Progress report for WY-CUSP: Characterization of the premier storage reservoirs and geological CO_2 storage site in Wyoming

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Carbon Management Institute

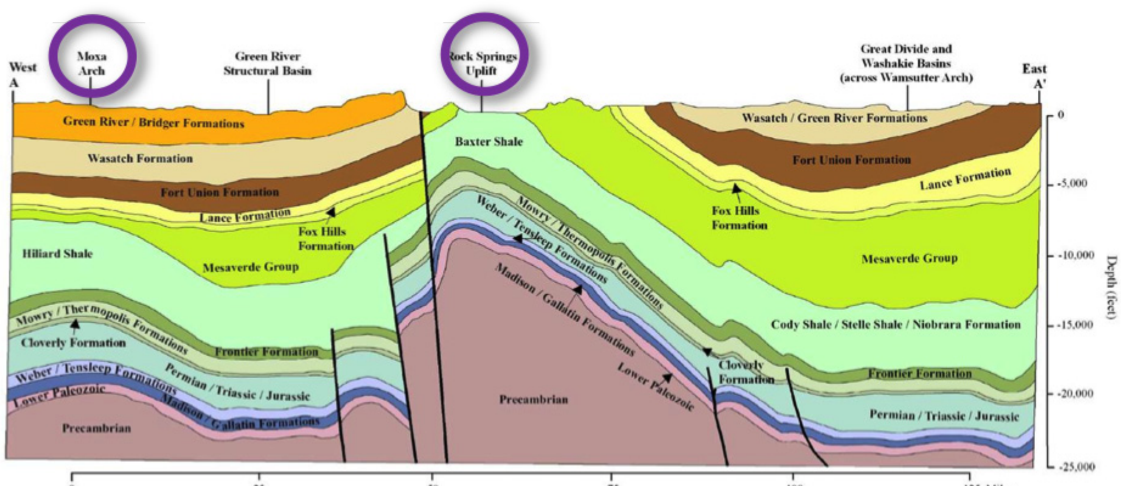
Executive summary

This study – funded by U.S. Department of Energy National Energy Technology Laboratory award DE-FE0002142 and the state of Wyoming – uses outcrop and core observations, a diverse electric log suite, a VSP survey, in-bore testing (i.e., DST, injection tests, and fluid sampling), a variety of rock/fluid analyses, and a wide range of seismic attributes derived from a 3-D seismic survey to thoroughly characterize the highest-potential storage reservoirs and confining layers at the premier CO_2 geological storage site in Wyoming. An accurate site characterization was essential to assessing the following critical aspects of the storage site: 1) to estimate the CO_2 reservoir storage capacity, 2) to evaluate the long-term integrity and permanence of the confining layers, 3) to manage injection pressures and brine production, and 4) to integrate CO_2 utilization into carbon storage strategies.

CO_2 storage capacity

To obtain accurate CO_2 storage capacities, it was necessary to accomplish the following four tasks.

1. Inventory and prioritize potential storage reservoir intervals and CO_2 storage sites, using outcrop and regional well data to select the most outstanding targets for characterization studies (**Figure 1**).
2. Acquire robust databases for the target storage domains and adjacent areas. Recommended data sources include a 3-D seismic survey and customized processing, and a stratigraphic test well designed to provide a diverse log suite, cores, a VSP survey, in-bore testing (DST, injection, and rock property testing), and a variety of rock/fluid sampling (**Figure 2**).
3. Construct realistic 3-D geological/petrophysical models of targeted storage reservoirs and associated confining layers. Property models can be constructed by combining lithofacies/petrophysical analyses with seismic attribute computations and mapping (calibrate with laboratory measurements, sonic and log porosity, and acoustic impedance and density porosity; see **Figure 3**).
4. Export the 3-D property model (i.e., porosity, permeability, and lithofacies models) to numerical simulations for performance assessments. A diverse data set can be evaluated to determine the optimum CO_2 storage capacity for the target storage reservoir and the regional storage domain (**Figure 4**).



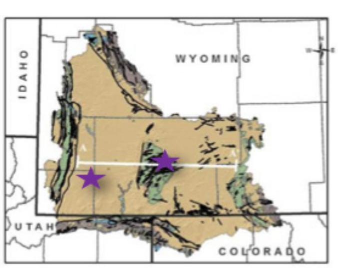


Figure 1. Map and cross section of two premier CO_2 storage sites in Wyoming.

Figure 2. From left to right, this figure shows results from the 3-D seismic survey, core from the stratigraphic test well, and a well log suite from the WY-CUSP study site at the Rock Springs Uplift.

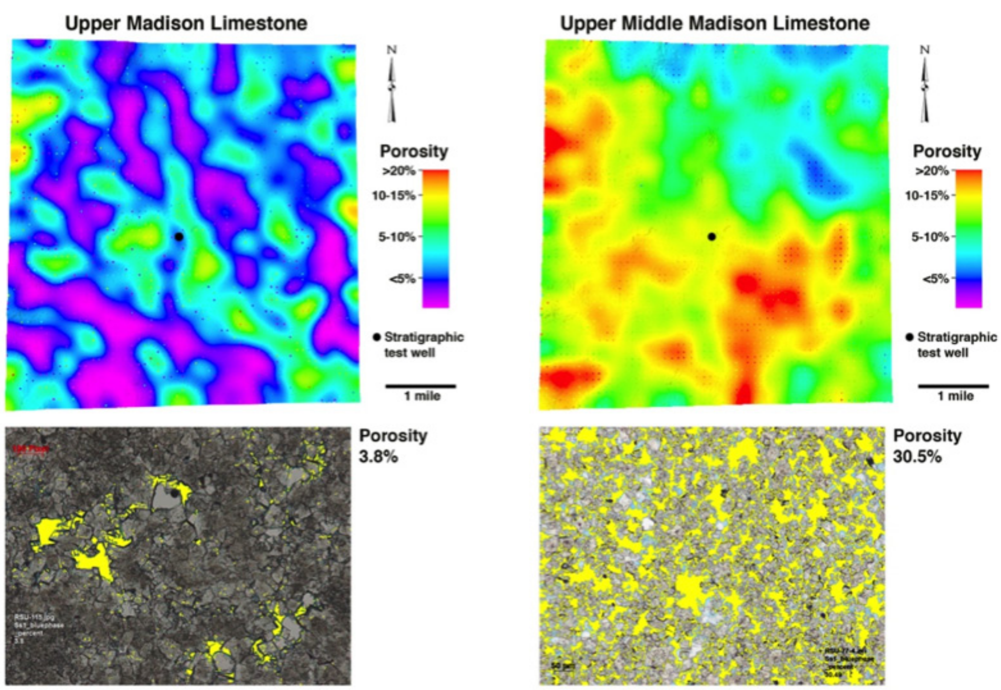


Figure 3. The upper two diagrams represent stratal slices through the Upper and Middle Madison Limestone showing the variability of reservoir properties within the formation. The lower two diagrams are thin section photographs and illustrate the extreme differences in porosity within the Madison Limestone.

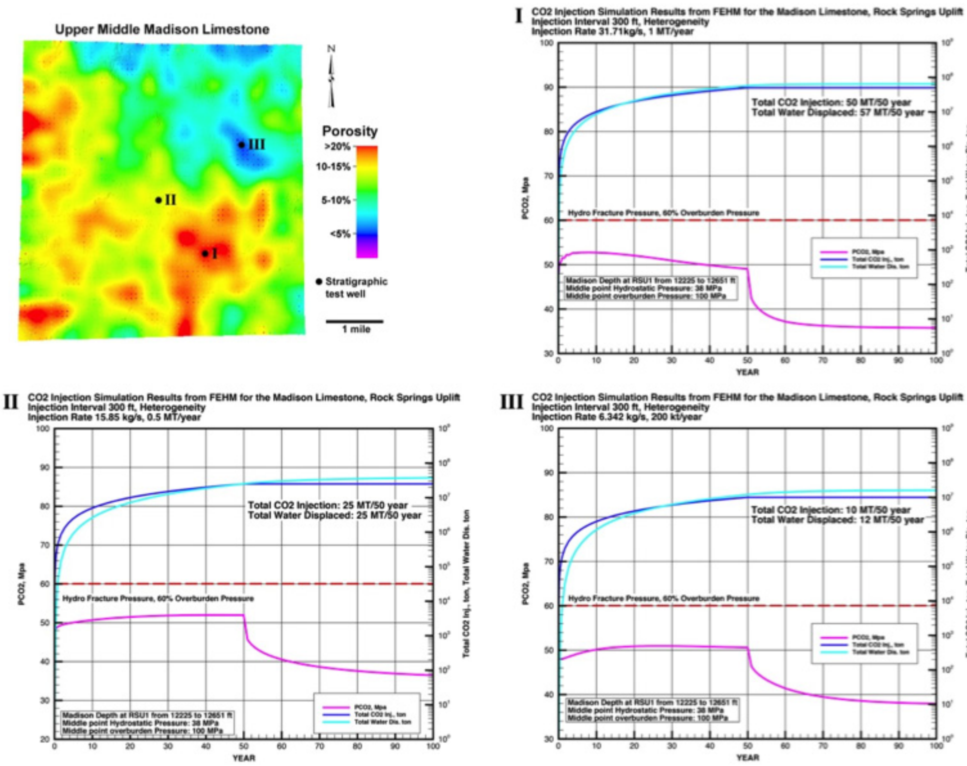


Figure 4. Numerical simulations of three CO_2 injection scenarios representing three different locations within the best reservoir interval in the Madison Limestone: the Upper Middle Madison.

Confining layer integrity/permanence

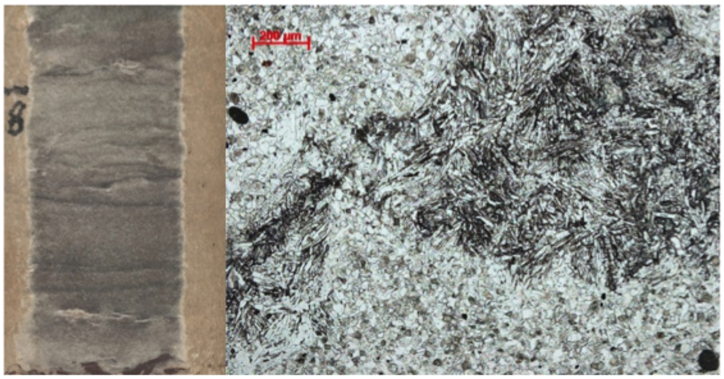
To evaluate the long-term integrity and permanence of the confining layers, it was essential to complete the following three tasks.

1. Select potential confining layers for petrographic evaluation and laboratory analyses for capillary properties (i.e., displacement pressures and CO_2 sealing capacity) and rock strength (**Figure 5**).
2. Analyze the differences in dissolved gas compositions, rock/fluid inclusion volatiles, and isotopic compositions of reservoir units separated by confining layers (**Figure 6**).
3. Use seismic attributes such as semblance coherency, instantaneous phase, curvature, dip azimuth, dip magnitude, and energy-normalized amplitude gradient to evaluate confining layer continuity (i.e., spatial distribution, scale, and structural setting; see **Figure** 7).

Pressure management

To estimate the need for pressure management during CCUS projects on the Rock Springs Uplift, the following three tasks were completed.

1. Evaluate a range of CO_2 injection/storage scenarios for target reservoir intervals using numerical simulation techniques (performance assessments; **Figure 8**).
2. If pressure management is required to maintain the integrity of the storage domain, or to ensure domain boundaries, evaluate the plume volume and rate of formation fluid removal necessary for low-risk storage (**Figure 9**).
3. If formation fluid production is required during CO_2 injection/storage, design a treatment plan that converts the economic penalty of pressure management during CO_2 storage via brine production/treatment into a source of revenue (**Figure 10**).



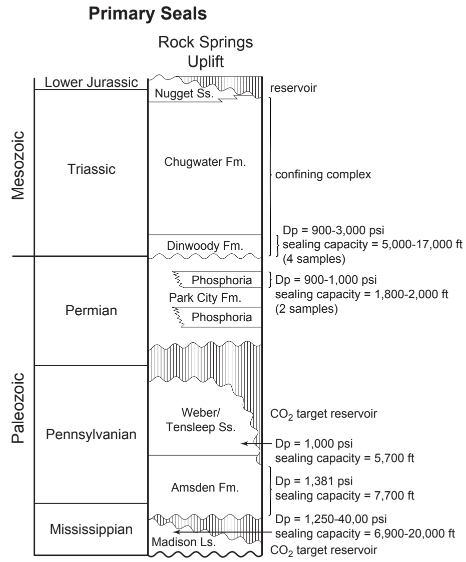
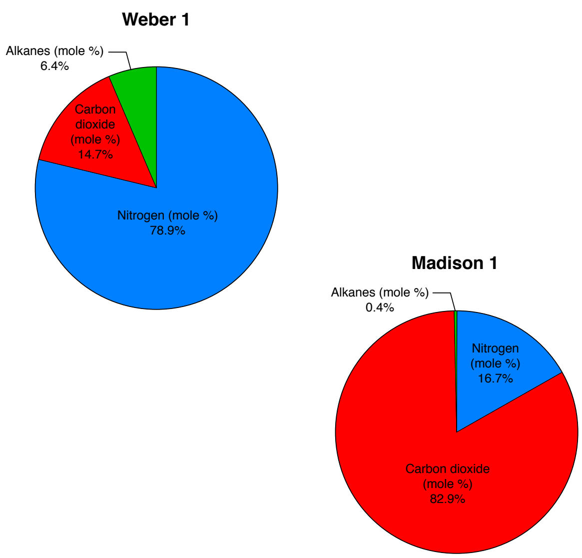


Figure 5. Thin section and core photograph of an outstanding confining layer capable of trapping helium in the Dinwoody Formation (above). Modified stratigraphic column of the Rock Springs Uplift identifying confining layers and target CO_2 storage reservoirs (right). Modified from Love, Christiansen, and VerPloeg (1993).



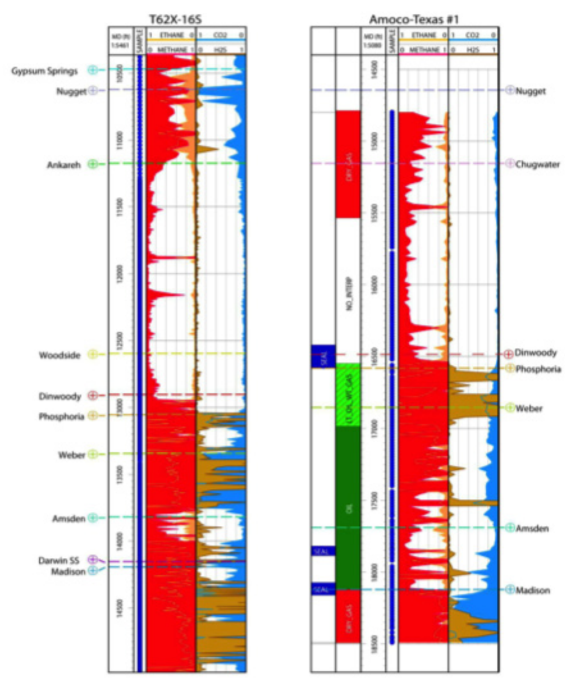


Figure 6. Pie charts showing dissolved gas composition of the Weber and Madison Formation fluids (above). The substantial differences in composition suggest that the Madison and Weber formation fluids are not in communication. Fluid inclusion compositions for wells from the Moxa Arch and Rock Springs Uplift (right; from Campbell-Stone et al. (2010)). In both cases, the Triassic units have acted as hydrocarbon seals above the Madison and Weber formations.

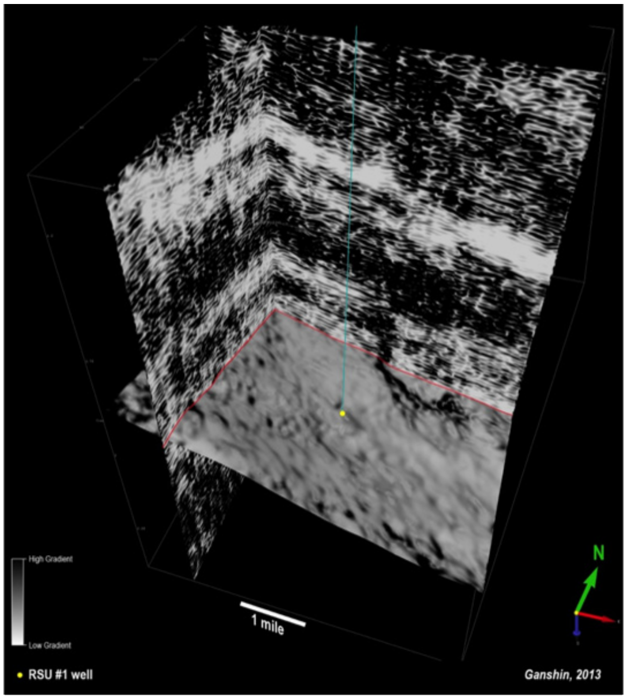


Figure 7. Vertical sections and stratal slice through the 3-D seismic volume. The homogenous nature of the Upper Madison suggests that this interval has continuous confining integrity.

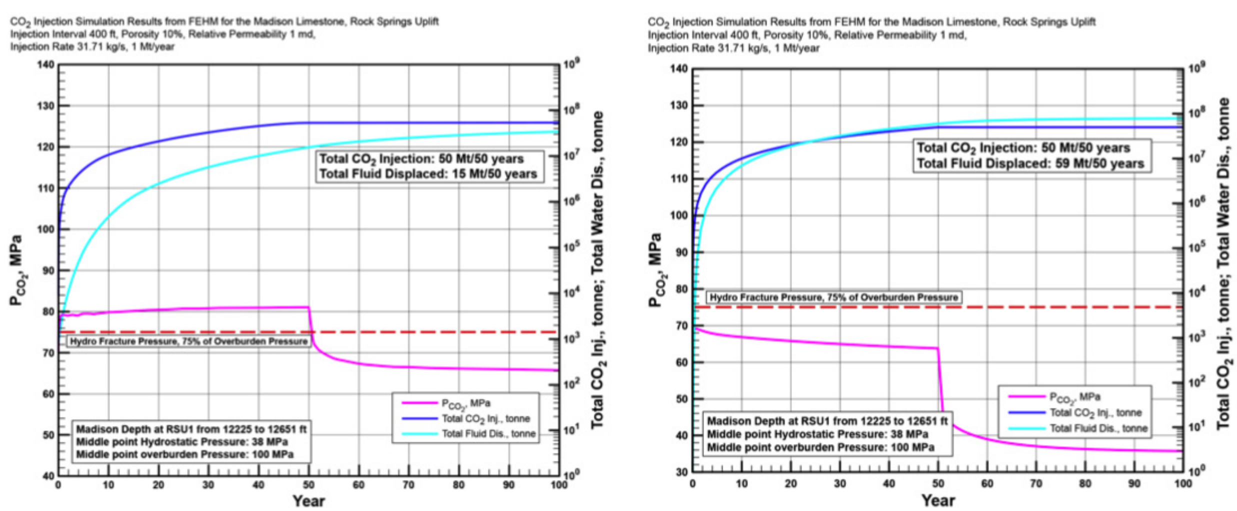


Figure 8. Output from numerical simulations of two CO_2 injection scenarios. The left panel shows a scenario in which only a small amount of formation fluid is produced during CO_2 injection, while the right panel shows a scenario in which the volume of formation fluid produced equals the volume of CO_2 injected (1:1 ratio). Note that in the left panel, CO_2 injection causes the pressure to rapidly approach fracture pressure.

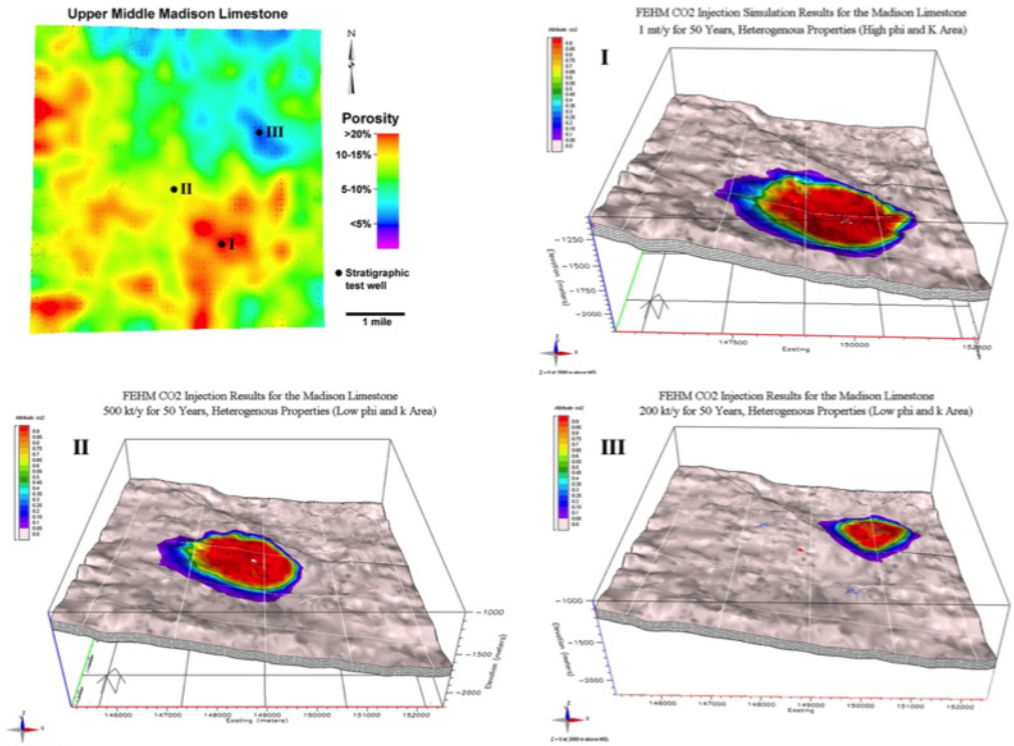


Figure 9. Diagram showing the size of the CO_2 plume resulting from CO_2 injection into the Madison Limestone from CO_2 injection at three locations in the study area (shown in upper left panel).

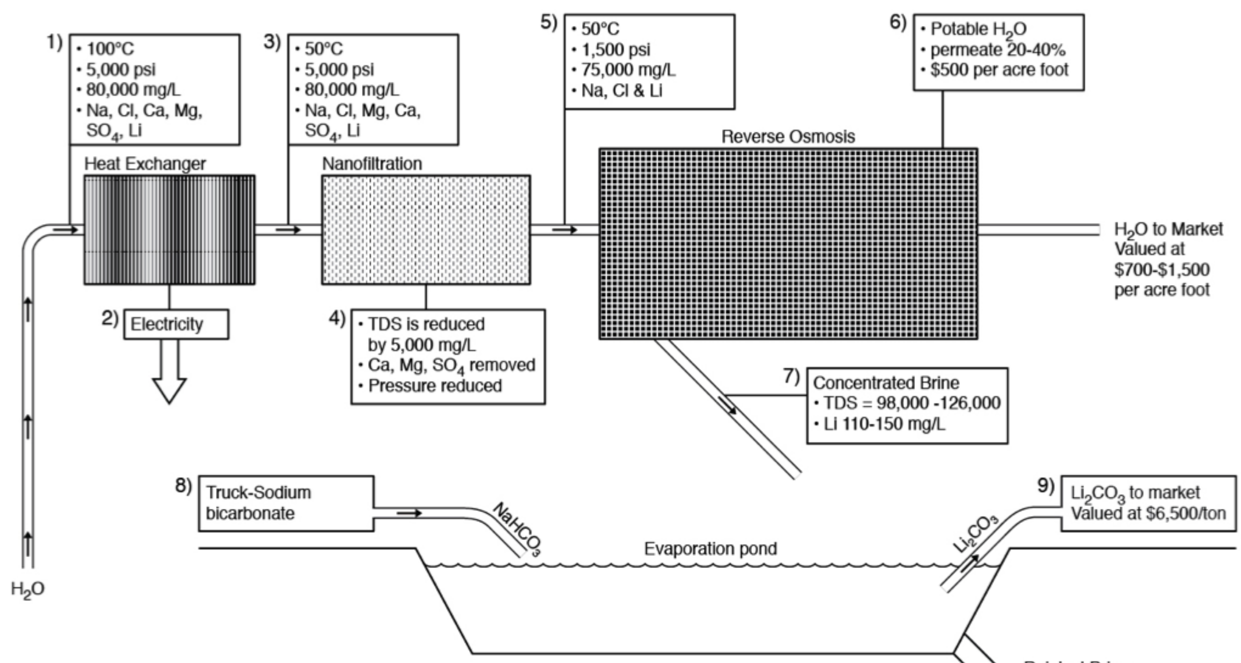


Figure 10. Schematic diagram of proposed formation fluid treatment resulting from CO_2 injection into the Madison and Weber formations on the Rock Springs Uplift. Potable water and metals are produced from the fluid, and residual brines are reinjected.

CO_2 utilization

To survey the potential for CO_2 utilization at the Rock Springs Uplift, the following three tasks were completed.

1. Construct integrated source-sink strategies to optimize CO_2 utilization (**Figure 11**).
2. Select EOR targets based on permeability, oil saturation, anomalous pressures, reservoir heterogeneity, and distance to CO_2 sources (**Figure 12**).
3. Design multiple resource development plans as a synergistic system that increases efficiency of development, minimizes environmental footprints, and sustains and stabilizes long-term resource utilization (**Figure 13**).

Summary

Overcoming the four major hurdles to CCUS activities at the Rock Springs Uplift (i.e., improving the estimates of CO_2 storage capacity of the reservoirs, establishing long-term integrity and permanence of confining layers, designing a profitable strategy for pressure management, and evaluating CO_2 utilization) has greatly enhanced the CCUS potential in Wyoming and elsewhere.

The ultimate mission of the WY-CUSP program managed by the U.W. Carbon Management Institute – delivery of a certified commercial CO_2 storage site in Wyoming that could be used as a surge tank for CO_2 utilization – is being accomplished. Financial data for the project may be found on the last page of this report.

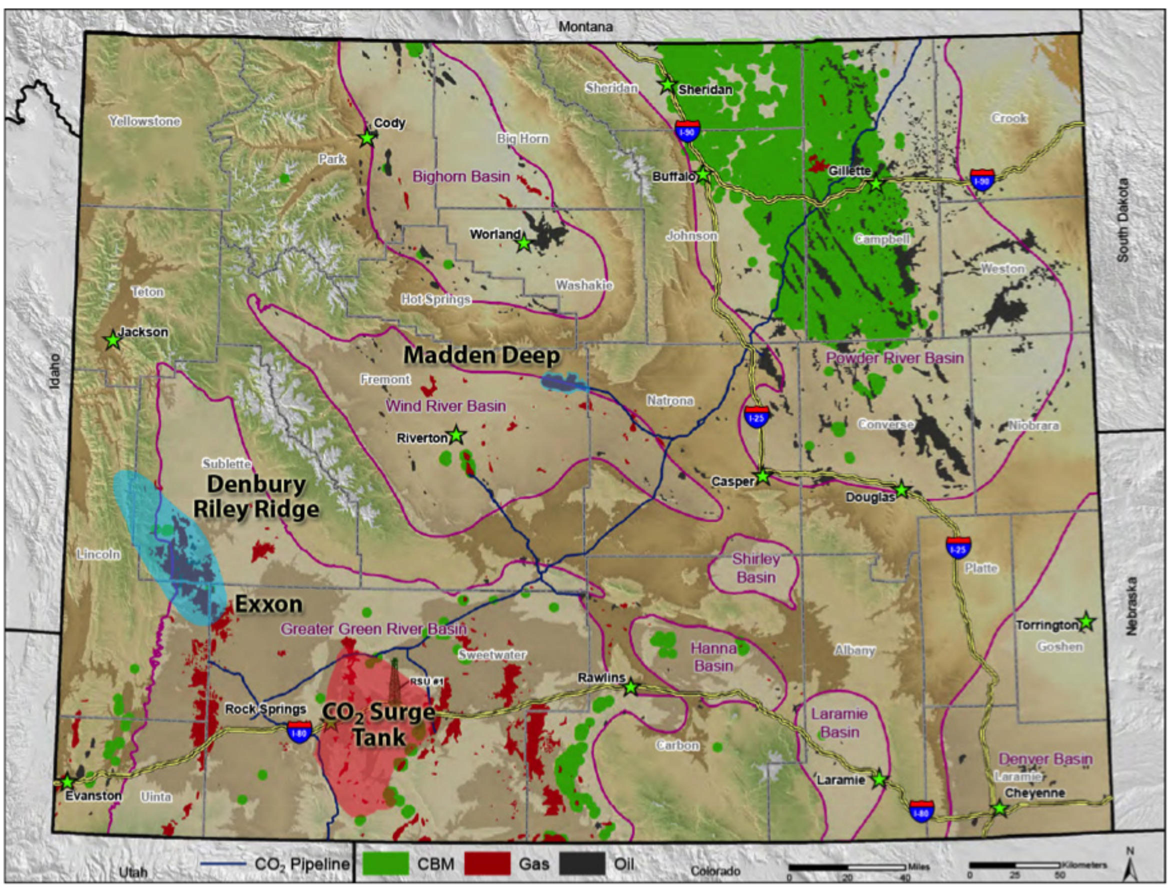


Figure 11. Map showing the location of the EOR targets (black), CO_2 pipelines (blue), CO_2 production sites (blue), and position of the Rock Springs Uplift as a regional surge tank for CO_2 and EOR projects.

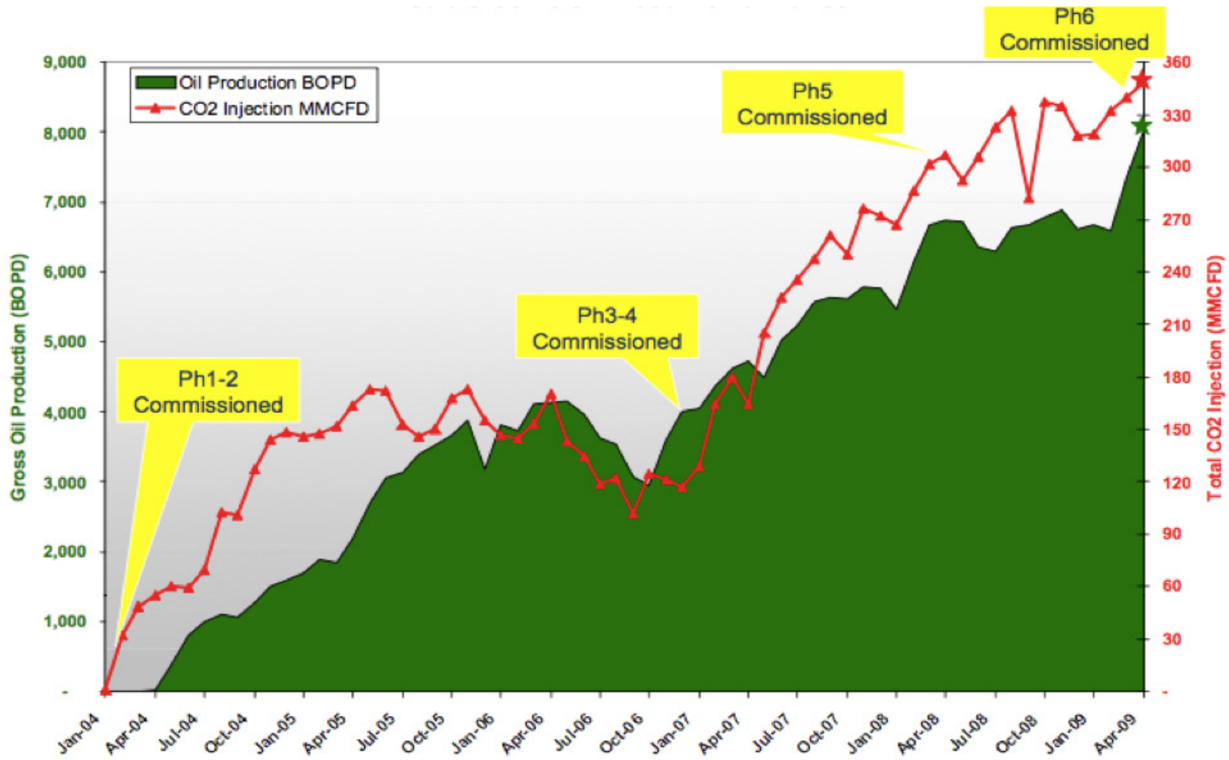


Figure 12. Example of CO_2 flooding and stranded oil recovery at the Salt Creek Oil Field.

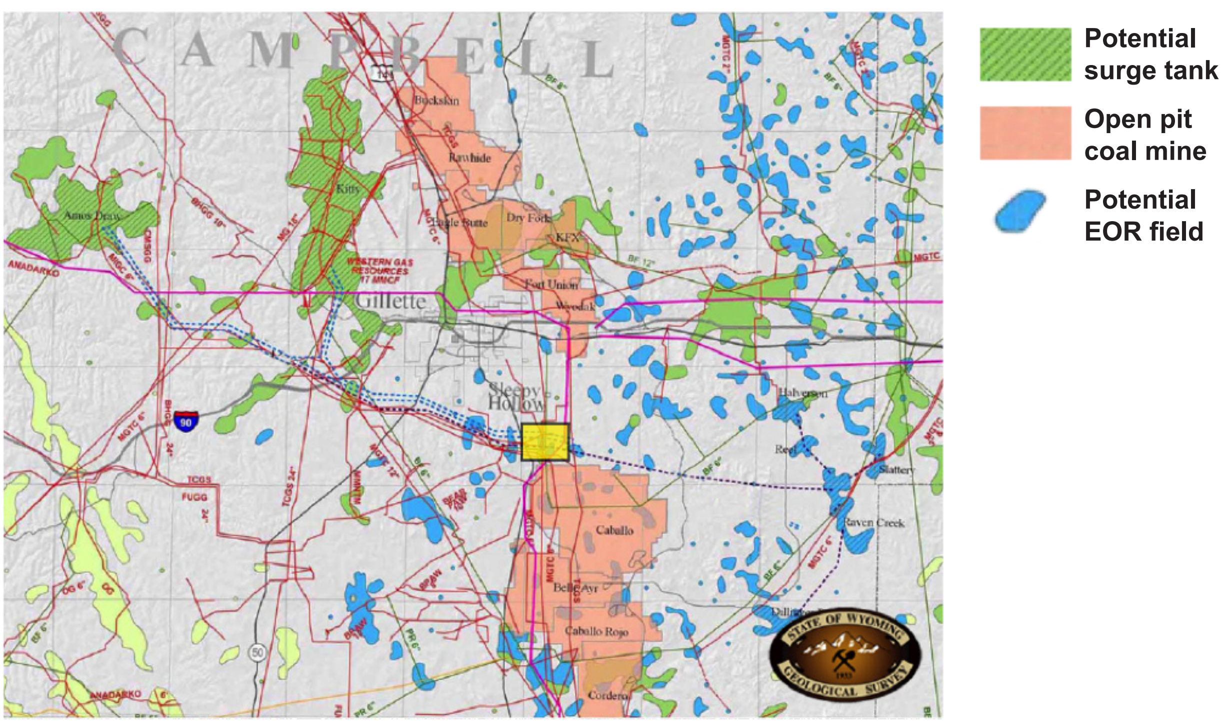


Figure 13. Example of a potential integrated schematic strategy for resource development in the Powder River Basin. This type of strategy more efficiently and effectively recovers energy resources by exploiting synergistic relationships among resources, thereby increasing sustainability. The yellow box is the location of a coal-to-chemical plant, the one element of this plan that has not yet been deployed in the Powder River Basin.

Conclusions

The Wyoming Carbon Underground Storage Project (WY-CUSP), funded by the U.S. Department of Energy and the state of Wyoming, and managed by the University of Wyoming Carbon Management Institute (CMI), will end in December 2013. The results of the WY-CUSP CO_2 storage site characterization program have produced numerous scientific articles, presentations at professional meetings, new scientific discoveries, and a first of its kind book titled *Geological CO_2 storage characterization – the key to deploying clean fossil energy technology* (Springer-Verlag publication date December 2013). The WY-CUSP program has brought UW, CMI, and SER to the forefront of geological CO_2 storage research, and also international recognition as leaders in carbon management. During the WY-CUSP program, CMI has acquired the expertise and experience to excel at applied research directed at many of the state's most important energy/environmental problems.

Further work on many aspects of this CMI program that would greatly benefit Wyoming will require additional research. However, at present there are no funds to continue work on the following projects:

1. Evaluate deep brine production and treatment technologies including potable water recovery and metals/volatile extraction (i.e., Li^+, K^+, B^{3+}, and helium).
2. Design systematic, integrated, and sustainable energy/environmental resource development strategies for each of the Wyoming basins.
3. Assist in the deployment of existing added-value product coal conversion technologies in Wyoming (coal to methanol, ethanol, gasoline, diesel, acetate, fertilizer, etc.). Under present EPA regulations, the deployment of these technologies will require CO_2 capture and storage.
4. Implement advanced CO_2 utilization techniques, including EOR, CO_2 fracs, and enhanced coal bed methane (ECBM).
5. Determine deep brine evolutionary pathways for all Wyoming basins in order to evaluate future potential for potable water and metal recovery
6. Inventory natural gas storage sites in all Wyoming basins, particularly with respect to supplying energy support for wind power generation.

All of these studies and other projects at CMI would greatly benefit the efficient and effective development of the state's economy, and sustain Wyoming's quality of life and traditions. Without new funding, many of the tasks required to complete these projects will be delayed or never accomplished. Without additional funding, the team at CMI will concentrate their efforts on obtaining additional funding and the following presently funded projects:

1. U.S. Department of Energy Project DE-FE0009202 – Optimizing accuracy of determinations of CO_2 storage capacity and permanence, and designing more efficient storage operations: an example from the Rock Springs Uplift (budget and project performance period approximately $514,000 through September 2015)
2. U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium (sponsored by DOE Cooperative Agreement No. DE-P10000017) – Theme 6, CO_2 Storage and Utilization (budget and project performance period approximately $1,070,000 through September 2015)

The emphasis of CMI through September 2015 will be directed toward these two projects. In summary, the primary CMI effort in the next two years, given the present support structure, will focus on understanding the integrity and permanence of confining layers at the Rock Springs Uplift, and comparing geological CO_2 storage sites in the Shaanxi Province of China with those in Wyoming.

In completing the WY-CUSP program, the team at CMI has thoroughly characterized the geological CO_2 storage potential of the Rock Springs Uplift. This work has provided the state with a legitimate commercial-scale geological CO_2 storage site. If and when the federal government requires that anthropogenic CO_2 be captured and stored, Wyoming will be prepared with a certified CO_2 storage site. It is important to note that stationary sources in Wyoming presently emit approximately 60 Mt of CO_2 annually, and half these emissions come from industrial facilities in the southwestern part of the state. The Rock Springs Uplift CO_2 storage site is ideally situated at the geographic center of half of Wyoming's industrial CO_2 emissions. The results of the WY-CUSP program will provide operators in Wyoming with information that will be necessary to obtain the permits required to construct commercial-scale CO_2 storage facilities on the Rock Springs Uplift. As such, the CMI team has accomplished the ultimate WY-CUSP mission: delivery to Wyoming of a thoroughly characterized, certified CO_2 storage site that can be used as a surge tank for CO_2 utilization.

Carbon Management Institute
As of September 30, 2013

	AML Funding	DOE Funding
Total Funding	6,951,922	9,625,379
Supplies	192,813	17,465
Salaries	1,434,763	429,259
Fringe	531,449	146,262
Travel	231,111	21,398
Equipment	20,877	0
Other	102,397	30,468
Sub-Contracts	3,826,213	8,720,379
Total Expenses	6,339,623	9,365,231
Remaining	$612,299	$260,148