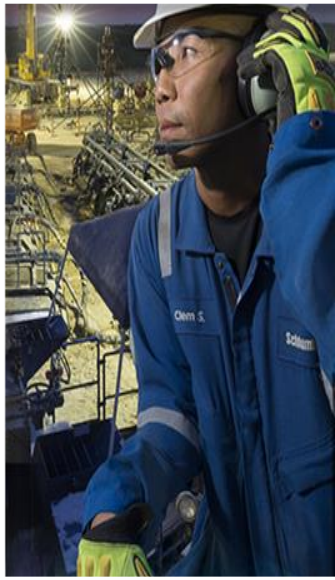
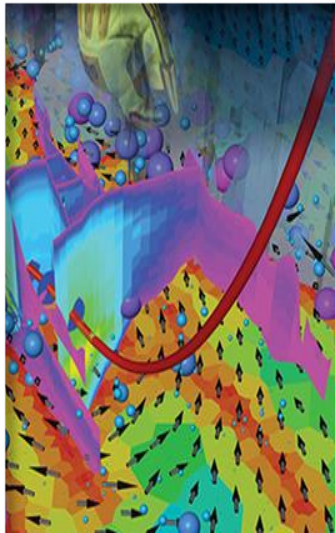
Schlumberger





CO_2 Storage Associated with Unconventional/Shale

Wayne Rowe – N. America Decarbonization Projects

Presented at the 16th Annual CO_2 EOR Carbon Mgmt Workshop Midland, Texas Dec 3, 2018

CO2 ROZ Conference
www.CO2Conference.net

OUTLINE

Conventional CO_2 Storage

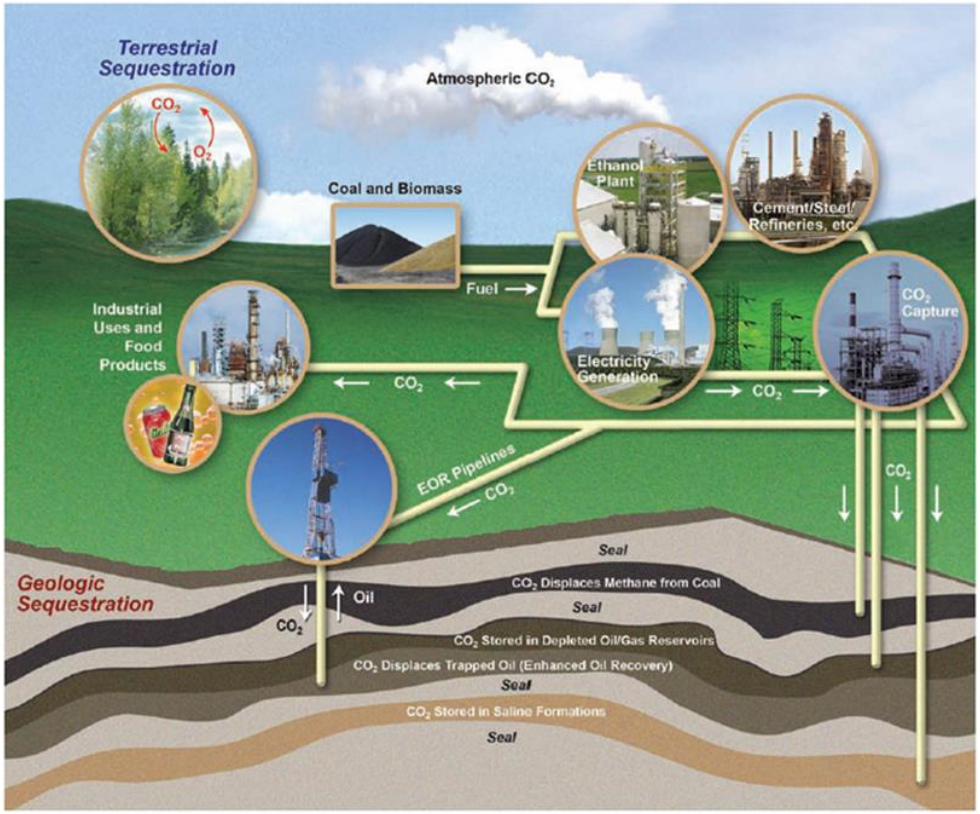
Unconventional CO_2 Storage

Unconventional CO_2 EGR

Shale Resource and CO_2 Availability

Impact of 45Q Tax Credit Enhancement

CO_2 Storage Geologic Storage Reservoir Types



- DEEP SALINE FORMATIONS
- DEPLETED O&G RESERVOIRS (EOR)
- UNMINEABLE COAL
- BASALT AND OTHER VOLCANIC
- OTHER

Cira 2005

Storage in Conventional VS Unconventional (Shales)

Conventional Reservoirs
- Structural
- Capillary
- Solubility
- Mineral trapping

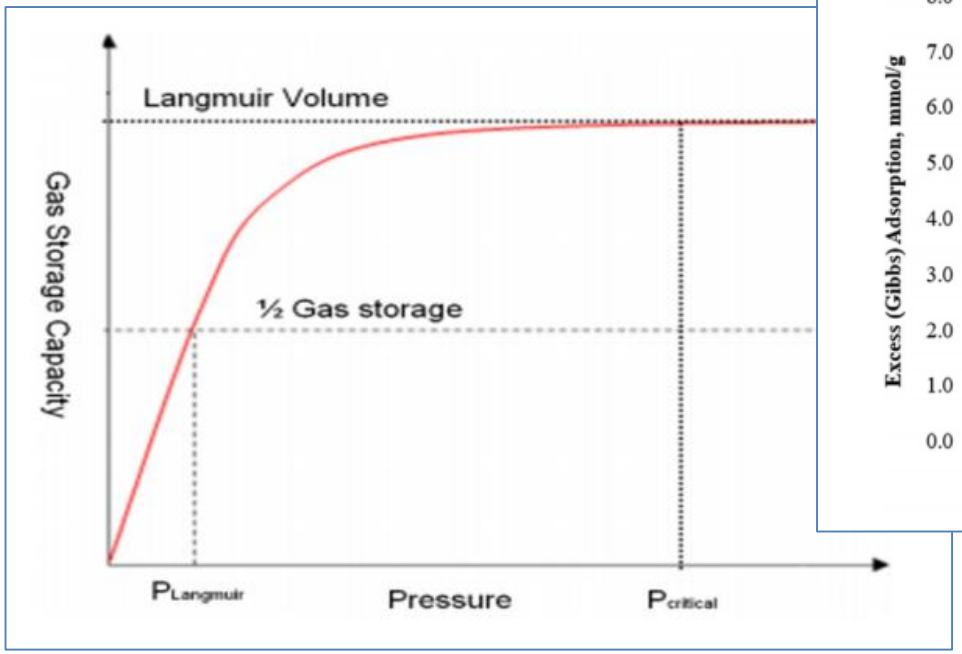
$MCO_2e = A \times h \times \varphi \times \rho CO_2 \times E$

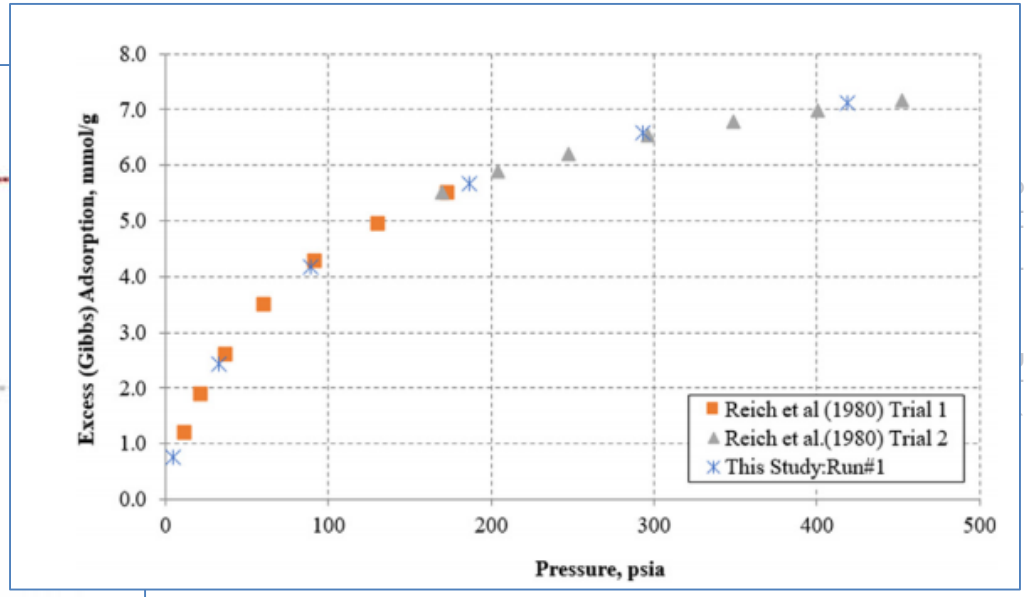
Unconventional/Shale Reservoirs
- CO_2 Adsorption onto organic materials and clay minerals
- ranging from 20% to 80% of original-gas-in-place (OGIP)
- CO_2 is adsorbed preferentially over methane (CH4) (up to a 5:1 ratio by molecule)
- potential added benefit of enhanced gas recovery (EGR)

$$G_{st} = \frac{32.0368}{B_g}\left[\frac{\phi(1-S_w)}{\rho_{rock}} - \frac{2.001\times10^{-3}\widehat{M}C}{\rho_{mc}}\right] + \left(1518C\left(\frac{\rho_{ads}}{\rho_{mc}} - \frac{\rho_{gas}}{\rho_{mc}}\right)\right)$$

Shale Storage Capacity - Adsorption

Theoretical – Langmuir Isotherms





Lab Analysis – using experimental adsorption data and adsorption models

Adsorption Tendancy

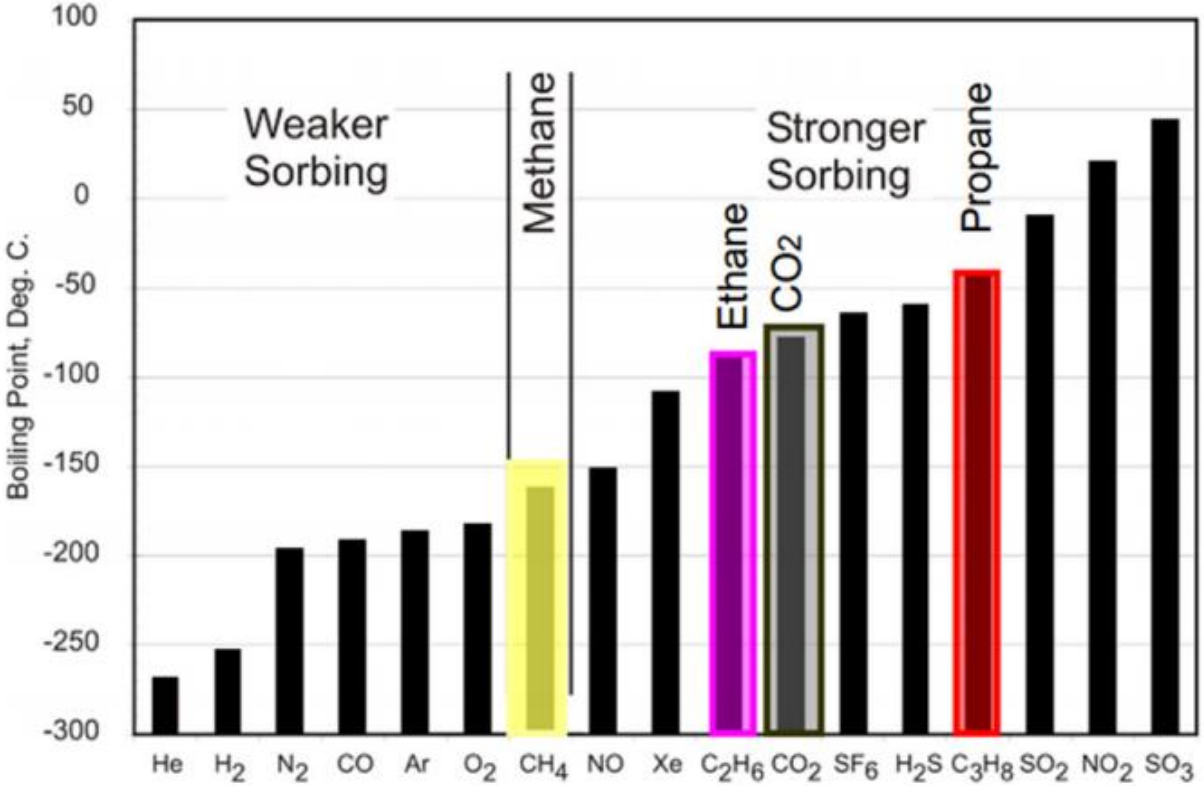
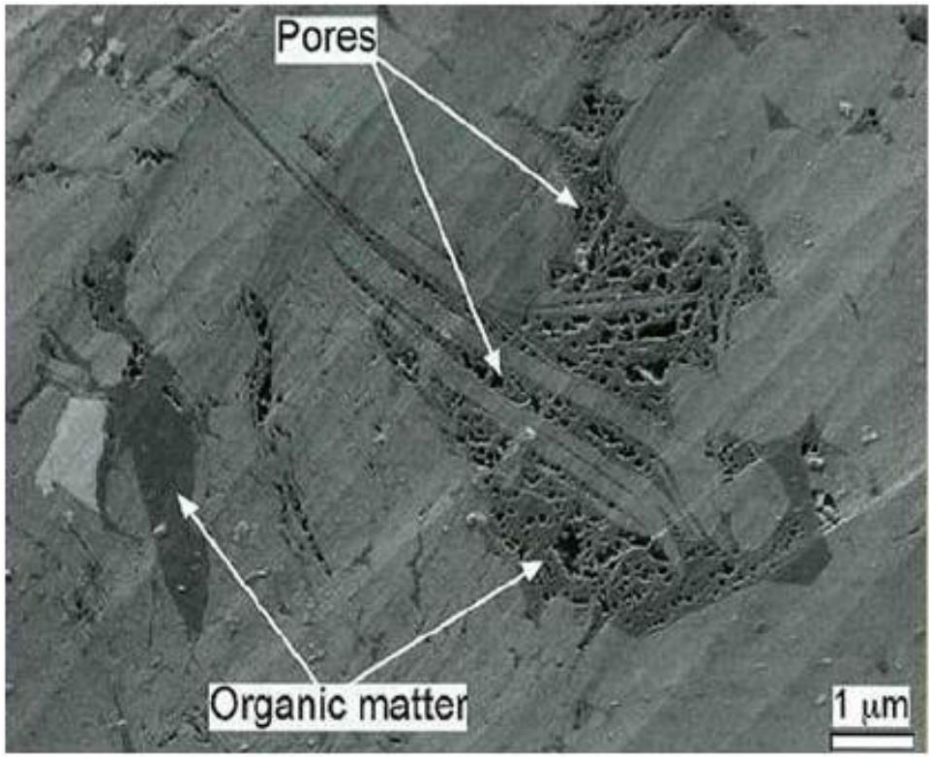


Fig. 13. Adsorption tendency of some components in relationship to fluid boiling point (Breig, 2010).

Organic Matter & Clay Mineral Heterogeneity



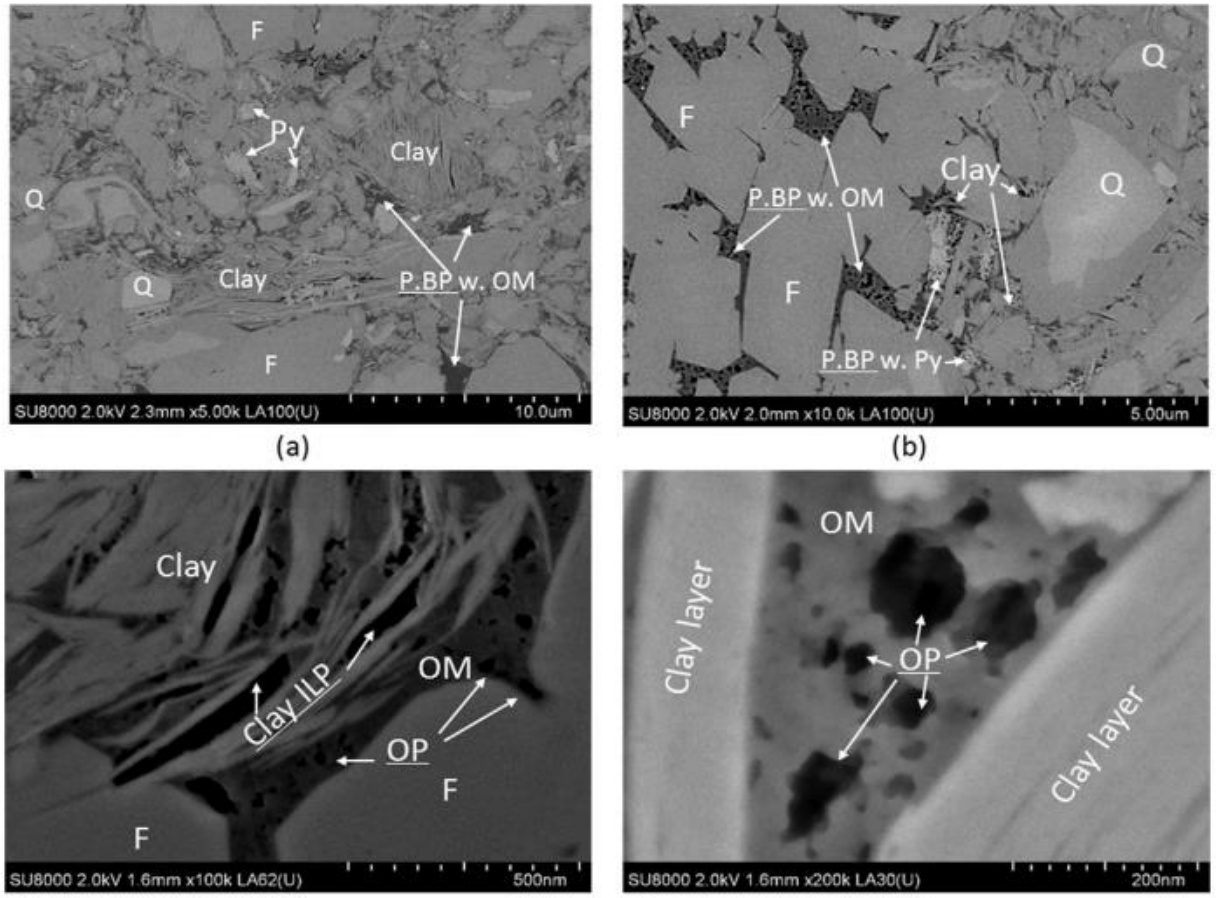
Shales contain porous solid organic matter

Small pore size means different transport physics

Pore geometry and chemistry control transport

Heterogeneity at micron length scale

Organic Matter & Clay Mineral Heterogeneity



quartz
feldspar
clay minerals
organic matter
various pores.

Shale Characterization

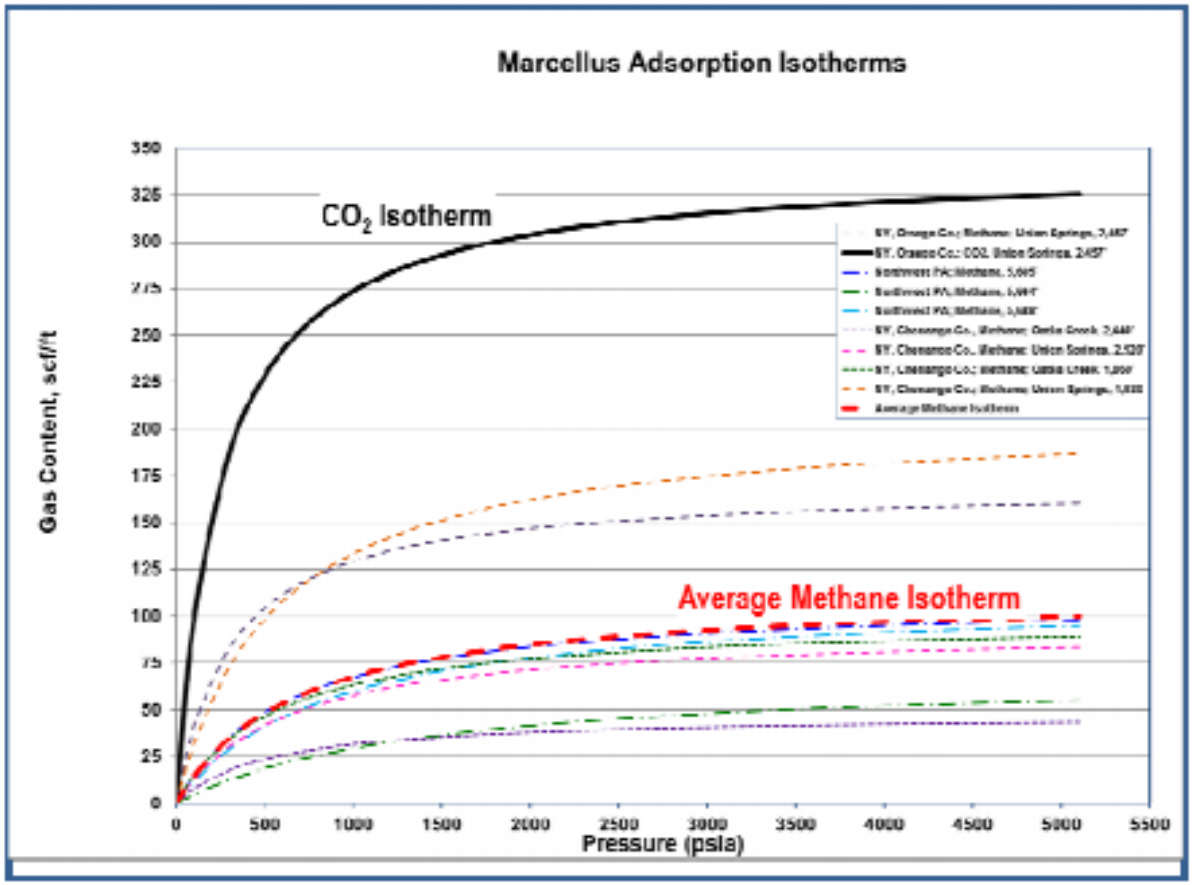
Formation	Period	Location	TOC wt%	Vitrinite reflectance	Color
Antrim Shale	Late Devonian	Michigan Basin, US	0.5–24	0.4–0.6	Black
Barnett Shale	Mississippian	Fort Worth and Permian Basin, US	3.2	2.25	Dark Gray
Marcellus Shale	Devonian	New York, Ohio, Pennsylvania, West Virginia, US	3.8	1.56	Black
Haynesville Shale	Late Jurassic	Louisiana, East Texas, US	4.2	2.37	Black
Woodford Shale	Devonian-Mississippian	Oklahoma, Texas, US	2	1.51	Gray
Duvernay Shale	Devonian	Alberta, Canada	4–11	0.4–1.41	Dark Brown

Shale Gas Formations and Their Potential for Carbon Storage: Opportunities and Outlook Roozbeh Khosrokhavar & Steve Griffiths & Karl-Heinz Wolf

Total Organic Carbon (TOC) And Vitrinite Reflectance (VR)

VR of 0.5%-0.6% Oil Generation, VR of 0.85%-1.1% Gas Generation

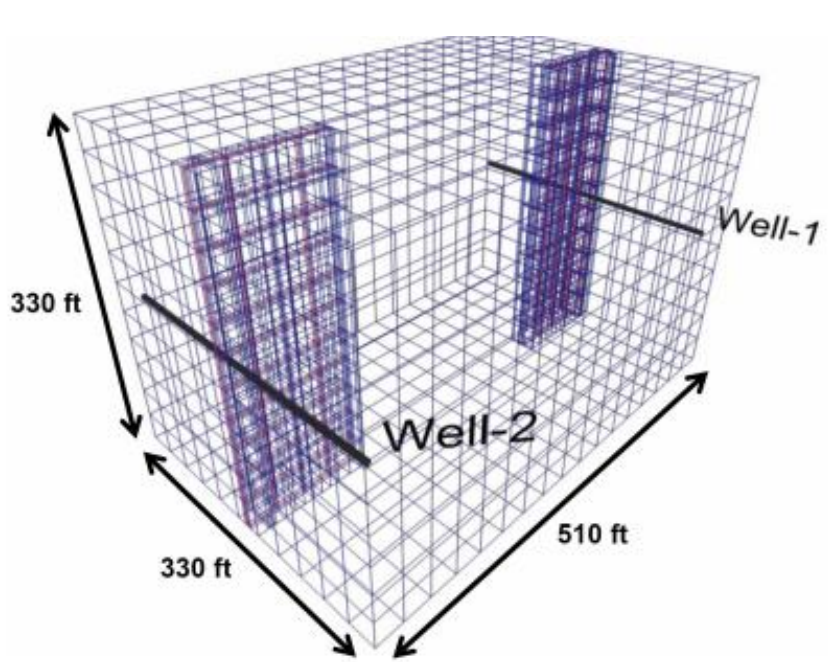
Marcellus CH_4 and CO_2 Adsorption Isotherms



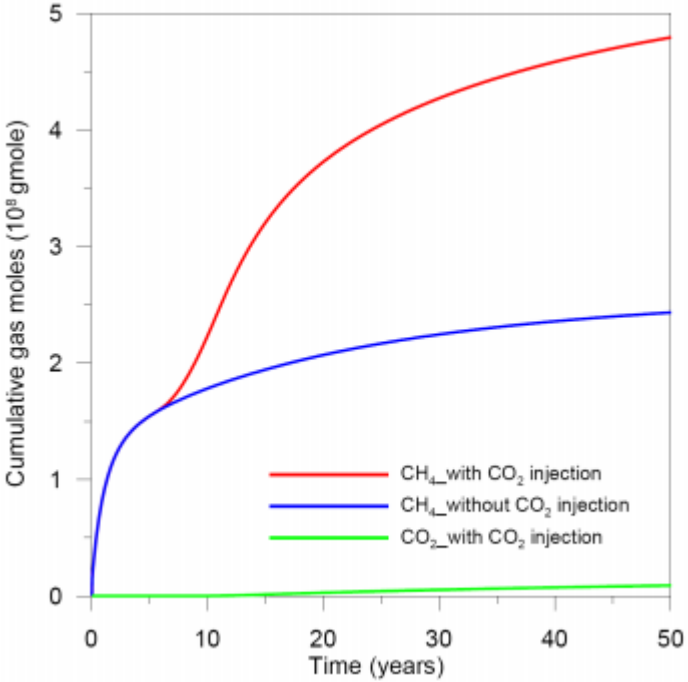
Michael Godec et al. / Energy Procedia 63 (2014) 5849 – 5857

Modeling of CO_2 Injection

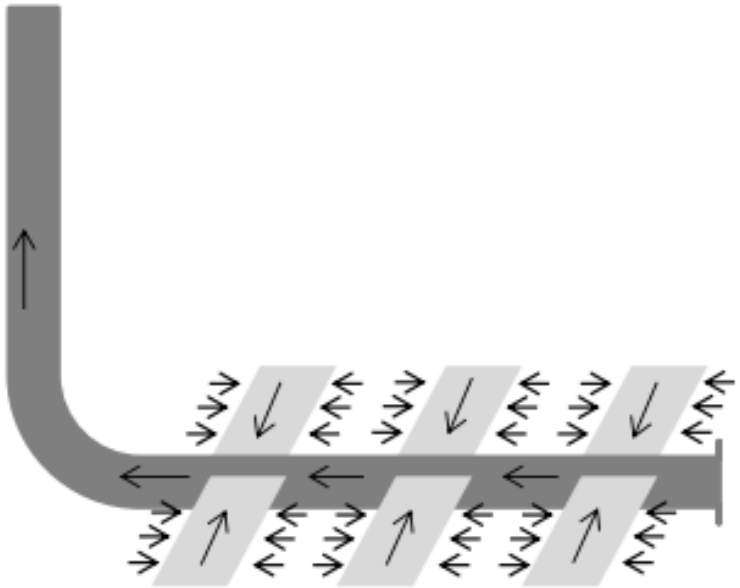
Schematic View of Shale Gas Reservoir Model for the CO_2 Injection



Cumulative gas Moles of the CH_4 and CO_2 with and without CO_2 Injection

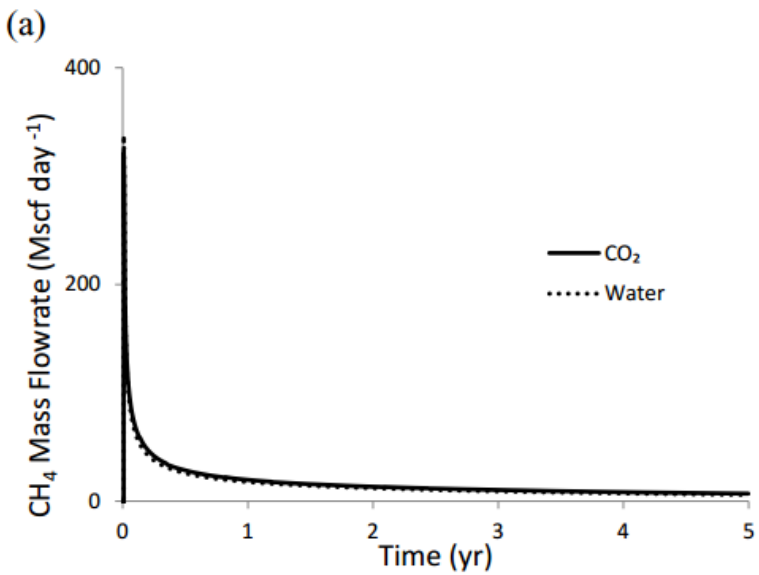


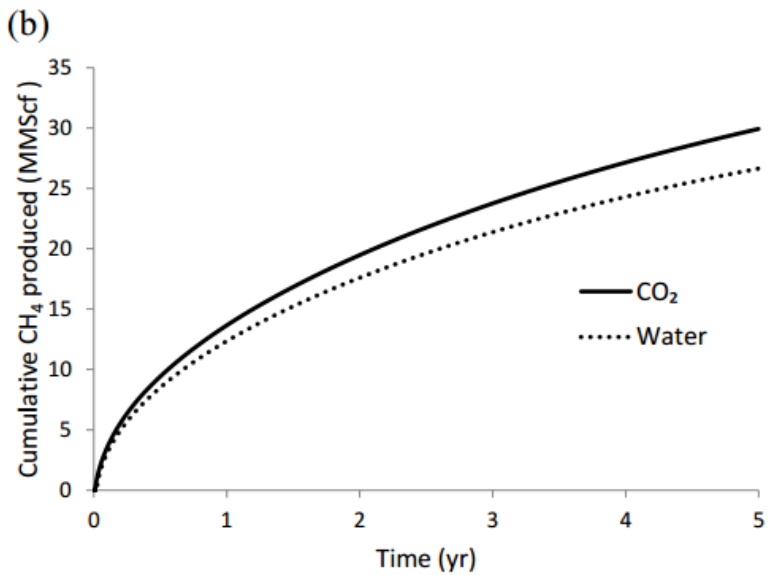
CO_2 Frac Vs Water Frac – Marcellus Example



CH_4 Langmuir K (MPa)	0.17
CO_2 Langmuir K (MPa)	0.1
Max. CH_4 Adsorption (kg m^{-3})	*6.5*
Max.CO_2 Adsorption (kg m^{-3})	*5*
Adsorbed Phase density	1000
Reservoir Properties	
Effective Permeability (nD)	*25*
Gas Saturation %	75
Porosity %	6
Reservoir Pressure (MPa)	*25*
Fracture properties	
Fracture Height, V (m)	32
Fracture Width, H (m)	200
Half spacing between fractures (m)	15

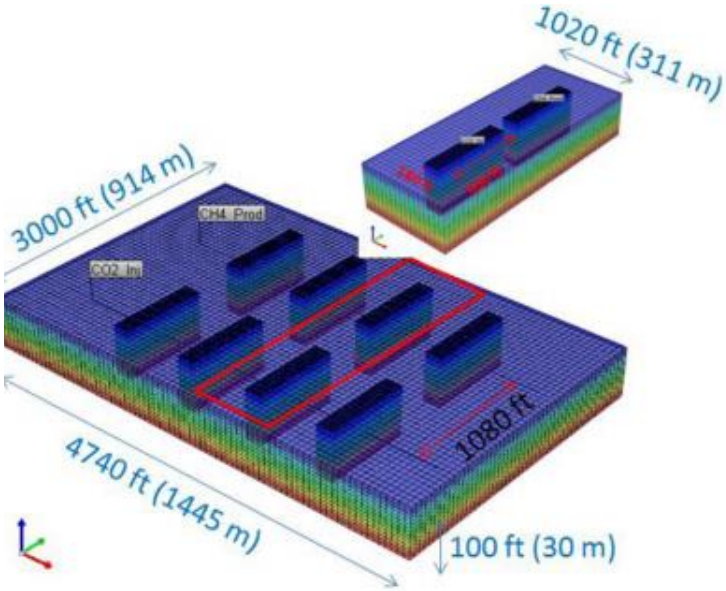
CO_2 Frac Vs Water Frac – Marcellus Example



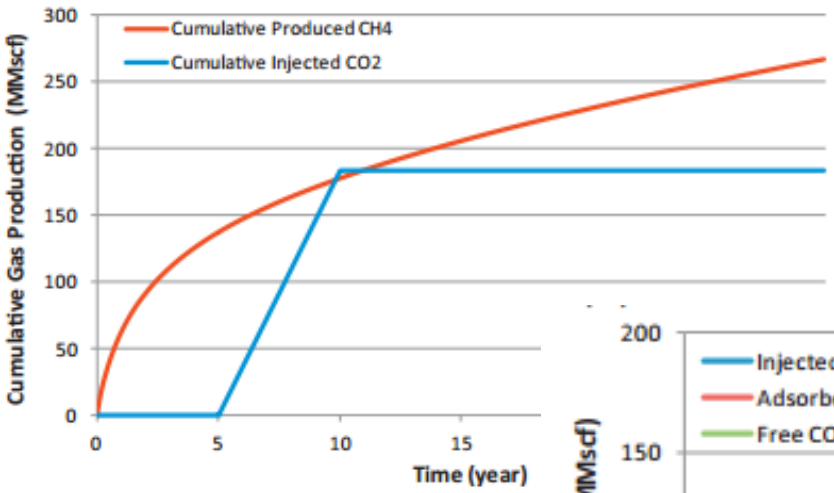


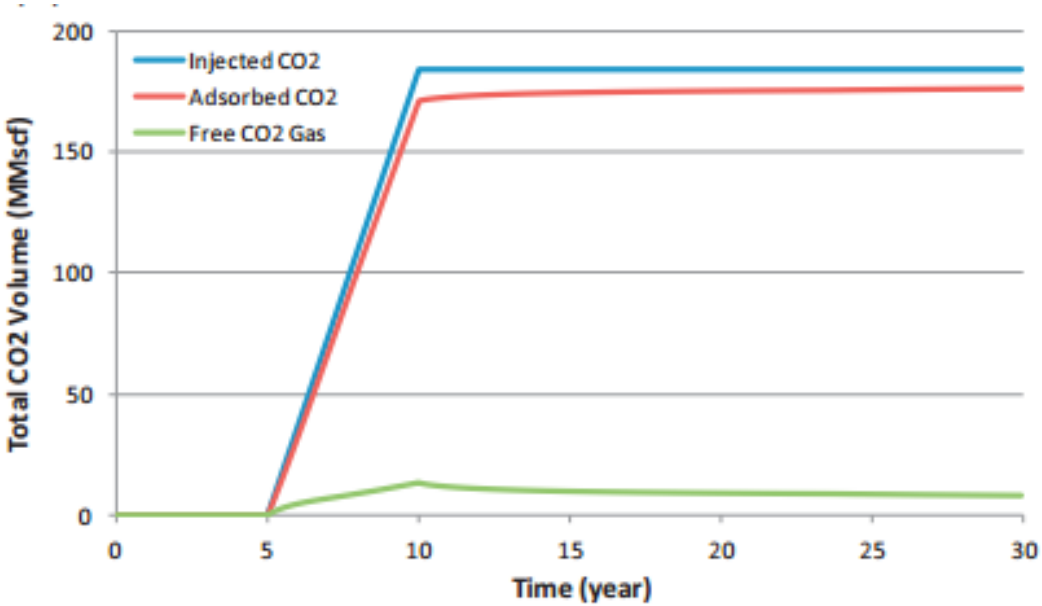
CO_2 Storage Example – New Albany Shale

Reservoir properties	
Depth	1378 ft (420 m)
Thickness	100 ft (30 m)
Temperature	86 °F
Initial pressure gradient	0.3 psi/ft (6.8 kPa/m)
Lithostatic pressure gradient	0.9 psi/ft (20.4 kPa/m)
Porosity	10–14%
Matrix permeability	150 nD
Diffusivity	1×10^{-9} m^2/s
Water saturation	40%
Rock density	2.4 g/cm^3
Natural fracture conductivity	20 μD-ft[a]
Rock geochemistry properties	
TOC	12%
Maximal adsorbed gas (CO_2)	510.1 scf/ton[b]
Langmuir adsorption constant (CO_2)	0.000896 1/psi[c]
Maximal adsorbed gas (CH_4)	119.5
Langmuir adsorption constant (CH_4)	0.001119 1/psi
Rock geomechanical properties	
Matrix compressibility	3E–6 1/psi
Fracture compressibility	3E–4 1/psi
Well properties	
Well length	4200 ft (1280 m)
Hydraulic fracture stages	4
Hydraulic fracture conductivity	100 mD-ft
Hydraulic fracture half length	450 ft (137 m)

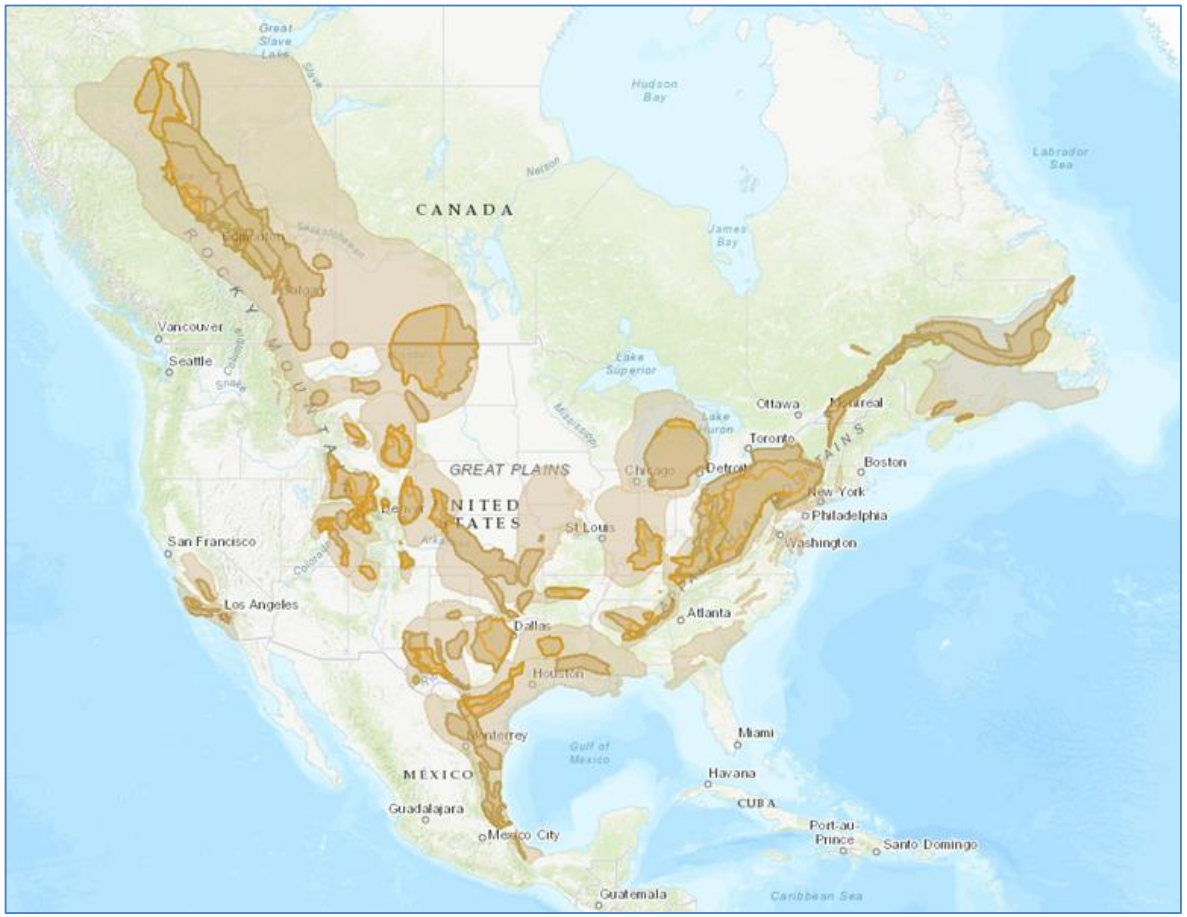


CO_2 Storage Example – New Albany Shale

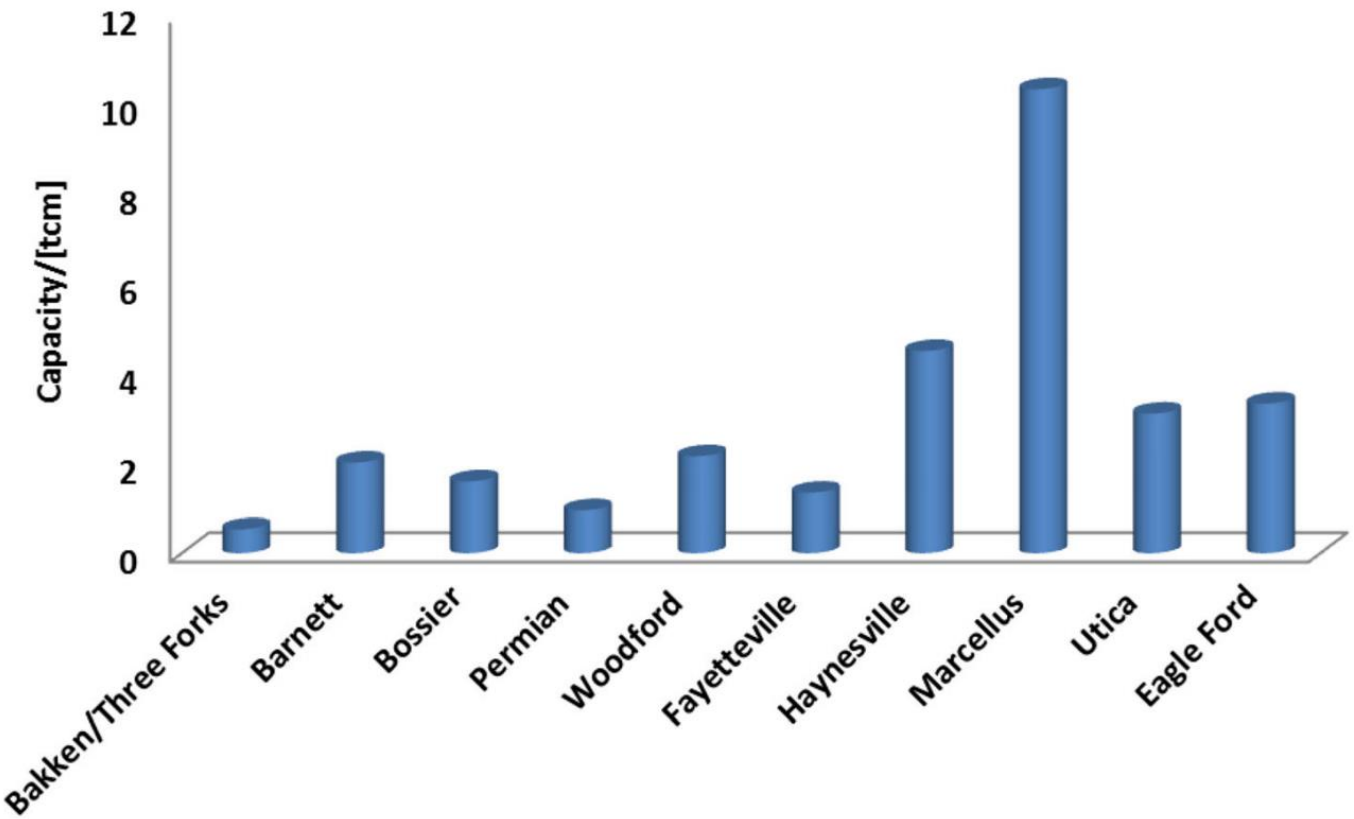




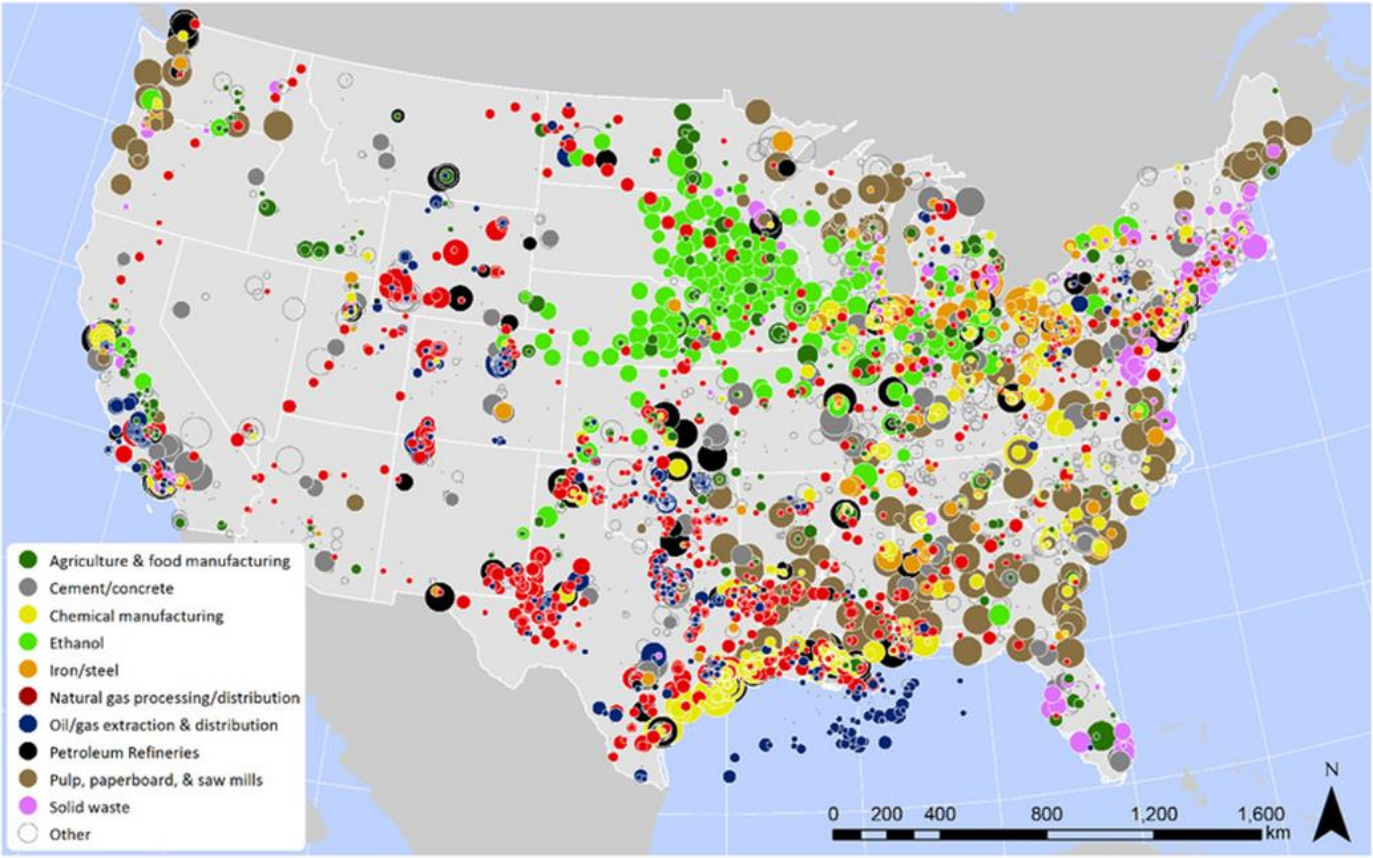
US Shale Reservoirs



US Shale Reservoirs

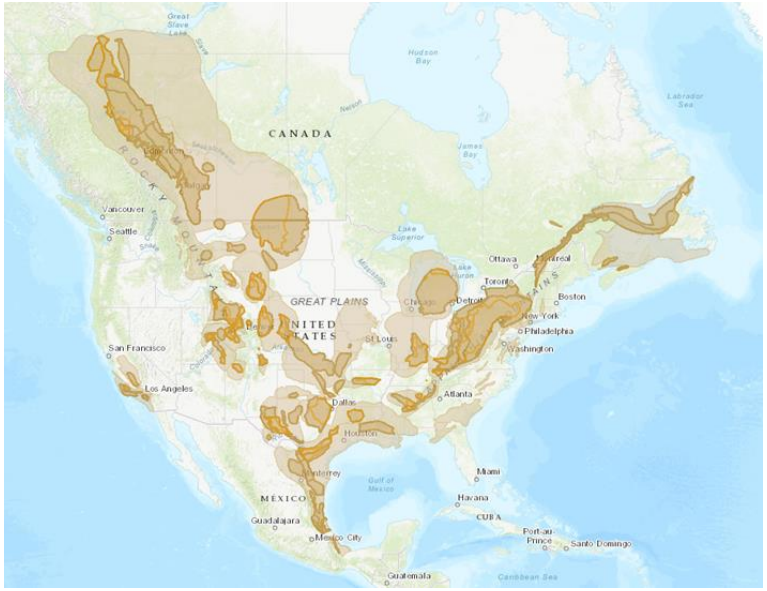


US CO_2 Emissions

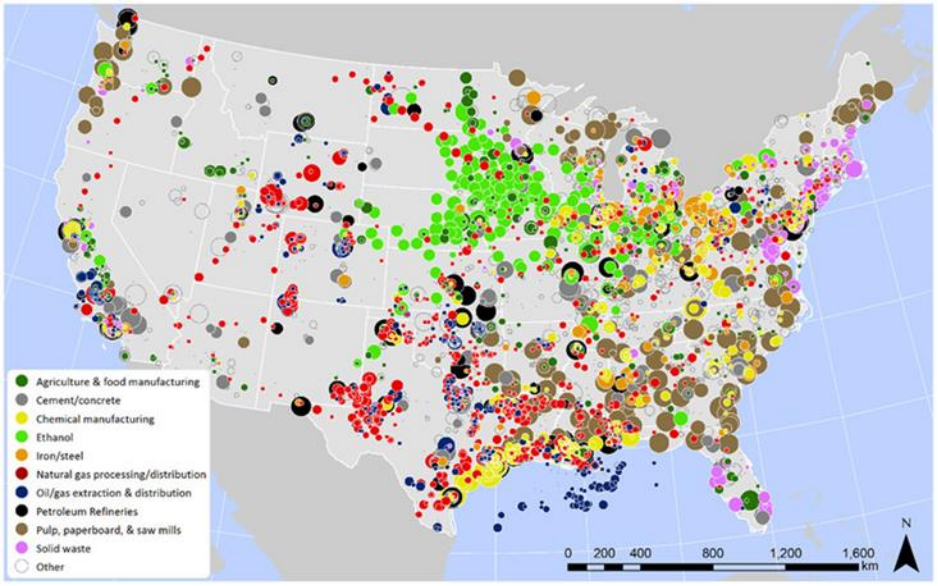


Significant Shale Reservoirs VS. High Volume Emitters

Shale Reservoirs

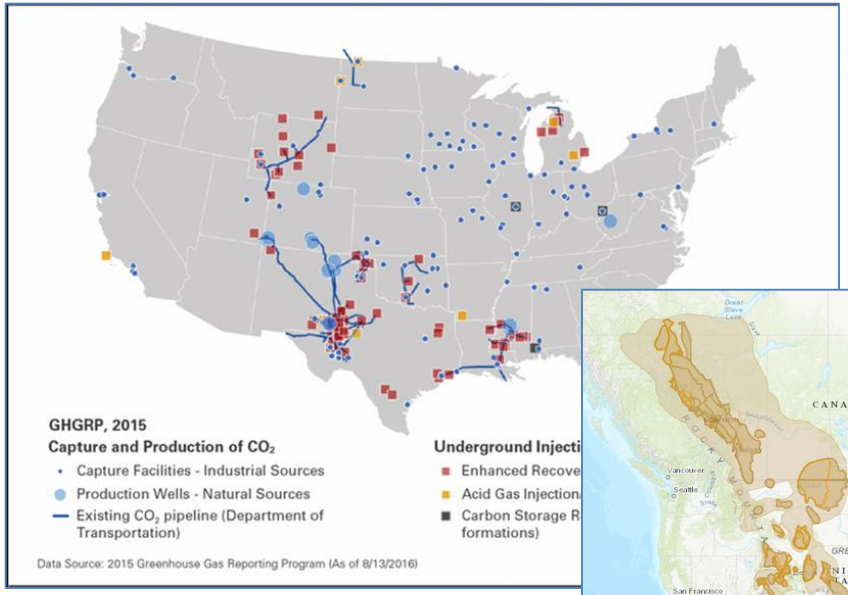


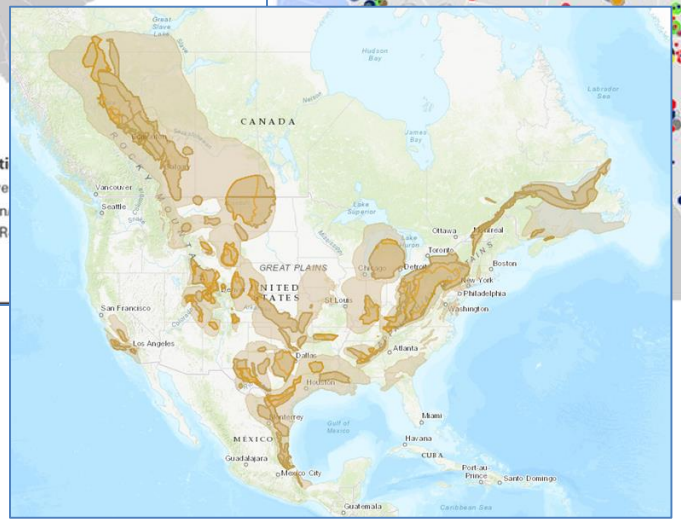
CO_2 Emissions



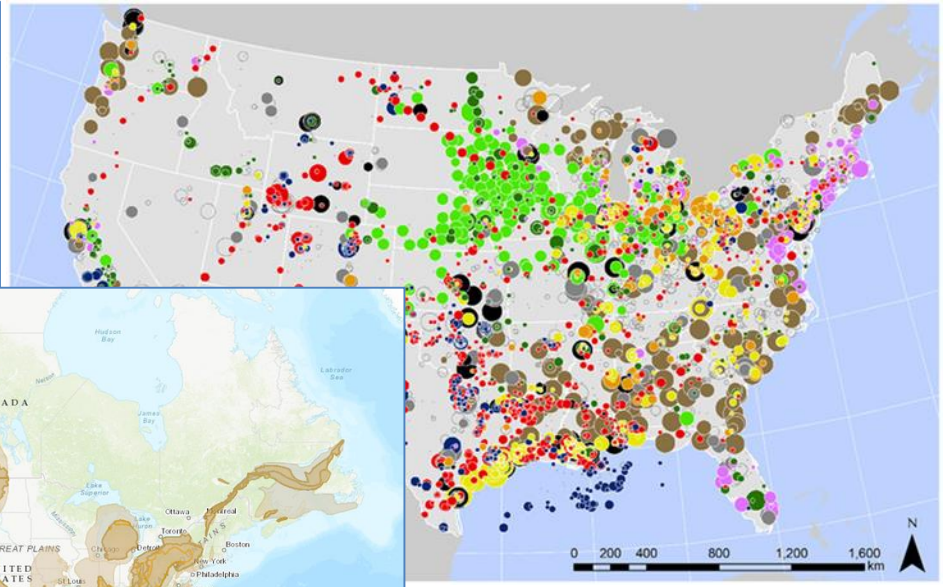
Current CO_2 Infrastructure VS. High Volume Emitters

CO_2 EOR Infrastructure



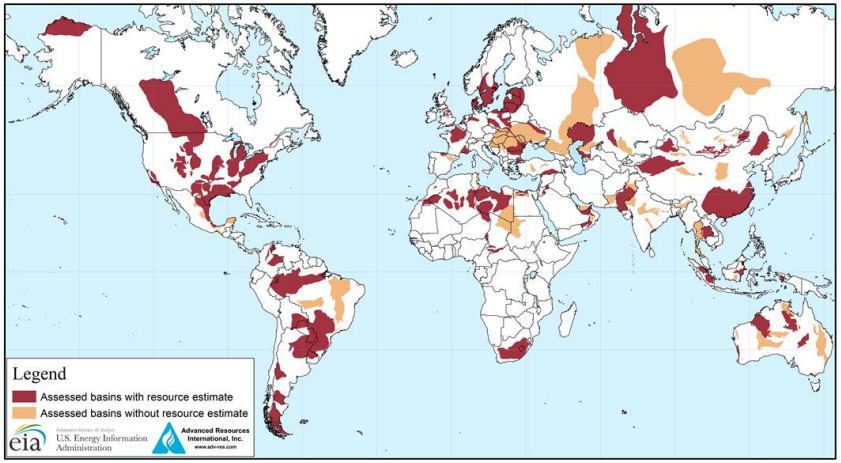


CO_2 Emissions

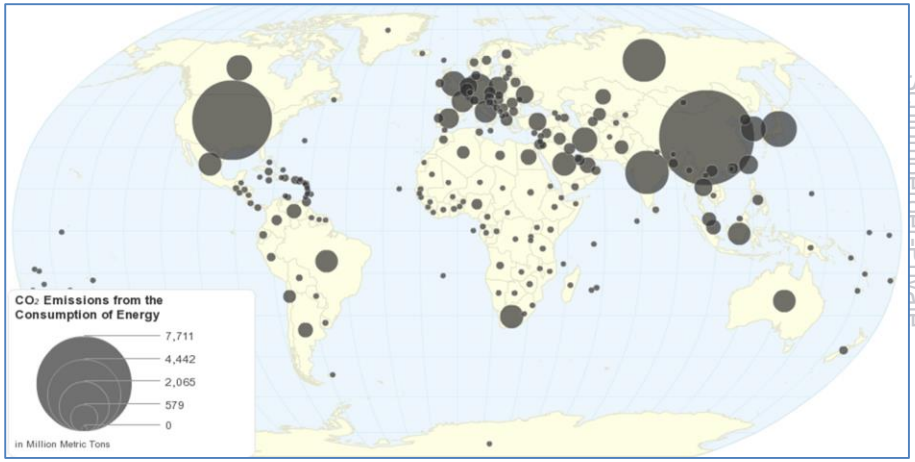


Significant Shale Reserves VS. High Volume Emitters

Shale Reservoirs



Co_2 Emissions

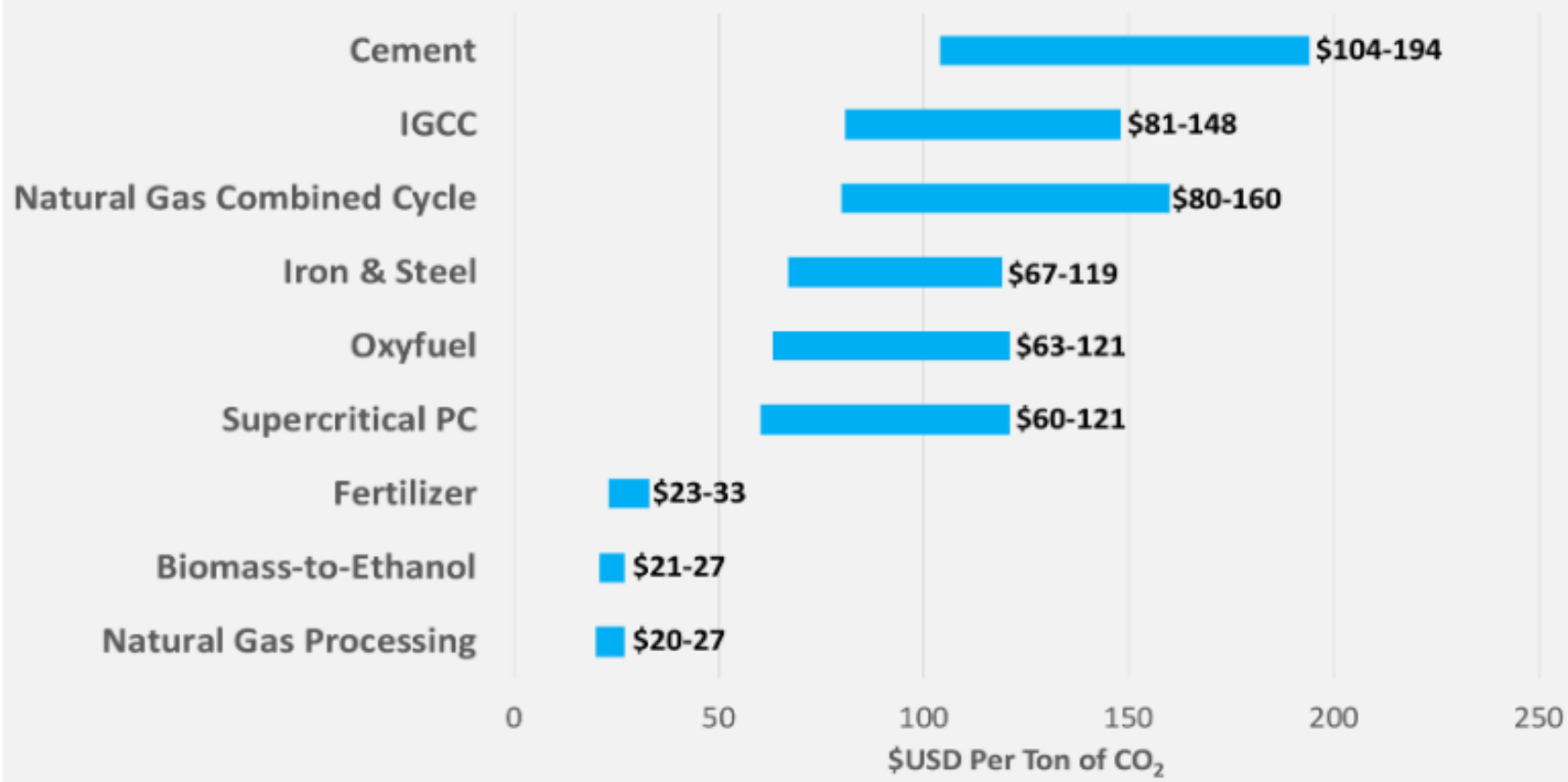


S.1535 - Future Act

- Introduced July 12, 2017 by Senator Heitkamp (D ND)
- Signed into Law Feb 9, 2018 as part of Bipartisan Budget Act of 2018

	Pre-Budget Act Qualified Sequestration	Post-Budget Act Qualified Sequestration
EOR, Other Industrial Utilization[2]	$10/ton plus inflation	$12.83/ton to $35/ton plus inflation (linear increase through 2026; inflation adjustment thereafter)
	75 million ton limit	Credit applies for 12 years beginning on date equipment placed in service
Sequestration	$20/ton plus inflation	$22.66/ton to $50/ton plus inflation (linear increase through 2026; inflation adjustment thereafter)
	75 million ton limit	Credit applies for 12 years beginning on date equipment placed in service

Estimated and Measured FOAK* Costs for CCUS



Source: Adapted from the Global CCS Institute, 2017. EFI, 2018.

* First of a Kind

Tax Credit Available for Different Sources and Uses of CO_2

	Minimum Size of Eligible Carbon Capture Plant by Type ($ktCO_2/yr$)			Relevant Level of Tax Credit in a Given Operational Year ($USD/$tCO_2$)									
Type of CO_2 Storage/Use	Power Plant	Other Industrial Facility	Direct Air Capture	2018	2019	2020	2021	2022	2023	2024	2025	2026	Beyond 2026
Dedicated Geological Storage	500	100	100	28	31	34	36	39	42	45	47	50	Indexed to Inflation
Storage via EOR	500	100	100	17	19	22	24	26	28	31	33	35	
Other Utilization Processes[1]	25	25	25	17[2]	19	22	24	26	28	31	33	35	

[1] Each CO_2 source cannot be greater than 500 $ktCO_2/yr$

[2] Any credit will only apply to the portion of the converted CO_2 that can be shown to reduce overall emissions

ENERGY FUTURES INITIATIVE

Source: Closely adapted from Simon Bennett and Tristan Stanley, Commentary: US budget bill may help carbon capture get back on track, International Energy Agency.

Key Points

- ✓ Potential for CO_2 Storage in Shales is Significant
- ✓ Shales Resources Available Both US and Worldwide
- ✓ Opens up Eastern US for CO_2 Infrastructure Development
- ✓ CO_2 Preferentially adsorbed over CH_4 – Win/Win
- ✓ US 45Q Tax Credit Enhancements A Game Changer
- ✓ Will spur lower capture cost industrial plant into action – Now

Acknowledgements / Thank You / Questions?

Advanced Research International
Battelle
Energy and Environmental Research Center
Global CCS Institute
Illinois State Geologic Survey
National Energy Technology Lab
Petroleum Recovery Research Center
Petroleum Technology Research Center
The Southern Company
SaskPower
University of Wyoming Carbon Management Institute