

# THE STATE AGENCY FOR GEOLOGIC INFORMATION

# Is Carbon Sequestration in Arizona's Future?

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### INTRODUCTION

Continental glaciers are retreating, sea levels are rising, boreal forests are shifting northward, and cold-climate growing seasons are lengthening. Although there are some dissenters from these views, many would argue that these changes are real and are caused by, or at least exacerbated by, anthropogenic greenhouse gas emissions. Worldwide, many scientists have rallied around the notion that anthropogenic greenhouse gases, led by carbon dioxide (CO<sub>2</sub>) production, will become, or may be already, a major cause of global warming.

### Geological sequestration involves capturing CO<sub>2</sub> emissions from power plants and other sources and injecting it deep underground where it is securely stored.

In an effort to control  $CO_2$  emissions, especially if and when costs are significantly reduced for capture from power plants, the U.S. Department of Energy (DOE) formed a nationwide network of regional partnerships to explore the potential of storing  $CO_2$  – carbon sequestration – in geologic reservoirs (http://www.netl.doe.gov/technologies/carbon\_seq/partnerships/partnerships.html). The DOE established three phases to the carbon sequestration initiative: a Characterization Phase (2003-2005) to identify opportunities for carbon sequestration; a Validation Phase (2005-2009) to implement smallscale field tests; and a Deployment Phase (2008-2017) to conduct large volume carbon-storage tests. What role can Arizona play?

The Arizona Geological Survey (AZGS) is a member of the Southwest Regional Partnership on Carbon Sequestration (SWP), which includes the states of Arizona, Colorado, New Mexico, Oklahoma,

Power plant  $CO_2$  emissions from power plant CO2 emissions Oil/Ga Impervious onfining rock CO<sub>2</sub> displaces methane from deep unmineable coal seams Impervious confining rock CO2 displaces trapped oil and gas Impervious confining rock Depleted oil and gas eservoirs store CO Impervious confining rock Deep saline reservoirs store CO2

(Diagram courtesy of

Ohio Department of Natural Resources,

Division of Geological Survey)

Utah, and parts of Texas and Wyoming and the West Coast Regional Carbon Sequestration Partnership (WESTCARB), which includes the states of Alaska, Arizona, California, Oregon, Nevada, and Washington. In Arizona,

### **MISSION**

To inform and advise the public about the geologic character of Arizona in order to increase understanding and encourage prudent development of the State's land, water, mineral, and energy resources.

### ACTIVITIES

#### **PUBLIC INFORMATION**

Inform the public by answering inquiries, preparing and selling maps and reports, maintaining a library, databases, and a website, giving talks, and leading fieldtrips.

### **GEOLOGIC MAPPING**

Map and describe the origin and character of rock units and their weathering products.

### HAZARDS AND LIMITATIONS

Investigate geologic hazards and limitations such as earthquakes, land subsidence, flooding, and rock solution that may affect the health and welfare of the public or impact land and resource management.

### ENERGY AND MINERAL RESOURCES

Describe the origin, distribution, and character of metallic, nonmetallic, and energy resources and identify areas that have potential for future discoveries.

#### OIL AND GAS CONSERVATION COMMISSION

Assist in carrying out the rules, orders, and policies established by the Commission, which regulates the drilling for and production of oil, gas, helium, carbon dioxide, and geothermal resources.





Figure 1. Major point sources and potential geologic sinks in Arizona

the AZGS investigated potential geologic carbon-sequestration sites during the characterization phase by compiling data on potential geologic sinks such as oil and gas fields, deep reservoirs not associated with oil and gas, and unminable coal seams.

A good geologic sink is close to a  $CO_2$  emission source, has porous and permeable (reservoir) rock surrounded by impermeable (seal) rock to prevent leakage, is preferably deeper than 2,600 ft so that (hydrostatic) overburden pressure will keep the  $CO_2$  in a high-density, liquid-like state, and has a large reservoir volume.

No sites for small-scale field tests were identified in Arizona by the SWP, but WESTCARB identified three potential sites to investigate the storage capacity of deep reservoirs beneath power plants in northern Arizona. One validation-phase test is scheduled to begin in the first half of 2008. Neither the SWP nor WESTCARB identified any areas in Arizona for deployment phase tests.

### Major utility point sources of CO<sub>2</sub>

The six major utility point sources in Arizona discharged 41 million metric tons of  $CO_2$  in 2002 (Table 1). The Navajo Generating Station near Page was the leader, discharging 18 million metric tons of  $CO_2$ . The Cholla plant came in a distant second at eight mil-

Table 1. Potential Carbon Sequestration Capacity for Arizona   (in Million Metric Tons)					
CO <sub>2</sub> Emissions in 2002		Total Geologic Sink Capacity			
Navajo	18	24,094			
Cholla	8	401			
Springerville	6	18			
Coronado	5	18			
Apache	3	629			
Irvington	1	186			
Red Rock	0	366			
Higley	0	469			
Luke	0	386			
Mohawk	0	688			
San Cristobal	0	252			
Oil & gas fields	0	14			
Total	41	27,521			

lion metric tons. All six major utility point sources are located over potential deep reservoirs. None of the major utility point sources are located near oil and gas fields.

# Sequestration capacity of geologic sinks in Arizona

We estimated that the total  $CO_2$  sequestration capacity of geologic sinks in Arizona was about 27,520 million metric tons (Table 1). Deep reservoirs on the Colorado Plateau of northern Arizona and the intermountain basins of southern Arizona account for essentially all of this capacity even though they have greater uncertainty as to  $CO_2$  retention effectiveness as compared to the oil and gas fields (Figure 1). We did not estimate the  $CO_2$  sequestration capacity of coal because the deepest Arizona coal deposits are less than 2,000 ft, which is



too shallow to keep CO<sub>2</sub> in a liquid-like state.

**Oil and Gas Fields.** There are 14 small oil and gas fields in northeastern Arizona (Figure 1) with total  $CO_2$  sequestration capacity of about 14.1 million metric tons (less than one thousandth of the total for Arizona). Only two of the fields are large enough to be considered by the SWP as preferable geologic sink candidates. These two are the Dineh-bi-Keyah field with a cumulative past oil production of 18.3 million barrels and the East Boundary Butte field with a cumulative past gas production of 10 billion cubic feet. The total estimated sequestration capacity of Dineh-bi-Keyah and East Boundary Butte is 11 million metric tons, which is sufficient for three months of Arizona CO2 emissions at current emission rates. Neither field is in close proximity to a major point source of  $CO_2$ .

**Deep reservoirs.** The total maximum  $CO_2$  sequestration capacity for the ten deep reservoirs identified in Table 1 is estimated at 27,500 million metric tons. Three of the deep reservoirs are in rocks of Paleozoic age near Page, Holbrook, and St. Johns in northern Arizona. The remaining seven are basin-fill sediments located in the Tertiary basins of southern Arizona. Six of the deep reservoirs underlie major utility point sources of  $CO_2$  including the Navajo, Cholla, Coronado, and Springerville power plants in northern Arizona (Figure 1).

The paucity of deep drill holes, particularly in the Tertiary basins, greatly limits our knowledge of potential deep reservoirs. We estimated porosity, depth and thickness on driller's descriptions and old electrical logs from the limited number of deep wells that were available. We used the 3,000 ft depth-to-bedrock contour to estimate the area of the deep reservoirs in the Tertiary basins that are deeper than the 2,600 ft depth needed to keep the  $CO_2$  in a near-liquid state.

### **Navajo Generating Station**

The Navajo Generating Station (NGS) receives special focus here because it produces nearly 50 percent of stationary point-

source  $CO_2$  emissions in Arizona (Table 1). The 2,400 MW coal-fired NGS is approximately five miles southeast of Page on property leased from the Navajo Nation.

Potential CO<sub>2</sub> sequestration reservoirs underlying the NGS include the Kaibab Limestone, Coconino Sandstone, and Cedar Mesa Sandstone of Permian age; the Redwall Limestone of Mississippian age; and the Tapeats Sandstone of Cambrian age. Important reservoir seals are the Muav Limestone, Bright Angel Shale, Organ Rock Shale, and Chinle and Moenkopi Formations. Table 2 shows the estimated reservoir and seal depths and thicknesses underlying the NGS.

There are no deep exploratory wells in the immediate vicinity of the NGS. Formation depths and thickness

Table 2. Stratigraphic units beneath Navajo Generating Station				
Formation Name	Elevation of Formation top above sea level (ft)	Depth to top of Formation (ft)	Estimated Formation Thickness (ft)	
Chinle-Moenkopi	3825	525	1155	
Kaibab Limestone	2670	1680	15*	
Coconino Sandstone	2655	1695	555	
Organ Rock Shale	2100	2250	455	
Cedar Mesa Sandstone	1645	2705	1315	
Redwall Limestone	-235	4585	545	
Muav Limestone-Bright Angel Shale	-1525	5875	615	
Tapeats Sandstone	-2140	6490	330	
* Assumes Kaibab pinches out at the Sinclair Oil Navajo Tribal #1 well				

estimates below the NGS are projected from formation tops in the Shell Soda Unit #1 well in Utah and the Sinclair Oil Navajo Tribal #1 well in Arizona. The Shell and Sinclair wells are approximately 39 miles northeast and 38 miles southeast of the NGS, respectively. Figure 2 illustrates the location of the two wells and the subsurface geology at the NGS.

Kaibab Limestone and Coconino and Cedar Mesa Sandstones. The Kaibab Limestone and Coconino Sandstone are the chief groundwater aquifers on the southern part of the Colorado Plateau where the two strata are connected hydraulically and form the C-multiple aquifer system. The Kaibab and Coconino are not used as aquifers on the northern part of the Colorado Plateau. The Kaibab Limestone is not present in the Sinclair well and, assuming the unit pinches out at the well, is of negligible thickness (15 ft) beneath the NGS. The projected Coconino Sandstone thickness below the NGS is approximately 550 ft.

The Kaibab and Coconino are above a depth of 2,600 ft in the vicinity of the NGS (Table 2, Figure 2) making them unsuitable geologic reservoirs for carbon sequestration.

The Cedar Mesa Sandstone, at a depth of about 2,700 ft, is the shallowest deep reservoir below the preferred depth of 2,600 ft and underlies approximately 455 ft of Organ Rock Shale, which is a good seal that would prevent the potential escape of sequestered  $CO_2$ . The Cedar Mesa Sandstone is projected to be about 1,300 ft thick below the NGS.

**Redwall Limestone.** The Redwall Limestone, at a projected depth of about 4,585 ft below the NGS, is deep enough to keep sequestered  $CO_2$  in a near liquid state. Permeability and porosity in the Redwall is mostly in the form of numerous solution channels and cavities. The Redwall is about 540 ft thick in the Sinclair well and 595 ft thick in the Shell well. The estimated thickness underlying the NGS is 545 ft.

**Tapeats Sandstone.** The Tapeats Sandstone, with approximately 6,500 ft of overburden, is the deepest reservoir under consideration for  $CO_2$  sequestration at the NGS. It is not considered an aquifer due to its depth and salinity. The Hopi have used seeps from the Tapeats near the mouth

of the Little Colorado River as a source of salt. Lenses of conglomerate near the basal contact of the Tapeats may enhance its reservoir volume. The Sinclair well did not fully penetrate the Tapeats but the Shell well penetrated 215 ft of Tapeats. The estimated thickness underlying the NGS is 330 ft.

### **Other Generating Stations**

The Cholla power plant is underlain by potential sequestration reservoirs in the Naco Limestone of Pennsylvanian age. Injection targets include carbonate or clastic rocks within the Naco at depths of 2,500 to 3,000 ft., and possibly Devonianage rocks below 3,000 ft. Extensive salt deposits may provide effective seals. The Naco is estimated to be about 900 ft thick at the Cholla power plant.

The Coronado and Springerville power plants overly porous and permeable clastic rocks of Permian age. However, shallow depths to the potential reservoir rocks, generally less than 2,600 ft to granite, and low (hydrostatic) overburden pressures are issues that need further evaluation at these sites.

The Apache and Irvington power plants near Wilcox and Tucson, respectively, are located on thick, basin-fill clastic deposits of Tertiary age. The basin-fill deposits are potential sequestration reservoirs with injection targets ranging from 2,500 to 6,000 ft.

### Conclusion

Deep reservoirs offer good potential for carbon sequestration near existing and possible future power plants in Arizona. All that is needed now is additional drilling and coring to obtain direct information about the thickness and extent of the potential reservoir rocks and seals and to confirm the capacity of these geologic sinks.

-continued on page 5

FYI: We did not publish a winter-2007 issue (Vol. 37, No. 4) of Arizona Geology.

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### Dramatic Increase in Oil & Gas Leasing in Arizona 2007-2008

Oil, natural gas, helium, and carbon dioxide  $(CO_2)$  prices are on the rise. In Arizona, the acreage being leased is increasing, too. Between January and December 2007, State and Federal land leased for oil and gas increased nearly three fold from 401,000 to 1.075 million acres. The biggest increase is for oil and natural gas in northern Arizona.

So far in 2008, Arizona's Oil and Gas Commission issued 21 permits to drill, with ten wells drilled; in 2007 three permits were issued and eleven wells were drilled. We anticipate that permitting and drilling activity will remain strong throughout 2008. So far, all activity involves  $CO_2$ and helium between St. Johns and Springerville in westcentral Arizona. The biggest use of  $CO_2$  is for enhanced recovery in old oil fields.

## Landslide closes Hy 87 near Payson. For AZGS

preliminary reports, images, annotated aerial photographs, Geology of the Kitty Joe Canyon Area & more visit us at www.azgs.az.gov/hazard\_hwy87landslide\_mar08.html

Abstracts available offinite through Geological Society of America at http://gsa.comex.com/gsa/2006CD/htmaprogram/				
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This spring, AZGS is partnering with the Bureau of Land Management to open a one-stop shop for recreational and public land-use information. We are located on the groundfloor of the Phelps-Dodge Tower at One North Central St., Phoenix. We'll carry land-use information, maps, and professional reports from BLM, USFS, USGS, USNPS, USF&W, AZGS, AZ State Parks, ADWR, and more. And we'll have a suite of outdoor books and guides for hikers, climbers, OHVers, campers, boaters, and others showcasing Arizona's public lands.

Come see us! (www.explorearizona.org; 602.417.9300)



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