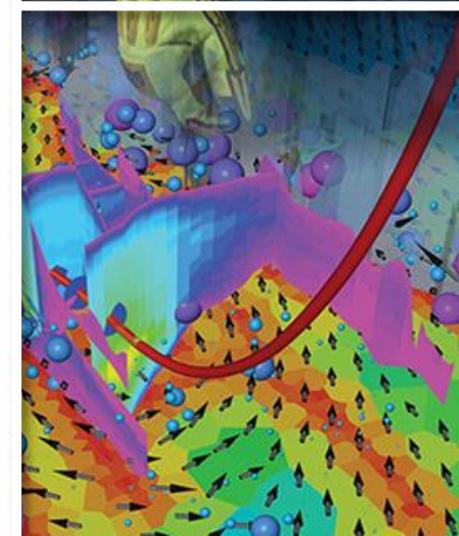


Schlumberger



CO₂ Storage Associated with Unconventional/Shale

Wayne Rowe – N. America Decarbonization Projects

OUTLINE

Shale Resources Worldwide

US Shale Resources

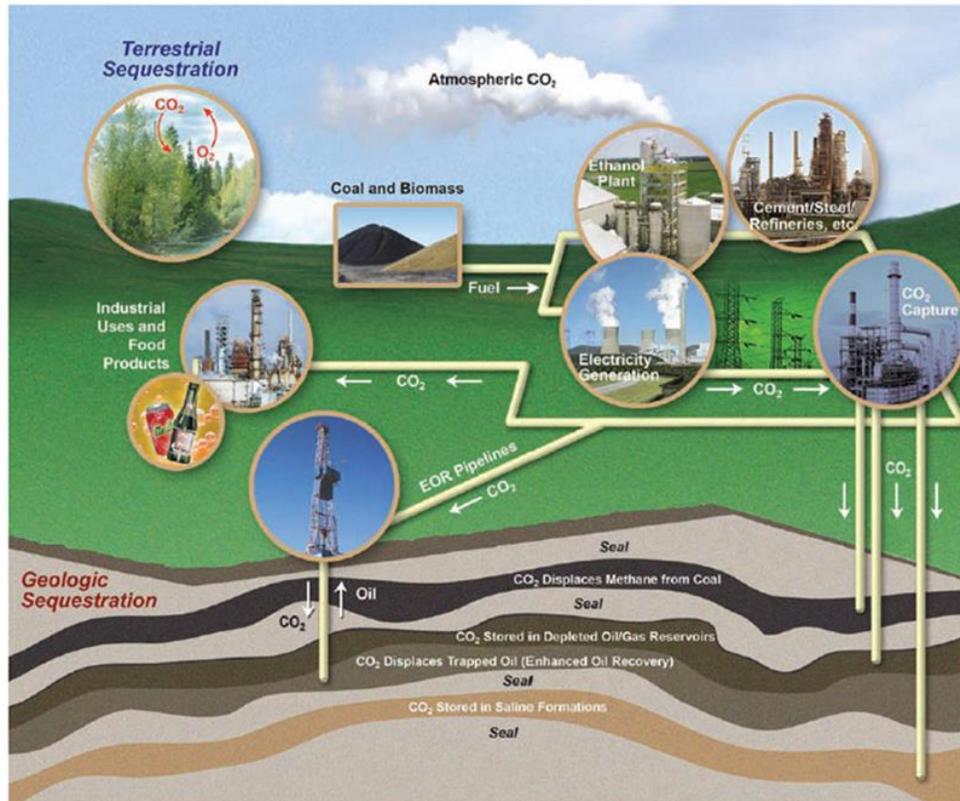
CO₂ Storage in Shales*

45Q Tax Credit Enhancement – Future Act

Two Hypothetical CCUS Examples applying 45Q

* *Will focus primarily on Shale Gas for near-term CCUS potential*

CO₂ Storage Geologic Storage Reservoir Types



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

OUTLINE

Shale Resources Worldwide

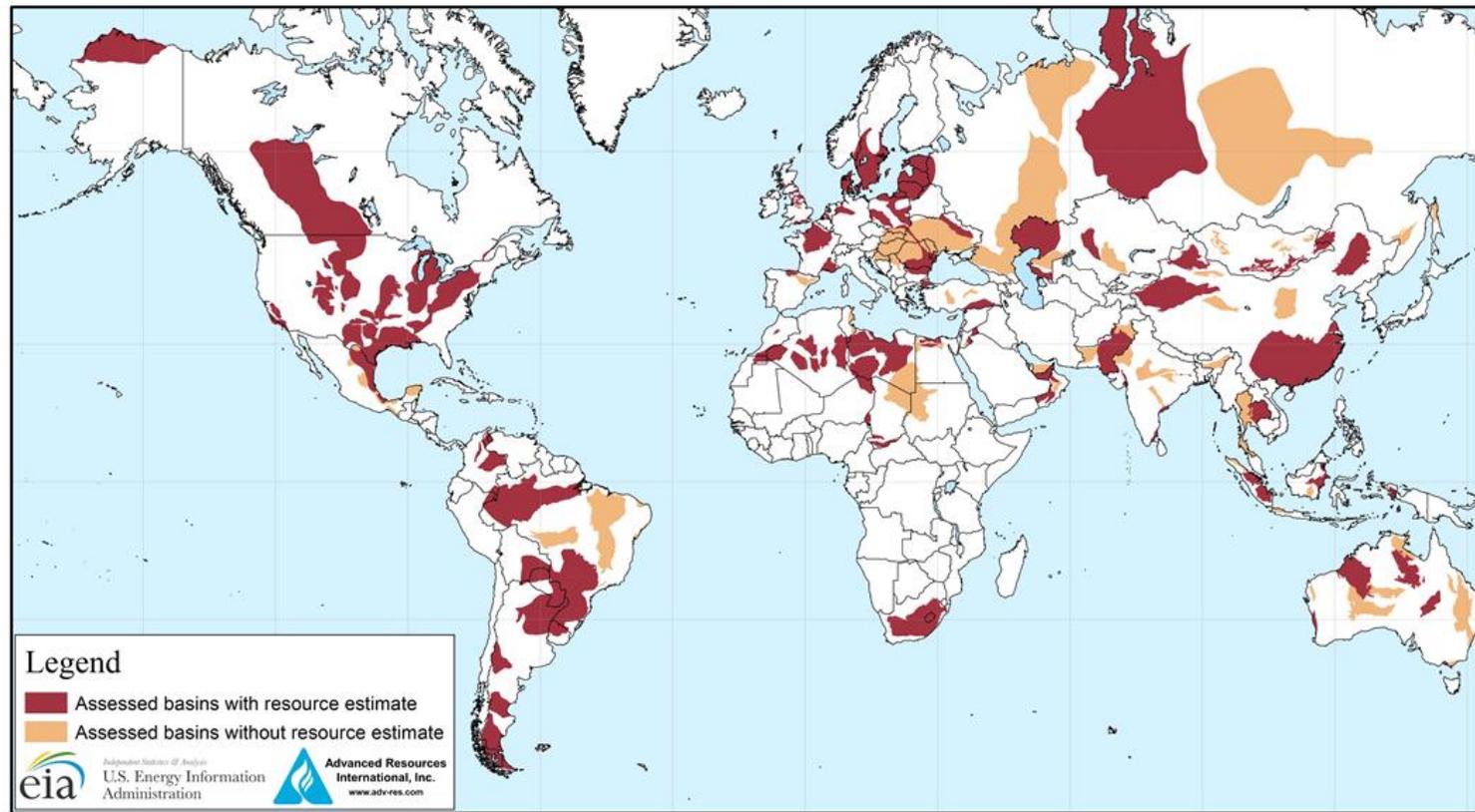
US Shale Resources

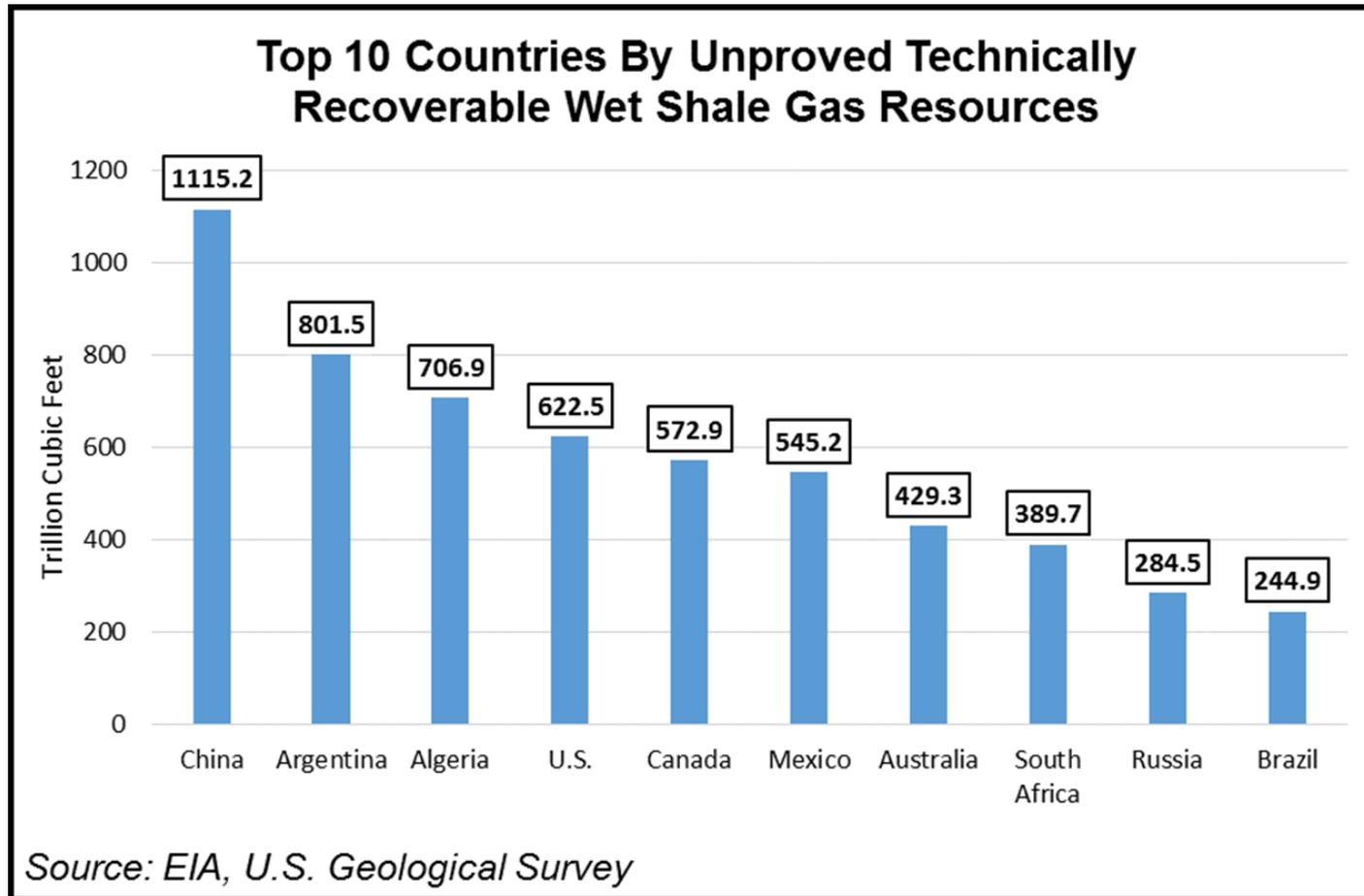
CO₂ Storage in Shales*

45Q Tax Credit Enhancement – Future Act

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Shale Reservoirs Worldwide



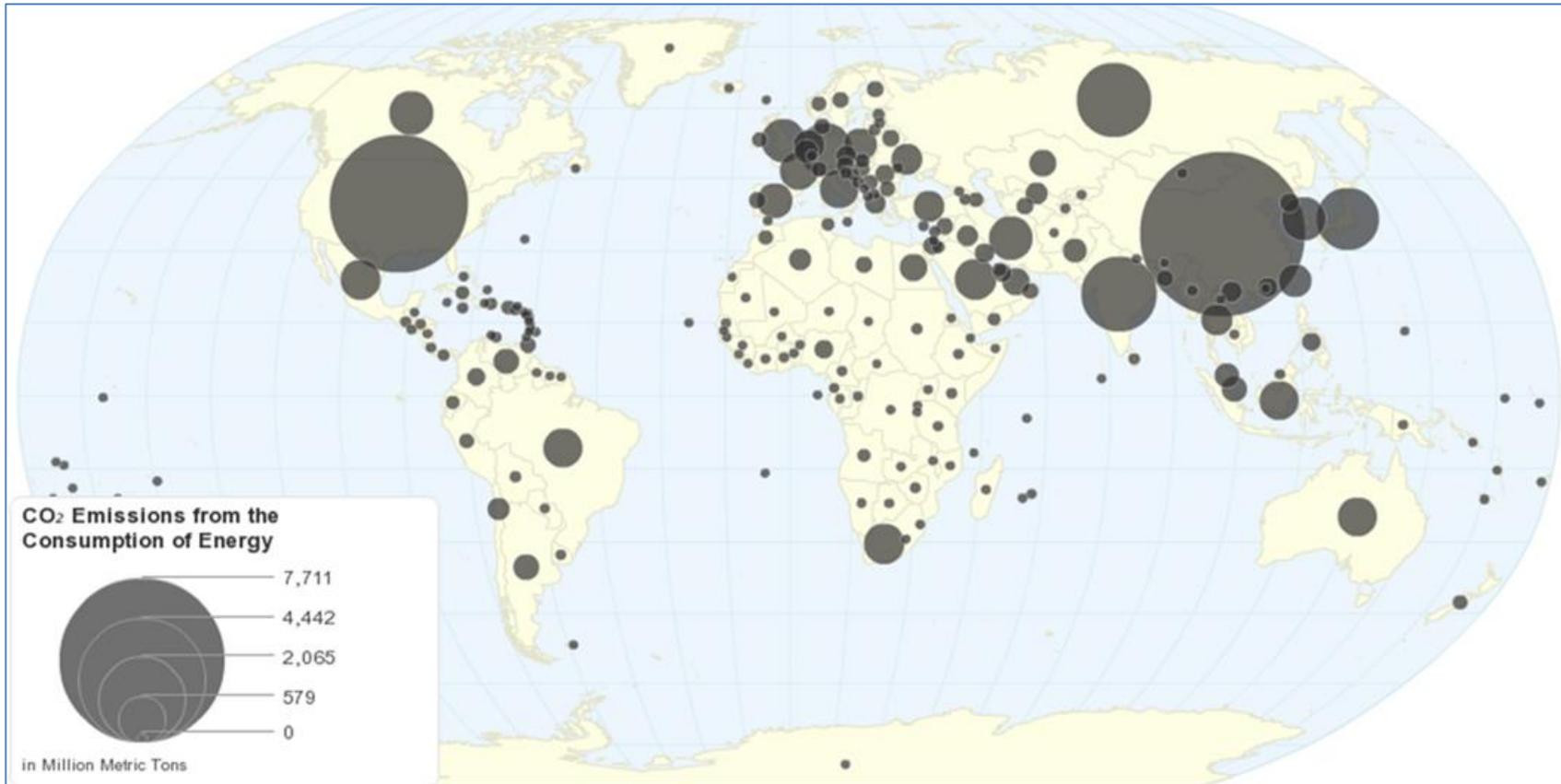


Summary of Recoverable Resources and CO₂ Storage Potential of the World's Gas Shale Basins, by Region

Region	Country	Risked Gas In-Place (Tcm)	Risked Technically Recoverable Potential (Tcm)	Risked Technically Achievable CO ₂ Storage Potential (Gt)	Risked Economically Recoverable Potential (Tcm)	Risked Economically Achievable CO ₂ Storage Potential (Gt)
North America	United States	93	24	134	9	51
	Canada	42	11	43	4	16
	Mexico	67	19	72	7	27
	<i>Sub-Total</i>	<i>202</i>	<i>55</i>	<i>249</i>	<i>21</i>	<i>95</i>
South America	Northern South America	3	1	3	0	1
	Southern South America	126	34	119	13	45
	<i>Sub-Total</i>	<i>129</i>	<i>35</i>	<i>122</i>	<i>13</i>	<i>46</i>
Europe	Poland	22	5	19	2	7
	Eastern Europe	8	2	7	1	3
	Western Europe	43	11	47	4	18
	<i>Sub-Total</i>	<i>73</i>	<i>18</i>	<i>72</i>	<i>7</i>	<i>27</i>
Africa	Central North Africa	53	14	55	5	21
	Morocco	8	2	6	1	2
	South Africa	52	14	52	5	20
	<i>Sub-Total</i>	<i>112</i>	<i>30</i>	<i>113</i>	<i>11</i>	<i>43</i>
Asia	China	145	36	132	14	50
	India/Pakistan	14	3	11	1	4
	Turkey	2	0	2	0	1
	<i>Sub-Total</i>	<i>160</i>	<i>40</i>	<i>144</i>	<i>15</i>	<i>55</i>
Oceania	Australia	39	11	39	4	15
Grand Total		717	188	740	71	281

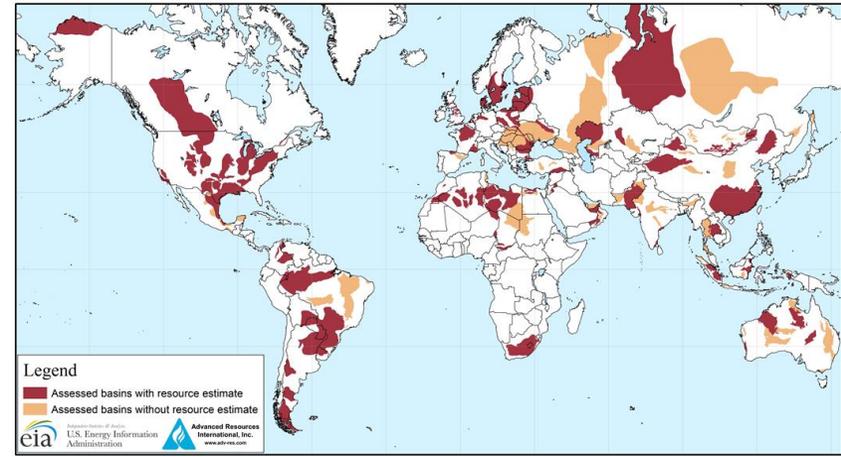
Enhanced Gas Recovery and CO₂ Storage in Gas Shales: A Summary Review of its Status and Potential. Michael Godeca*, George Kopernaa, Robin Petrusaka, and Anne Oudinot

CO₂ Emissions Worldwide

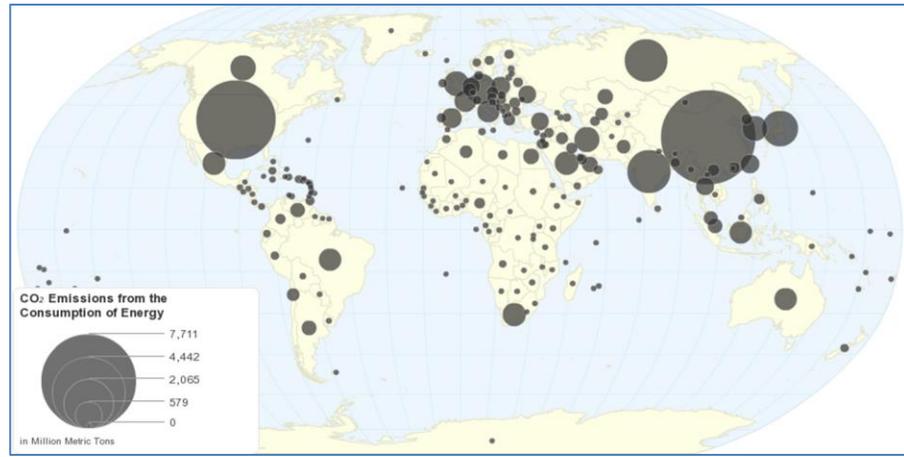


Significant Shale Reserves VS. High Volume Emitters

Shale Reservoirs



CO₂ Emissions



Schlumberger-Private

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Shale Resources Worldwide

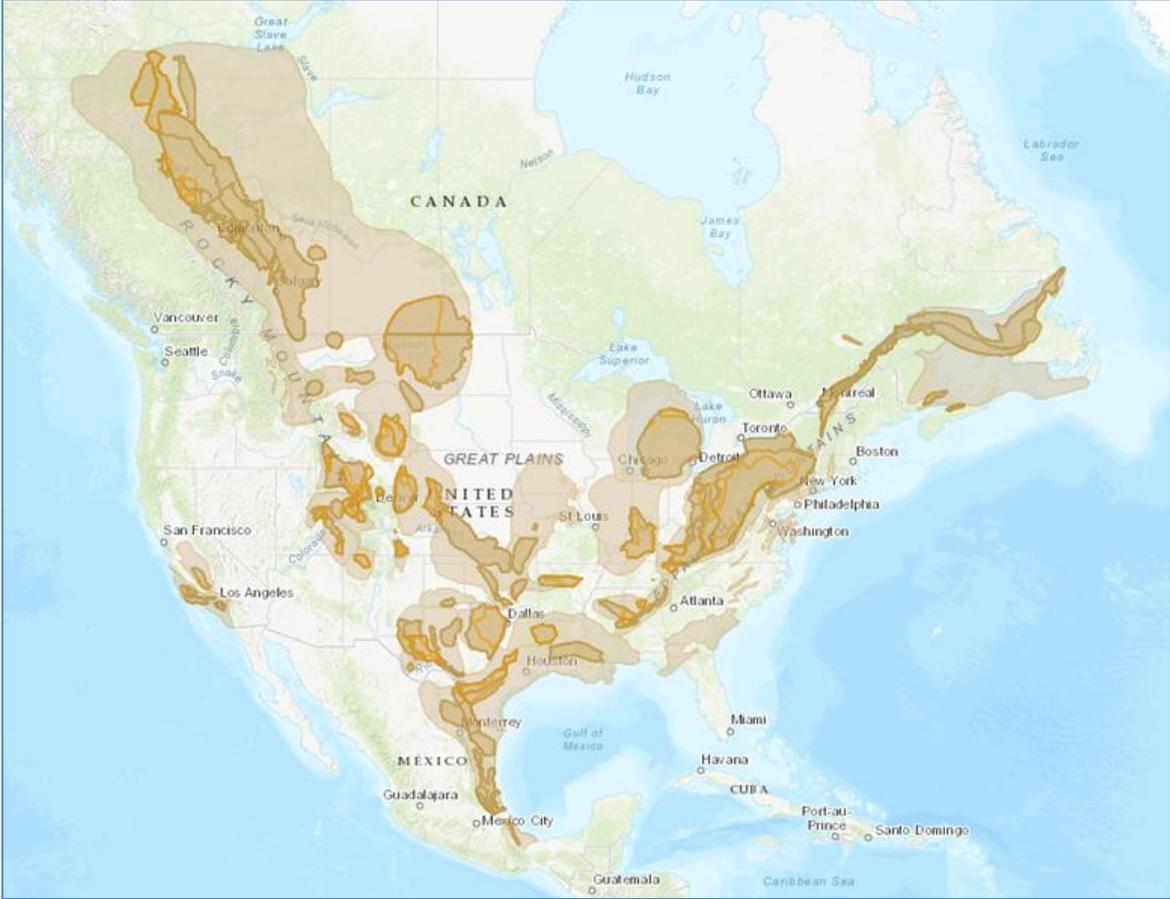
US Shale Resources

CO₂ Storage in Shales

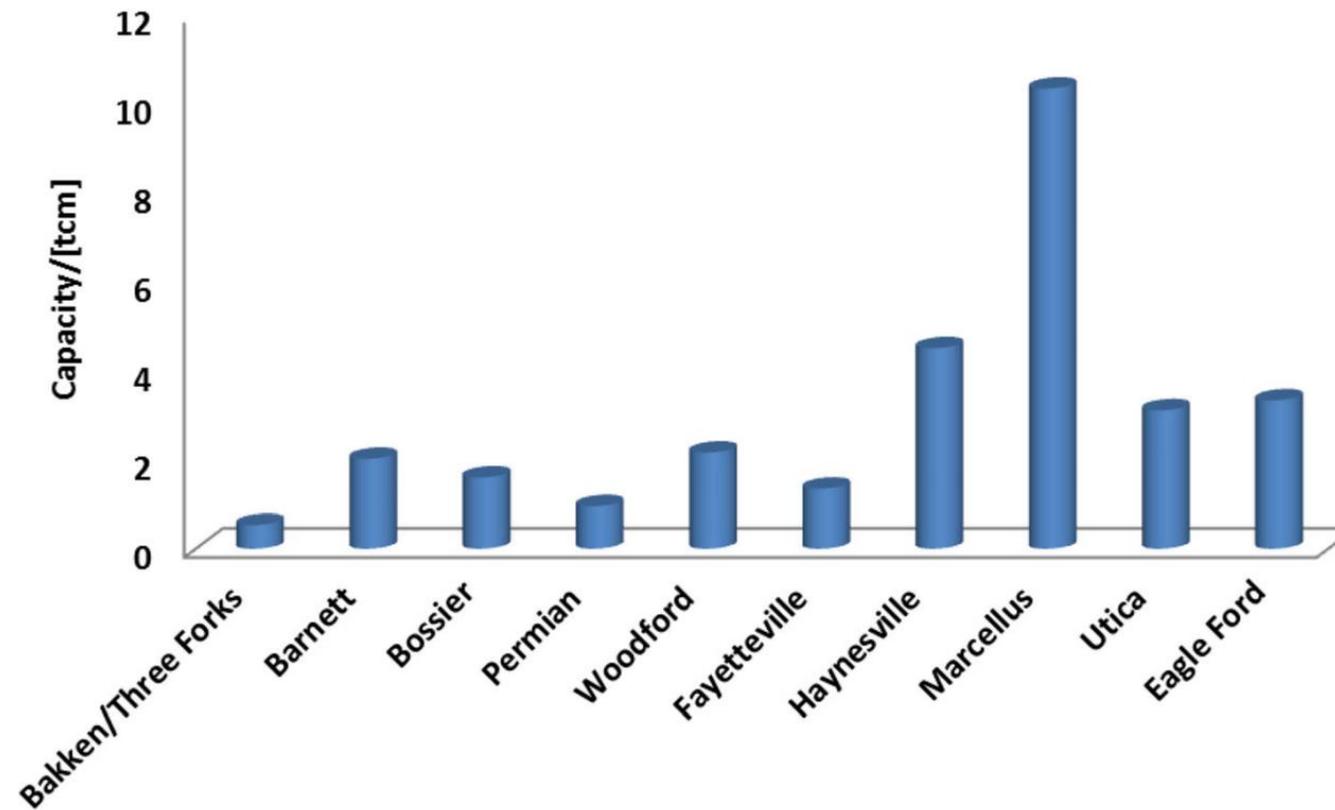
45Q Tax Credit Enhancement – Future Act

Two Hypothetical CCUS Examples applying 45Q

US Shale Reservoirs

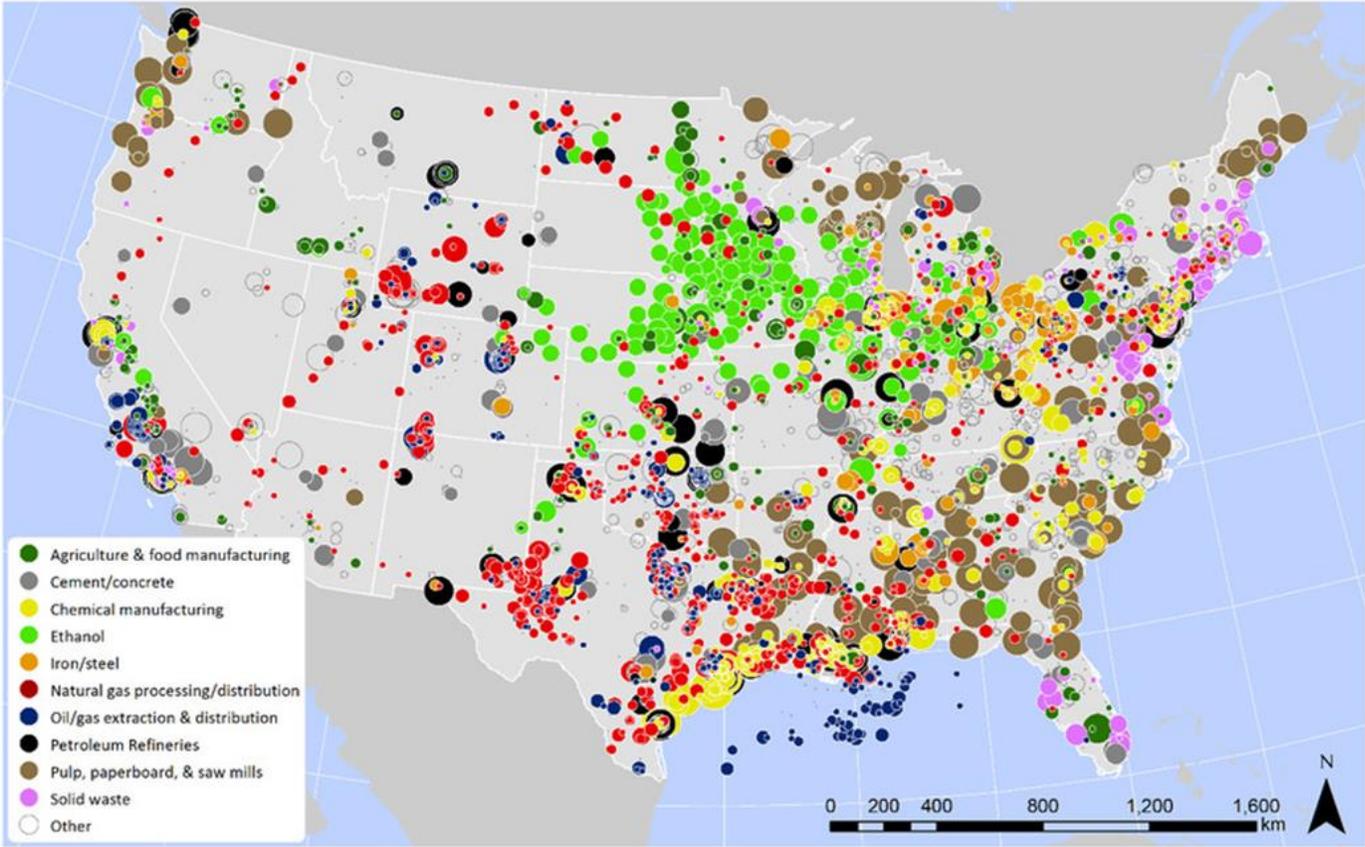


US Shale Reservoirs



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

US CO₂ Emissions

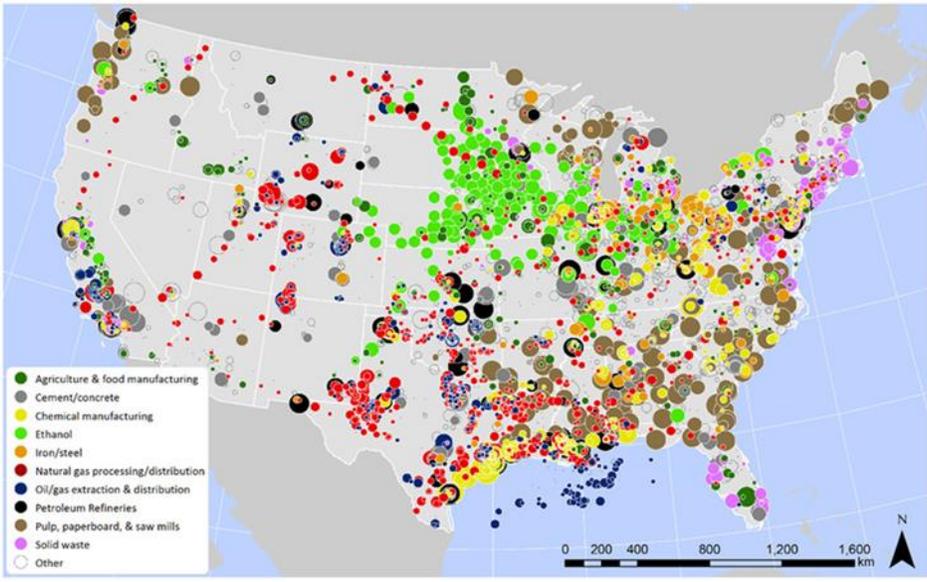


Significant Shale Reservoirs VS. High Volume Emitters

Shale Reservoirs

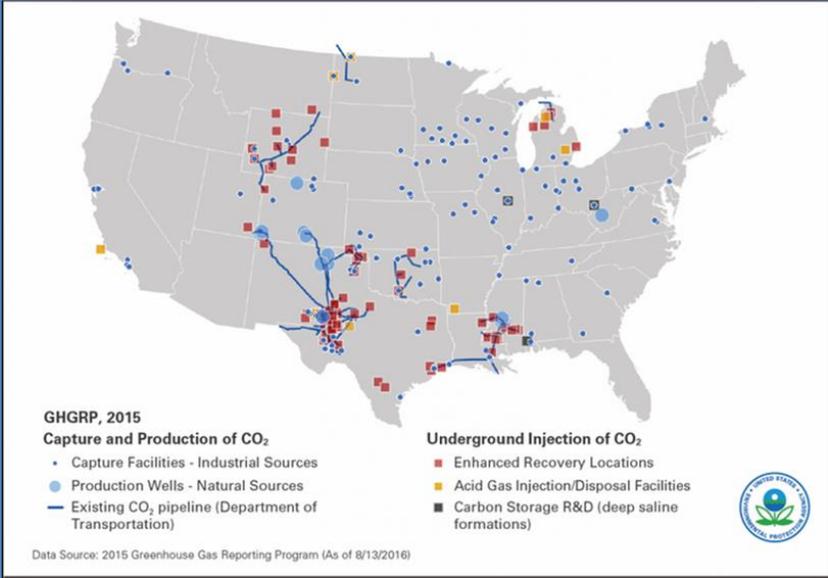


CO₂ Emissions

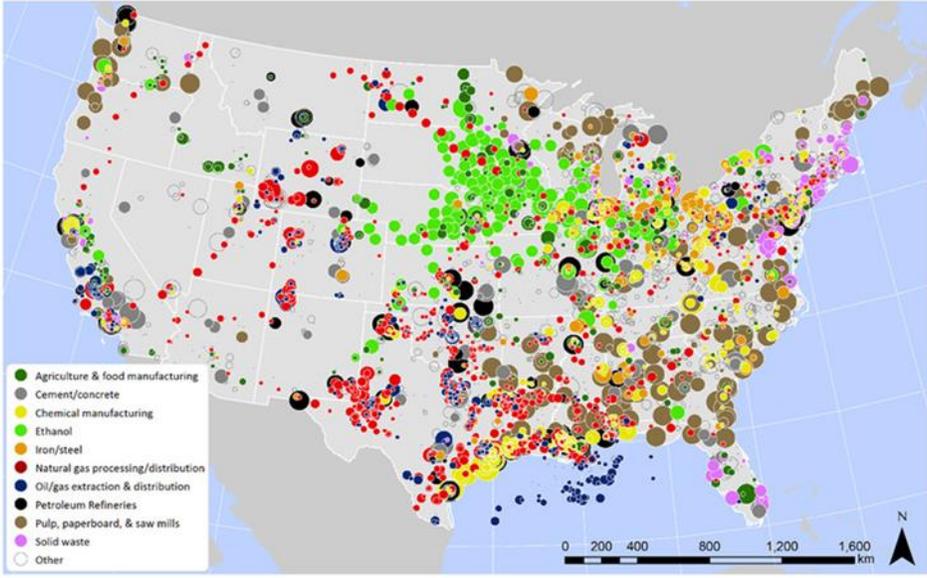


Current CO₂ Infrastructure VS. High Volume Emitters

CO₂ EOR Infrastructure



CO₂ Emissions



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Shale Resources Worldwide

US Shale Resources

CO₂ Storage in Shales

45Q Tax Credit Enhancement – Future Act

Two Hypothetical CCUS Examples applying 45Q

Storage in Conventional VS Unconventional/Shales

Conventional Reservoirs

- Structural
- Capillary
- Solubility
- Mineral trapping

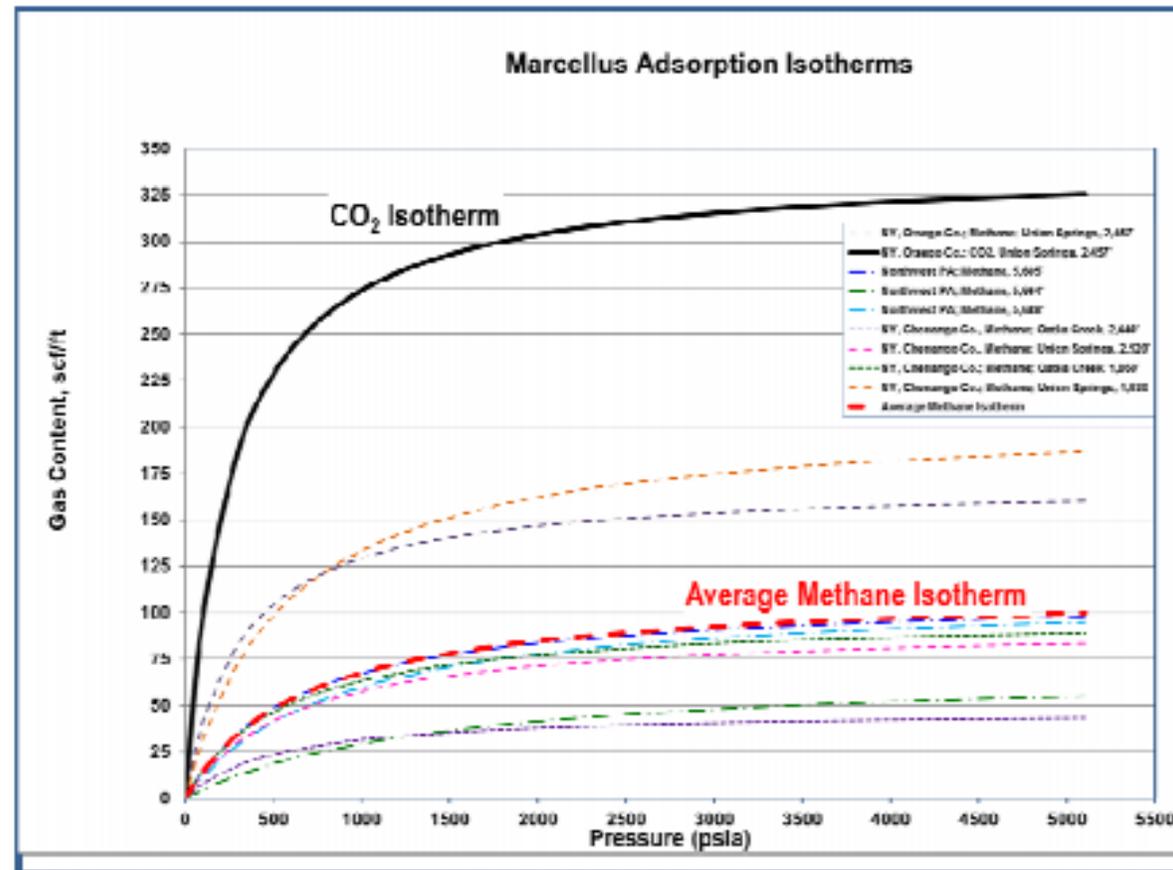
$$MCO_2e = A \times h \times \varphi \times \rho_{CO_2} \times E$$

Unconventional/Shale Reservoirs

- CO₂ Adsorption onto organic materials and clay minerals
- ranging from 20% to 80% of original-gas-in-place (OGIP)
- CO₂ is adsorbed preferentially over methane (CH₄) (up to a 5:1 ratio by molecule)
- potential added benefit of enhanced gas recovery (EGR)

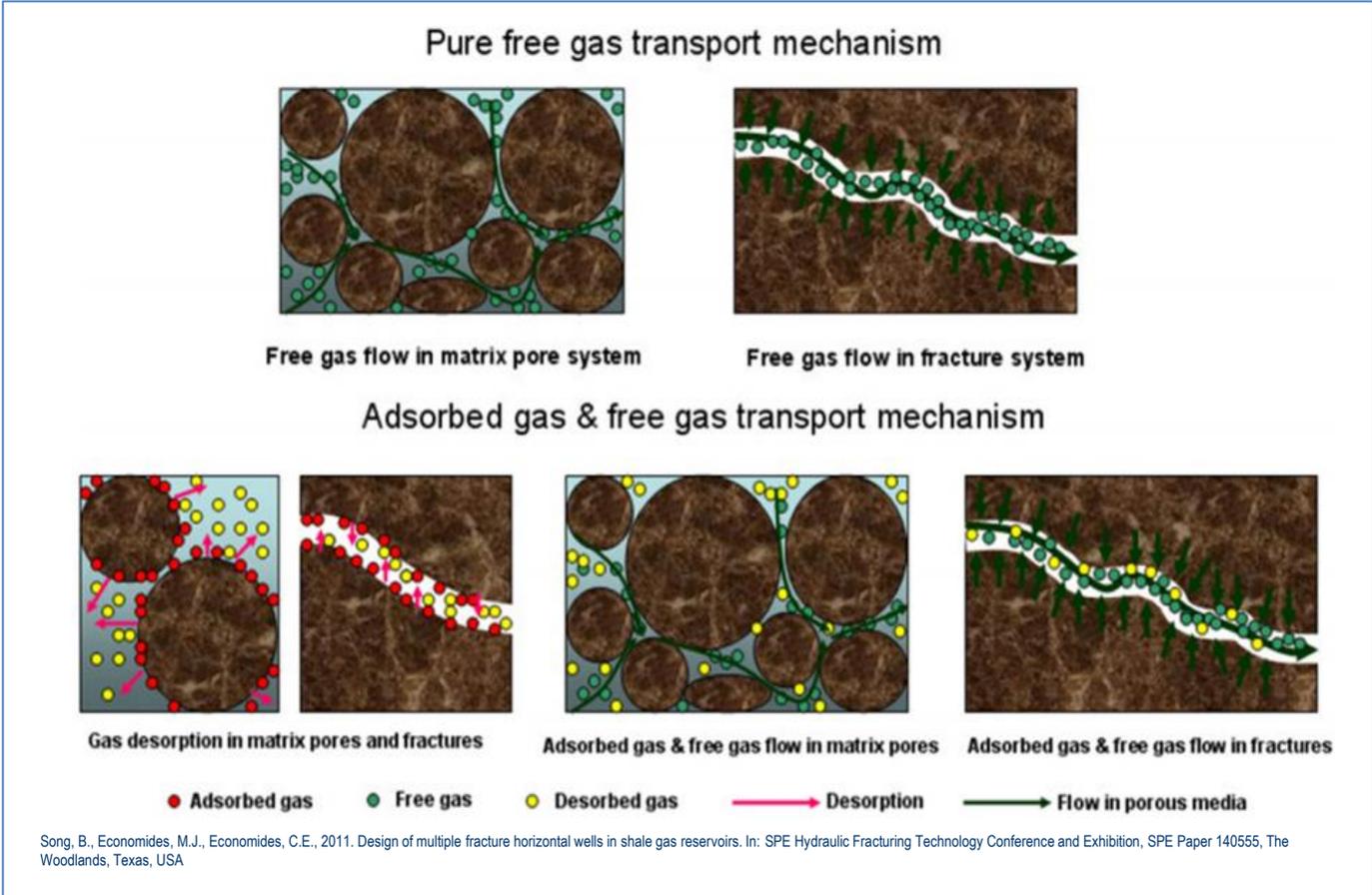
$$G_{st} = \frac{32.0368}{B_g} \left[\frac{\phi(1 - S_w)}{\rho_{rock}} - \frac{2.001 \times 10^{-3} \hat{M}C}{\rho_{mc}} \right] + \left(1518C \left(\frac{\rho_{ads}}{\rho_{mc}} - \frac{\rho_{gas}}{\rho_{mc}} \right) \right)$$

Marcellus CH₄ and CO₂ Adsorption Isotherms



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

Conventional VS Shale Storage Mechanisms



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

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

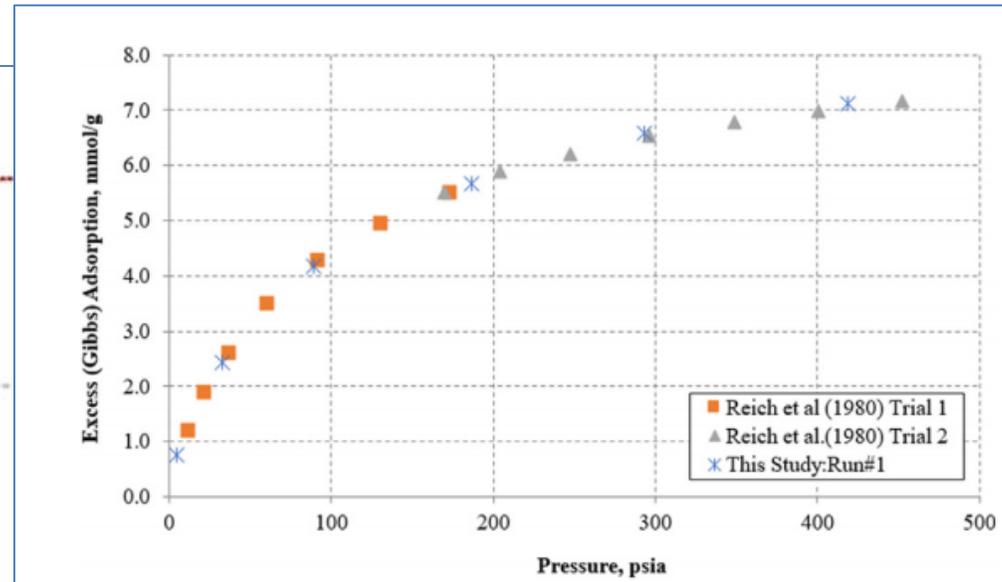
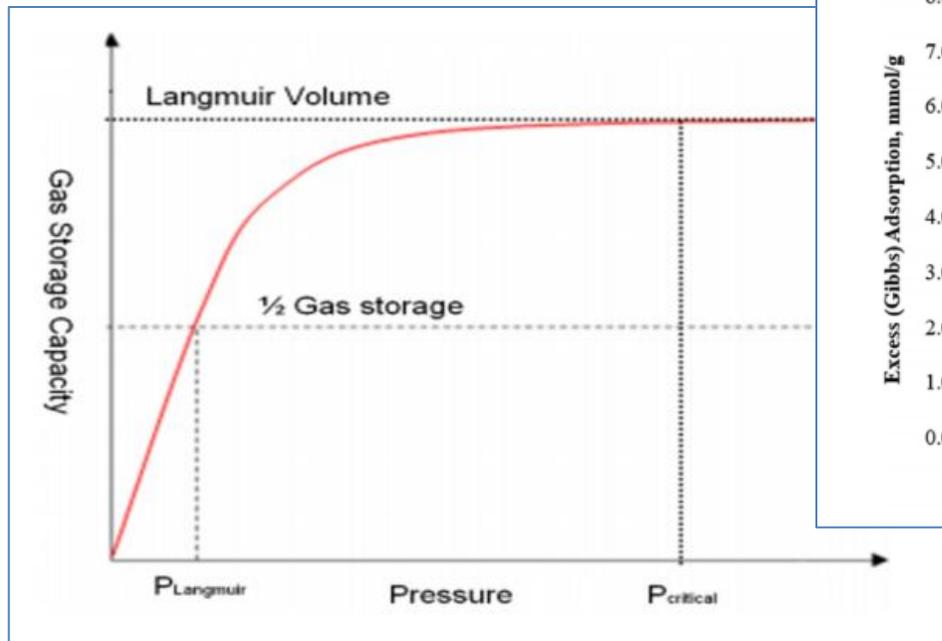
Shale Gas Formations and Their Potential for Carbon Storage: Opportunities and Outlook Roozbeh Khosrokhavar & Steve Griffiths & Karl-Heinz Wolf

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

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

Shale Storage Capacity

Theoretical – Langmuir Isotherms

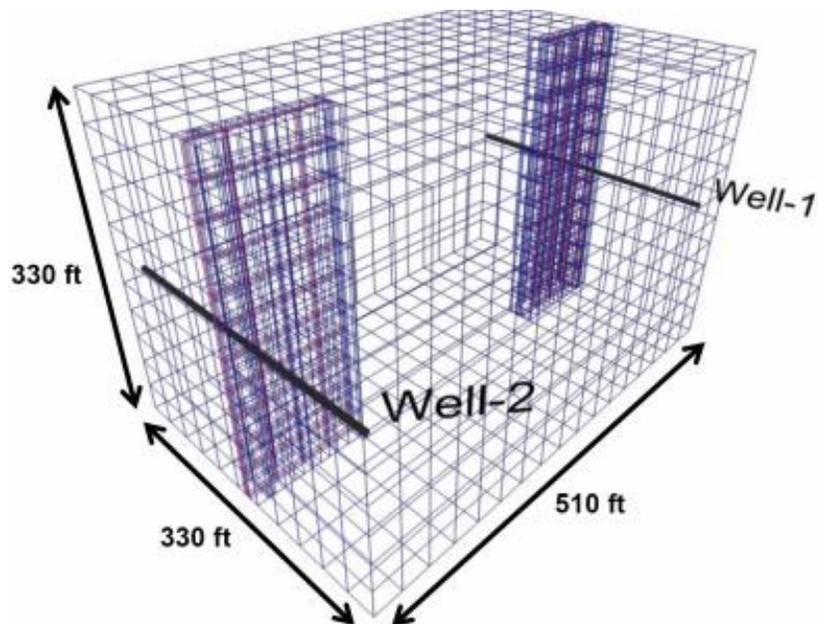


Lab Analysis – using experimental adsorption data and adsorption models

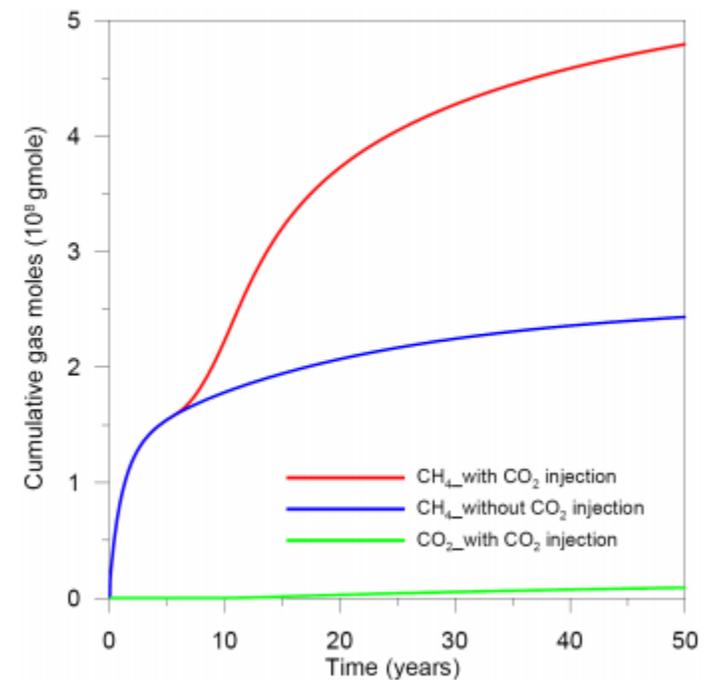
Analysis of carbon dioxide sequestration in shale gas reservoirs by using experimental adsorption data and adsorption models Sukru Meray*, Caglar Sinay

Modeling of CO₂ Injection

Schematic View of Shale Gas Reservoir Model for the CO₂ Injection



Cumulative gas Moles of the CH₄ and CO₂ with and without CO₂ Injection



OUTLINE

Shale Resources Worldwide

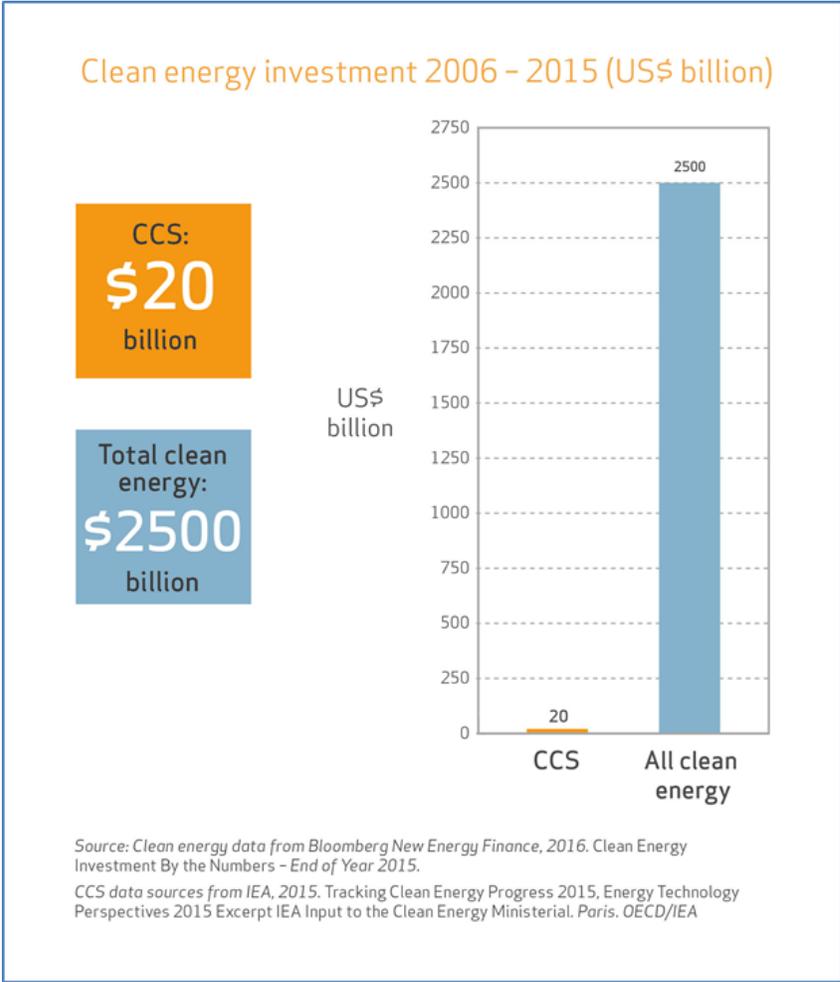
US Shale Resources

CO₂ Storage in Shales

45Q Tax Credit Enhancement – Future Act

Two Hypothetical CCUS Examples applying 45Q

Imbalance In Clean Energy Investment 2006 - 2015

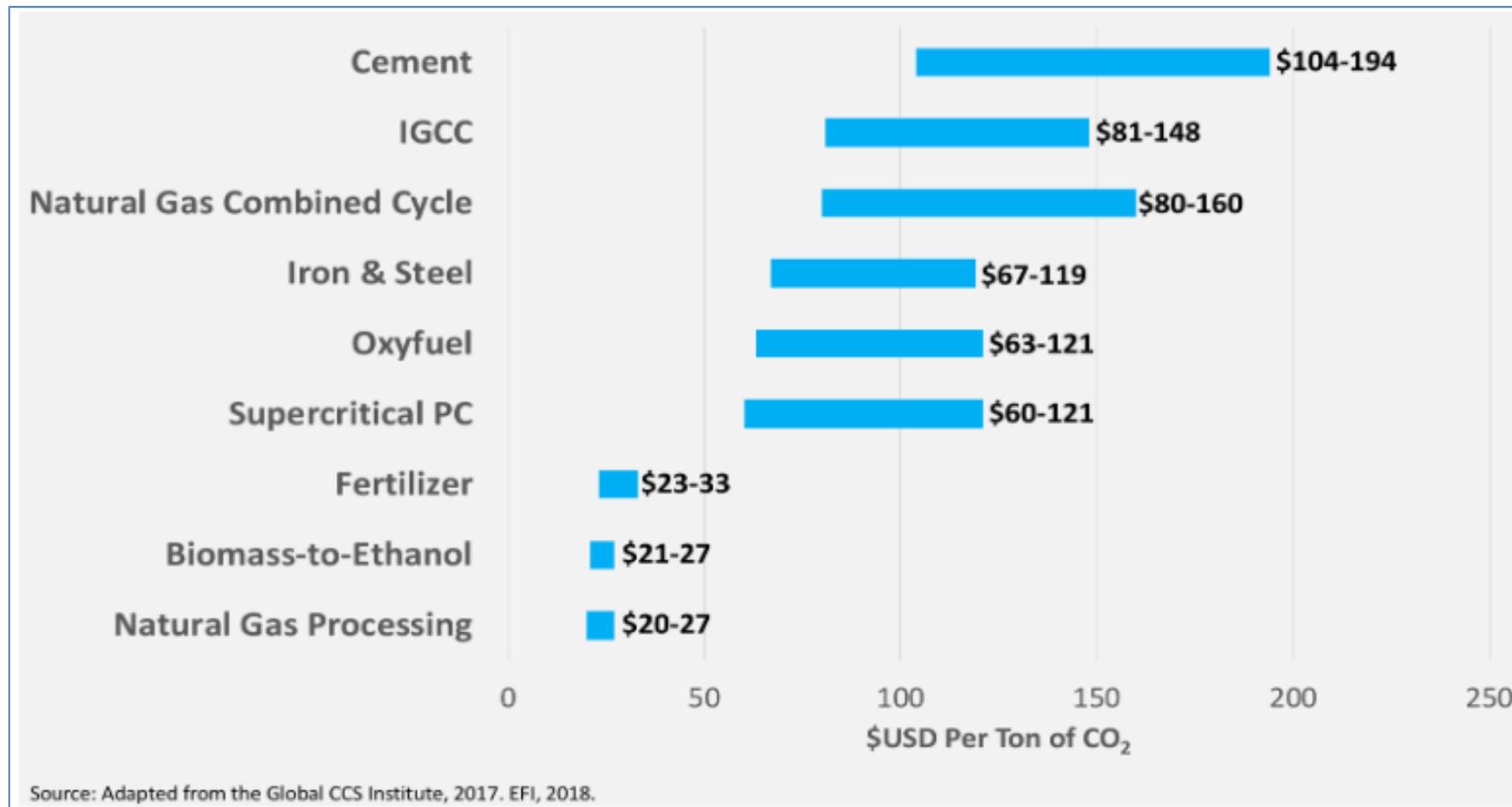


S.1535 - Future Act

- 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



* First of a Kind

OUTLINE

Shale Resources Worldwide

US Shale Resources

CO₂ Storage in Shales

45Q Tax Credit Enhancement – Future Act

Two Hypothetical CCUS Examples applying 45Q

Tax Credit Available for Different Sources and Uses of CO₂

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 CO₂ source cannot be greater than 500 ktCO₂/yr
² Any credit will only apply to the portion of the converted CO₂ 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.

Hypothetical Ethanol or Ammonia Plant – Geologic Storage

Geologic Storage	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Credit per Tonne	31.00	34.00	36.00	39.00	42.00	45.00	47.00	50.00	51.00	52.02	53.06	54.12
	1	2	3	4	5	6	7	8	9	10	11	12
45Q (\$M)	\$ 31.0	\$ 65.0	\$ 101.0	\$ 140.0	\$ 182.0	\$ 227.0	\$ 274.0	\$ 324.0	\$ 375.0	\$ 427.0	\$ 480.1	\$ 534.2
CO2 SALES (\$M)	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
TOTAL (\$M)	\$ 31.0	\$ 65.0	\$ 101.0	\$ 140.0	\$ 182.0	\$ 227.0	\$ 274.0	\$ 324.0	\$ 375.0	\$ 427.0	\$ 480.1	\$ 534.2
FACILITIES (\$M)	\$ (5.5)	\$ (11.0)	\$ (16.5)	\$ (22.0)	\$ (27.5)	\$ (33.0)	\$ (38.5)	\$ (44.0)	\$ (49.5)	\$ (55.0)	\$ (60.5)	\$ (66.0)
O&M (\$M)	\$ (1.0)	\$ (2.0)	\$ (3.0)	\$ (4.0)	\$ (5.0)	\$ (6.0)	\$ (7.0)	\$ (8.0)	\$ (9.0)	\$ (10.0)	\$ (11.0)	\$ (12.0)
TRANS (\$M)	\$ (1.0)	\$ (2.0)	\$ (3.0)	\$ (4.0)	\$ (5.0)	\$ (6.0)	\$ (7.0)	\$ (8.0)	\$ (9.0)	\$ (10.0)	\$ (11.0)	\$ (12.0)
STORAGE(\$M)	\$ (7.0)	\$ (14.0)	\$ (21.0)	\$ (28.0)	\$ (35.0)	\$ (42.0)	\$ (49.0)	\$ (56.0)	\$ (63.0)	\$ (70.0)	\$ (77.0)	\$ (84.0)
												\$ 360.20

1M Tonne/Year

Capital Cost \$66M

Pipeline Cost \$12M (Inj well on Plant Site)

O&M 1M/year

CO₂ Injected in a Saline Aquifer

Hypothetical Ethanol or Ammonia Plant Selling CO₂ for EOR

Geologic Storage	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Credit per Tonne	31.00	34.00	36.00	39.00	42.00	45.00	47.00	50.00	51.00	52.02	53.06	54.12
	1	2	3	4	5	6	7	8	9	10	11	12
45Q (\$M)	\$ 31.0	\$ 65.0	\$ 101.0	\$ 140.0	\$ 182.0	\$ 227.0	\$ 274.0	\$ 324.0	\$ 375.0	\$ 427.0	\$ 480.1	\$ 534.2
CO2 SALES (\$M)	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
TOTAL (\$M)	\$ 31.0	\$ 65.0	\$ 101.0	\$ 140.0	\$ 182.0	\$ 227.0	\$ 274.0	\$ 324.0	\$ 375.0	\$ 427.0	\$ 480.1	\$ 534.2
FACILITIES (\$M)	\$ (5.5)	\$ (11.0)	\$ (16.5)	\$ (22.0)	\$ (27.5)	\$ (33.0)	\$ (38.5)	\$ (44.0)	\$ (49.5)	\$ (55.0)	\$ (60.5)	\$ (66.0)
O&M (\$M)	\$ (1.0)	\$ (2.0)	\$ (3.0)	\$ (4.0)	\$ (5.0)	\$ (6.0)	\$ (7.0)	\$ (8.0)	\$ (9.0)	\$ (10.0)	\$ (11.0)	\$ (12.0)
TRANS (\$M)	\$ (1.0)	\$ (2.0)	\$ (3.0)	\$ (4.0)	\$ (5.0)	\$ (6.0)	\$ (7.0)	\$ (8.0)	\$ (9.0)	\$ (10.0)	\$ (11.0)	\$ (12.0)
STORAGE(\$M)	\$ (7.0)	\$ (14.0)	\$ (21.0)	\$ (28.0)	\$ (35.0)	\$ (42.0)	\$ (49.0)	\$ (56.0)	\$ (63.0)	\$ (70.0)	\$ (77.0)	\$ (84.0)
												\$ 360.20

1M Tonne/Year

Capital Cost \$66M

Pipeline Cost \$36M

O&M 1M/year

CO₂ Sold for EOR at \$15/Tonne

Summary

- ✓ Potential for CO₂ Storage in Shales is Significant
- ✓ Shales Resources Available to Largest Emitting Countries
- ✓ Opens up Eastern US for CO₂ Infrastructure Development
- ✓ CO₂ Preferentially adsorbed over CH₄ – 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