Chapter 2
The Story of the Wyoming Carbon Underground Storage Project (WY-CUSP), and the Regional Inventory and Prioritization of Potential CO_2 Storage Reservoirs in Wyoming

Ramsey D. Bentley and Ronald C. Surdam

Abstract The Wyoming Carbon Underground Storage Project (WY-CUSP) is a statewide effort to identify, inventory, prioritize, and characterize the most outstanding CO_2 storage reservoirs and the premier storage site in Wyoming. The WY-CUSP project is managed by the Carbon Management Institute (CMI) at the University of Wyoming with support from the US Department of Energy, State of Wyoming, and industrial partners. In its search for an optimum carbon dioxide storage reservoir in Wyoming, CMI first inventoried and examined the state's hydrocarbon reservoirs, for these are reservoirs with proven fluid storage capacity. The inventory and prioritization of storage reservoirs and storage sites was based on the following criteria: (1) thickness, areal extent, and petrophysical properties of the reservoir rocks, (2) presence of a fluid trap and adequate confining layers, (3) suitable temperature, pressure, and rock/fluid chemistry regimes, (4) salinity of the formation fluids in the storage reservoir rocks, and (5) volumetrics of the storage site. It became apparent that the Mississippian Madison Limestone and Pennsylvanian Weber/Tensleep Sandstone were the highest-priority potential CO_2 storage stratigraphic intervals, and that the Rock Springs Uplift (RSU) in southwestern Wyoming was the premier CO_2 storage site in the state. A drill site on the northeastern flank of the RSU was highly prospective in offering high-quality reservoir rock at a depth that provides sufficient temperature and pressure for carbon dioxide storage. A very-large-scale, large-capacity trap on the RSU has several competent sealing rock units, and available data show that the reservoir rocks contain very saline formation water. Abundant sources of carbon dioxide are nearby, notably the Jim Bridger Power Plant.

R. D. Bentley (✉) · R. C. Surdam
Carbon Management Institute Laramie, University of Wyoming, Laramie, USA
e-mail: RBentley@uwyo.edu

R. C. Surdam
e-mail: rsurdam@uwyo.edu

R. C. Surdam (ed.), *Geological CO_2 Storage Characterization,*
Springer Environmental Science and Engineering, DOI 10.1007/978-1-4614-5788-6_2,

2.1 WY-CUSP and the RSU Model

The Wyoming Carbon Underground Storage Project (WY-CUSP) is a pioneering research initiative to investigate and characterize two potential carbon storage reservoirs, the Weber and Madison Formations, both deep saline aquifers on the Rock Springs Uplift (RSU) in southwestern Wyoming. WY-CUSP is managed by the Carbon Management Institute (CMI), a part of the University of Wyoming, School of Energy Resources. Scientists from the University of Wyoming, the Wyoming State Geologic Survey, and Los Alamos National Laboratory, and industry partners collaborated with CMI on the project. The WY-CUSP Program has resulted in a detailed characterization of the potential storage reservoirs and storage site.

Site characterization is the process of assessing the suitability of a reservoir for CO_2 storage. This process includes conducting geophysical surveys, drilling test wells, and using sophisticated computer models to predict where the injected CO_2 will migrate, how efficiently the storage volume will be filled, and how well the storage site will perform over time. The strategy, evolution, techniques, and results of our site characterization on the Rock Springs Uplift, described in subsequent chapters, compose the RSU Model for carbon sequestration, storage, and use.

2.2 Inventory and Evaluation of Potential Storage Reservoirs

To inform our choice among possible CO_2 storage reservoirs and storage sites in Wyoming, CMI first inventoried and examined the state's hydrocarbon reservoirs, for these are reservoirs with proven fluid storage capacity. Wyoming has an abundance of hydrocarbon reservoirs. To determine their suitability as target sites and formations for carbon storage and sequestration, these reservoirs were inventoried and examined statewide. Every major sedimentary basin in the state showed potential, and each contained the promising target formations described below, although in a variety of geologic settings (Fig. 2.1). Cretaceous reservoirs in the Powder River Basin were of particular interest, as were several older and deeper Paleozoic units in all the basins.

To identify an optimum CO_2 storage reservoir in Wyoming and a corresponding optimum WY-CUSP test well site, CMI prioritized reservoirs on the basis of the following characteristics (Surdam and Jiao 2007):

- Reservoir rock of sufficient area and thickness (capacity) and with sufficient porosity (unit capacity, percentage of voids) and permeability (deliverability) to accommodate substantial amounts of CO_2.
- A fluid trap, a geologic setting in which the reservoir-rock fluids are trapped by adjacent nearly impermeable rock units and sealing faults.
- Reservoir conditions of temperature, pressure, and rock/fluid chemistry that allow the reservoir to accept large amounts of CO_2 without incurring damage.

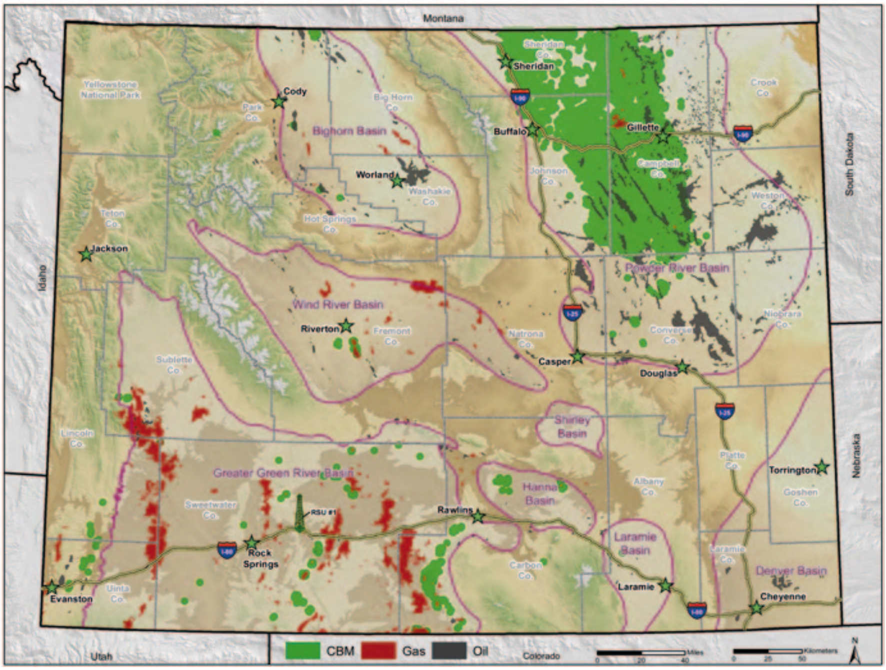

Fig. 2.1 Major sedimentary basins and hydrocarbon reservoirs in Wyoming. Modified from Debruin, 2007, 2012

- Water quality in the reservoir of more than 10,000 ppm total dissolved solids, as prescribed by the Safe Drinking Water Act Underground Sources of Drinking Water (USDW) criterion that groundwater containing less than 10,000 ppm total dissolved solids may be suitable for development as drinking water and therefore must be protected.

Upper and Lower Cretaceous rocks in the Powder River Basin (PRB) were targeted primarily because many of them were oil and gas producers characterized as discrete compartmentalized sandstone units fully sealed and encased by shales. Because they were isolated as compartmentalized units, once they had been produced for hydrocarbons and essentially "emptied out" of fluids they could provide space for CO_2 storage; their impermeable enclosing seals would preclude refilling by meteoric or formation water from aquifers above or below the compartmentalized units. Included in this field category was the Muddy Sandstone in several fields, including Amos Draw. Other targets included the Dakota Sandstone (uppermost Cloverly Formation) at Buck Draw, and the Shannon Sandstone at Hartzog Draw and Sussex Sandstone at House Creek (both members of the Cody Shale).

Although these field areas were promising, they are relatively small. Large storage capacity is necessary for commercial-scale sequestration because the sources of the CO_2, power plants and other stationary fossil-fuel-burning sites, produce large amounts of CO_2. This size factor does not preclude these smaller sites as potential small-scale storage sites, for example in integrated power generation/enhanced oil recovery (EOR) projects (see Chap. 12). Opportunities for EOR are many in the PRB, both in the Cretaceous reservoirs cited and in deeper Paleozoic oil reservoirs, such as the Minnelusa.

The Minnelusa Formation in the PRB is equivalent to the Weber/Tensleep Sandstone in other Wyoming basins. One of the most prolific oil and gas producing formations in the state, the Weber/Tensleep is a prime target for CO_2 sequestration and storage site selection.

Another Paleozoic unit, the Madison Limestone, is a well-developed reservoir unit throughout the state. The Madison showed promise as a sequestration target in the PRB but was deemed unsuitable due to its status as an underground source of drinking water (USDW) for the City of Gillette, among others. This factor became increasingly important in sequestration site selection, ruling out the Madison in the PRB and in much of the Bighorn Basin, where it is found in very favorable geologic structural situations but is shallow and connected to fresh-water recharge. The Tensleep and Madison at greater depth and toward the center of the Bighorn Basin were considered, but sparse drill-stem data and undetermined trapping made their prospects tenuous.

As the inventory and evaluation progressed, the Weber/Tensleep Sandstone and the Madison Limestone continued to stand out as particularly suitable for carbon storage and sequestration. Both were proven fluid storage units statewide, especially in southwest Wyoming (DeBruin 1993). As well, several large geologic structures containing the two formations presented opportunities for large-scale storage-reservoir development. These structures include the Moxa Arch and the Rock Springs Uplift; the latter chosen as the location of the WY-CUSP project. These structures hold the two formations in deep, isolated environments, with formation-water TDS well above 10,000 ppm and no hydrologic connection to outcrop (Surdam and Jiao 2007). Numerous oil and gas accumulations occur in both formations in the Greater Green River Basin (GGRB). The Madison is host to one of the largest accumulations of carbon dioxide, methane, and helium in the world on the Labarge Anticline (the northern part of the Moxa Arch), located approximately 90 mi northwest of the WY-CUSP well site (Stilwell 1989).

The Rock Springs Uplift is a large (50 × 35 mi, 80 × 55 km) doubly-plunging anticlinal structure, asymmetric with the steeper limb on the west side, and is host to 45 distinct oil and gas fields. Most production is from Upper Cretaceous Mesaverde Group reservoirs (Almond, Ericson, Rock Springs, and Blair Formations) (Surdam and Jiao 2007). Several oil and gas fields produce from the Pennsylvanian Weber and Mississippian Madison, and these fields lie within approximately 20 mi of the RSU #1 well site. The North Brady and South Brady fields lie about 20 mi southeast of the well site; both produce prolifically from the Weber (among other, shallower zones). About 20 mi east–southeast of the well site lies Table Rock field, where both the Weber and Madison are prolific hydrocarbon producers. Both the Brady North/South and Table Rock field areas are on faulted anticlines on the east and southeast flanks of the Rock Springs Uplift. These fields are separated from the main RSU by faults that appear to form up-dip seals. North Baxter Basin field is located approximately 14 mi west of the RSU #1 well site on the crest of the RSU. Several deep wells drilled there during field development tested significant amounts of CO_2 from both the Weber and the Madison (Wyoming Oil and Gas Conservation Commission (2007–2013); Oil and Gas Fields Symposium Committee 1979). Although they are distant from the RSU #1 drill site, these fields, as well as others in the GGRB, were evidence that reservoir-quality rocks would be present at the site chosen for the RSU #1 well, and confirmed the proven storage potential of these two targeted formations. In fact, the Weber and Madison were already proven as CO_2 reservoirs on the basis of drill-stem tests at North Baxter field. With the great areal extent of the RSU, preliminary estimates of sequestration potential at the Rock Springs Uplift were huge, in the neighborhood of 26 billion tonnes of CO_2. This amount of saline storage reservoir capacity could accommodate 485 years of Wyoming's annual CO_2 emissions of approximately 54 million tonnes per year (2007 figures; Surdam and Jiao 2007).

Because the Weber and Madison were seen to be reservoir-quality formations, it followed that they had impermeable confining layers acting as seals to fluid movement or upward leakage. On the basis of reported fluid characteristics of each oil and gas field in the area, it was evident that each formation had a particular mix of formation fluids. These fluids varied from one oil and gas field to another depending on local structural setting, subsurface fluid flow, and stratigraphic facies changes. What was evident were differences in fluid composition between the Weber and the Madison and between the Weber and overlying Phosphoria. Not only did it appear that each formation has a competent seal of its own, the Amsden capping the Madison, the Phosphoria capping the Weber; it was also recognized that multiple thick seals exist up-section in Triassic rocks such as the Dinwoody Formation as well as much higher up in the thick section of Cretaceous shales. This combination of seals, actually stacked multiple seals, led to further confidence in the premise that injected CO_2 would remain within the Weber and the Madison on the RSU.

2.3 The Choice of Site and Reservoirs

With this combination of high-quality reservoir rock, stacked competent sealing units, a very large trapping structure, and highly saline formation water in the target zones (saline aquifers), the RSU became the area of choice as a substantial CO_2 sequestration/storage site. To test this choice, a suitable drill site was located on the northeastern flank of the RSU, within 2 mi of the Jim Bridger power plant, the largest coal-fired plant in Wyoming and largest single producer of CO_2.

In summary, the Rock Springs Uplift and the RSU #1 well site were chosen on the basis of these criteria:

- Good quality and quantity of reservoir rock, Madison Limestone and Weber Sandstone, coupled with adjacent highly effective sealing formations, including the Amsden, Phosphoria, and Dinwoody. Drillstem tests from the RSU and producing wells on the LaBarge Platform have demonstrated that these confining layers are capable of trapping helium.

- Effective geologic structure: the Rock Springs Uplift, a very large anticlinal structure with four-way closure.
- Saline aquifers: both the Weber and Madison formation waters have TDS of well over 10,000 ppm, easily above USDW standards.
- CO_2 source proximity: Jim Bridger coal-fired power plant less than two miles away, largest CO_2 emitter in the state. Nearby trona plants.
- State land with state-owned mineral estate available; provided relative ease and timeliness of permitting.
- Site access: a Black Butte Coal Company haul road runs through the available state section. This haul road was suitable for mobilizing a drilling rig and heavy traffic. The Black Butte Coal Company was very cooperative in allowing use of their haul road for access, which reduced costs considerably by eliminating the need to build an expensive access road.
- Drilling-water source available nearby at Jim Bridger plant site.

References

DeBruin R (1993) Overview of oil and gas geology of Wyoming. In: Snoke AW, Steidtmann JR, Roberts SM (eds) Geology of Wyoming. Wyoming State Geologic Survey Memoir No. 5, pp 836–873

DeBruin RH (2007, 2012) Oil and gas map of Wyoming. Wyoming State Geological Survey Map Series 55 (MS-55). Scale 1:500,000

Stilwell DP (1989) CO_2 resources of the Moxa Arch and the Madison reservoir. Wyoming Geologic Association Fortieth Field Conference Guidebook, pp 105–115

Surdam RC, Jiao J (2007) The Rock Springs Uplift – an outstanding geologic CO_2 sequestration site in southwest Wyoming. Wyoming State Geologic Survey Challenges in Geologic Resource Development No. 2

Oil and Gas Fields Symposium Committee (eds) (1979) Wyoming oil and gas fields symposium, Greater Green River Basin, Wyoming. Wyoming Geologic Association

Wyoming Oil and Gas Conservation Commission http://wogcc.state.wy.us/. Accessed 2007–2013

http://www.springer.com/978-1-4614-5787-9

Geological CO2 Storage Characterization
The Key to Deploying Clean Fossil Energy Technology
Surdam, R.C. (Ed.)
2013, XV, 301 p. 134 illus., 111 illus. in color.,
Hardcover
ISBN: 978-1-4614-5787-9