Enhanced Oil Recovery and CO$_2$ Resource Studies at the U.S. Geological Survey

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The 12th Annual (2014) EOR Carbon Management Workshop – Midland, Texas
Part of the Annual CO$_2$ Conference Week December 8-12, 2014

U.S. Geological Survey
Department of the Interior
Outline for Presentation

• Energy Independence and Security Act
• Helium Stewardship Act of 2013
• Current activities associated with CO$_2$-EOR
• Current activities associated with natural CO$_2$
• Current activities associated with natural He
• Summary
ENERGY INDEPENDENCE AND SECURITY ACT 2007

TITLE VII—CARBON CAPTURE AND SEQUESTRATION

Subtitle B—Carbon Capture and Sequestration Assessment and Framework

SEC. 711. CARBON DIOXIDE SEQUESTRATION CAPACITY ASSESSMENT.

(b) METHODOLOGY—...shall develop a methodology for conducting an assessment under subsection (f), taking into consideration—

(1) the geographical extent of all potential sequestration formations in all States;

(2) the capacity of the potential sequestration formations;

(3) the injectivity of the potential sequestration formations;

(4) an estimate of potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations;

(5) the risk associated with the potential sequestration formations; and

(6) the work done to develop the Carbon Sequestration Atlas of the United States and Canada that was completed by U.S. Department of Energy (DOE).

(c) COORDINATION—

(1) Federal Coordination

(2) State Coordination
USGS National Assessment of Geologic Carbon Dioxide Storage Resources
by U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013a,b,c

Three companion assessment reports:

a. Data - USGS Data Series 774:
   http://pubs.usgs.gov/ds/774/

b. Results - USGS Circular 1386:
   http://pubs.usgs.gov/circ/1386/

c. Summary - Fact Sheet 2013–3020:
   http://pubs.usgs.gov/fs/2013/3020/
SEC. 16. HELIUM GAS RESOURCE ASSESSMENT.

….the United States Geological Survey, shall—

(1) in coordination with appropriate heads of State geological surveys—

complete a national helium gas assessment that identifies and quantifies the quantity of helium, including the isotope helium-3, in each reservoir, including assessments of the constituent gases found in each helium resource, such as carbon dioxide, nitrogen, and natural gas…

USGS is working with U.S. Bureau of Land Management (BLM) and State geological surveys


**Task 1:** Methodology development and assessment of national CO$_2$ enhanced oil recovery (CO$_2$-EOR) and associated CO$_2$ storage potential

**Task 2:** Geological studies of reservoirs and seals in selected basins with high potential for CO$_2$ storage

**Task 3:** Natural CO$_2$ and helium resources and analogues for anthropogenic CO$_2$ storage

**Task 4:** Economics of CO$_2$ storage and enhanced oil recovery

**Task 5:** Storage of CO$_2$ in unconventional geologic reservoirs

**Task 6:** Induced seismicity associated with CO$_2$ geologic storage

**Task 7:** Outreach
Methodology development and assessment of national CO₂ enhanced oil recovery and associated CO₂ storage potential

• Requested by Energy Independence and Security Act

• Goal is to develop a probabilistic assessment methodology and then estimate the technically recoverable (pre-economic) hydrocarbon potential using CO₂-EOR within the United States

• The recoverable hydrocarbon volume occupies potential pore space that may be available for sequestration of anthropogenic CO₂ in subsurface hydrocarbon reservoirs
USGS Methodology: Volumetric Approach

Step 1: Build a comprehensive resource database for reservoirs within U.S. basins using:

- Primary data sources: IHS Energy Group (2011); IHS Inc. (2012), and Nehring Associates Inc. (2012)

- Other publicly available or donated proprietary data sets

Populate database for missing data using:

- Analogs
- Algorithms
- Simulations
USGS Methodology: Volumetric Approach (cont.)

Step 2: The CO$_2$-EOR volume for each reservoir is modeled by the original oil-in-place (OOIP) multiplied by a recovery factor (RF):

\[ \text{EOR} = \text{OOIP} \times \text{RF} \]

Step 2.1: The largest uncertainty of the OOIP depends on the uncertainties of two basic values: rock volume and richness of OOIP per acre foot.

\[ \text{OOIP per acre foot} = 7,758((\varnothing)(S_{oi}))/FVFo \]

where OOIP is expressed in terms of barrels per acre foot, \( \varnothing \) is porosity in fraction, \( S_{oi} \) is initial oil saturation in fraction, and \( FVFo \) is the oil formation volume factor in barrels per stock tank barrel (STB).
Step 2.3: The uncertainty of RF will be based on:

- Decline curve analysis and recoverable hydrocarbon volume
- Reservoir simulation and type curves
- Recovery factors reported in the literature

Step 3: Associated CO$_2$ storage resulting from CO$_2$-EOR will be based on:

- Reservoir simulation and type curves
- CO$_2$ storage (loss) reported in the literature
Step 4: The assessment procedure will generate a probability for each reservoir within a play.

Step 5: The numerical distributions will be aggregated at the play, basin, region, and national levels by a process that closely follows that of the USGS national CO₂ storage assessment (U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013b) as it is described in Blondes and others (2013).

Step 6. Final probability distributions can be used to extract information about uncertainty in the results, such as means, 5th percentiles, medians or 95th percentiles.
Screening Criteria for Reservoirs where CO$_2$ is either Miscible or Immiscible in the Oil

<table>
<thead>
<tr>
<th>Screening criteria (units)</th>
<th>Miscible</th>
<th>Immiscible</th>
</tr>
</thead>
<tbody>
<tr>
<td>API gravity (API)</td>
<td>&gt;25</td>
<td>≥13 to ≤22</td>
</tr>
<tr>
<td></td>
<td>(Mosbacher and others, 1984)</td>
<td>(Hite, 2006)</td>
</tr>
<tr>
<td>Viscosity (cp)</td>
<td>&lt;10</td>
<td>&gt;1,400</td>
</tr>
<tr>
<td></td>
<td>(Andrei and others, 2010)</td>
<td>(Henline and others, 1985)</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reservoir Pressure (psi)</td>
<td>Minimum miscibility pressure ≤ fracture pressure - 400</td>
<td></td>
</tr>
</tbody>
</table>
Natural CO$_2$ and Helium Resources - Analogs for Anthropogenic CO$_2$ Storage

• To evaluate the potential geologic risks associated with CO$_2$ storage
• To collect samples of gas and produced water from wells producing CO$_2$ (>~10%) to define the origin, migration history, and ultimate fate of natural CO$_2$ and associated He
• To determine the origin of CO$_2$ that is in natural gas reservoirs by using geochemical and isotopic analyses of gas and reservoir rocks
• Conduct field and rock core investigations to help determine the degree and rate of CO$_2$-derived diagenesis (mineralization, recrystallization, dissolution, bleaching) that has occurred in the reservoir rocks
• Estimate natural CO$_2$ resources that may be available, and that might compete with anthropogenic CO$_2$ resources, for use in CO$_2$-EOR
• To work with BLM to evaluate the distribution of natural helium resources in the United States
Can we develop a total carbon dioxide/helium system model that can be used in a national assessment of *undiscovered* CO$_2$ and helium resources?

Gas sample cylinders  Noble gas sample tubes

Produce water sample collection
Potential sources of CO$_2$ in petroleum reservoirs (Thrasher and Fleet, 1995)

<table>
<thead>
<tr>
<th>$\delta^{13}C_{CO_2}$‰</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>+15 to -30</td>
<td>Bacteria</td>
</tr>
<tr>
<td>-10 to -25</td>
<td>Kerogen maturation</td>
</tr>
<tr>
<td>2 to -2</td>
<td>Marine carbonates</td>
</tr>
<tr>
<td>-10 to -20</td>
<td>Contact metamorphism in coals</td>
</tr>
<tr>
<td>-5 to -15</td>
<td>Thermochemical sulfate reduction</td>
</tr>
<tr>
<td>+2 to -12</td>
<td>Contact metamorphism in carbonates</td>
</tr>
<tr>
<td>0 to -15</td>
<td>Regional metamorphism</td>
</tr>
<tr>
<td>-4 to -7</td>
<td>Mantle degassing</td>
</tr>
</tbody>
</table>

Sources of noble gases (Cassidy and Ballentine, 2006)
Natural CO$_2$ and Helium Resources - Analogs for Anthropogenic CO$_2$ Storage (cont.)

Areas of focus:

- California Basins
- Northern Rocky Mountains
- Southern Rocky Mountains
- Southwestern Permian Basin, TX
- Jackson Dome, MS
- Eastern United States
Natural CO$_2$ Source Analogs – Southwestern Permian Basin

- Producing gas wells with greater than 10% CO$_2$ were identified using the U.S. Bureau of Mines and BLM geochemical databases and the Texas Railroad commission website: http://www.rrc.state.tx.us/

- Hot springs in the study area were located and we are in the process of contacting current owners to get permission to sample the hot springs

- Hot spring and well sampling planned for 2014 - 2015
Brown dots represent gas data collected from wells that produced $>10\%$ CO$_2$ (USGS, 2009). Additionally, natural hot springs (red dots) located along the southwestern margin of the basin may contain elevated CO$_2$ concentrations (Henry, 1979).
• Regional increase in CO₂ content towards the Marathon thrust belt (MBT)

• Average of about 3% in the basin center to as high as 97% on the foredeep margin of the thrust belt

From Ballantine and others (2001, Nature)

Location of the JM-Brown Bassett (JM-BB) natural gas field. Arrows show the direction of the regional increase in CO₂ content and CO₂/³He ratio towards the Marathon thrust belt (MTB). CO₂ and ³He data for the JM-BB field are from Ballentine and others (2001). Other data are from Chevron (unpublished). Inset, basins: 1, Delaware; 2, Midland; 3, Palo-Duro; 4, Anadarko; 5, Arkoma; 6, Ft Worth; 7, Kerr. Uplifts: A, Sierra Diablo; B, Central basin; C, Ozona; D, Concho arch; E, Llano; F, Devils River. (Figure from Ballentine and others, 2001.)
USGS Activities to Implement a National Helium Assessment

- USGS and BLM are in the process of building a combined DOI natural gas geochemical database that could be used for a national assessment of helium resources. The database will include both national and international data on helium occurrence in geologic formations. An on-line, map-based data portal is being designed.

- A request for State participation was made at the 2014 annual meeting of the Association of American State Geologists to contribute to the natural gas geochemical database. Several State geological surveys are compiling data to be incorporated in the database.

- USGS and BLM plan to work together to assess discovered and undiscovered national CO₂ and helium resources.
Summary

• The USGS is developing a probabilistic assessment methodology and then will estimate the technically recoverable hydrocarbon potential using CO$_2$-EOR within the United States.

• Natural CO$_2$/helium studies are now underway in various parts of the United States to better understand total carbon dioxide/helium systems.

• The USGS is building a national geochemical database that can be used to evaluate the occurrence and distribution of He and CO$_2$ resources occurring in natural gas reservoirs in the country.

• The USGS welcomes the opportunity to sample gas wells that are producing >10 percent CO$_2$. 
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http://energy.usgs.gov

http://go.usa.gov/8X8  (USGS geologic CO₂ project website)
References Cited


Henry, C.D., 1979, Geologic setting and geochemistry of thermal water and geothermal assessment, Trans- Pecos Texas: Austin, TX: Bureau of Economic Geology, University of Texas at Austin, 48 p.


