Eleventh Annual Conference on Carbon Capture, Utilization & Sequestration

Assessments of CO_2 Storage Capacity

U.S. Geological Survey Geologic Carbon Dioxide Storage Resource Assessment of the United States – 2012 Project Update

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April 30 – May 3, 2012 • David L. Lawrence Convention Center • Pittsburgh, Pennsylvania

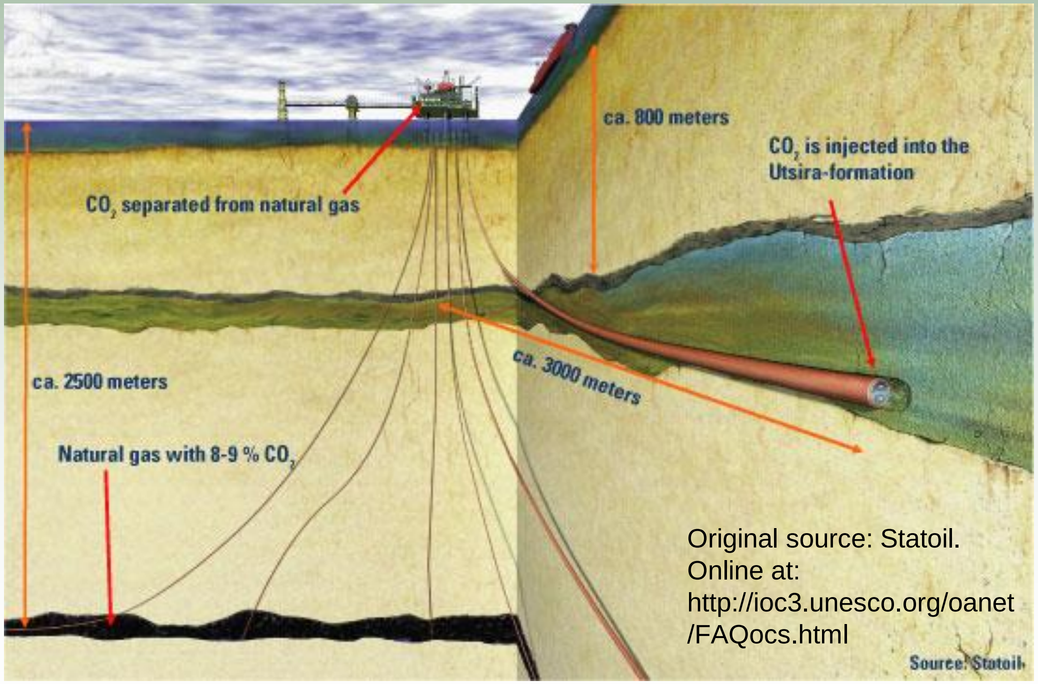
USGS

Outline for Presentation

- USGS CO_2 Storage Assessment Activities
  - USGS Geologic Model
  - Assessment Methodology
- CO_2 Enhanced Oil Recovery
- CO_2 storage in unconventional reservoirs
- Induced seismicity
- Future work

Energy Independence and Security Act 2007

- METHODOLOGY …shall develop a methodology for conducting an assessment… taking into consideration:
  - Geographical extent of all potential sequestration [non-coal] formations in all States
  - Capacity of the potential sequestration formations
  - Injectivity of the potential sequestration formations
  - Estimate of potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations
- COORDINATION
  - Federal Coordination
  - State Coordination



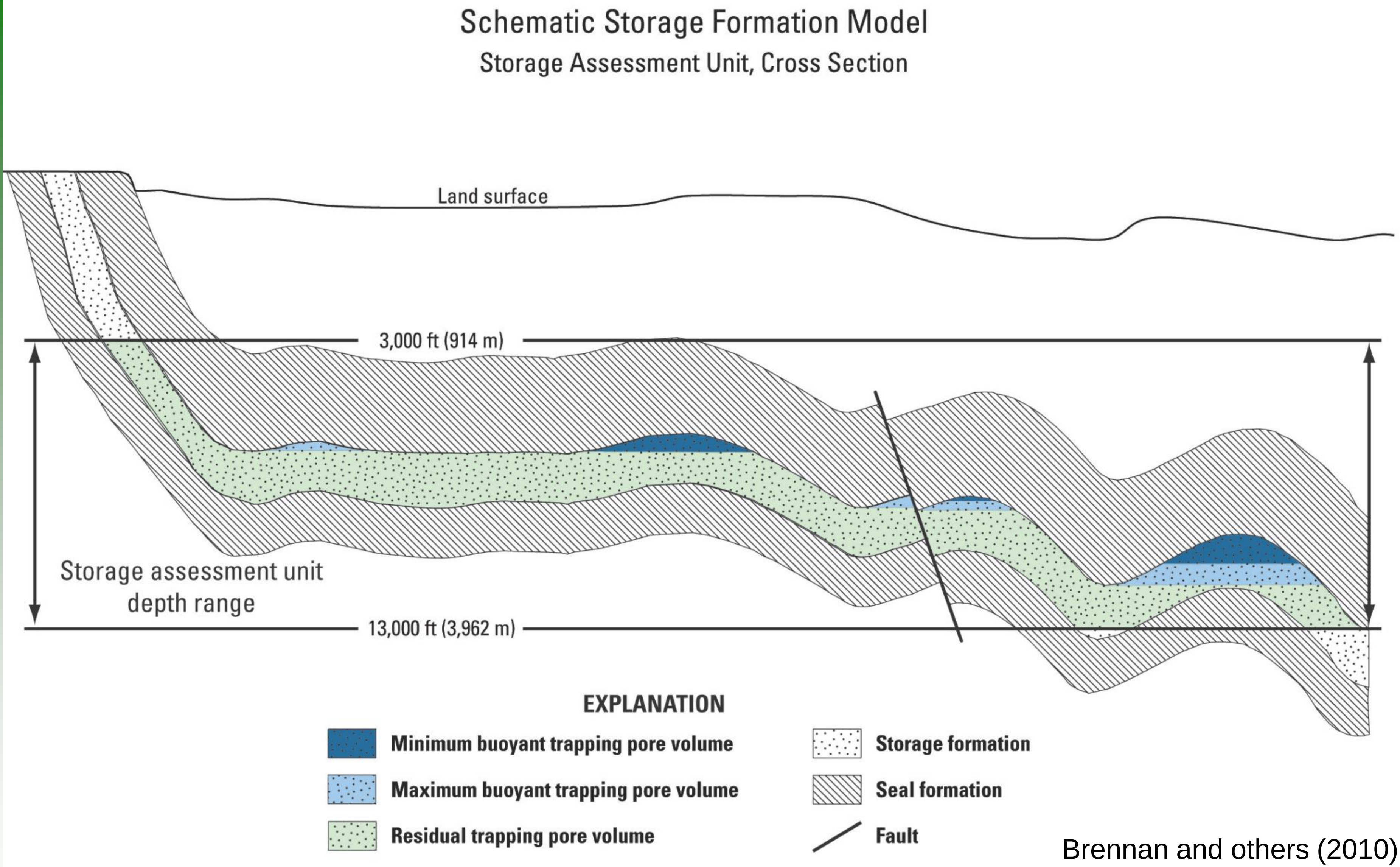
Original source: Statoil.
Online at:
http://ioc3.unesco.org/oanet/FAQocs.html

For more information on the Energy Independence and Security Act
See: https://www.federalregister.gov/articles/2010/07/08/2010-16236/energy-independence-and-security-act-pub-l-110-140

USGS Assessment Methodology for Geologic CO_2 Storage Capacities

- The USGS assessment focuses on CO_2 injected at depths of 3,000 to 13,000 ft below the land surface
- CO_2 is buoyant and displaces existing water, oil, or gas
- Storage formation must be sealed to retain buoyant CO_2
- USGS assessment methodology addresses buoyant and residual trapping
- Salinity of water in storage formation must be >10,000 ppm TDS per Environmental Protection Agency (EPA) regulations
- Assessment results provide probabilistic ranges of storage capacities

USGS CO_2 Assessment Methodology



Brennan and others (2010)

Salinity of water in storage formation must be > 10,000 ppm TDS per USEPA (2008) regulations

Final CO_2 Assessment Report

- USGS Circular assessment report with assessment results at National, basin and formation scales

- On-line supporting data (as completed)

    Maps with storage assessment unit (SAU) boundaries

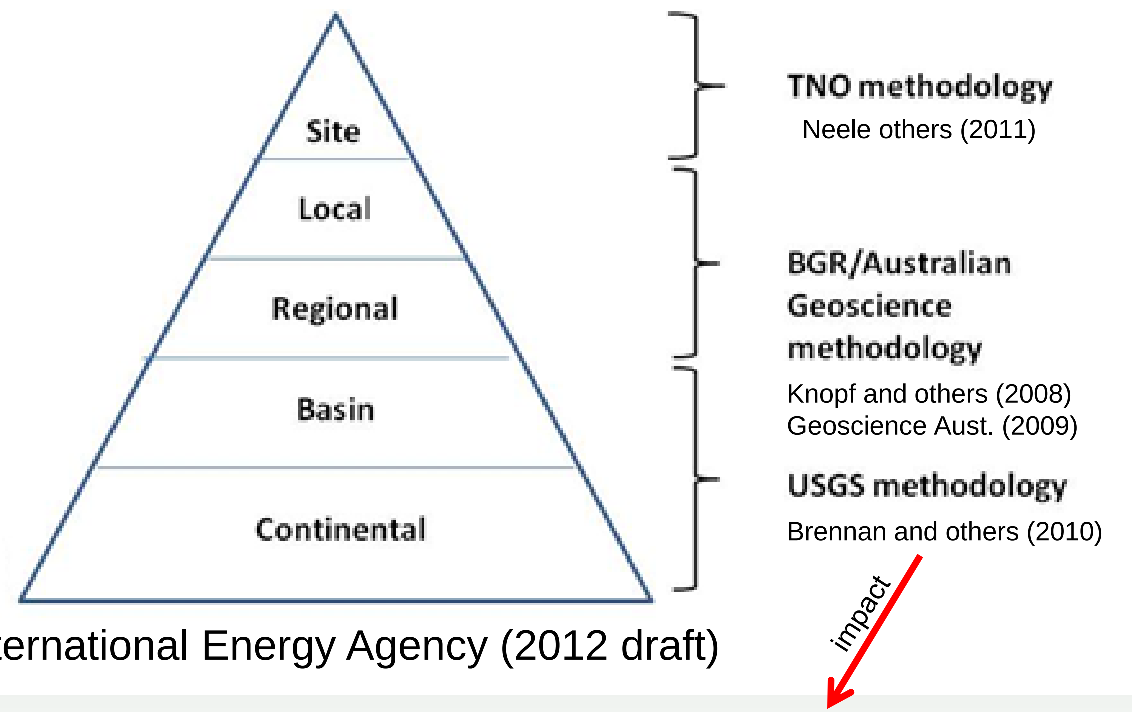
    Summary reports for SAU

http://energy.usgs.gov/HealthEnvironment/EnergyProductionUse/GeologicCO2Sequestration.aspx

Continuum of storage capacity estimates

Reserve

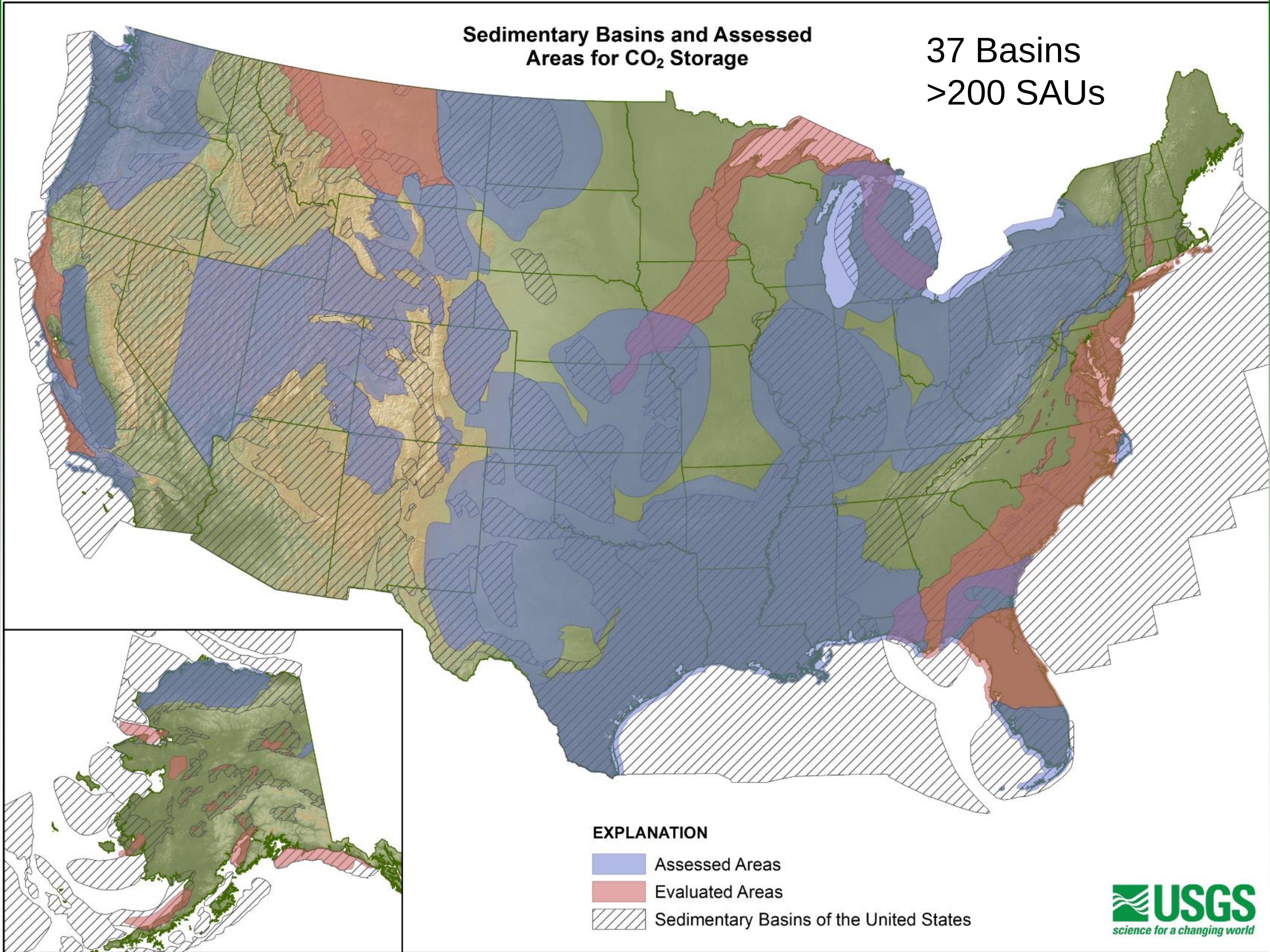
Resource

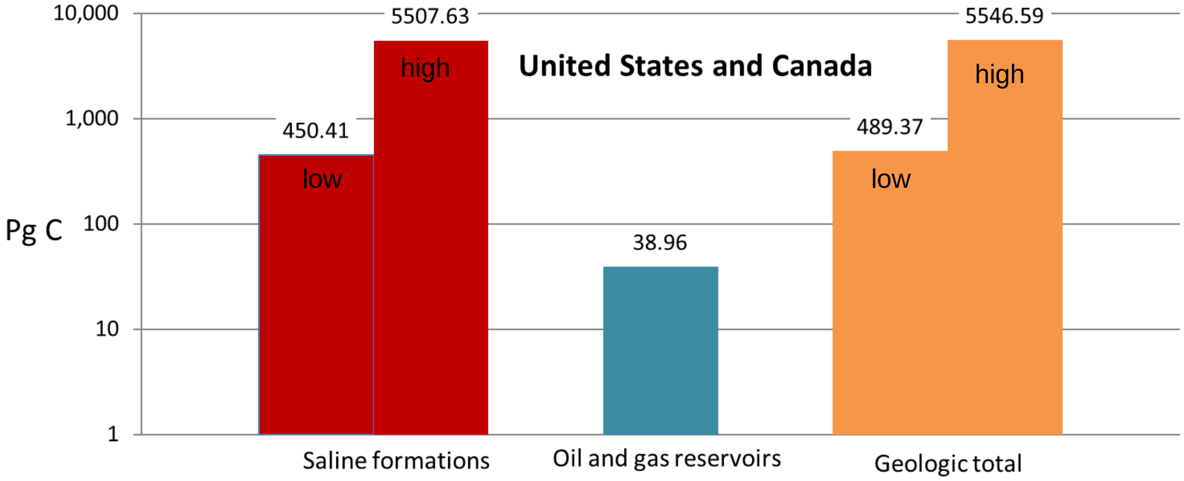


International Energy Agency (2012 draft)

- U.S. DOE National Energy Technology Lab (NETL, 2010) & Bureau of Ocean Energy Management assessment methodologies
- USGS/NETL/The University of Texas at Austin, Petroleum & Geosystems Engineering and Bureau of Economic Geology/Southeast Regional Carbon Sequestration Partnership (SECARB) Storage Efficiency Workshop July, 2012

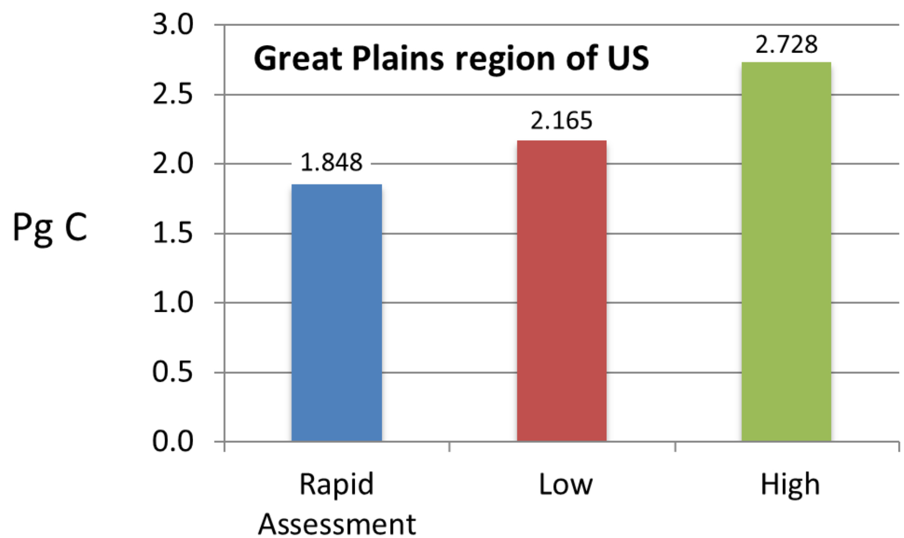
37 Basins
>200 SAUs





Geologic carbon sequestration resource estimates from U.S. Department of Energy, National Energy Technology Laboratory (2010) which provided high and low estimates for saline formations

Estimated biologic carbon sequestration potential of the Great Plains region (26.7 %) of the United States (Sundquist and others, 2009; Zhu and others, 2011)



1 petagram (Pg) = 1 billion metric tons (Gt); 1 metric ton C = 3.67 metric tons of CO_2

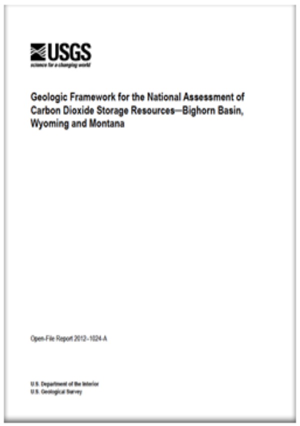
Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources—Bighorn Basin, Wyoming and Montana

By Jacob A. Covault,[1] Marc L. Buursink, William H. Craddock, Matthew D. Merrill, Madalyn S. Blondes, Mayur A. Gosai, and Philip A. Freeman

Chapter A

of Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources

Edited by Peter D. Warwick and Margo D. Corum


USGS

Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources—Bighorn Basin, Wyoming and Montana

Abstract

The 2007 Energy Independence and Security Act (*Public Law 110–140*) directs the U.S. Geological Survey (USGS) to conduct a national assessment of potential geologic storage resources for carbon dioxide (CO_2). The methodology used for the national CO_2 assessment follows that of previous USGS work. The methodology is non-economic and intended to be used at regional to subbasinal scales.

This report identifies and contains geologic descriptions of twelve storage assessment units (SAUs) in six separate packages of sedimentary rocks within the Bighorn Basin of Wyoming and Montana and focuses on the particular characteristics, specified in the methodology, that influence the potential CO_2 storage resource in those SAUs. Specific descriptions of the SAU boundaries as well as their sealing and reservoir units are included. Properties for each SAU such as depth to top, gross thickness, net porous thickness, porosity, permeability, groundwater quality, and structural reservoir traps are provided to illustrate geologic factors critical to the assessment. Although assessment results are not contained in this report, the geologic information included here will be employed, as specified in the methodology of earlier work, to calculate a statistical Monte Carlo-based distribution of potential storage space in the various SAUs. Figures in this report show SAU boundaries and cell maps of well penetrations through the sealing unit into the top of the storage formation. Wells sharing the same well borehole are treated as a single penetration. Cell maps show the number of penetrating wells within one square mile and are derived from interpretations of incompletely attributed well data, a digital compilation that is known not to include all drilling. The USGS does not expect to know the location of all wells and cannot guarantee the amount of drilling through specific formations in any given cell shown on cell maps.

[1] Current address: Chevron Energy Technology Company, Clastic Stratigraphy R&D, Houston, Texas 77002, USA

First posted March 27, 2012

- Report PDF (10 MB)

Download compressed filess (.zip) of Bighorn Basin (C5034) digital data.

- Well Density
- Storage Assessment Units

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USGS ERP: Geologic CO_2 Sequestration

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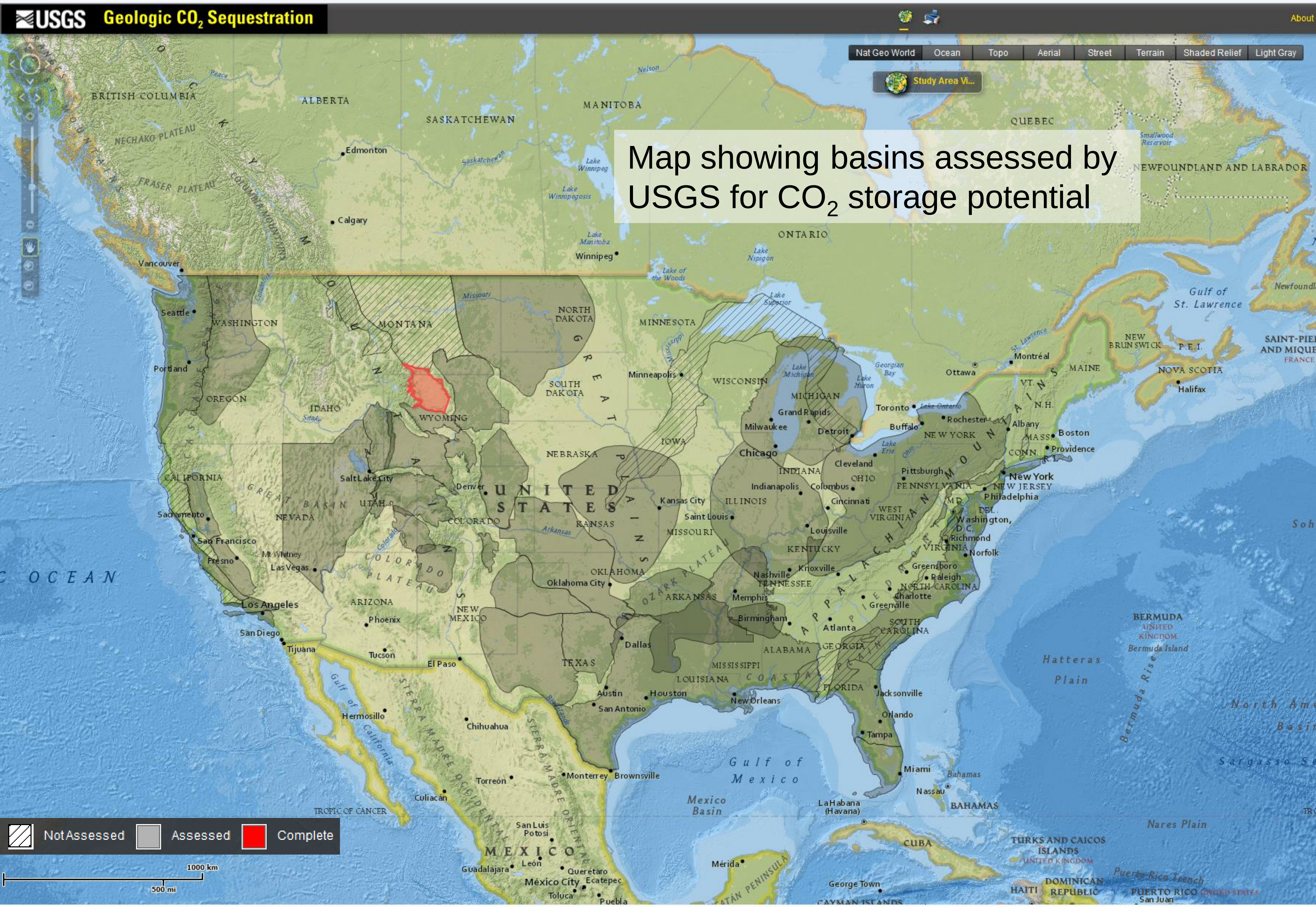
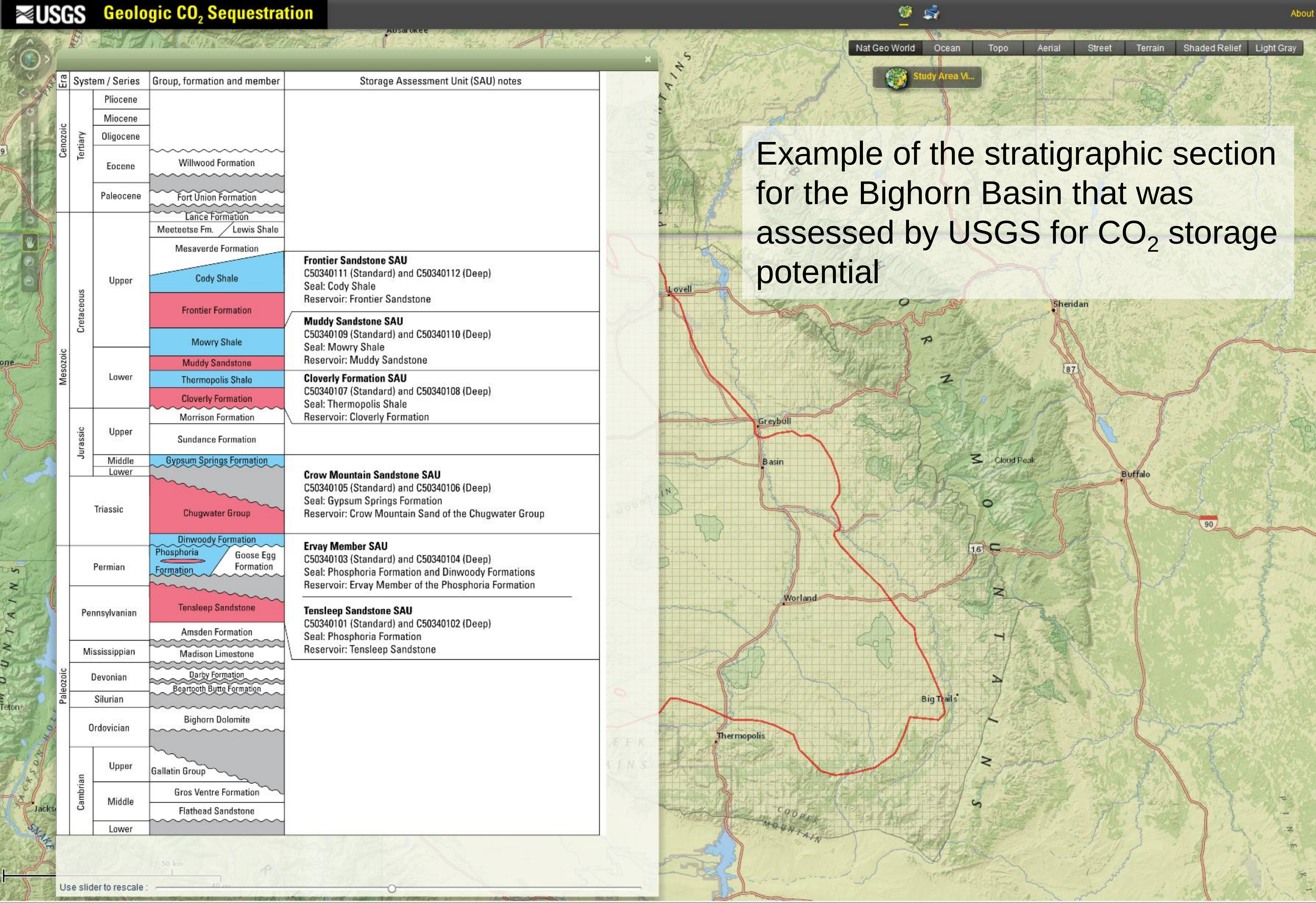
http://pubs.usgs.gov/of/2012/1024/a/

Map showing basins assessed by USGS for CO_2 storage potential

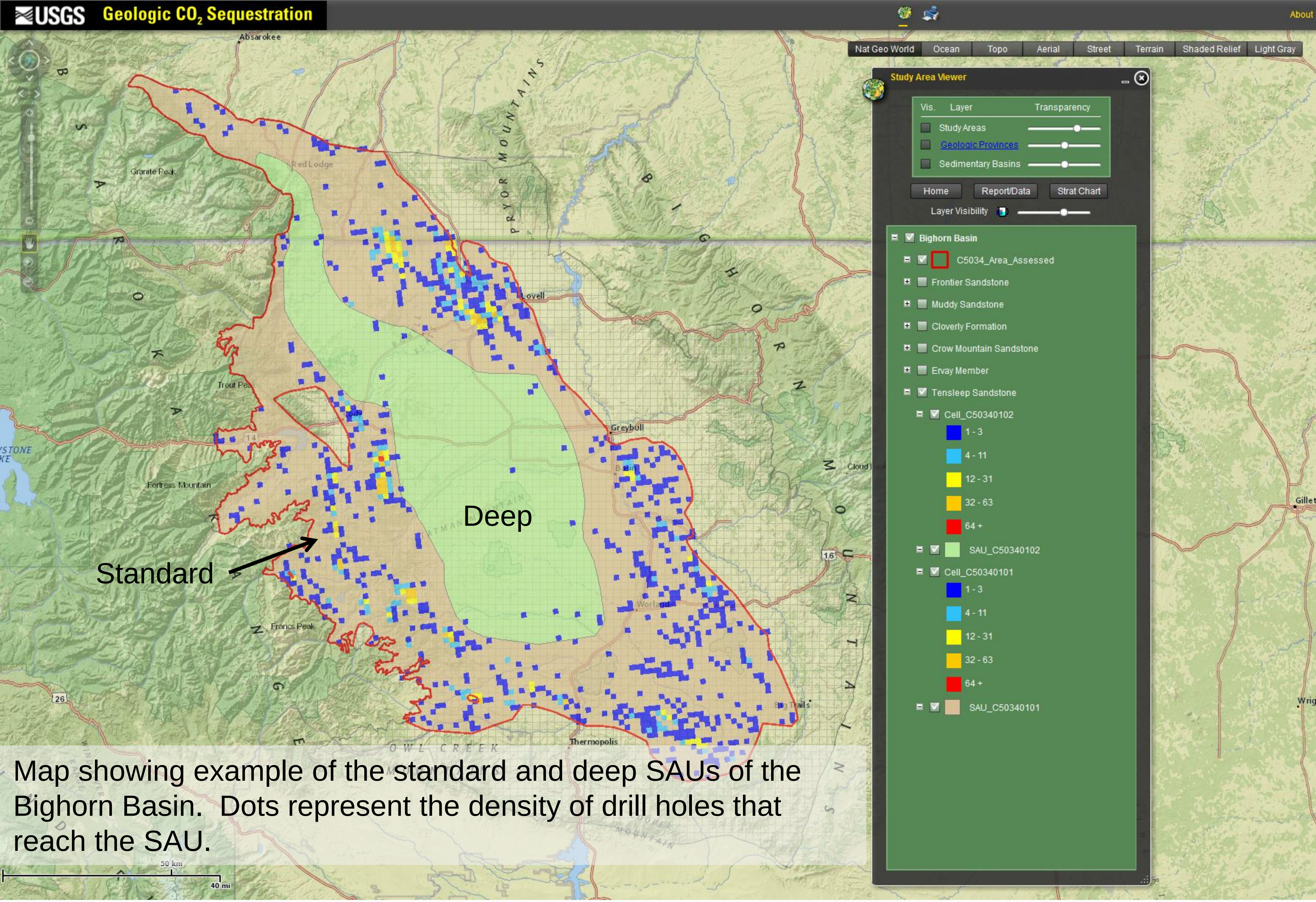


http://energy.usgs.gov/HealthEnvironment/EnergyProductionUse/GeologicCO2Sequestration.aspx

Example of the stratigraphic section for the Bighorn Basin that was assessed by USGS for CO_2 storage potential



http://energy.usgs.gov/HealthEnvironment/EnergyProductionUse/GeologicCO2Sequestration.aspx



Map showing example of the standard and deep SAUs of the Bighorn Basin. Dots represent the density of drill holes that reach the SAU.

http://energy.usgs.gov/HealthEnvironment/EnergyProductionUse/GeologicCO2Sequestration.aspx

USGS CO_2 Science Support

A secondary objective of the USGS National Geologic Carbon Dioxide Sequestration Assessment project is to conduct relevant research that will help to refine the current and future CO_2 storage assessments

- Geochemical characterization of CO_2 interactions with organic-rich seals and other reservoir rocks with emphasis on CO_2 retention
- Characterization of reservoir compartmentalization and injectivity
- Problems associated with enhanced oil and gas recovery and potential methods for assessing CO_2 storage potential
- Research related to the storage of CO_2 in unconventional reservoirs (coal, shale, mafic and ultramafic rocks)
- Statistical methods to handle dependencies and aggregation of assessment results at the basin, State, and National scales
- Research on the potential impacts of induced seismicity related to CO_2 injection and subsurface storage

USGS science for a changing world

GCEP

USGS EOR-CO_2 Sequestration Workshop

May 10-11, 2011

Stanford University

USGS – Stanford Global Climate and Energy Project

Workshop Goals: Identifed key geologic and engineering parameters that needed to be considered in a USGS methodology to assess recoverable hydrocarbons associated with CO_2 sequestration.

Verma and Warwick (2011)
http://pubs.usgs.gov/fs/2011/3075/pdf/fs2011-3075.pdf

USGS science for a changing world

Development of an Assessment Methodology for Hydrocarbon Recovery Potential Using Carbon Dioxide and Associated Carbon Sequestration: Workshop Findings

Geologic carbon dioxide (CO_2) sequestration coupled with enhanced oil recovery using CO_2 in existing hydrocarbon reservoirs can increase the U.S. hydrocarbon recoverable resource volume and prevent CO_2 release to the atmosphere, potentially limiting CO_2 contribution to global warming as a greenhouse gas.

Introduction

The Energy Independence and Security Act of 2007 (Public Law 110–140) authorized the U.S. Geological Survey (USGS) to conduct a national assessment of geologic storage resources for carbon dioxide (CO_2) and requested that the USGS estimate the "potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations" (121 Stat. 1711). The USGS developed a noneconomic, probability-based methodology to assess the Nation's technically assessable geologic storage resources available for sequestration of CO_2 (Brennan and others, 2010) and is currently using the methodology to assess the Nation's CO_2 geologic storage resources. Because the USGS has not developed a methodology to assess the potential volumes of technically recoverable hydrocarbons that could be produced by injection and sequestration of CO_2, the Geologic Carbon Sequestration project initiated an effort in 2010 to develop a methodology for the assessment of the technically recoverable hydrocarbon potential in the sedimentary basins of the United States using enhanced oil recovery (EOR) techniques with CO_2 (CO_2-EOR). In collaboration with Stanford University, the USGS hosted a 2-day CO_2-EOR workshop in May 2011, attended by 28 experts from academia, natural resource agencies and laboratories of the Federal Government, State and international geologic surveys, and representatives from the oil and gas industry. The geologic and the reservoir engineering and operations working groups formed during the workshop discussed various aspects of geology, reservoir engineering, and operations to make recommendations for the methodology. The findings of the two groups are discussed below.

Workshop Findings

Geologic Aspects

A new assessment methodology could use and build upon the reservoir and associated data already assembled by the USGS National Oil and Gas Assessment (NOGA) project (*http://energy.cr.usgs.gov/oilgas/noga/*) in previous assessments of undiscovered hydrocarbon resources. The assessment methodology could then assess individual oil reservoirs that are appropriate for CO_2-EOR injection techniques at the basin scale to estimate recoverable hydrocarbons using CO_2 injection. The assessed reservoirs within each basin could be grouped based on previously defined NOGA Total Petroleum System assessment units with similar lithology and geologic characteristics.

Each assessed reservoir would meet the minimum size criteria used by the NOGA (0.5 million barrels of oil), and further characterization would be based on oil-to-gas ratio, depth, temperature, pressure, viscosity, and the API (American Petroleum Institute) gravity of the oil.

The methodology would estimate the original oil in place, if not available from the databases or publicly available sources, and use production data, such as cumulative production, reported reserves, and all other geologic parameters, for each reservoir by consulting commercial, State, and Federal databases and the petroleum geology and reservoir engineering literature for a comprehensive assessment. These same data sources would be consulted for an estimated hydrocarbon recovery factor for primary, secondary (with water floods), and tertiary recovery techniques that would use CO_2 injected into the reservoir to improve oil recovery.

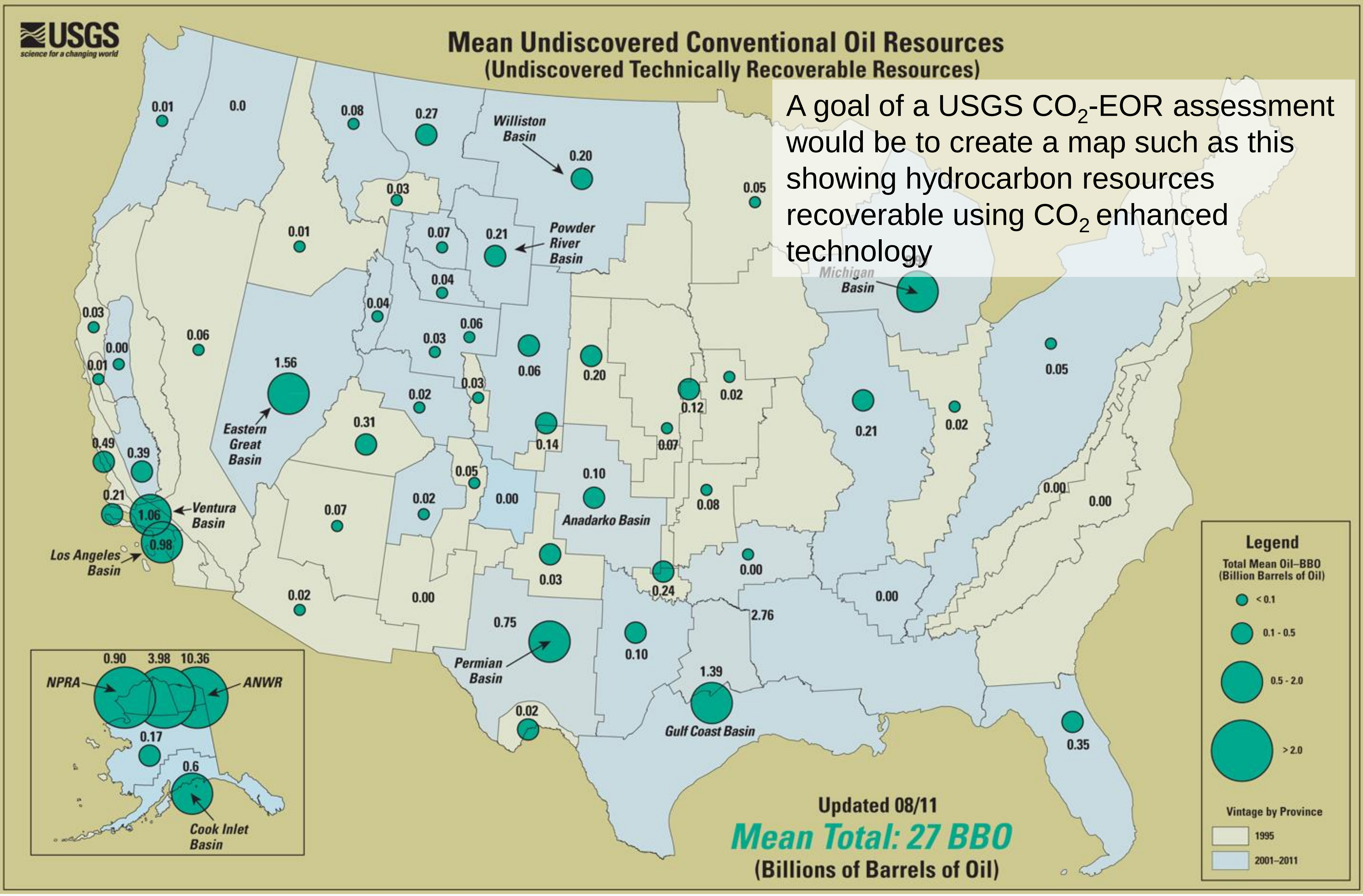
The assessment methodology would not include the residual oil zone (ROZ), which is the transition zone at the bottom of oil column, until the ROZ production viability has been established. The ROZ was discussed at the workshop as having future potential for additional oil recovery and therefore would be noted in the assessment for future study.

Reservoir Engineering and Operations Aspects

A volumetric approach to estimate recoverable hydrocarbon volumes for all conventional reservoirs at the field scale would be used. If sufficient data exist, production-based methods would be used for reservoirs in the primary or waterflood phase to determine estimated ultimate recoverable (EUR) hydrocarbon volumes; this may provide some check on volumetric estimates and in some cases may be the only source for an indirect estimate of the oil-in-place value.

Exponential decline-curve analysis can be used to estimate EUR volumes for most reservoirs that are currently not under pressure maintenance or EOR, and hyperbolic decline-curve analysis can be used for some reservoirs with early decline, strong water drive or horizontal wells. The exponential decline-curve analysis uses a semilogarithmic plot of the cumulative oil recovery versus the oil production rate to estimate the ultimate

A goal of a USGS CO_2-EOR assessment would be to create a map such as this showing hydrocarbon resources recoverable using CO_2 enhanced technology



http://certmapper.cr.usgs.gov/data/noga00/natl/graphic/2011/mean_conv_oil_2011_large.png

CO2 Sequestration in Unconventional Reservoirs Workshop
March 28-29, 2012
National Conservation Training Center, Shepherdstown, WV

The goals of the workshop were:

1) To determine the current state of laboratory, modeling, and pilot projects.

2) To discuss the feasibility of CO_2 storage in unconventional reservoirs (coal, shale, basalts).

3) To build a set of recommendations that could be used for underpinning a USGS methodology to assess the CO_2 storage potential in unconventional reservoirs, if such storage proves feasible.

Induced seismicity and CO_2 sequestration

Currently working with USGS Earthquake Science Center to identify unique characteristics of injected CO_2 and the potential for induced seismicity

Injected CO_2 is unlike injected waste water:

- Liquid CO_2 is buoyant
- Potential for mineralization
- Other subsurface reactions along fault zones

Ohio rumblings. Wastewater injected at this site in Youngstown triggered jolting earthquakes that prompted injection-well shutdowns and strong new regulations.

SEISMOLOGY

Learning How to NOT Make Your Own Earthquakes

As fluid injections into Earth's crust trigger quakes across the United States, researchers are scrambling to learn how to avoid making more

First off, fracking for shale gas is not touching off the earthquakes that have been shaking previously calm regions from New Mexico to Texas, Ohio, and Arkansas. But all manner of other energy-related fluid injection—including deep disposal of fracking's wastewater, extraction of methane from coal beds, and creation of geothermal energy reservoirs—is in fact setting off disturbingly strong earthquakes. These quakes of magnitude 4 and 5 are rattling the local populace, shutting down clean energy projects, and prompting a flurry of new regulations.

Researchers have known for decades that deep, high-pressure fluid injection can trigger sizable earthquakes. But after a decades-long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors. When triggered quakes surprise drillers, "we're often in the position of ambulance chasers without the necessary science done ahead of time," says seismologist William Ellsworth of the U.S. Geological Survey (USGS) in Menlo Park, California.

As researchers link cause and effect in recent cases of triggered seismicity, they are beginning to see a way ahead: learn as you go. Thorough preinjection studies followed by close monitoring of cautiously increasing injection offer to lower, although never eliminate, the risk of triggering intolerable earthquakes.

An injection too deep

"I'm told it feels like a car running into the house," says Stephen Horton, speaking of the magnitude-4 triggered quakes he saw coming a couple of years ago in north-central Arkansas. In the current March/April issue of *Seismological Research Letters*, the University of Memphis seismologist recounts his learn-as-you-go experience with injection-triggered quakes strong enough to seriously shake up the locals.

Fracking for natural gas, formally known as hydraulic fracturing, had come to Arkansas around 2009. Not that a seismologist in Memphis would have noticed. Injecting water into gas-bearing shale at high pressures does break the rock to free the gas—that's the point, after all. But the resulting tiny quakes rarely get above magnitude 0 (the logarithmic scale includes negative numbers), never mind to the magnitude-3 quakes that people might feel.

But shale gas drillers need to dispose of the millions of liters of water laden with natural brines and added chemicals that flow back up after a shale gas well has been fracked (*Science*, 25 June 2010, p. 1624). Injecting fracking wastewater into deep rock is a common solution, so starting in April 2009, 1- to 3-kilometer-deep disposal wells were sunk in the vicinity of Guy (population 706) and Greenbrier (population 4706), Arkansas.

That's when Horton and Scott Ausbrooks of the Arkansas Geological Survey took note of a curious cluster of earthquakes near Greenbrier. The Guy-Greenbrier area had had only one quake of magnitude 2.5 or greater in 2007 and two in 2008. But there were 10 in 2009, the first year of deep disposal, and 54 in 2010. The suspicious timing of the quake cluster—which included hundreds of small quakes with one of magnitude 3.0—and its location near the first disposal well got their attention.

Once alerted to the suspicious quakes, Horton and Ausbrooks cast a network of seismometers around two new wells that would start injecting in July and in August 2010. On 1 October of that year, Horton warned the director of the Arkansas Oil and Gas Commission, the state agency that regulates deep injection, to "watch out" for more earthquakes. Ten days later, a magnitude 4.0 struck about a kilometer northeast of the deeper of the two new wells. On 20 November, a magnitude 3.9 struck 2 kilometers farther to the northeast toward Guy. Then, in February 2011, magnitude-4.1 and -4.7 quakes struck to the southwest of the deeper well, toward Greenbrier.

By spring, nearly 1000 recorded quakes had struck the area since the wells had started up. "People were feeling a lot of earthquakes,"

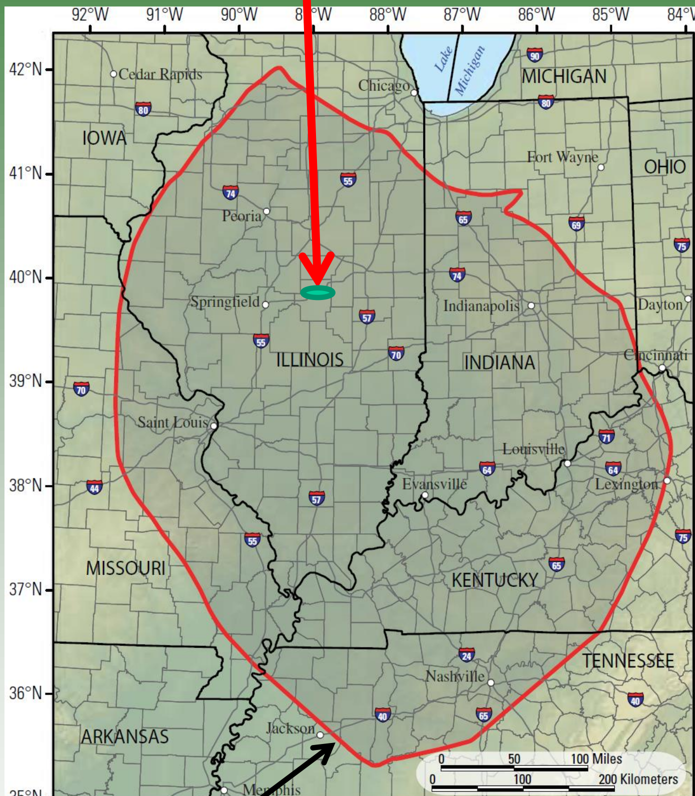
Quake masters. USGS geophysicists Barry Raleigh (*left*) and Jack Healy are poised to open a valve and pressurize deep rock to turn on earthquakes. They could also turn them off in this 1970s study.

CREDITS (TOP TO BOTTOM): AMY SANCETTA/AP PHOTO; C. BARRY RALEIGH

Kerr (2012)

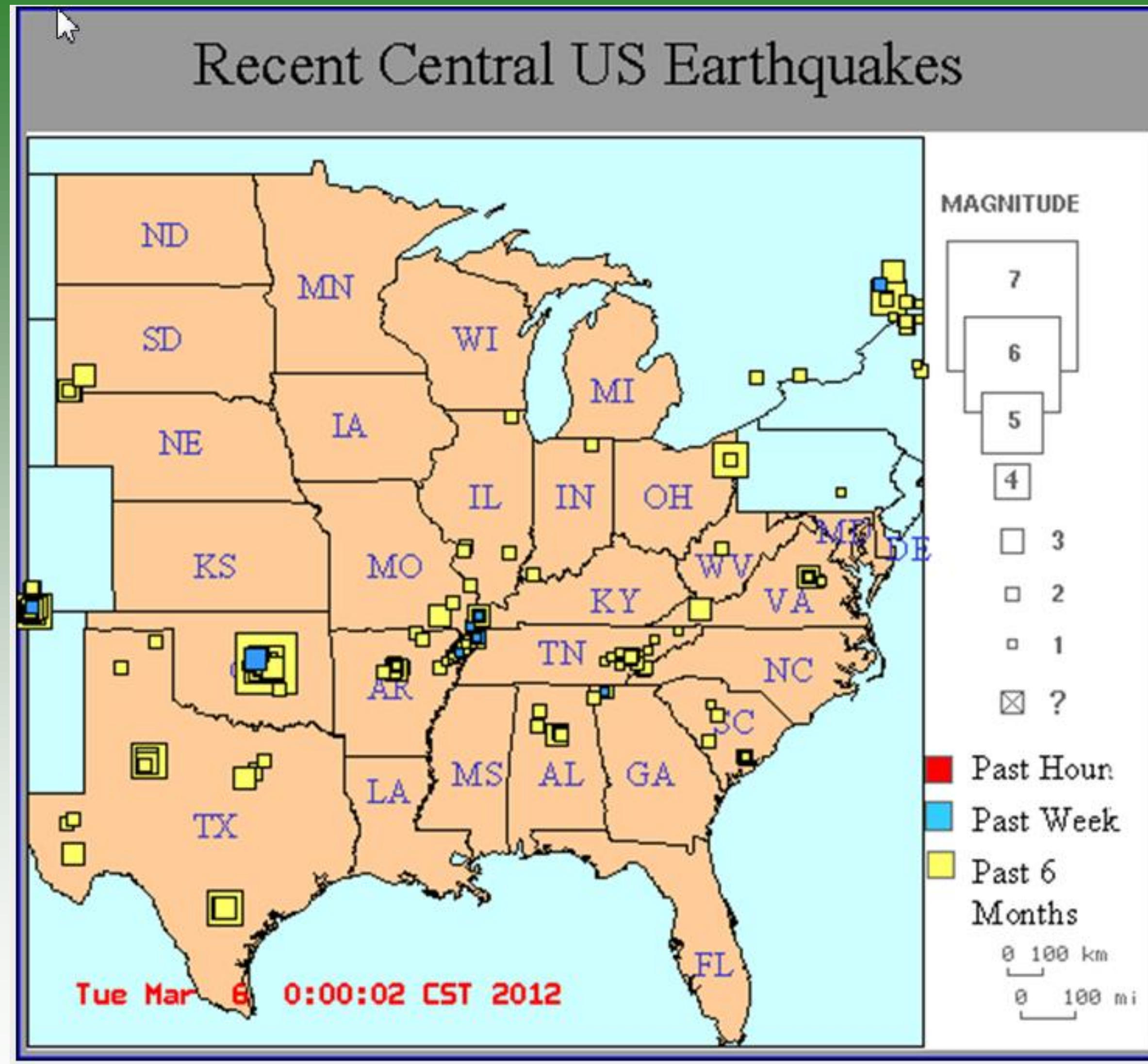
Seismicity in the Past 6 Months
from Center for Earthquake Research and Information, as of 3/5/2012

Decatur Project



Illinois Basin
http://pubs.usgs.gov/fs/2007/3058/fs2007-3058.pdf

CO_2 injection started
Nov 2011



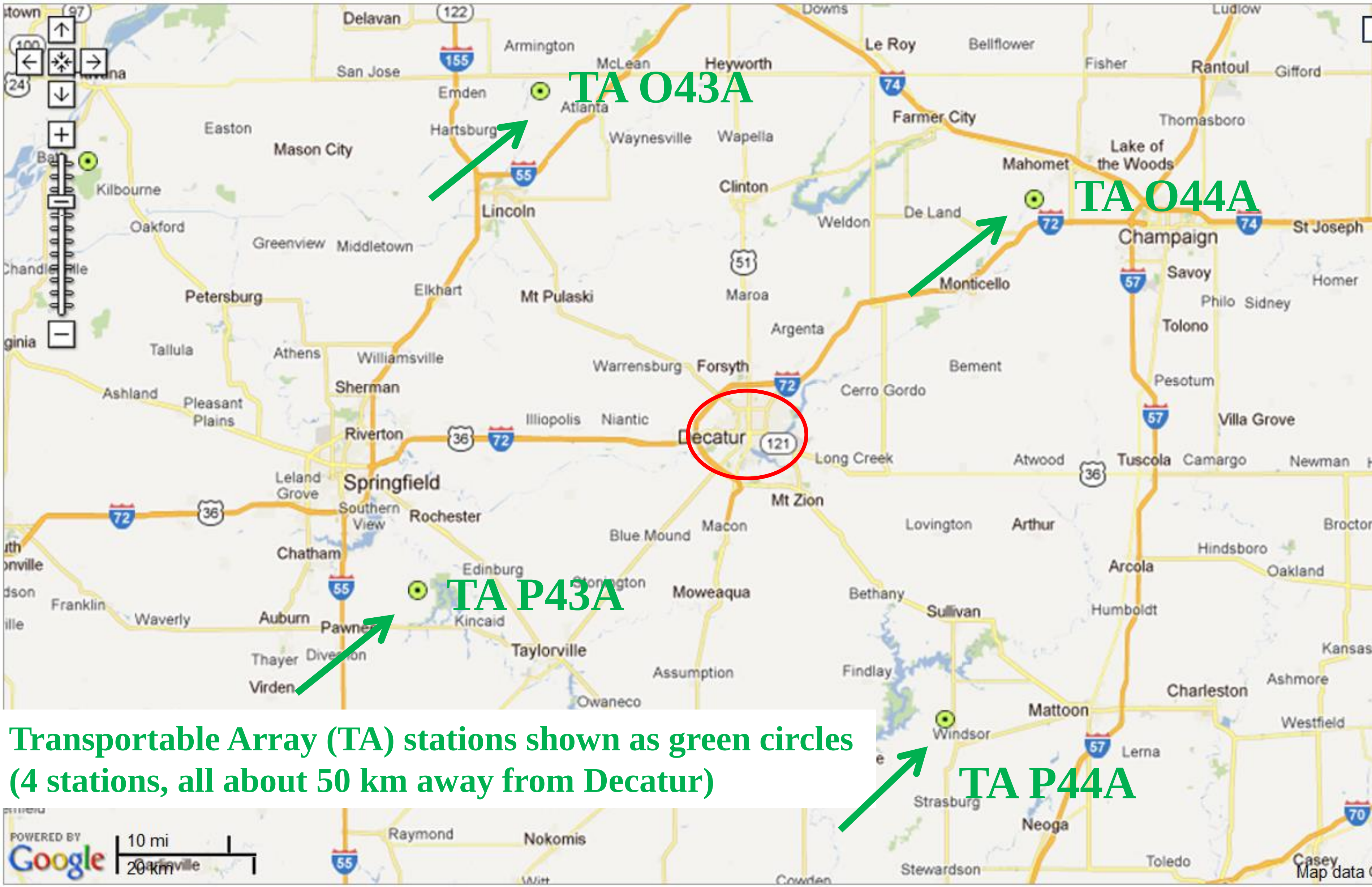
http://folkworm.ceri.memphis.edu/recenteqs/

USGS

Slide courtesy of Stephen Hickman, USGS

Operating USArray Transportable Array Stations

IRIS GMS Usage



Transportable Array (TA) stations shown as green circles (4 stations, all about 50 km away from Decatur)

USGS

Slide Courtesy of Stephen Hickman, USGS; TA stations are a component of the USArray managed by Incorporated Research Institutions for Seismology (IRIS) and funded by National Science Foundation as part of the EarthScope program.

Geologic CO_2 Sequestration Next Steps

- Complete National assessment and basin reports
- Geologic studies and in-depth assessment of major basin(s)
- Geology of natural and anthropogenic CO_2 storage sites
- Methodology and assessment of EOR coupled with CO_2 sequestration
- Methodology and assessment for unconventional CO_2 storage reservoirs
- Integrate these assessments with future USGS Energy Program NOGA assessments
- Current methodology improvements
- Economics of geologic carbon sequestration
- Induced seismicity related to CO_2 injection

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