U.S. Geological Survey National Assessment of Geologic Carbon Dioxide Storage Resources and Associated Research

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U.S. Energy Association

U.S. Geological Survey
Department of the Interior

Outline for Presentation

- Overview of geologic carbon dioxide storage
- Energy Independence and Security Act
- USGS assessment methodology
- Geologic model
- Assessment results
- Discussion of results
- Current research and assessment activities
- Helium Stewardship Act of 2013
- Summary

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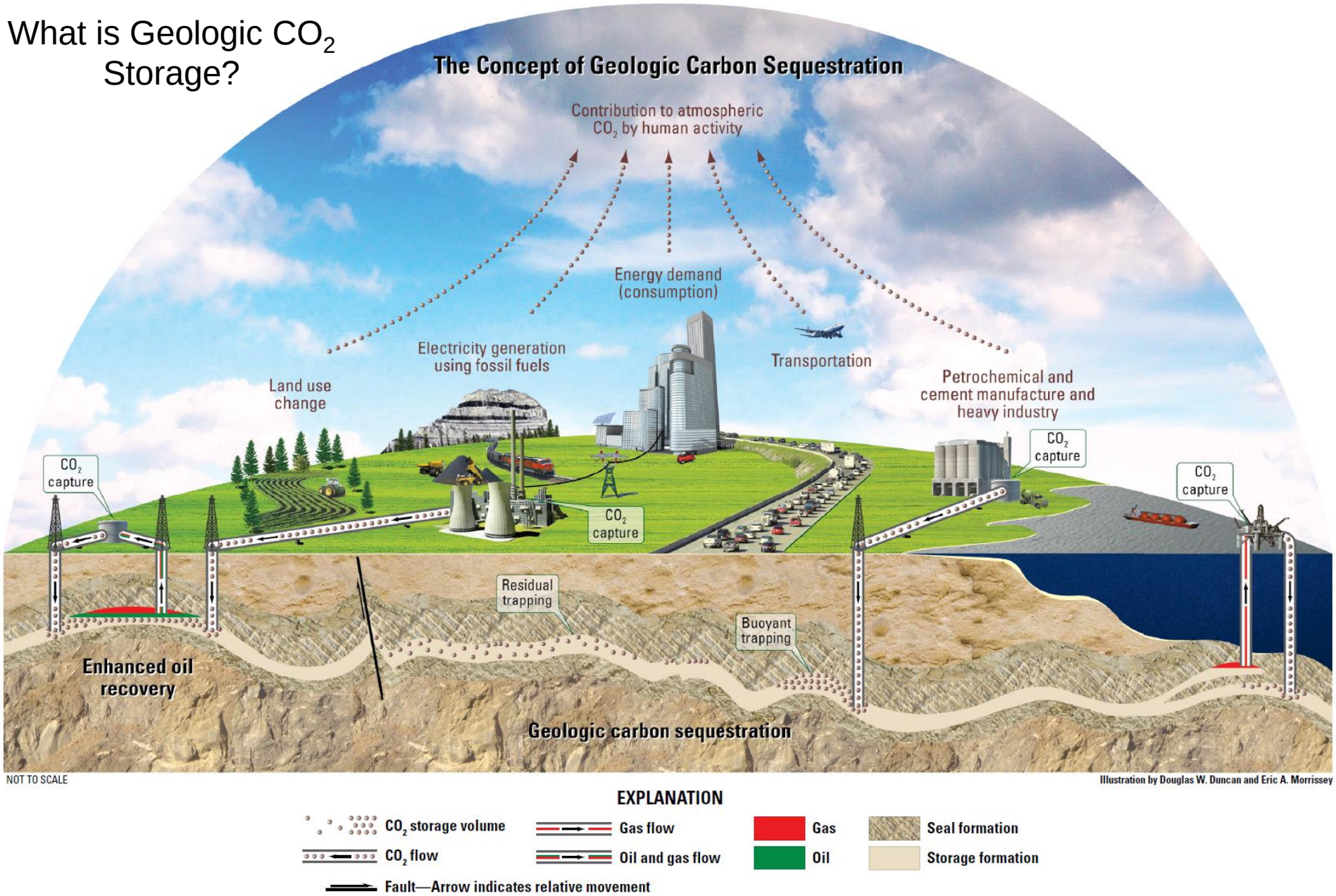
What is Geologic CO_2 Storage?



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Duncan and Morrissey (2011)

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 DOE.

(c) COORDINATION—

(1) Federal Coordination

(2) State Coordination

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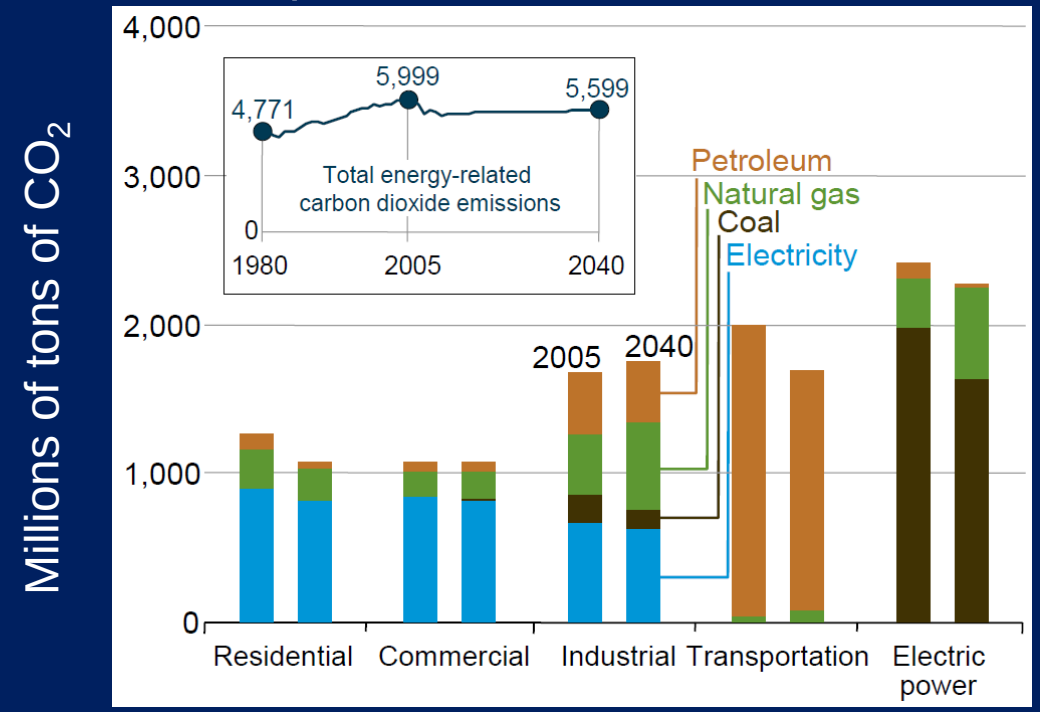
How much CO_2 needs to be stored? Some examples illustrate the range:

- World: ~ 9.5 Gt carbon/year or ~ 35 Gt CO_2 /year (Peters and others, 2013)
- U.S. total all energy sectors in 2012 → ~ 5.2 Gt/year CO_2 (U.S. Energy Information Administration, 2013)
- Laramie River 2&3 PC plant 1100 MWe → 8.7 Mt/yr CO_2 at 85% capacity factor (Brennan and Burruss, 2006)

U.S. energy-related carbon dioxide emissions by sector and fuel, 2005 and 2040
(EIA 2014, Annual Energy Outlook)



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Source: North American Carbon Storage Atlas (2012)

USGS Methodology

Brennan and others (2010); Blondes and others (2013)

- Geologically-based, statistically-sound hypotheses for quantities of resource
- Comprehensive and consistent treatment (compatible/comparable to USGS assessments in other areas)
- Transparent – published methodology, assumptions
- Probabilistic – range of values to reflect geologic uncertainty
- Storage resources are combined to basin, regional, and national scales using probabilistic aggregation to correctly propagate uncertainty
- Geological models are developed for each region, estimates are regional and not project site specific
- External expert input and multiple reviews
- Does not include coal bed or unconventional (shale or tight sand) reservoirs

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USGS Methodology – cont.

Brennan and others (2010); Blondes and others (2013)

- Identifies storage assessment units (SAUs) at depths of 3,000 to 13,000 ft to maintain the CO_2 in a supercritical state and maximize the storage resource per unit volume
- Storage formations must be sealed regionally to retain buoyant CO_2
- Estimates all pore volume within a storage formation available for CO_2 storage
- Incorporates underground source of drinking water (USDW) regulations of the EPA that exclude potential storage formations with water with less than 10,000 milligrams per liter (mg/L) of total dissolved solids (TDS)
- Identifies two storage types: buoyant and residual trapping (with 3 permeability classes)
- Endorsed by the International Energy Agency (IEA, 2013) and representatives from multiple national geological surveys, which recommend that regional-scale assessments of geologic CO_2 storage capacities should follow the USGS methodology

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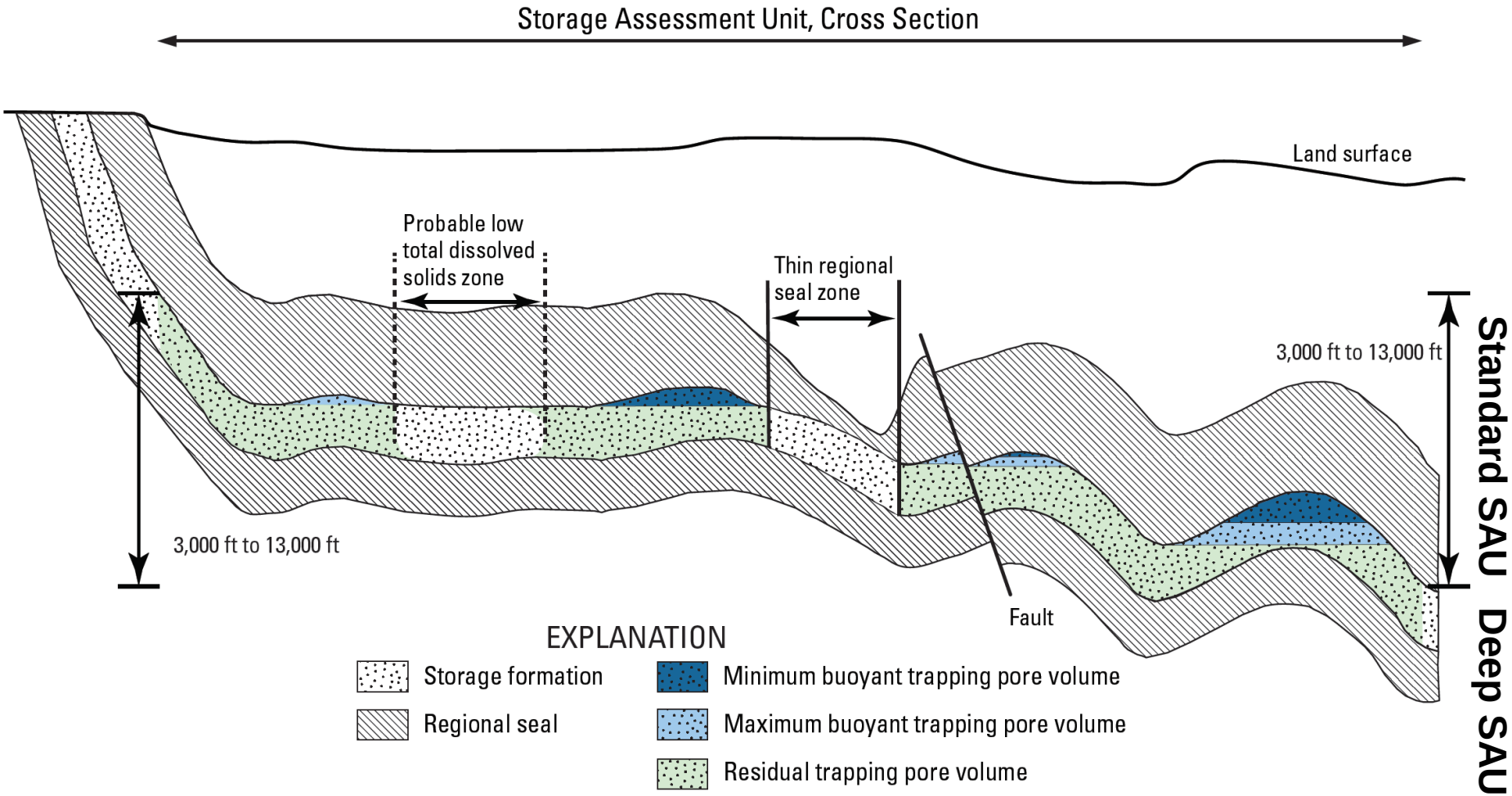
Geologic Model



Salinity of water in storage formation must be > 10,000 mg/L TDS per EPA regulations

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Brennan and others (2010); Blondes and others (2013)

Assessment Assumptions and Constraints

The USGS methodology of Brennan and others (2010) and Blondes and others (2013):

- Does not factor in engineering issues such as injection rate or time-dependent variables to determine the storage potential of SAUs
- Estimates resources without consideration either of accessibility due to land-management or regulatory restrictions or of economic viability
- Assessment covers on-shore and State water areas of the U.S.
- Assumes that increases in pressure within the reservoir during CO_2 injection can be mitigated by pressure management:
  - By water production from the storage formation
  - To prevent failure of reservoir or seal rock integrity
  - To prevent induced seismicity

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Assessment Resource Categories

1. **<u>Buoyant trapping storage resource</u>**: mass of CO_2 that can be stored buoyantly beneath structural or stratigraphic traps with the potential to contain greater than 500,000 barrels of oil equivalent (BOE) ***(B_{SR})***

2. **<u>Residual trapping storage resource</u>**: mass of CO_2 that can be stored by residual trapping in rocks
   a) with permeability greater than 1 D (***$R1_{SR}$)***
   b) with permeability between 1 mD and 1 D (***$R2_{SR}$)***
   c) with permeability less than 1mD (***$R3_{SR}$)***

TOTAL = <u>Technically accessible storage resource</u>: total mass of CO_2 that can be stored in the storage assessment unit ***(TA_{SR})***

1. **<u>Known recovery replacement storage resourc</u>**e: mass of CO_2 that can be stored in existing producing hydrocarbon reservoirs (***KRR_{SR})***

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Data Sources

- USGS National Oil and Gas Assessment publications were a significant source of reservoir characteristics and other geologic input parameters

- Data-sharing agreements with numerous State geological surveys and universities, many of which are members of the DOE National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnerships

- Two principal proprietary petroleum databases were mined for a substantial proportion of the data used in the assessments; these are the oil and gas field and reservoir database from Nehring Associates, Inc., and the databases of individual well information from IHS Inc.

- Water-quality data from USGS, NETL, and other datasets available from State sources

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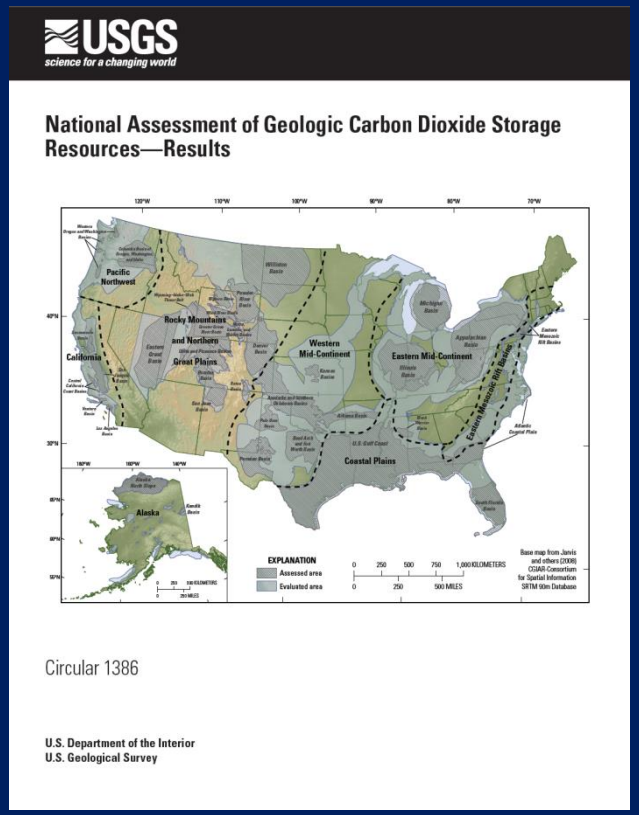
USGS National Assessment of Geologic Carbon Dioxide Storage Resources

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/

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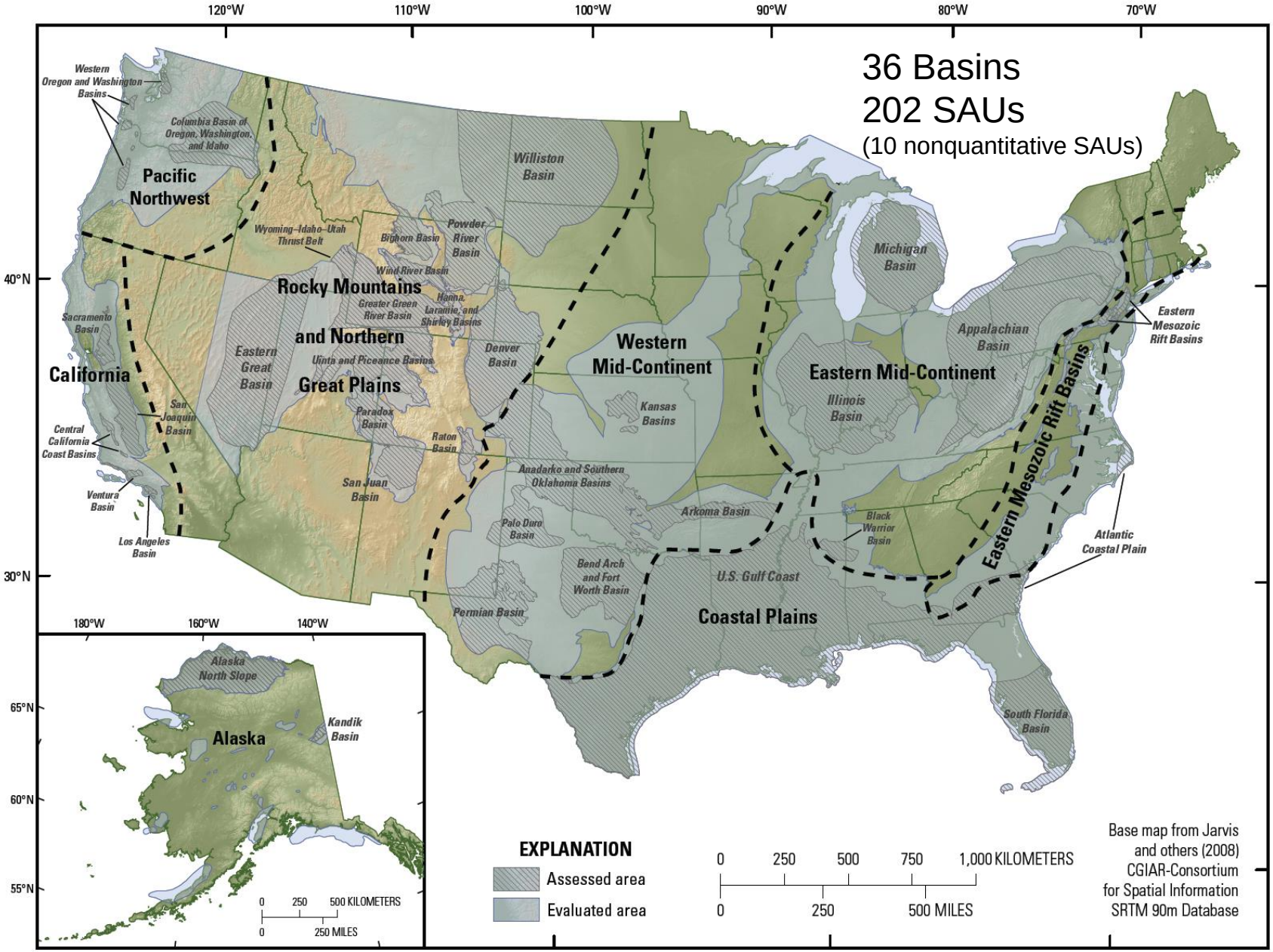
36 Basins
202 SAUs
(10 nonquantitative SAUs)
Pacific Northwest
Rocky Mountains and Northern Great Plains
California
Western Mid-Continent
Eastern Mid-Continent
Coastal Plains
Eastern Mesozoic Rift Basins
Western Oregon and Washington Basins
Columbia Basin of Oregon, Washington, and Idaho
Williston Basin
Wyoming–Idaho–Utah Thrust Belt
Bighorn Basin
Powder River Basin
Wind River Basin
Hanna, Laramie, and Shirley Basins
Greater Green River Basin
Eastern Great Basin
Uinta and Piceance Basins
Denver Basin
Paradox Basin
Raton Basin
San Juan Basin
Sacramento Basin
San Joaquin Basin
Central California Coast Basins
Ventura Basin
Los Angeles Basin
Kansas Basins
Anadarko and Southern Oklahoma Basins
Arkoma Basin
Palo Duro Basin
Bend Arch and Fort Worth Basin
Permian Basin
U.S. Gulf Coast
Michigan Basin
Appalachian Basin
Illinois Basin
Black Warrior Basin
Atlantic Coastal Plain
South Florida Basin
Alaska North Slope
Alaska
Kandik Basin
EXPLANATION
Assessed area
Evaluated area
0 250 500 750 1,000 KILOMETERS
0 250 500 MILES
0 250 500 KILOMETERS
0 250 MILES
Base map from Jarvis and others (2008)
CGIAR-Consortium for Spatial Information
SRTM 90m Database

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Results of the Assessment

Estimates of national totals for technically accessible storage resources (TA_{SR}) for carbon dioxide (CO_2) in the United States by resource type and class

CO_2 storage resource type and class		P_5	P_{50}	P_{95}	Mean
Symbol	Name				
Storage resource estimated from geologic models					
B_{SR}	Buoyant trapping storage resource	19	31	110	44
$R1_{SR}$	Residual trapping class 1 storage resource	97	140	200	140
$R2_{SR}$	Residual trapping class 2 storage resource	2,100	2,600	3,300	2,700
$R3_{SR}$	Residual trapping class 3 storage resource	58	120	230	130
TA_{SR} (total)	Technically accessible storage resource	2,300	3,000	3,700	3,000
Storage resource estimated from petroleum production volumes					
KRR_{SR}	Known recovery replacement storage resource	11	13	15	13

Estimates are in billions of metric tons (gigatons, Gt); mean values sum to totals but all values are reported to only two significant figures.

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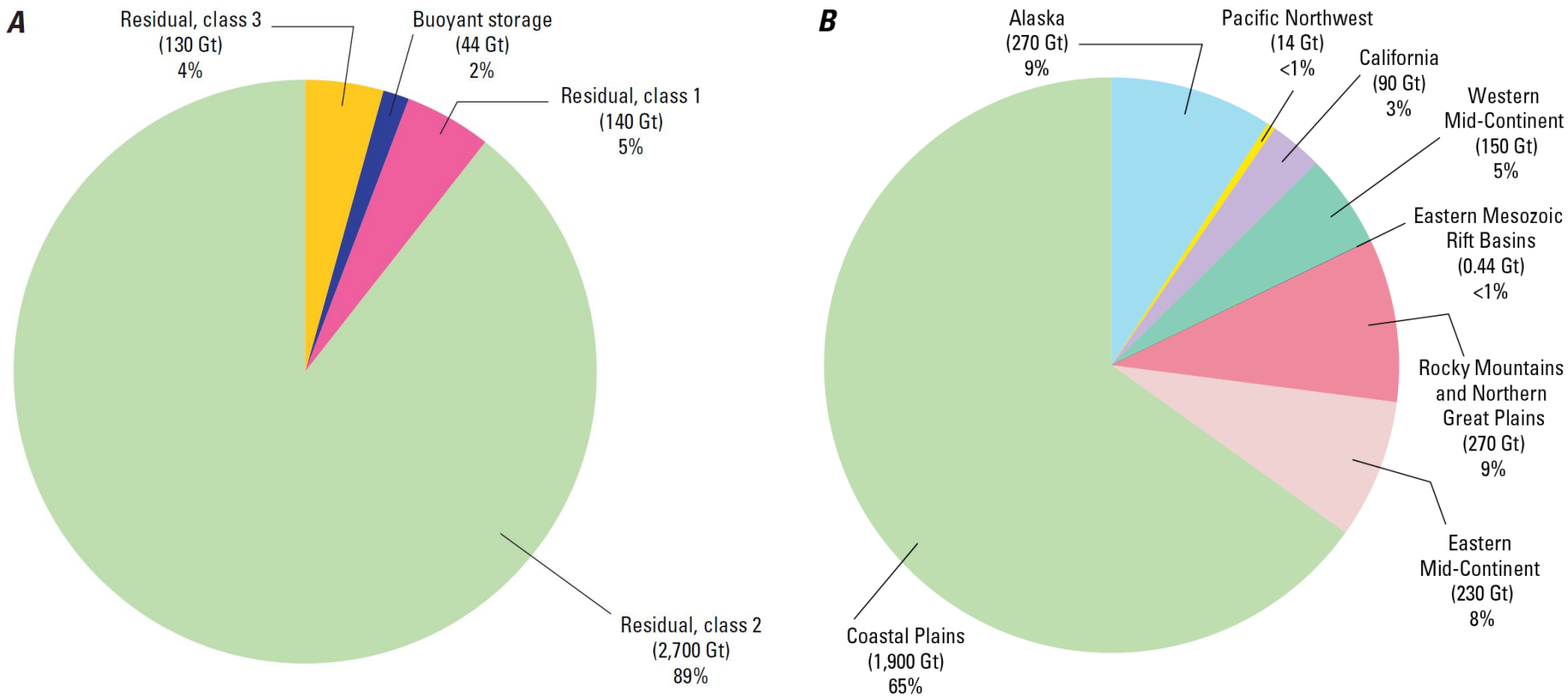
Pie charts showing mean estimates of technically accessible storage resources (TA_{SR}) for carbon dioxide (CO_2) in the United States by (*A*) type and class and (*B*) region.



Most (89 percent) of the TA_{SR} is in the residual trapping class 2 storage resource category (mean estimate of 2,700 Gt)

The regions with the largest technically accessible storage resources are the Coastal Plains (mostly in the U.S. Gulf Coast), Rocky Mountains and Northern Great Plains, and the Alaska (North Slope)

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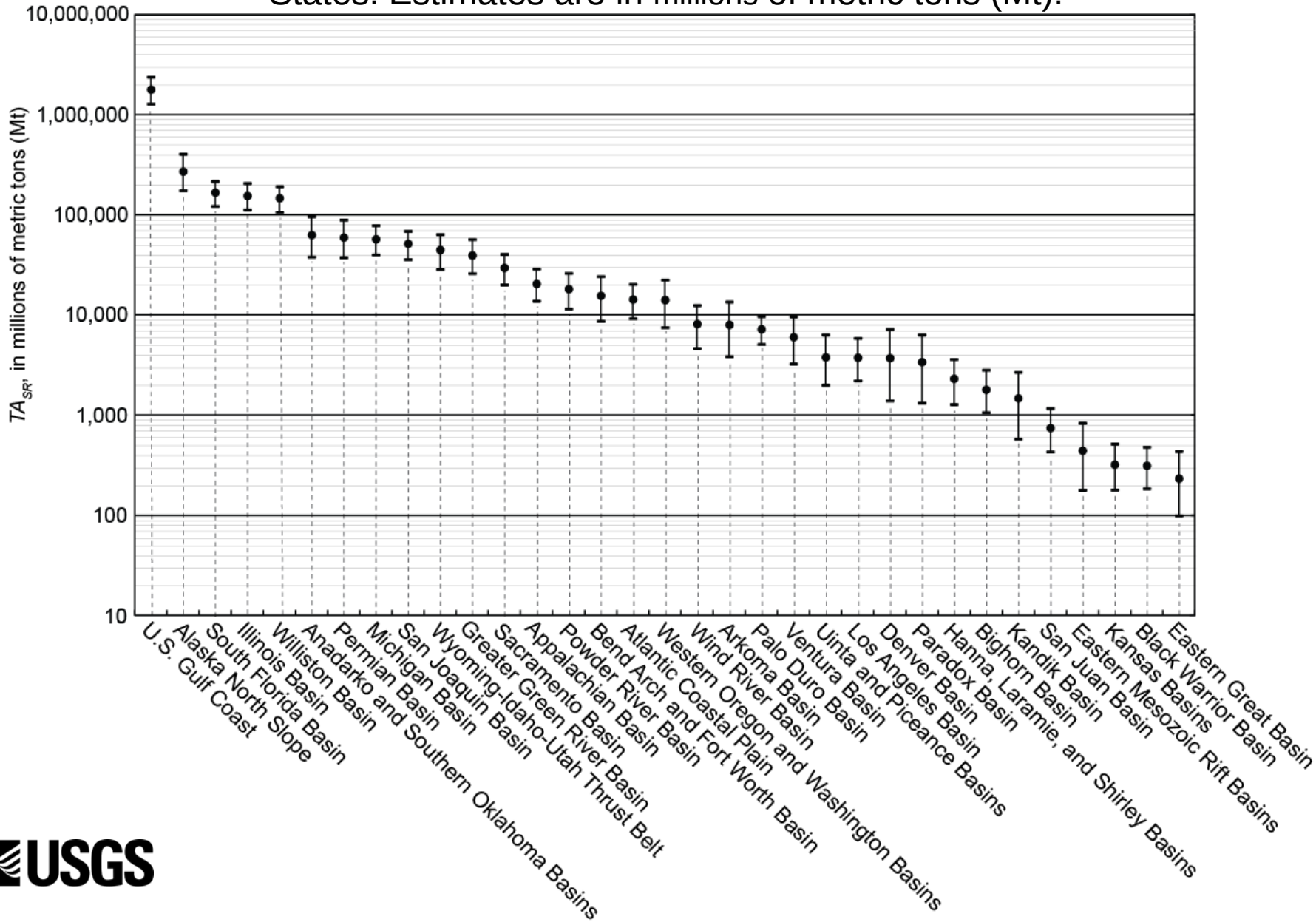
Graph showing the range estimated for the technically accessible storage resource (TA_{SR}) for carbon dioxide (CO_2) in each assessed basin in the United States. Estimates are in millions of metric tons (Mt).



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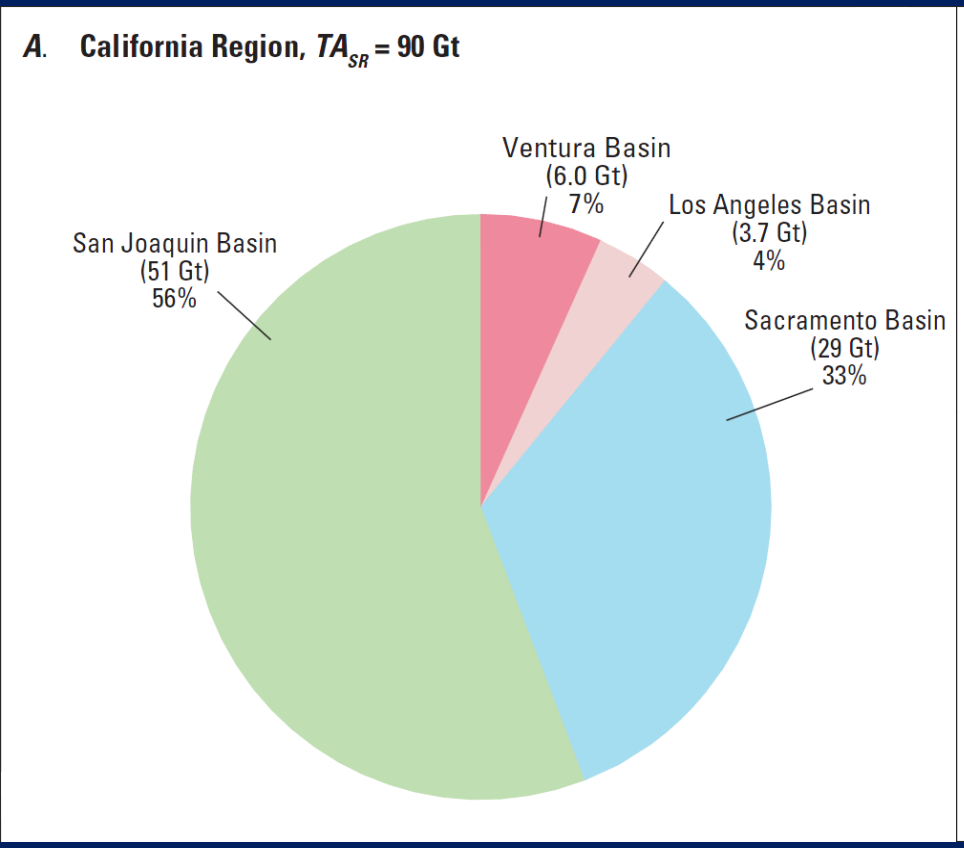
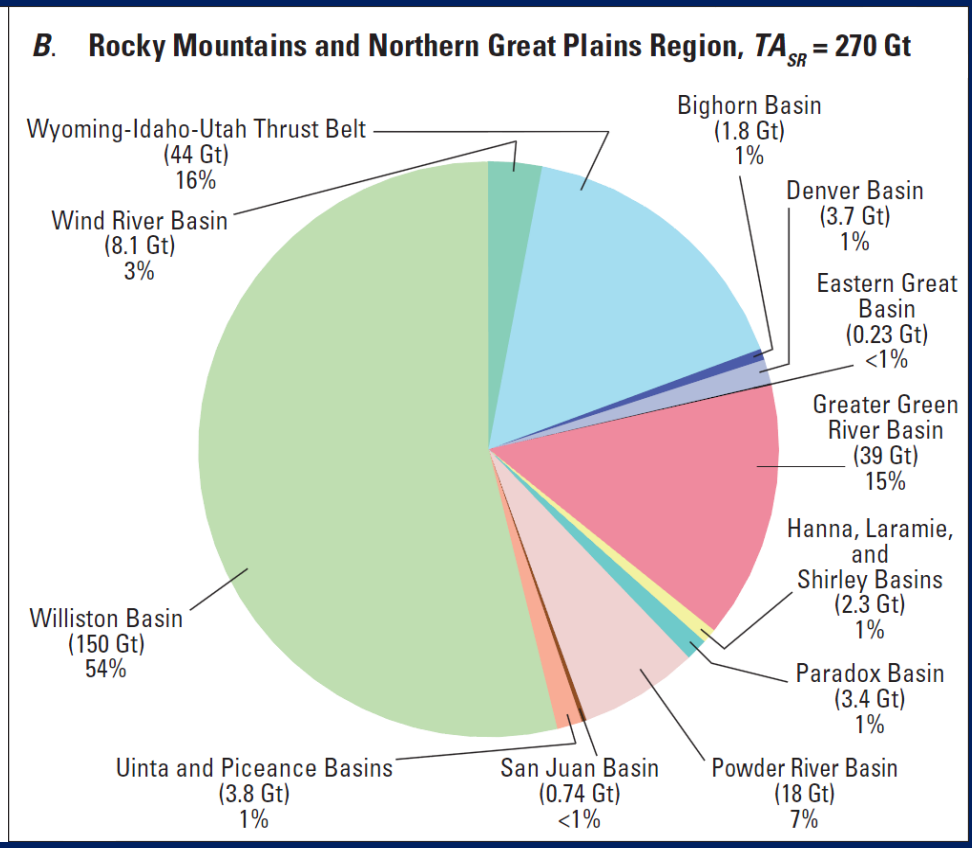
Pie charts showing mean estimates of technically accessible storage resources (TA_{SR}) for carbon dioxide (CO_2) in selected regions of the United States





Western U.S. basins contain variable amounts of freshwater (<10,000 mg/L TDS), which will restrict the use of the CO_2 storage resource capacity in these basins

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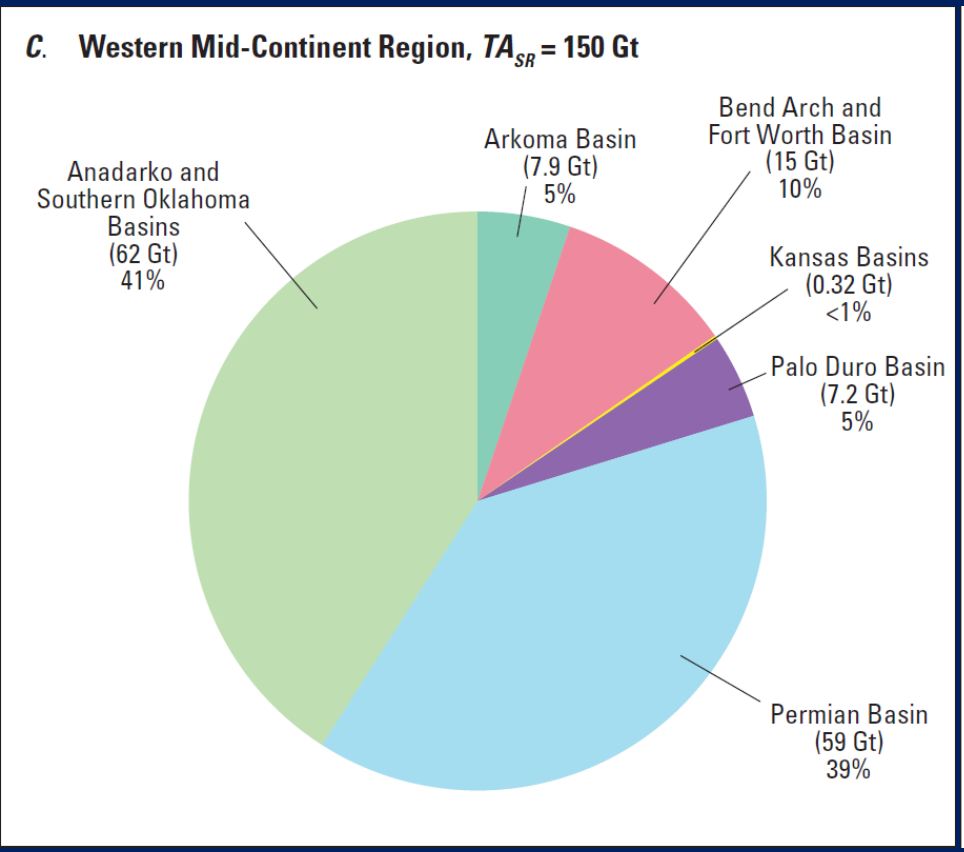
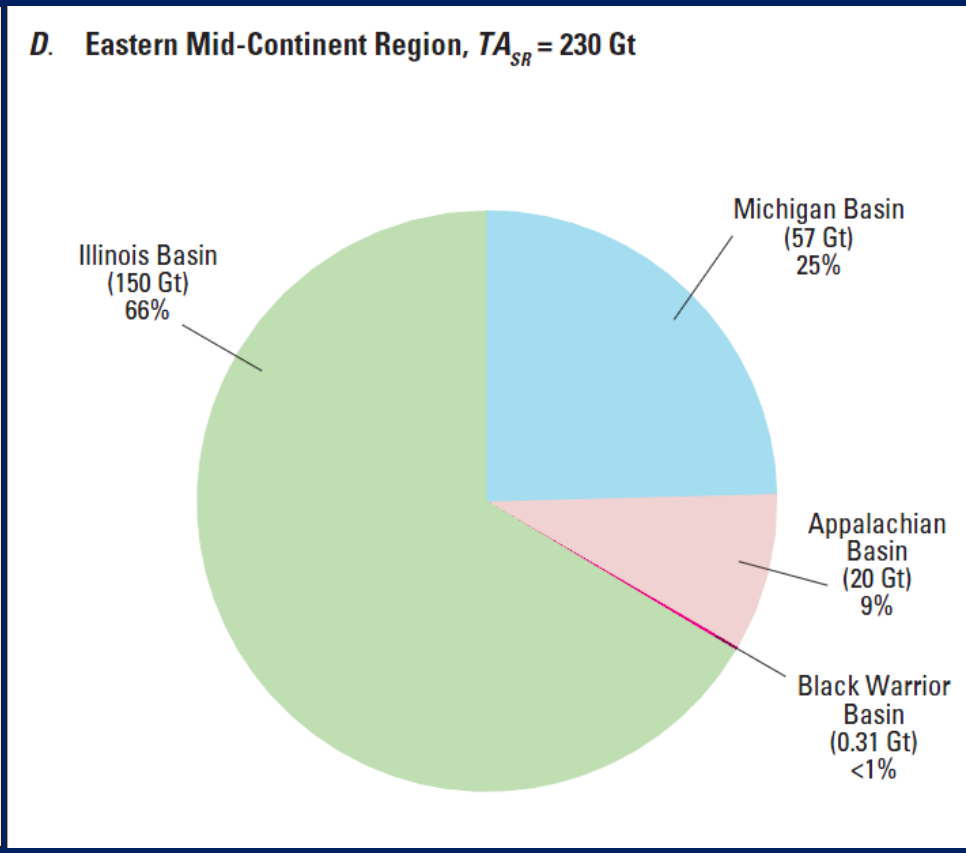
Pie charts showing mean estimates of technically accessible storage resources (TA_{SR}) for carbon dioxide (CO_2) in selected regions of the United States – cont.





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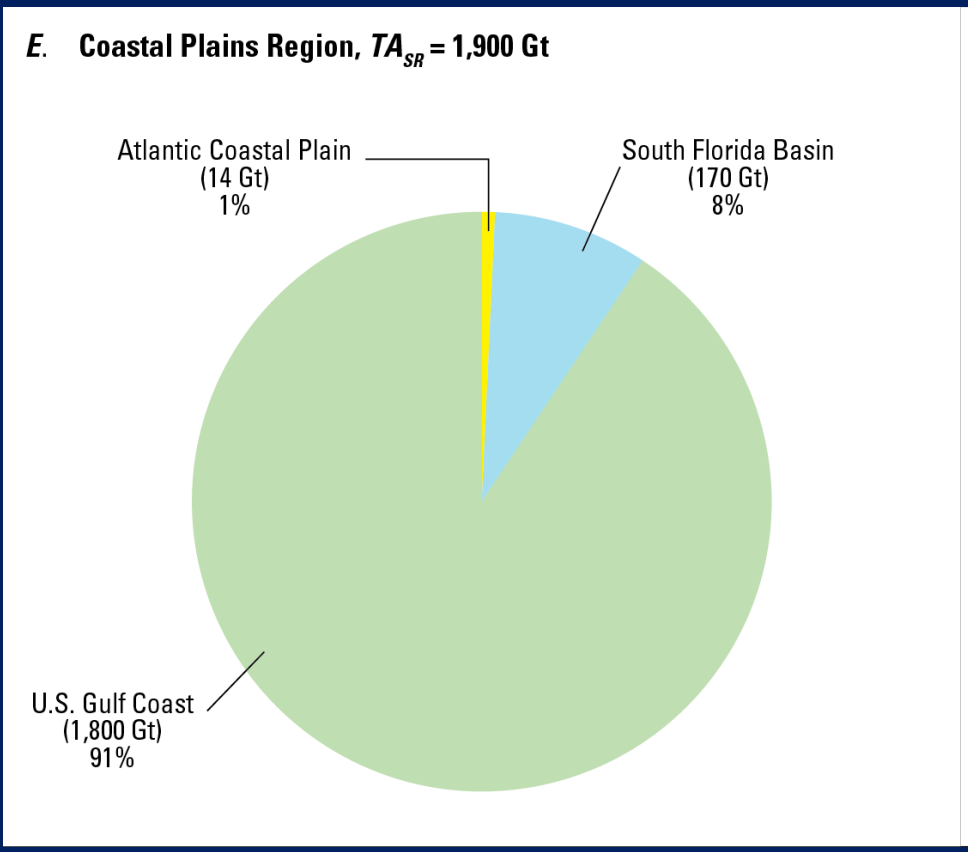
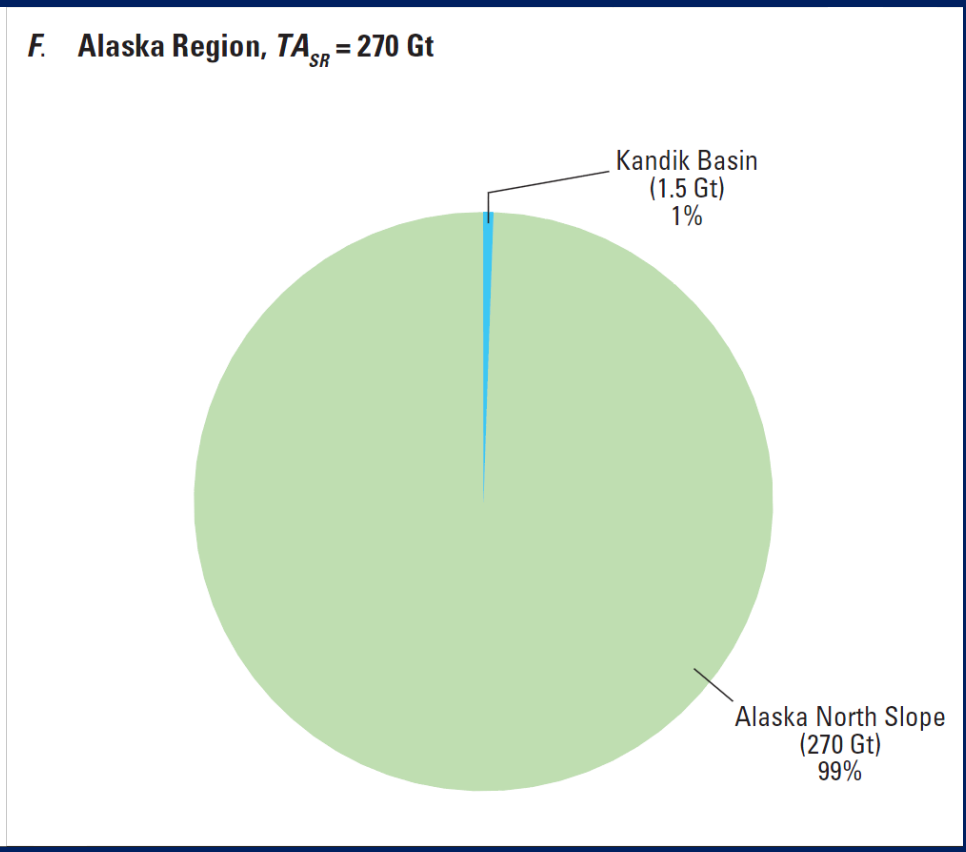
Pie charts showing mean estimates of technically accessible storage resources (TA_{SR}) for carbon dioxide (CO_2) in selected regions of the United States – cont.





The Alaska North Slope petroleum industry may utilize subsurface petroleum reservoirs for storage of CO_2 that is coproduced with hydrocarbons or stored during the enhanced-oil-recovery process using CO_2.

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Discussion of Results

- The 44 Gt (mean estimate) of buoyant trapping storage resources includes non-hydrocarbon-bearing reservoir formations, but most of the resources are well defined by hydrocarbon exploration data

- Deep SAUs account for 16 percent of the total TA_{SR}. Any potential developer of the deep SAUs has to consider the increased operational pressures needed to inject CO_2 at depths greater than 13,000 ft.

- The total geologic storage resources for CO_2 in the United States are large, and both types (buoyant and residual) will probably be needed to store anthropogenic CO_2

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Discussion of Results – cont.

- The U.S. Energy Information Administration (2013) estimated that the 2012 national energy-related CO_2 emissions were 5.2 Gt. The mean estimate by the USGS of the technically accessible geologic storage resource (TA_{SR}) for CO_2 in the United States is 3,000 Gt, which is more than 500 times the annual energy-related CO_2 emissions

- However, the mean buoyant trapping storage resource (B_{SR}) of 44 Gt is approximately eight times the annual energy-related CO_2 emissions, which means that the use of residual trapping storage resources for CO_2 will be required to significantly reduce anthropogenic CO_2 emissions into the atmosphere during the next few decades

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CARBON SEQUESTRATION – GEOLOGIC RESEARCH AND ASSESSMENTS

2014 – 2018

Task 1: Methodology development and assessment of national CO_2 enhanced oil recovery (CO_2-EOR) and associated CO_2 storage potential

- Requested by EISA legislation; Goal to complete methodology and conduct an assessment
- Topics of interest: CO_2 utilization, oil recovery factors, reservoir characterization

Task 2: Geological studies of reservoirs and seals in selected basins with high potential for CO_2 storage

- Geopressure and geothermal gradient study of mid-continent sedimentary basins
- Comparison of carbonate reservoirs within the U.S. for CO_2 sequestration
- Seal character and effects of hydrofracturing for shale gas development

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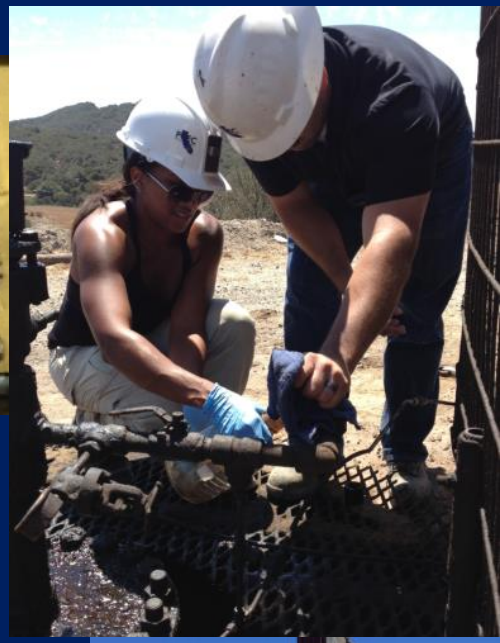
CARBON SEQUESTRATION – GEOLOGIC RESEARCH AND ASSESSMENTS

Task 3: Natural CO_2 reservoirs as analogues for CO_2 storage and resources for EOR



- California Sedimentary Basins
- Northern Rocky Mountains
- Southern Rocky Mountains
- Southern Permian Basin
- Jackson Dome, Mississippi
- Evaluate natural CO_2 and helium resources

Task 4: Economics of CO_2 storage and CO_2-EOR

- Develop model projects to evaluate sequestration and CO_2-EOR projects
- Focus on geologic storage

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CARBON SEQUESTRATION – GEOLOGIC RESEARCH AND ASSESSMENTS

Task 5: Storage of CO_2 in unconventional geologic reservoirs

- Develop and publish maps of U.S. deep coal and shale units suitable for potential storage of CO_2

Task 6: Induced seismicity associated with CO_2 geologic storage

- Seismic monitoring at Decatur and FutureGen projects, IL

Task 7: Outreach

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HELIUM STEWARDSHIP ACT OF 2013

PUBLIC LAW 113–40, OCT. 2, 2013

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 plans to work with U.S. Bureau of Land Management and State geological surveys

SUMMARY

- The USGS has completed an evaluation of the TA_{SR} for CO_2 for 36 sedimentary basins in the onshore areas and State waters of the United States. The mean assessment results are: TA_{SR} = 3,000 Gt of total subsurface CO_2 storage capacity that is technically accessible

- New assessments are underway for recoverable hydrocarbons associated with CO_2-EOR; and natural CO_2 and helium resources

- New research is focused on natural CO_2 reservoirs as analogues for CO_2 storage, storage of CO_2 in unconventional reservoirs, and induced seismicity associated with CO_2 injection

- Economic evaluations will focus on the results of the USGS assessment of recoverable hydrocarbons associated with CO_2-EOR and the 2013 National CO_2 storage assessment

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http://energy.usgs.gov

http://go.usa.gov/8X8 (USGS geologic CO_2 project website)

http://pubs.usgs.gov/ds/774/ (USGS CO_2 storage assessment data)

http://pubs.usgs.gov/circ/1386/ (USGS CO_2 storage assessment results)

http://pubs.usgs.gov/fs/2013/3020/ (USGS CO_2 storage assessment summary)

References

Blondes, M.S., Brennan, S.T., Merrill, M.D., Buursink, M.L., Warwick, P.D., Cahan, S.M., Cook, T.A., Corum, M.D., Craddock, W.H., DeVera, C.A., Drake, R.M., II, Drew, L.J., Freeman, P.A., Lohr, C.D., Olea, R.A., Roberts-Ashby, T.L., Slucher, E.R., and Varela, B.A., 2013, National assessment of geologic carbon dioxide storage resources—Methodology implementation: U.S. Geological Survey Open-File Report 2013–1055, 26 p., available only at *http://pubs.usgs.gov/of/2013/1055/.*

Brennan, S.T., and Burruss, R.C., 2006, Specific storage volumes-A useful tool for CO2 storage capacity assessment: Natural Resources Research, v. 15, no. 3, p. 165-182, DOI: 10.1007/s11053-006-9019-0.

Brennan, S.T., Burruss, R.C., Merrill, M.D., Freeman, P.A., and Ruppert, L.F., 2010, A probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage: U.S. Geological Survey Open-File Report 2010–1127, 31 p., available only at *http://pubs.usgs.gov/of/2010/1127*.

Duncan, D.W., and Morrissey, E.A., 2011, The concept of geologic carbon sequestration: U.S. Geological Survey Fact Sheet 2010-3122, 2 p., available at *http://pubs.usgs.gov/fs/2010/3122/.*

International Energy Agency, 2013, Methods to assess geologic CO_2 storage capacity: status and best practice: International Energy Agency Workshop Report 2013, 44 p., available at http://www.iea.org/publications/freepublications/publication/workshop_report_methodstoassessgeologicCO2storagecapacity.pdf.

Jarvis, A., Reuter, H.I., Nelson, Andrew, and Guevara, Edward, 2008, Hole-filled SRTM [Shuttle Radar Topographic Mission] for the globe, version 4: available from the CGIAR [Consultative Group for International Agricultural Research]-Consortium for Spatial Information SRTM 90m Database; Jarvis, A., Reuter, H.I., Nelson, Andrew, and Guevara, Edward, 2008, Hole-filled SRTM [Shuttle Radar Topographic Mission] for the globe, version 4: available from the CGIAR [Consultative Group for International Agricultural Research]-Consortium for Spatial Information SRTM 90m Database; available online at *http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1#acknowledgements.*

North American Carbon Atlas Partnership, 2012, The North American carbon storage atlas (1st ed.): U.S. Department of Energy, National Energy Technology Laboratory, 52 p., available online at *http://www.netl.doe.gov/technologies/carbon_seq/refshelf/NACSA2012.pdf*.

Peters, G.P., Andrew, R.M., Boden, Tom, Canadell, J.G., Ciais, Philippe, Le Quéré, Corinne, Marland, Gregg, Raupach, M.R., and Wilson, Charlie, 2013, The challenge to keep global warming below 2 °C: Nature Climate Change, v. 3, p. 4-6, doi:10.1038/nclimate1783 *[may require subscription to access].*

Warwick, P.D., and Corum, M.D., eds., 2012, Geologic framework for the national assessment of carbon dioxide storage resources: U.S. Geological Survey Open-File Report 2012–1024, available only at *http://pubs.usgs.gov/of/2012/1024/.*

U.S. Energy Information Administration, 2014, Annual energy outlook 2014 with projections to 2040: U.S. Energy Information Administration [Report] DOE/EIA-0383(2014), ES1 – G1 p., accessed June 4, 2014, at *http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf*.

U.S. Energy Information Administration, 2013, U.S. energy-related carbon dioxide emissions, 2012: U.S. Energy Information Administration Web site, accessed June 4, 2014, at *http://www.eia.gov/environment/emissions/carbon/pdf/2012_co2analysis.pdf*.

U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013a, National assessment of geologic carbon dioxide storage resources—Data: U.S. Geological Survey Data Series 774, 13 p., plus 2 appendixes and 2 large tables in separate files, *http://pubs.usgs.gov/ds/774/.*

U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013b, National assessment of geologic carbon dioxide storage resources—Results: U.S. Geological Survey Circular 1386, 41 p., *http://pubs.usgs.gov/circ/1386/*.

U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013c, National assessment of geologic carbon dioxide storage resources—Summary: U.S. Geological Survey Fact Sheet 2013–3020, 6 p., *http://pubs.usgs.gov/fs/2013/3020/.*

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