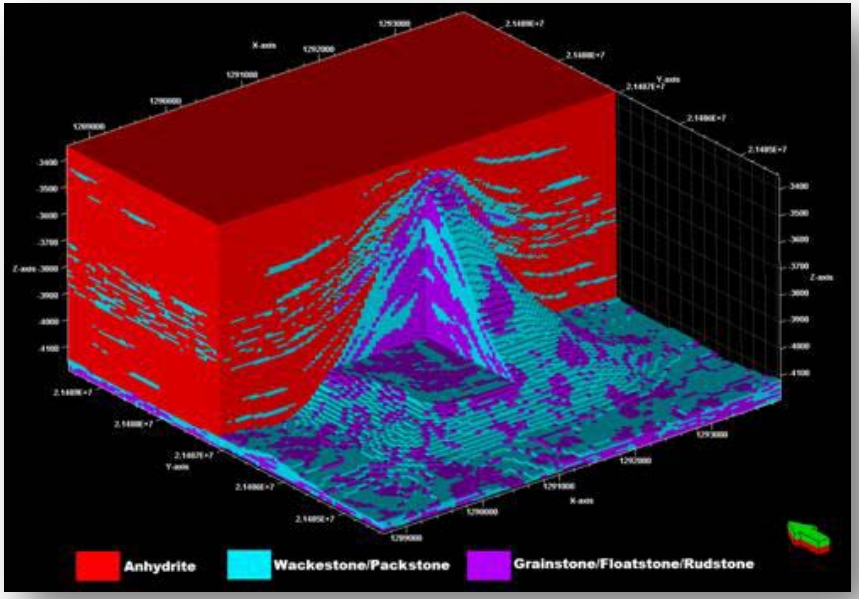




Holloway et al, 2004

Closed Systems





Closed systems are governed by **compression.**

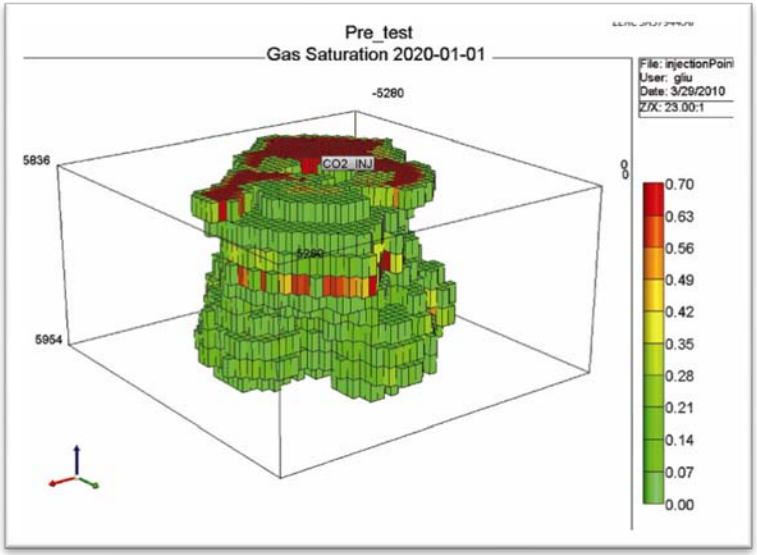
$$G_{CO_2} = A * h * \phi * \rho_{CO_2} * E$$

(DOE, 2008; Gorecki et al., 2009)

$$E_{comp} = \Delta V_t / V_{po} = (c_w + c_p)\Delta p$$

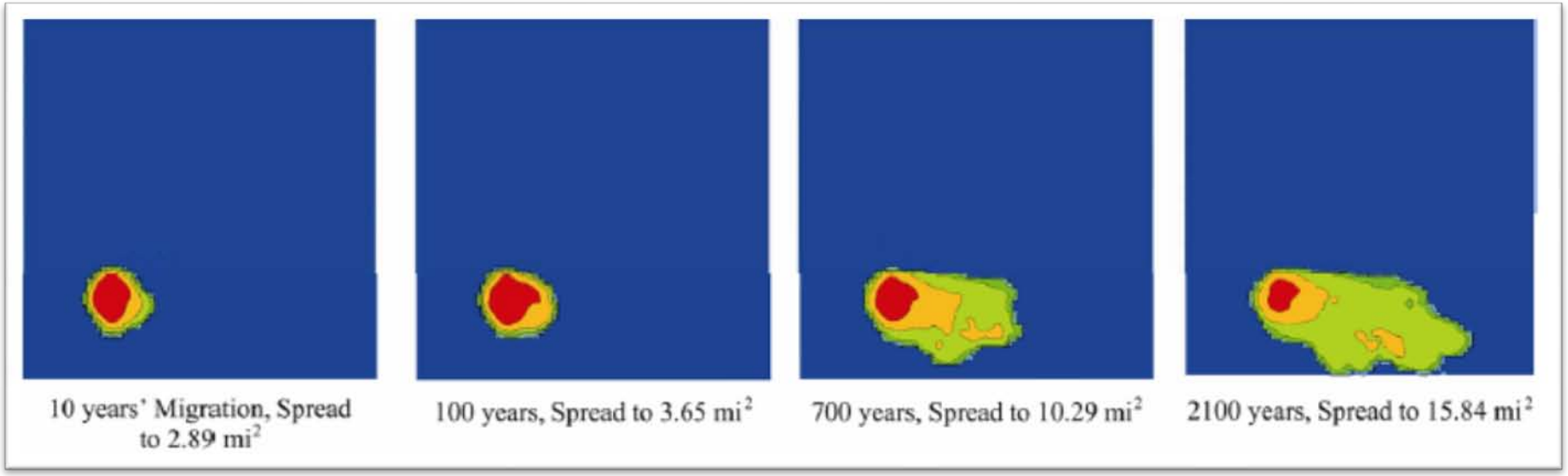
(Gorecki et al., 2009)

Dynamic Storage Resource/Capacity



Is efficiency calculated:

- At the end of injection?
- When free-phase CO_2 stops moving?
- An arbitrary length of time?
- Dynamically through injection and postinjection?

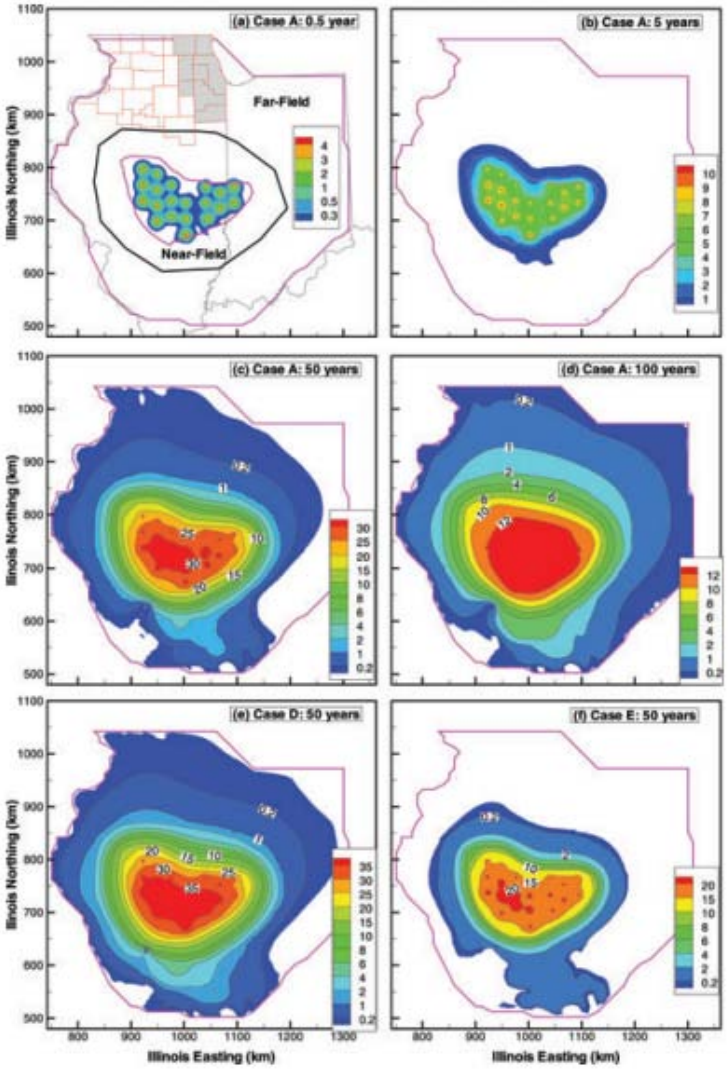


Dynamic Storage Resource/Capacity Cont.

Total capacity influenced by:

- Injection rate
- Injection pattern
- Timing of injection(s)
- Plume development

A wide range of potential capacities exists for the majority of storage projects.



Zhou et al., 2010

Pressure Management

Open Systems

- At the end of injection, pressures will diminish to original conditions.
- Increased capacity even for very large storage volumes.
- Potential for migration of formation fluids.

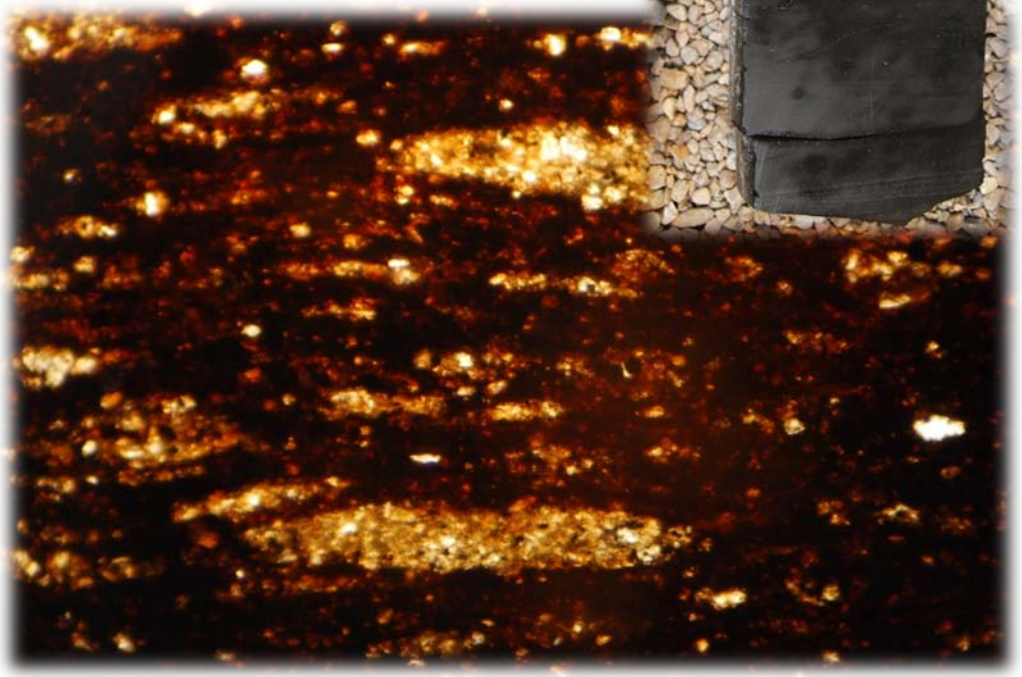
Closed Systems

- At the end of injection, pressures will remain elevated.
- Capacity potentially limited.
- Limited or nonexistent fluid migration.

Image from www.activebuilding.com

Shale Permeability

- Deep saline formations are unlikely to be completely closed if sealed by low (nonzero)-permeability shales.
- Interfacial tension effects are high and prevent multiphase flow.
- Shales may behave as semipermeable membranes, allowing water (pressure) to bleed off, yet retain injected CO_2.

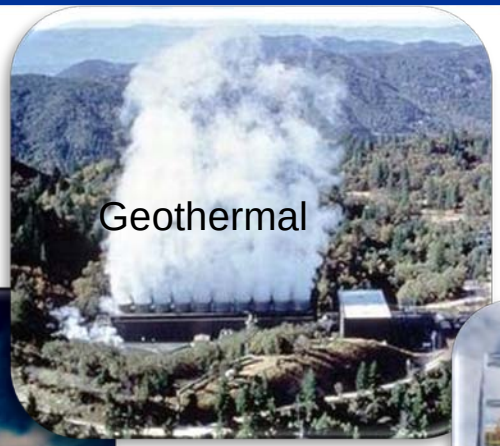


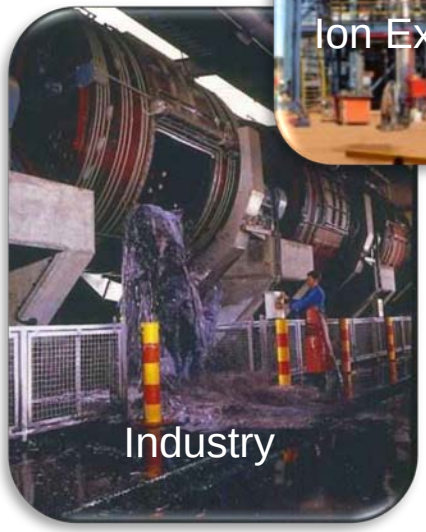
Bakken Shale, 100x mag. PP light

Water Extraction

- Extraction of formation water for CO_2 plume and pressure plume management may provide the following benefits:
  - Reduction of overall scope and costs of monitoring, verification, and accounting (MVA) activities.
  - Reduction of storage reservoir pressure.
  - Increase in overall CO_2 storage volume.
  - Generation of supplemental water to surface and subsurface supplies, providing immediate and tangible benefits to local and regional stakeholders.

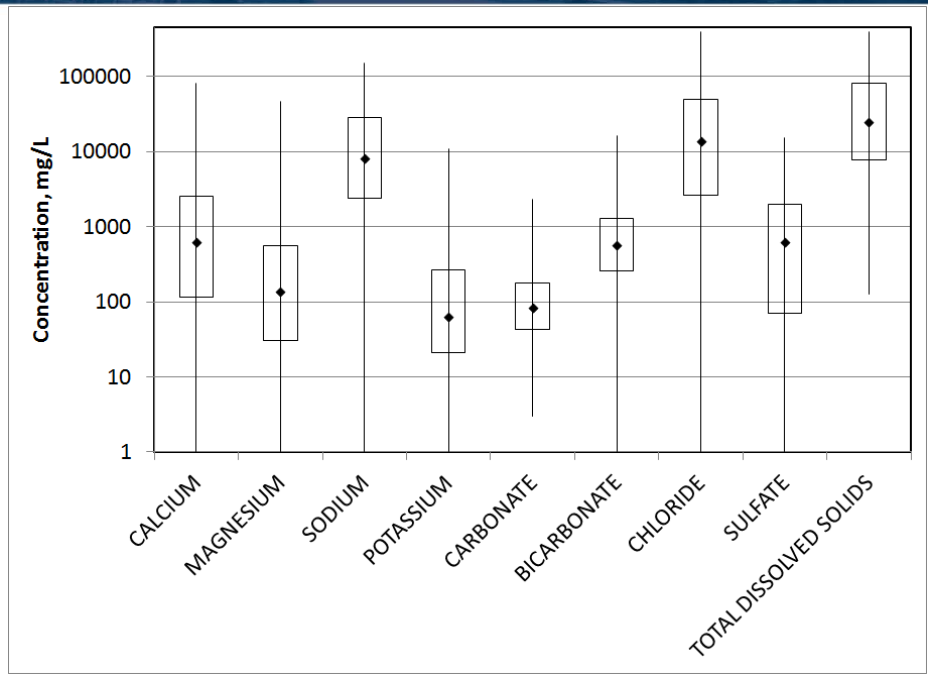
Extracted Water Beneficial Use

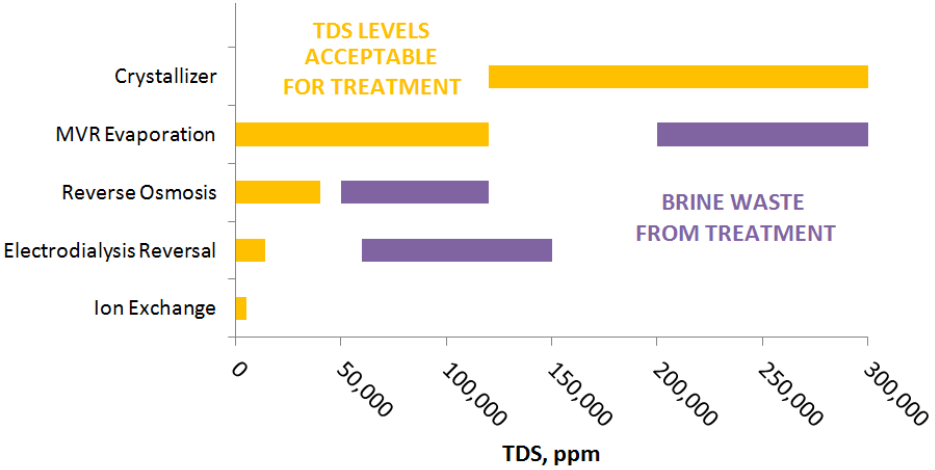




Options for Extracted Water Management

- Water quality potential for extracted water:
  - Total dissolved solids (TDS) range = low to very high.
- Water quality needed for beneficial use:
  - Most uses require lower TDS than expected.
- Water treatment processes:
  - Desalination methods will be used to match extracted water quality to water quality needs.





Research Needs

- Consistent methodology and terminology needs to be agreed upon to develop consistent and comparable results.
- The potential impact of water extraction on storage capacity requires further development.
- The understanding of the impact and influence of dynamic storage methodologies remains limited as it has the potential to dramatically influence final total capacity.
- Need remains for additional real-world results and real-world data.

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Thanks!!

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