CO₂ Storage Associated with Unconventional/Shale

Wayne Rowe – N. America Decarbonization Projects

Presented at the 16th Annual CO₂ EOR Carbon Mgmt Workshop Midland, Texas Dec 3, 2018
OUTLINE

Conventional CO₂ Storage
Unconventional CO₂ Storage
Unconventional CO₂ EGR
Shale Resource and CO₂ Availability
Impact of 45Q Tax Credit Enhancement
CO₂ 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

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)

\[ M_{CO_2e} = A \times h \times \phi \times \rho_{CO_2} \times E \]
Shale Storage Capacity - Adsorption

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

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

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

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

T.H. Kim, S.S. Park and K.S. Lee
CO₂ Frac Vs Water Frac – Marcellus Example

CH₄ Langmuir K (MPa) 0.17
CO₂ Langmuir K (MPa) 0.1
Max. CH₄ Adsorption (kg m⁻³) 6.5
Max. CO₂ 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
CO₂ Frac Vs Water Frac – Marcellus Example

(a) 
\[ \text{CH}_4 \text{ Mass Flowrate (Mscf day}^{-1}) \]

(b) 
\[ \text{Cumulative CH}_4 \text{ produced (MMScf)} \]

- \text{CO}_2
- \text{Water}
**CO₂ Storage Example – New Albany Shale**

<table>
<thead>
<tr>
<th>Reservoir properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>1378 ft (420 m)</td>
</tr>
<tr>
<td>Thickness</td>
<td>100 ft (30 m)</td>
</tr>
<tr>
<td>Temperature</td>
<td>86 °F</td>
</tr>
<tr>
<td>Initial pressure gradient</td>
<td>0.3 psi/ft (6.8 kPa/m)</td>
</tr>
<tr>
<td>Lithostatic pressure gradient</td>
<td>0.9 psi/ft (20.4 kPa/m)</td>
</tr>
<tr>
<td>Porosity</td>
<td>10–14%</td>
</tr>
<tr>
<td>Matrix permeability</td>
<td>150 nD</td>
</tr>
<tr>
<td>Diffusivity</td>
<td>1 x 10⁻⁹ m²/s</td>
</tr>
<tr>
<td>Water saturation</td>
<td>40%</td>
</tr>
<tr>
<td>Rock density</td>
<td>2.4 g/cm³</td>
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<tr>
<td>Natural fracture conductivity</td>
<td>20 μD-ft a</td>
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</table>

<table>
<thead>
<tr>
<th>Rock geochemistry properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC</td>
<td>12%</td>
</tr>
<tr>
<td>Maximal adsorbed gas (CO₂)</td>
<td>510.1 scf/ton b</td>
</tr>
<tr>
<td>Langmuir adsorption constant (CO₂)</td>
<td>0.000896 1/psi c</td>
</tr>
<tr>
<td>Maximal adsorbed gas (CH₄)</td>
<td>119.5</td>
</tr>
<tr>
<td>Langmuir adsorption constant (CH₄)</td>
<td>0.001119 1/psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rock geomechanical properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix compressibility</td>
<td>3E−6 1/psi</td>
</tr>
<tr>
<td>Fracture compressibility</td>
<td>3E−4 1/psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Well properties</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Well length</td>
<td>4200 ft (1280 m)</td>
</tr>
<tr>
<td>Hydraulic fracture stages</td>
<td>4</td>
</tr>
<tr>
<td>Hydraulic fracture conductivity</td>
<td>100 mD-ft</td>
</tr>
<tr>
<td>Hydraulic fracture half length</td>
<td>450 ft (137 m)</td>
</tr>
</tbody>
</table>
CO$_2$ Storage Example – New Albany Shale
US Shale Reservoirs
US Shale Reservoirs

Shale Gas Formations and Their Potential for Carbon Storage: Opportunities and Outlook
Roozbeh Khosrokhavar & Steve Griffiths & Karl-Heinz Wolf
US CO$_2$ Emissions
Significant Shale Reservoirs VS. High Volume Emitters

Shale Reservoirs

CO\textsubscript{2} Emissions
Current CO₂ Infrastructure VS. High Volume Emitters

CO₂ EOR Infrastructure

CO₂ Emissions

[Map showing distribution of CO₂ EOR infrastructure and emissions across the United States, with data from GHGRP (2015) and additional details as indicated.]
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

<table>
<thead>
<tr>
<th></th>
<th>Pre-Budget Act Qualified Sequestration</th>
<th>Post-Budget Act Qualified Sequestration</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOR, Other Industrial Utilization²</td>
<td>$10/ton plus inflation</td>
<td>$12.83/ton to $35/ton plus inflation (linear increase through 2026; inflation adjustment thereafter)</td>
</tr>
<tr>
<td></td>
<td>75 million ton limit</td>
<td>Credit applies for 12 years beginning on date equipment placed in service</td>
</tr>
<tr>
<td>Sequestration</td>
<td>$20/ton plus inflation</td>
<td>$22.66/ton to $50/ton plus inflation (linear increase through 2026; inflation adjustment thereafter)</td>
</tr>
<tr>
<td></td>
<td>75 million ton limit</td>
<td>Credit applies for 12 years beginning on date equipment placed in service</td>
</tr>
</tbody>
</table>
Estimated and Measured FOAK* Costs for CCUS

- Cement: $104-194
- IGCC: $81-148
- Natural Gas Combined Cycle: $80-160
- Iron & Steel: $67-119
- Oxyfuel: $63-121
- Supercritical PC: $60-121
- Fertilizer: $23-33
- Biomass-to-Ethanol: $21-27
- Natural Gas Processing: $20-27

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

* First of a Kind
### Tax Credit Available for Different Sources and Uses of CO$_2$

<table>
<thead>
<tr>
<th>Type of CO$_2$ Storage/Use</th>
<th>Power Plant</th>
<th>Other Industrial Facility</th>
<th>Direct Air Capture</th>
<th>Relevant Level of Tax Credit in a Given Operational Year ($USD/tCO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated Geological Storage</td>
<td>500</td>
<td>100</td>
<td>100</td>
<td>28, 31, 34, 36, 39, 42, 45, 47, 50</td>
</tr>
<tr>
<td>Storage via EOR</td>
<td>500</td>
<td>100</td>
<td>100</td>
<td>17, 19, 22, 24, 26, 28, 31, 33, 35, Indexed to inflation</td>
</tr>
<tr>
<td>Other Utilization Processes$^1$</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>17$^2$, 19, 22, 24, 26, 28, 31, 33, 35</td>
</tr>
</tbody>
</table>

$^1$ 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

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 CO₂ Storage in Shales is Significant
✓ Shales Resources Available Both US and Worldwide
✓ 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?

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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