Part I

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

Part II

Plan for WY-CUSP Phase II – Delivery of a certified commercial storage site to Wyoming

Submitted by:

Ronald C. Surdam, *Director*
Shanna Dahl, *Deputy Director*
Rob Hurless, *Deputy Director*

University of Wyoming Carbon Management Institute,
a part of the School of Energy Resources

October 27, 2011

Carbon Management Institute

Statutory requirements

(I) An evaluation of the feasibility of proceeding with the project based upon the data derived from the test well. To date, all data analysis results continue to support the Rock Springs Uplift site as a prime candidate for geological storage of CO_2.

(II) A draft plan for the development and operation of the project. The draft plan shall include an explanation of how carbon dioxide for the project will be secured and of how liability issues with regard to injection and storage will be addressed and a plan for the beneficial use and treatment of produced water. A detailed plan for WY-CUSP Phase II follows in Part 2 of this report. WY-CUSP Phase II will use water as a surrogate for liquid (supercritical) CO_2 in the proposed field-scale injection test of the Rock Springs Uplift site. Therefore, procurement and liability issues pertaining to large-scale CO_2 injection demonstrations do not apply to the proposed project. Liability for water injection will be addressed under the regulations for Class I UIC wells, and will involve only site reclamation. As part of the WY-CUSP Phase I characterization project, the Carbon Management Institute will deliver plans for the production, treatment, and beneficial use of the reservoir fluids displaced by injection in its final report to DOE.

(III) A draft budget for the development and operation of the project over a period of time that is reasonable for the demonstration of monitoring, verification, and accountability (MVA), including the extent to which commitments for non-state resources to support development of the project have been secured. A draft budget for the proposed Phase II of WY-CUSP is included in this report. The Carbon Management Institute is currently pursuing matching funds for Phase II of the project from a variety of sources, and has attracted the interest of several major potential corporate partners. The table below shows WY-CUSP Phase I funds spent to date.

(IV) A draft schedule for development. A proposed timeline for Phase II of WY-CUSP is included in this report.

Carbon Management Institute

As of September 20, 2011

	AML Funding	DOE Funding
Total Funding	$6,977,572.00	$9,625,379.00
Supplies	45,279.76	2,359.15
Salaries	618,602.70	50,253.22
Fringe	148,060.95	8,918.38
Travel	77,933.08	3,351.59
Equipment	20,876.78	0.00
Other	3,551.69	0.00
Sub-Contracts	2,781,664.27	7,609,971.73
Total Expenses	3,695,969.23	7,674,854.07
Remaining	$3,281,602.77	$1,950,524.93

WY-CUSP Phase I expenditures to date.

Executive summary

With global energy consumption growing at about 25% per decade, it is essential for energy exporting states like Wyoming to optimize energy development during the 21st century in order to safeguard our nation's economy and energy security. In the future, the results from the Wyoming Carbon Underground Storage Project (WY-CUSP) will prove critical to the optimization of responsible energy resource development in Wyoming. The coal extraction, enhanced oil recovery, coal-fired electricity generation, and coal-to-chemical industries will need either CO_2 or a place to store CO_2. To facilitate deployment of any new and/or improved energy delivery technologies and associated industries in Wyoming, the state will have to document the existence of available commercial CO_2 storage capacity, along with infrastructure to transport CO_2 from its source to the storage site, and finally to the end point of use.

The WY-CUSP program consists of two parts: 1) CO_2 storage site characterization (Phase I); and 2) commercial-scale CO_2 injection/storage demonstration (Phase II). The greatest uncertainty in evaluating CO_2 storage processes is characterizing geological heterogeneity in three dimensions, and the most critical problem with commercial-scale geological storage is management of displaced fluids. Phase I of WY-CUSP is addressing and solving these issues. The characterization work is creating an expanded and more robust database for carbon storage in the Rock Springs Uplift. This database results from the integration of seismic attributes interpreted from a 3-D seismic survey at the project site with observations from log suites, core, and samples collected from a stratigraphic test well drilled in the center of the seismic survey area. The integration allowed project researchers to construct 10-square-mile porosity, permeability, lithofacies, and fracture distribution volumes for the Weber and Madison reservoirs (**Figure 1**). Project researchers can now detect and delineate 3-D geological heterogeneity in detail for the two reservoir intervals. This ability will greatly reduce uncertainty in all future numerical simulations of performance assessments and subsequent risk analyses. Additional results will substantially improve the Carbon Management Institute's ability to design a reservoir formation fluid production and treatment strategy.

To accelerate delivery of a certified commercial CO_2 storage site to Wyoming, the Carbon Management Institute (CMI) suggests that a productive strategy would involve continuing the Legislature's proactive approach to CO_2 storage by moving to WY-CUSP Phase II.

The decisive, determinative question that remains in developing a commercial-scale geological CO_2 storage site on the Rock Springs Uplift is *Can the storage reservoirs (with a cumulative thickness of more than 1,000 feet) accept large volumes of fluid using a reasonable number of injection wells at a specific site 25 square miles in area?* WY-CUSP Phase II will answer this question. If the answer is affirmative, the last major technical barrier to delivering a certified commercial CO_2 storage site in Wyoming will be overcome. CMI proposes to accomplish the objective of Phase II by approaching the problem in a way that differs substantially from previous attempts. The CMI approach minimizes significant hurdles that have plagued all existing approaches to answering the key questions, particularly with respect to unattainable large volumes of CO_2, insurmountable liability issues, and public resistance.

CMI will answer the question by integrating the results from WY-CUSP Phase I with a large-scale fluid injection using water as a surrogate for CO_2 in Phase II. The WY-CUSP team intends to use subsurface Nugget Formation water as the injection fluid, and to supplement this supply with available wastewater from the adjacent Jim Bridger power plant if possible. One million tons of water will be injected in each of two injection wells over a two-year period. Achieving the Phase II objective will not require any costly CO_2, and the strategy eliminates any possibility of competition with the oil and gas industry for a share of the limited supply of "natural" CO_2. Another major benefit of the proposed approach is the timing of a long-term liability solution: liability issues related to CO_2 injection can be resolved after site certification but before construction of a commercial storage facility for anthropogenic CO_2. The necessary permits for Phase II activities can be obtained within an existing regulatory framework based on conventional procedures (currently, Wyoming has 50+ water injection wells). The significance of the proposed Phase

II program is enormous: it will circumvent the huge obstacles that have stymied all previous large-scale demonstration-only CO_2 storage projects, but more importantly, the completion of WY-CUSP Phase II will position Wyoming to take immediate advantage of CO_2 capture technology when it becomes commercially available and legislatively imperative. *Most importantly, this project will make it possible to store a huge amount of CO_2 that later can be used to recover 8–10 billion barrels of stranded oil in Wyoming, and make a substantial coal-to-chemical industry a reality in the state.*

Background

Global energy consumption is increasing by about 25% per decade. Consequently, the world will consume 50% more energy in 2030 than it does today, but increased consumption in the US for the same period will be closer to 25% (**Figure 2**). This increased demand for energy will have to be met by states like Wyoming, or foreign entities capable of exporting energy. Of the top 10 energy exporters to the US (which supply a total of 35 quadrillion btus), Wyoming is the leader, providing 30% of this energy. Coal accounts for 80% of the energy Wyoming exports to the US. It is absolutely essential that Wyoming's coal resources remain available to the nation: the state's coal must be protected from bypass in order for the US to meet future energy demands. To safeguard the viability of Wyoming's huge, readily available, and inexpensive energy supply – particularly with respect to electricity generation – the state must have a plan in place to comply with potential federal regulations that could require reductions in CO_2 emissions from coal-fired power plants. If the federal government regulates these emissions more stringently, survival of upstream and downstream coal-fired power plants and coal-to-chemical facilities will depend on geological CO_2 storage. Globally, CCS and energy conservation are the only large-scale, meaningful, available options capable of significantly reducing greenhouse gas emissions without requiring huge cultural changes and substantial sacrifice. Carbon capture and storage will be fundamental to preserving the future of Wyoming's natural resource economy – not only the extractive coal industry, but all aspects of future resource development in the state.

It is important to make the distinction between *CO_2 sequestration* and *CO_2 storage*: CO_2 sequestration involves the injection of CO_2 into the subsurface with no possibility of retrieval, whereas CO_2 storage allows operators to recover CO_2 stored in the subsurface to meet any future demand for it (such as demand from enhanced oil recovery operations), much the same as natural gas storage.

Rationale for CO_2 storage in Wyoming

The Wyoming Carbon Underground Storage Project (WY-CUSP) is critical to the optimization of energy resource development in Wyoming during the 21st century. For example, the Wyoming State Geological Survey (WSGS) and the University of Wyoming's Enhanced Oil Recovery Institute estimate that 4–8 billion barrels of stranded oil in Wyoming technically could be recovered by CO_2 flooding. The Bighorn Basin alone hosts 1.8 billion barrels of stranded oil (4.0 billion barrels if the residual oil zone is included). At current rates of CO_2 production at the Shute Creek and Lost Cabin gas processing plants, it would take 150 to 300 years to recover the stranded oil in the Bighorn Basin. Most importantly, all of the CO_2 at both gas processing plants is presently under contract (Salt Creek, Patrick Draw, Lost Soldier/Wertz, Beaver Creek, Grieve, Rangely, Bell Creek, and elsewhere) and unavailable for projects in the Bighorn Basin or additional projects in the Powder River Basin. Even if the number of gas processing plants doubled and all of the CO_2 produced stayed in Wyoming, it would still take more than 100 years to recover the state's stranded oil. Recovering only the Bighorn Basin's stranded oil in 20 years would require the CO_2 output from 7 to 8 gas processing plants similar in size to the Shute Creek facility, or one year of anthropogenic CO_2 emissions from stationary sources in Wyoming. These CO_2 estimates are based on industry experience in the Permian and Powder River basins (it takes approximately 10 Mcf of CO_2 to recover 1 barrel of oil, including recycled CO_2). Enhanced oil recovery operations in Wyoming desperately need an additional, substantial source of CO_2: anthropogenic CO_2.

Another industry that could flourish in Wyoming is coal-to-chemical production. The technology is in place and Wyoming has all of the ingredients necessary for success: it is only a matter of time until this

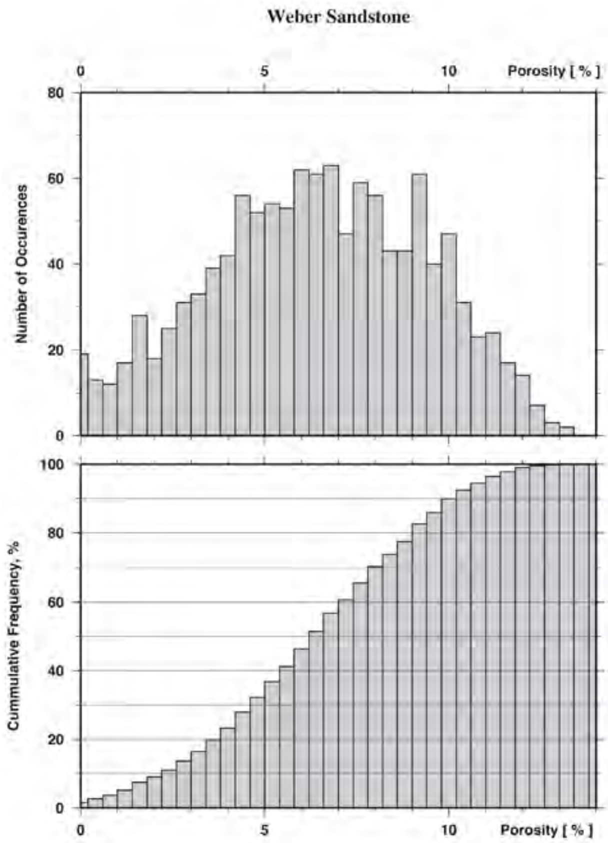


Figure 1a. *Histogram of porosity distribution within the Weber Sandstone unit (11,155–11,825 feet; total of 1,340 measurements). The upper panel shows the ordinary histogram, and the lower panel shows the cumulative histogram. Density porosity was calculated from the borehole size/mud weight corrected density log, assuming sandstone rock matrix of 2.67 g/cc and fluid density of 1.1 g/cc.*

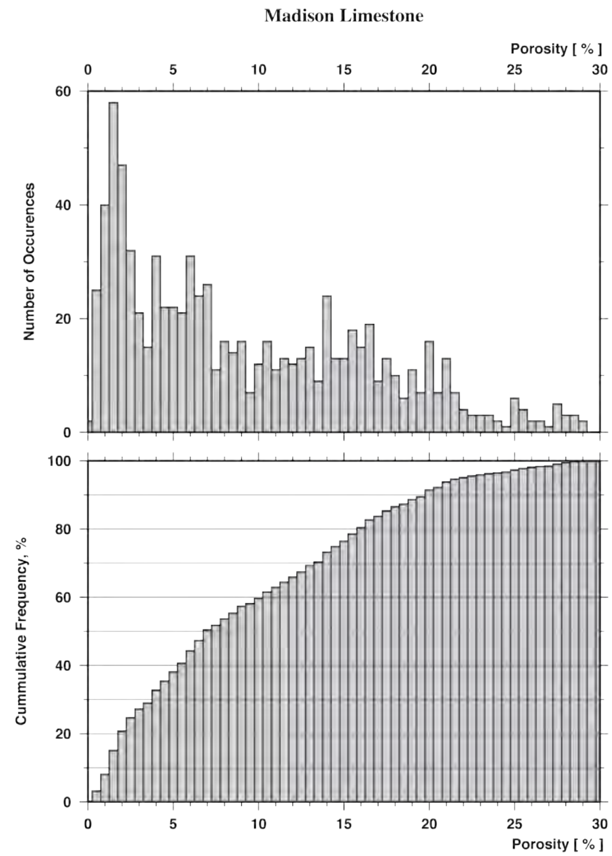


Figure 1b. *Histogram of porosity distribution within the Madison Limestone unit (12,230–12,650 feet; total of 840 measurements). The upper panel shows the ordinary histogram, and the lower panel shows the cumulative histogram. Density porosity was calculated from the borehole size/mud weight corrected density log, assuming limestone rock matrix of 2.74 g/cc, dolostone rock matrix of 2.87 g/cc, and fluid density of 1.1 g/cc.*

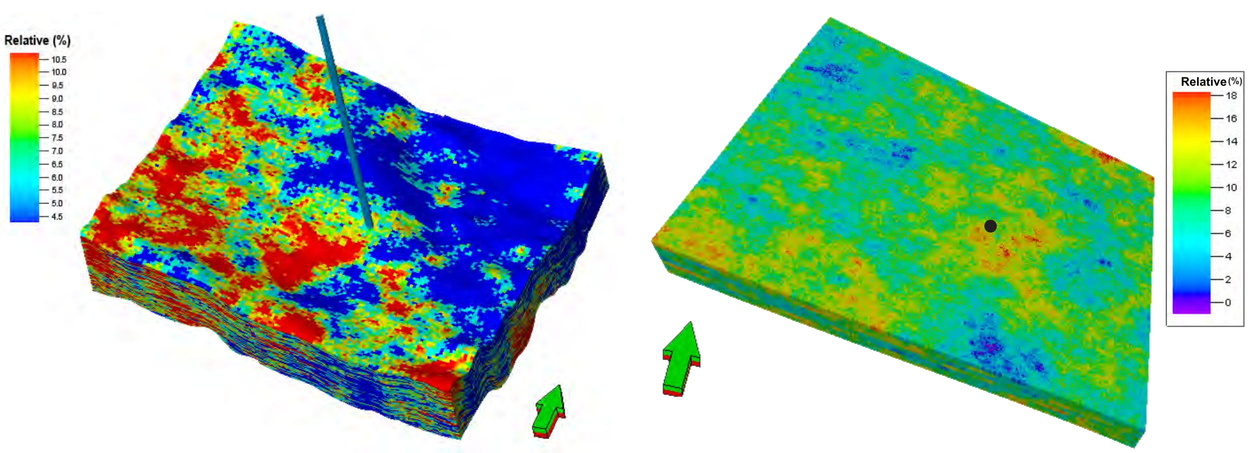


Figure 1c. *Porosity distribution of Weber Sandstone (left) and Madison Limestone (right) inverted from Jim Bridger 3-D seismic data. New data from well observations will allow the conversion from relative to real reservoir properties in three dimensions. Note legend. Vertical bar (left) and black dot (right) indicate location of stratigraphic test well.*

Figure 2

The energy challenge *of the next two decades*

Global energy consumption*

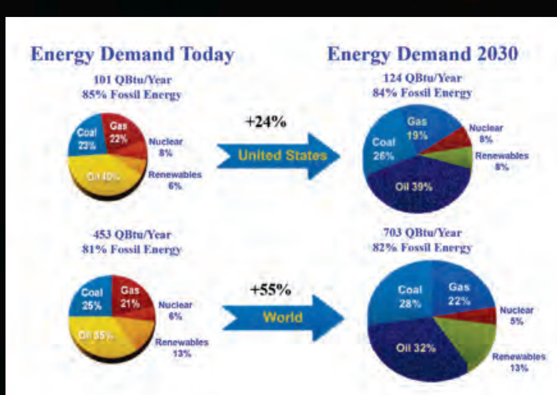
Global consumption for the 1995–2005 decade was 104.3 billion tons of oil equivalent (a 25% increase from consumption during the previous decade). Using the 1995–2005 rate of increase, the world will need:

- 177 billion tons of oil equivalent, or
- 1.3 trillion barrels of oil, or
- 7,500 Tcf (212 Tcm) of natural gas

In 2030, the world will consume 50% more energy than it does today.

In 2010, China and the US accounted for approximately 40% of global energy consumption.* China's energy consumption increased by 11% in 2010, while US energy consumption increased by 4%. Consequently, using a 25% energy increase per decade to predict consumption for 2010–2030 may yield a conservative estimate.

* Compiled from BP Statistical Review of World Energy (June 2006)



Current and projected (2030) energy demand for the U.S. and the world. Figure courtesy NETL. U.S. data from EIA Annual Energy Outlook 2008 Early Release, years 2006 and 2030; world data from IEA World Energy Outlook 2007, years 2005 and 2030.

Global fossil energy portfolio (technically recoverable)
(in barrels of oil equivalent)

Oil shale	3.0 trillion
Coal	4.1 trillion
Heavy oil	1–2 trillion
Deep-sea oil	0.1–0.7 trillion
Enhanced oil recovery	50 billion
Conventional and unconventional natural gas	1 trillion

industry experiences exponential growth in the US. All of the technologies that convert coal to chemicals via gasification inherently capture CO_2 and therefore can provide storage-ready CO_2. Consider that Peabody's global coal reserves sold as coal are valued at $288 billion, but sold as motor fuels are valued at $3.6 trillion. In China, the yearly production of chemicals derived from coal is astonishing – by 2015 China annually will produce 280 million barrels of methanol, 14 million barrels of diesel, 100 million barrels of acetate, and 1.2 Tcf of syngas from coal (at today's prices, these coal products are worth $34 billion per year). All of the coal-to-chemical processes produce substantial quantities of CO_2. However, unlike conventional coal-fired power plants, coal-to-chemical facilities can effectively and efficiently capture CO_2. For these technologies and associated industries to be deployed in Wyoming, the state will have to document the availability of huge commercial-scale CO_2 storage capacity.

The results from the WY-CUSP program will also assist in establishing additional natural gas storage in Wyoming – the improved reservoir characterization of the Weber/Tensleep and Madison formations will facilitate evaluation of scenarios involving natural gas storage in these formations on the crest of the Rock Springs Uplift and elsewhere in the state. Daily, it becomes more and more apparent that the use of natural gas will increase rapidly around the world in the 21st century. Wyoming is situated to take advantage of this growth – the state lies at the headwaters of a giant natural gas supply; has the necessary natural gas infrastructure in place; and possesses huge, unexploited, technically recoverable natural gas reserves. Unlike coal, natural gas has been plagued in the past by demand fluctuations, supply disruptions, and hedge price variations. Now, with the power-generating sector demanding more natural gas, we will see a premium on peak load demand as opposed to base load demand. This peak load demand will require gas storage sites capable of providing high deliverability of gas for short periods of time, to meet daily and hourly fluctuations at power generating facilities. At present, 44% of natural gas storage occurs in four states (Michigan, Illinois, Pennsylvania, and Texas). Wyoming currently accounts for 1.1% of the nation's natural gas storage capacity. For Wyoming to excel as a future significant natural gas supplier to the US, the state will require substantial additional gas storage capacity.

Clearly, CO_2 storage in Wyoming is key for energy and water development in the 21st century. Carbon storage is vital to protecting the coal extraction industry in Wyoming, particularly as it relates to helping the coal-fired power-generating sector of our economy prepare for the possibility of increasingly stringent regulation. However, viewing CO_2 storage and the WY-CUSP program in such a narrowly focused context does a great disservice to Wyoming. Instead, the Carbon Management Institute suggests that a much more productive strategy would involve continuing the Legislature's proactive approach to CO_2 storage and moving to Phase II of WY-CUSP – working to deliver a certified commercial storage site for CO_2 or natural gas to Wyoming, and bolstering the state's EOR industry by providing temporary storage and easy recovery of CO_2 for EOR.

Part I: Progress report

WY-CUSP Phase I: Site Characterization

The ultimate goal of the Wyoming Carbon Underground Storage Project (WY-CUSP) is to demonstrate that successful commercial-scale CO_2 storage can be achieved in Wyoming. The WY-CUSP program consists of two parts: 1) site characterization (Phase I), and 2) commercial-scale CO_2 injection/storage demonstration (Phase II). WY-CUSP Phase I focuses primarily on site characterization of Wyoming's most promising CO_2 and natural gas storage reservoirs (the Pennsylvanian Weber/Tensleep Sandstone and Mississippian Madison Limestone) and premier CO_2 storage site (Rock Springs Uplift).

The characterization work is creating an expanded and more robust database for carbon storage on the Rock Springs Uplift (i.e., 4-way closure; 2,200 mi^2 area; 10,000 feet of structural closure; multiple stacked confining layers, some of which trap helium; and a 1,000-foot-thick section of high-potential CO_2 storage reservoirs at depths and pressures where CO_2 will be supercritical; 8,000 feet of vertical separation from overlying fresh water aquifers). Results from the application of both the FutureGen and USGS diagnostic protocols for evaluating CO_2 storage capacity suggest that the Weber Sandstone and Madison

Limestone on the Rock Springs Uplift could store approximately 26 billion tons of CO_2.

Led by the University of Wyoming Carbon Management Institute (CMI) in the School of Energy Resources, WY-CUSP Phase I is supported by the US Department of Energy ($9,975,000), the State of Wyoming ($7,300,000), and industry matching funds ($2,200,000). All available surface data and most of the available subsurface data pertaining to the storage reservoirs, confining layers, and structural setting have been collected. On the Rock Springs Uplift (RSU), only 19 wells penetrate the targeted Paleozoic stratigraphic storage interval. Using existing data, numerical simulations for a wide variety of injection/storage scenarios document that the Rock Springs Uplift and Weber/Madison reservoirs can support numerous commercial CO_2 storage facilities, with enough storage capacity for all of the CO_2 emitted by two large coal-fired power plants (Jim Bridger, 2,300 MW, 18 Mt CO_2/year; and Naughton, 700 MW, 9 Mt CO_2/year), the world's largest concentration of trona processing plants, and any future coal-to-liquid plants and/or enhanced oil recovery projects constructed in Wyoming.

The most critical problem with commercial-scale CO_2 storage is management of displaced fluids. Working with Roger Aines and Tom Wolery at Lawrence Livermore National Laboratory (LLNL), CMI is in the process of designing a customized water treatment strategy for brines produced from the Weber/Tensleep and Madison formations. A portion of the LLNL work is financed by the Clean Coal Technology Fund administered by the UW School of Energy Resources (SER) and the Energy Resources Council (ERC). As previously described (Surdam et al., 2009), the storage of CO_2 in a geologic structure like the Rock Springs Uplift displaces enormous quantities of low-quality formation fluid (brines). The fluid management plan suggested by the CMI involves producing this fluid and treating it at the surface to Underground Sources of Drinking Water (USDW) standards, and then reinjecting the residual brine. Aines and Wolery, along with their colleagues at LLNL, have shown that these subsurface brines can be treated effectively and efficiently, and at approximately half the cost of desalinating seawater. For every ton of CO_2 stored, one ton of formation fluid will typically be produced and treated, yielding approximately 80% potable water and 20% residual brine.

As an example, storage of 15 million tons of CO_2 annually would produce an estimated 6,000 acre-feet of treated, potable water; over a 75-year period, storage of 15 Mt CO_2 per year could provide nearly 500,000 acre-feet of water (valued at $100 million to $600 million). In the event that 25% of the storage capacity of the Weber/Tensleep and Madison formations in the Rock Springs Uplift is used for CO_2 storage, an estimated 4.6 million acre-feet (11 cubic kilometers) of potable water could be available (i.e., equivalent to 12 times the capacity of Boysen Reservoir).

Water samples retrieved from the Weber and Madison formations in the Rock Springs Uplift #1 stratigraphic test well are accelerating this work. The WY-CUSP team will deliver designs for a reverse-osmosis water treatment plant capable of handling large quantities of pressurized fluids produced from the Weber/Madison reservoirs. In arid southwestern Wyoming, the need and demand for potable water is high: residential users, agricultural operations, coal-fired power plants, coal-to-chemical facilities, and downstream users in the Colorado River drainage, among others, will require ever-increasing amounts of water.

Of the ten CO_2 storage site characterization projects funded by DOE in 2009, the WY-CUSP program was the first to drill a stratigraphic test well and acquire a 3-D seismic survey (covering 25 square miles) for a nominated site. The 3-D seismic survey area and stratigraphic test well lie on the east flank of the RSU. Thanks to the excellent performance of our drilling operator, Baker Hughes, and the drill rig and crew provided by True Drilling of Casper, WY, the drilling of the stratigraphic test well was outstandingly successful: 916 feet of core was retrieved from the 12,810-foot-deep well, along with a complete log suite (including wellbore and a P_e log for mineral composition), borehole images, fluid samples, and a VSP survey. All components of the project are currently moving forward. PetroArc International is providing continuous visual documentation of the core, including grain size, mineralogy, facies distribution, and porosity. New England Research will perform continuous permeability and velocity scans of selected reservoir intervals. PENCOR and Energy Laboratories are chemically analyzing the fluid samples. The WY-CUSP team (CMI, UW students and faculty, colleagues at the Wyoming State Geological Survey, and Wyoming contractors) is completing all data interpretation and integration.

In addition, WY-CUSP Phase I has garnered attention from a wide variety of media outlets across the state, the nation, and the world. A partial list of media coverage of the WY-CUSP program is shown in **Appendix 1**.

WY-CUSP researchers are now integrating data from the 3-D seismic survey with well log results and core observations to construct 10-square-mile porosity, permeability, lithofacies, and fracture distribution volumes for the Weber and Madison reservoirs. Within these volumes, it is now possible to isolate individual reservoir horizons and construct maps of the distribution of seismic attributes and associated petrophysical properties (i.e., porosity and permeability). The three-dimensional distribution of heterogeneity in petrophysical properties of the reservoir intervals results from the seismic/log/core/geology integration (**Figure 1**). This project can significantly reduce risk for a diverse set of CO_2 storage/hydrocarbon (EOR)/ water production projects in the Rocky Mountain region. The CMI work, for the first time, establishes a strategy for dealing accurately with projects related to deep (>10,000 feet) injection/storage and production of CO_2/hydrocarbons/water in deep saline aquifers – reservoirs generally considered too deep and/or too tight.

Currently, only one piece of necessary data is missing from a complete characterization of the RSU #1 reservoir intervals – a measurement of in-situ injectivity. As part of Phase I, the WY-CUSP team will work with Baker Hughes to prepare the well bore for a series of small-scale water injectivity tests, which will be covered under the current DEQ Class I permit issued to the CMI. Under the conditions of the permit, the injectivity testing must be complete by September 2012. In addition, the WY-CUSP team will use core intervals to run a series of laboratory injectivity tests with both water and CO_2. These laboratory tests will allow researchers to calibrate the water and CO_2 injectivity tests. The liability on a UIC Class I well is basically site reclamation after completion of testing. CMI is currently preparing an injectivity plan and budget for submission to the ERC.

Data and analysis results from the 3-D seismic survey and stratigraphic test well will facilitate a smooth transition to Phase II of the project – delivery of a certified commercial storage site for CO_2 or natural gas to Wyoming.

Part 2: WY-CUSP Phase II Plan

Introduction

Phase II of WY-CUSP will push the envelope for development of CO_2 storage from single-well analyses to comprehensive full-scale field demonstrations and evaluations. Trying to achieve this objective via existing approaches has proved frustrating and painfully slow, resulting in a goal whose achievement remains just beyond reach, particularly in the Rocky Mountain region. The frustrations and constraints on progress arise mainly from the unattainable large volumes of CO_2 required for full-scale field experiments, insurmountable liability issues, and public resistance. In the Rocky Mountain region, public resistance stems not from perceived safety issues associated with CO_2 injection (as it does in other regions of the US), but instead from the belief that CO_2 storage projects compete with the enhanced oil recovery industry (which generates state revenue in the form of mineral royalties) for a limited supply of available CO_2.

CMI proposes to accomplish the objective of Phase II by employing a substantially different approach to the problem: one that minimizes the existing barriers to achieving full-scale geological storage demonstration in the Rocky Mountain region. Thus far, the Rock Springs Uplift has passed each of the scientific/engineering tests applied to it, and over time, the uncertainties associated with these tests have been and continue to be substantially reduced by the more robust database currently emerging from Phase I accomplishments. The big question remaining is *Can the storage reservoirs (with a cumulative thickness of more than 1,000 feet) accept large volumes of fluid using a reasonable number of injection wells at a specific site (25 square miles in area) on the Rock Springs Uplift?*

To answer this question in the most scientifically effective and economically efficient way possible, CMI proposes to integrate characterization results with data from the Phase I small-scale in-situ or laboratory CO_2 injectivity tests, and finally with large-scale fluid injections using water (H_2O) as a surrogate for CO_2 in Phase II. The proposed work will be conducted by an outstanding team of academic, industry, and federal laboratory scientists and engineers with extensive experience and expertise in all aspects of geological CO_2 storage. State-of-the-art research and commercially available modeling and simulation tools (FEHM, Eclipse, Petrel, EarthVision, BasinMod, Loganalyzer, Goldsim, CO_2-PENS, and Opentech, among others) will be used in conjunction with the new NCAR/Wyoming high-performance computational facility to model, design, implement, and evaluate the full-scale fluid injection experiment.

Achieving the project objective (delivery of a certified commercial geological storage site for CO_2 or natural gas) will not require substantial quantities of costly CO_2, nor will it necessitate competition with the oil and gas industry for a share of the limited supply of available "natural" CO_2. Another major benefit of the proposed approach is the timing of a long-term liability solution. Because large-scale injection of CO_2 will not occur during the full-scale storage demonstration, liability issues can be resolved after site certification but before construction of a facility to store anthropogenic CO_2. In addition, the necessary permits can be obtained within an existing regulatory framework based on conventional procedures (currently, Wyoming has more than 50 permitted water injection wells).

CMI intends to use subsurface Nugget Formation water as the injection fluid, and to supplement this supply with any available wastewater from the adjacent Jim Bridger power plant if possible. Water quality data compiled by the USGS and WSGS, and presented by the Wyoming Water Development Office, indicate that total dissolved solids (TDS) in the Nugget Formation fluids at the RSU #1 well site should range from 10,000 to 35,000 ppm. For injection purposes, water will be produced from the Nugget Sandstone (465 feet thick at a depth interval of 9,215–9,680 feet in the RSU #1 well), and injected into the Weber/Madison reservoir interval.

The performance and results of the full-scale fluid injection demonstration will reduce risk and uncertainty associated with using the Rock Springs Uplift as a large-scale regional geological storage site for CO_2 or natural gas. Most importantly, this project will accelerate the delivery of a certified regional CO_2/natural gas storage site in the nation's foremost energy-exporting region. Given the juxtaposition of our nation's ever-increasing demand for energy with the possible future regulation of carbon emissions, the significance of the proposed project is enormous:

it will not only circumvent the huge obstacles facing conventional large-scale demonstration-only CO_2 storage projects, but also position Wyoming to take immediate advantage of CO_2 capture technology when it becomes commercially available and legislatively imperative.

Value of WY-CUSP to Wyoming

The development of a certified commercial storage site for CO_2 or natural gas would 1) give the state's CO_2 infrastructure a huge surge tank to moderate swings in CO_2 inventory due to different rates of injection (storage), production, and consumption (i.e., EOR) of CO_2; and/or 2) help Wyoming take full advantage of the state's huge natural gas resources by providing a gas storage site that can deliver large volumes of gas over short periods of time to meet daily and hourly fluctuations at power generating facilities. With a few assumptions, the worth of a substantial regional CO_2 storage site to Wyoming can be established. The first assumption is that work by the Pipeline Authority, Enhanced Oil Recovery Institute, and Wyoming Governor's Office to construct a regional CO_2 pipeline infrastructure reaches fruition at about the same time as the construction of a CO_2 storage facility on the Rock Springs Uplift. Also, we assume that the integrated energy development strategy discussed below (i.e., CO_2 storage, recovery of stranded oil, production and treatment of associated brine, coal-to-chemical industry, and gas storage) takes place in Wyoming over a period of 20 years. This assumption is not unreasonable because in China, energy development of this magnitude has occurred over the past decade. In Wyoming, the discussion will revolve around adding value to raw energy resources.

First, the Bighorn and Powder River basins together host approximately 4 billion barrels of stranded oil: recovery of this oil depends on ready availability of the large quantities of CO_2 required for tertiary recovery. A regional CO_2 storage facility on the Rock Springs Uplift could supply the required CO_2 (40 Tcf). At $80/barrel, the recovered oil would be worth $320 billion. In addition, CO_2 flooding is the best choice for residual oil recovery, and use of CO_2 in EOR projects will add value to the CO_2. In terms of EOR projects, CO_2 is currently valued at about $2.00/Mcf, so the 40 Tcf of CO_2 required to recover the stranded oil would be worth $80 billion. Moreover, the injection and storage of 40 Tcf of CO_2 will displace 2 billion tons of formation brines that, when produced and treated, will yield 1.9 million acre-feet of potable water. This water will be worth $500 million to $2 billion, depending on its end use (agricultural or residential).

Second, if constructed, two coal-to-diesel plants, two coal-to-methanol plants, and two coal-to-syngas plants would add substantially to Wyoming's economy. Using China as an analog, the two coal-to-diesel plants could generate $1.4 billion annually, the two coal-to-methanol plants could produce $1.4 billion annually, and the two coal-to-syngas plants could yield $1.2 billion annually. Over a decade, the products from the six coal-to-chemical plants could be worth at least $40 billion. All aspects of this integrated fossil energy scenario depend on demonstrated availability of commercial-scale CO_2 storage capacity in the state. The added value, or additional worth, of the CO_2 storage-dependent energy resource production is estimated at $442 billion. Construction of the facilities described in the above scenario will cost $20 billion to $40 billion. This scenario focuses on CO_2 storage, but its benefit to the coal, oil, and natural gas industries is huge, as are the associated increased state revenues and economic robustness. $45 million is a small price to pay to demonstrate a technology pivotal to optimizing responsible development of Wyoming's energy/natural resource portfolio in the 21st century – a tremendous economic opportunity.

Scope

Work will focus on developing a full-scale, commercial CO_2 storage site in southwestern Wyoming. This important "to-scale" project will reduce the development time, costs, and risks associated with proving that a site has the capacity, injectivity, and containment mechanisms necessary for commercial carbon storage by using large volumes of injected water as a surrogate for CO_2. The project will demonstrate the viability of meeting the critical performance criteria required for site certification without the cost, liability, and long-term stewardship complications implicit in a large-scale CO_2 injection test. Operations will include drilling two injection wells constructed to UIC Class VI specifications but covered under UIC Class I, and one monitoring/

water production well, and converting the existing RSU #1 well for monitoring the Weber/Madison and producing fluid from the Nugget Formation. Staged go/no-go decision points will further reduce risk (see **Appendix 2**). The Weber/Madison dual-purpose monitoring/fluid production well will be drilled as a key component of a pressure management program necessitated by commercial-scale injection. In each injection well, a minimum of one million tons of H_2O will be injected over a period of two years into the "deep" Weber/Madison reservoir intervals at the Rock Springs Uplift site.

Assuming that these injection volumes and rates can be maintained in the Phase II injection wells, nine similar injection wells could handle 8–10 million tons of CO_2 per year. This capacity could help the Jim Bridger power plant comply with any potential new "clean coal" standards established by the federal government in the future.

The new monitoring/fluid production well will not only allow researchers to manage up-dip pressure, but will also serve as a source of formation brines for use in testing – at field scale – the facility designed for formation brine production and surface treatment of Weber/Madison formation waters.

Specific activities for Phase II include, but are not limited to, the following:

- Develop a strategy, plan, and campaign to raise the financial match for the funds made available by the Wyoming Legislature. At present, we are engaged in serious discussions with several possible corporate partners. Once permission is granted by the Legislature and UW – including the Energy Resources Council (ERC) – to proceed with WY-CUSP Phase II, CMI will accelerate efforts to raise the match with industry, federal entities, and private foundations. It is understood that a match is required before any of the CO_2 storage funds provided by the state may be spent.

- Revise and expand the existing single-well subsurface geologic model underlying the 25-square-mile site with data obtained in the staged drilling program (Phase II) using high performance computing capabilities to reduce field development risk and cycle time.

- Develop all materials necessary for obtaining permits associated with the large-volume water injection test, and prepare required NEPA and UIC documentation to the satisfaction of the Wyoming Oil and Gas Conservation Commission, the Wyoming Department of Environmental Quality (DEQ), the State Engineer's Office, and other vested agencies. It is important to note that during the decade spanning the years 2000 through 2010, 40,000 water well permit applications were active, and 164 wells were classified for industrial use.

- Drill, core, log, and complete two injection wells and one monitoring/Weber-Madison fluid production well at the Rock Springs Uplift site, with each well currently expected to be approximately 13,000 feet deep. Modify the existing RSU #1 well for monitoring of the Weber/Madison and fluid production from the Nugget. Pre-determined go/no-go decision points will mitigate field development risks (**Appendix 2**).

- Using two injection wells, inject 1 million tons/year of H_2O (Nugget Formation fluids > 10,000 ppm TDS) for two years. As part of this effort, monitor, model, and evaluate the efficacy of the injection and storage reservoir dispersion processes. Monitor and evaluate operating costs and issues associated with the equipment and infrastructure used in the process. Modify monitoring and modeling procedures as appropriate.

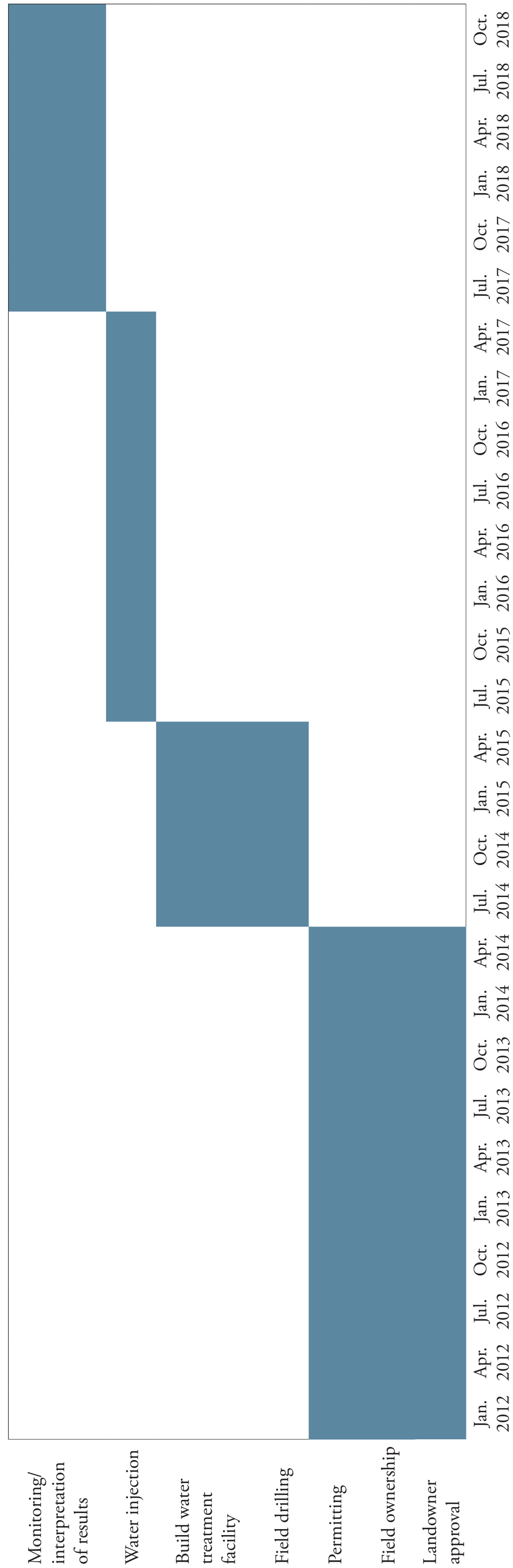
- Develop and validate monitoring, verification, and accounting (MVA) techniques relevant to using H_2O as the test medium and H_2O/CO_2 sensor response correlations.

- Develop best practices engineering documentation and continue to improve characterization of other regional formations for CO_2 and natural gas storage, as well as examine storage opportunities with additional state partners.

- Continue public outreach and educational efforts related to CO_2 and natural gas storage, and use of stored CO_2 for enhanced oil recovery. CMI will continue to build and expand relationships with local communities near the project site; state, federal, and local officials and agencies; non-governmental organizations; industry; and other relevant stakeholders.

Budget and timeline
The proposed project budget and timeline appear on the next two pages.

WY-CUSP Phase II proposed timeline



WY-CUSP Phase II Budget

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
Personnel		FTE		FTE		FTE		FTE		FTE		FTE
Director	70,000	33	70,000	33	70,000	33	105,000	50	105,000	50	105,000	50
Deputy Director	25,000	33	25,000	33	25,000	33	37,500	50	37,500	50	37,500	50
R.S. - Geologist	45,000	50	45,000	50	45,000	50	90,000	100	90,000	100	90,000	100
R. S. - Geophysist	24,676	33	24,676	33	24,676	33	37,014	50	37,014	50	37,014	50
R. S. - Geologist	23,344	33	23,344	33	23,344	33	35,016	50	35,016	50	35,016	50
R. S. - Water	23,344	33	23,344	33	23,344	33	35,016	50	35,016	50	35,016	50
R. S. - Petrology	23,344	33	23,344	33	23,344	33	35,016	50	35,016	50	35,016	50
R. S. - Visualization	23,344	33	23,344	33	23,344	33	35,016	50	35,016	50	35,016	50
Publications Coordinator	17,168	33	17,168	33	17,168	33	25,752	50	25,752	50	25,752	50
Business Manager	15,008	33	15,008	33	15,008	33	22,512	50	22,512	50	22,512	50
Total Personnel	290,228		290,228		290,228		457,842		457,842		457,842	
Benefits	132,228		132,228		132,228		208,593		208,593		208,593	
Travel	40,000		40,000		40,000		40,000		40,000		40,000	
Equipment	30,000		30,000									
Supplies	10,000		10,000		10,000		10,000		10,000		10,000	
Contractual												
Drilling Company			42,000,000									
Seismic									2,000,000			
Water Production Facility			10,000,000									
Infrastructure (Roads)			500,000		500,000							
Pipe/Pressure/Surface			5,000,000									
Permitting/Land owner	250,000		250,000									
Land Leases	4,000,000											
Mitigation/Reclamation											2,000,000	
Insurance	1,000,000		1,000,000		1,000,000		1,000,000		1,000,000		1,000,000	
Total	5,752,456		59,252,456		1,972,456		1,716,435		3,716,435		3,716,435	
Total Project Cost	$ 76,126,672											

Appendix I

Feds give university $5M more for coal research, Dustin Bleizeffer, *Casper Star Tribune*, 9/8/10.

Rock Springs meeting looks at carbon sequestration study, Star-Tribune staff, *Casper Star Tribune*, 11/17/10.

Officials: Rock Springs Uplift site ideal for carbon sequestration project, by Jeff Gearino, *Casper Star Tribune*, 11/18/10.

Wyoming officials have high hopes for carbon storage project, by Jeff Gearino, *Casper Star Tribune*, 11/19/10.

Wyoming clean coal efforts advance, Jeremy Fugleberg, *Casper Star Tribune*, 2/10/11.

Drilling to begin Sunday at carbon storage project site, (4/22/11), http://www.captureready.com.

Drilling to begin at Wyoming carbon storage project, Carbon Capture Journal, 4/27/11, (http://www.carboncapturejournal.com)

Baker Hughes resumes carbon storage test well, by Dustin Bleizeffer, *Wyofile* (http://wyofile.com; June 2011).

CMI sees saltwater dreams in Sweetwater County, by Seneca Flowers. *Wyoming Business Report* (6/22/11).

Drilling to start in US carbon dioxide storage project, Bellona, http://www.bellona.org/news. (Sweden/Norway)

Tests begin at Wyo. carbon storage site as challenges loom large, by Emanuele Bompan and Lucy Flood of SolveClimate News. Published in *InsideClimate News* (http://insideclimatenews).

> This story has been reprinted by numerous other news outlets, including Reuters (international), www.planetprofitreport.com (international), www.emanuelebompan.eu/index1.php (Italy), Wyoming Energy News (8/11/11), the Global CCS Institute, and others.

From gold to carbon, Aerin Curtis, *Wyoming Tribune Eagle*, 8/4/11.

Scientists from UW Carbon Management Institute to speak at Chinese conference, http://www.uwyo.edu/news (9/6/11).

CMI, Baker Hughes complete drilling at the Wyoming carbon storage project, by EBR staff writer. *Energy and Business Review* (9/14/11), http://carbon.energy-business-review.com.

University of Wyoming completes drilling and data collection, by Garrett Adams, KOWB 1290 (http://kowb1290.com; 9/16/11).

Drilling complete at WY-CUSP site in southwestern Wyoming, staff. *Rock Springs Rocket Miner,* (9/17/11).

Wyoming CO_2 storage project completes drilling, Carbon Capture Journal, (9/18/11).

CMI completes Wyoming CO_2 storage project drilling, by Anivash Tripathi, http://topnews.net.nz (New Zealand; 9/19/11).

Drilling complete at CO_2 storage study site, by staff, *Wyoming Business Report,* (9/20/11), http://www.wyomingbusinessreport.com).

Wyoming Public Radio, *Open Spaces*: 10/18/11, 7/8/11, and 3/19/10.

Appendix 2

Go/No-go points for WY-CUSP Phase II
Anticipated timeframe: January 2012 – December 2018

1. Landowner approval
   - Anticipated date: June 2013
   - Determining factor: If appropriate surface and sub-surface approval is not received, the project will not proceed.

2. Well ownership for field demonstration
   - Anticipated date: June 2013
   - Determining factor: If ownership of the field is not secured for the demonstration, the project will not proceed.

3. Permitting
   - Anticipated date: June 2014
   - Determining factor: If injection/production wells cannot be permitted appropriately, the project will not proceed.