Site characterization of the highest-priority geologic formations for CO_2 storage in Wyoming

DOE Project DE-FE0002142

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University of Wyoming Carbon Management Institute

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

Benefit to the program

- Program goals addressed

  Developing site characterization methods that support industry's ability to predict CO_2 storage capacity in geologic formations to within 30% on the Rock Springs Uplift in southwestern Wyoming

- Benefits statement

  This project will provide a complete, detailed characterization of the CO_2 storage potential of two deep saline aquifers (the Madison Limestone and Weber Sandstone) at a site on Wyoming's Rock Springs Uplift. This characterization will contribute to the Carbon Storage Program's effort to provide industry with the information necessary to accurately assess CO_2 storage capacity in geologic formations across the US.

Project overview

This project will provide detailed characterization of two deep saline aquifers on the Rock Springs Uplift of southwest Wyoming.
A comprehensive description of these aquifers will support the measurement and validation of reservoir characteristics to create baseline assessments that could directly support future industrial CCS injection operations in the region/storage formations.

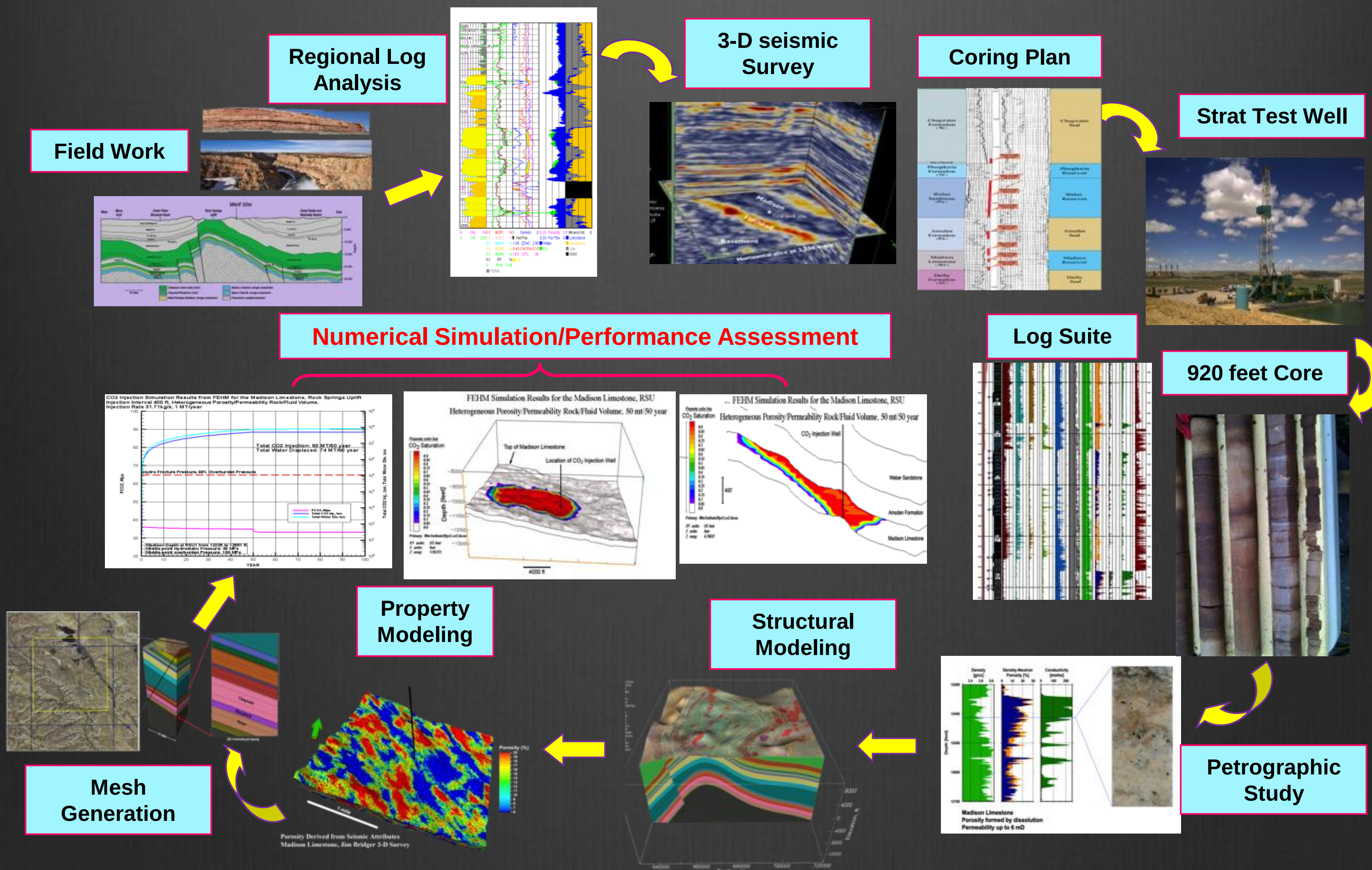
The following activities are included in the scope of work:

- Design and plan a sub-commercial CO_2 storage facility (ongoing)
- Research and identify commercial sources of CO_2 (ongoing).
- Compare FEHM and Eclipse numerical simulations using data obtained from the stratigraphic test well on the Rock Springs Uplift (complete).
- Design an efficient customized displaced water treatment facility based on new characterization information. This will include a displaced fluid management plan, which is critical for successful injection of commercial quantities (tens of millions of tons) of CO_2 (ongoing).

Project overview (cont.)

- Design and acquire 3-D/3-C seismic data and other geophysical surveys of the Rock Springs Uplift (RSU) to complement data previously obtained for the Rock Springs Uplift (complete).
- Design and complete a stratigraphic test well on the Rock Springs Uplift in order to obtain wireline logs, core, and cuttings (complete).
- Acquire a complete well log suite (complete).
- Design and complete the stratigraphic test well as a monitoring well (in progress).
- Design additional injection, monitoring, production and demonstration wells for the Rock Springs Uplift (ongoing).
- Complete detailed risk assessments and design commercial-scale sequestration projects for the site based on interpretations of the geophysical data, and on field and laboratory studies, measurements, and experiments on core and fluids (ongoing).

Rock Springs Uplift, Wyoming: an outstanding geological CO_2 storage site



R.C. Surdam[1], Z. Jiao[1], Y. Ganshin[1], R. Bentley[1], S.A. Quillinan[1], J.F. McLaughlin[1], Mario Garcia-Gonzalez[1], P. Stauffer[2], H. Deng[2]

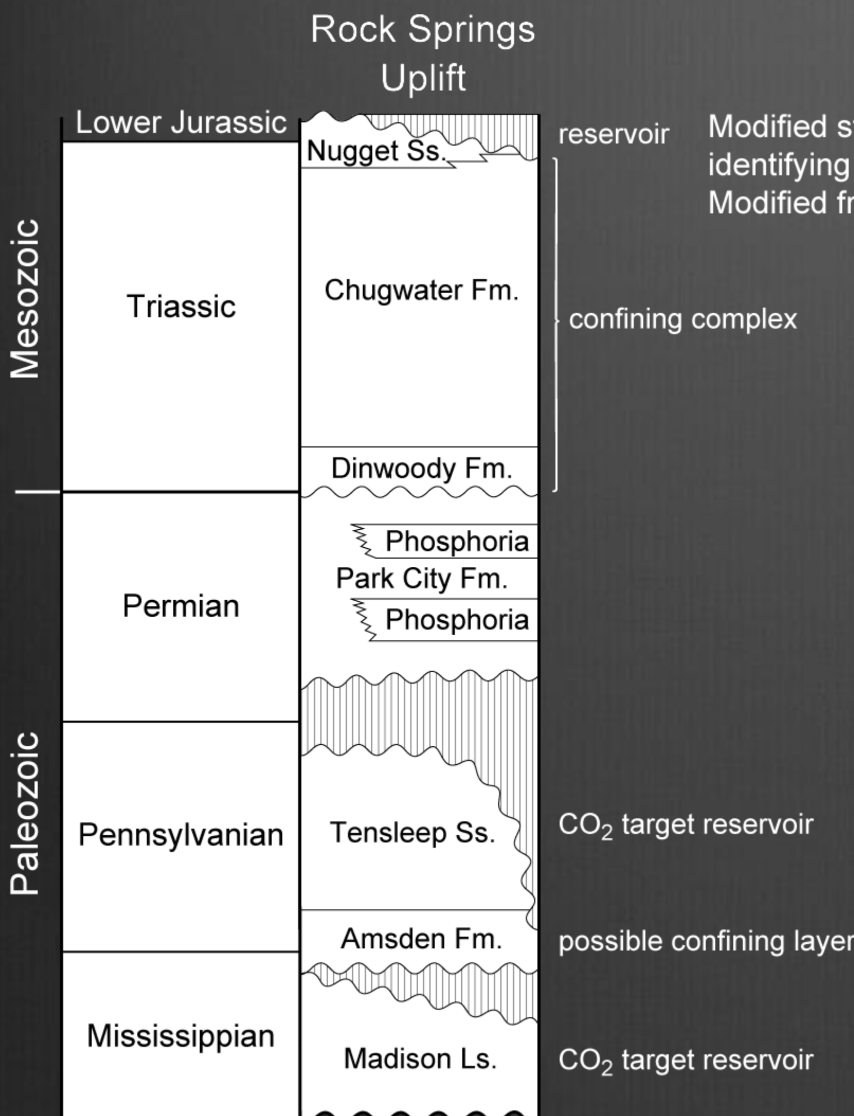
[1]University of Wyoming Carbon Management Institute, [2]Los Alamos National Laboratory

Partners and contributors

- Thank you to the crew from Baker Hughes, Inc., including Paul Williams, Sam Zettle, Dana Dale, and Danny Dorsey
- TRUE Drilling Co. of Casper, WY provided the large rig and an excellent drilling crew.
- The WY-CUSP characterization project is funded in part by DOE NETL (Project DE-FE0002142). CMI would like to thank DOE Project Manager Bill Aljoe.
- Other contributors include Los Alamos National Laboratory, Lawrence Livermore National Laboratory, PetroArc International, New England Research, Geokinetics, EMTek, and the Wyoming State Geological Survey.

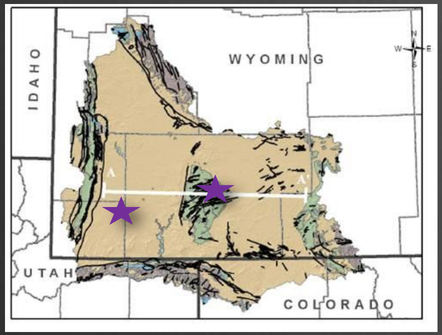
WY-CUSP program rationale

1. Protect Wyoming's coal extraction and future coal-to-chemical industries (provide storage capacity for anthropogenic CO_2)
2. Provide a source of anthropogenic CO_2 for enhanced oil recovery projects (at present rates of CO_2 production from gas processing plants, it will take 150 to 200 years to recover Wyoming's stranded oil)
3. Retrieve reservoir information essential for expansion of natural gas storage in Wyoming
4. Establish a more robust database for two important hydrocarbon reservoirs in Wyoming (substantially reduce uncertainty for all dynamic models of Tensleep-Weber/Madison fluid-flow and rock/fluid systems)

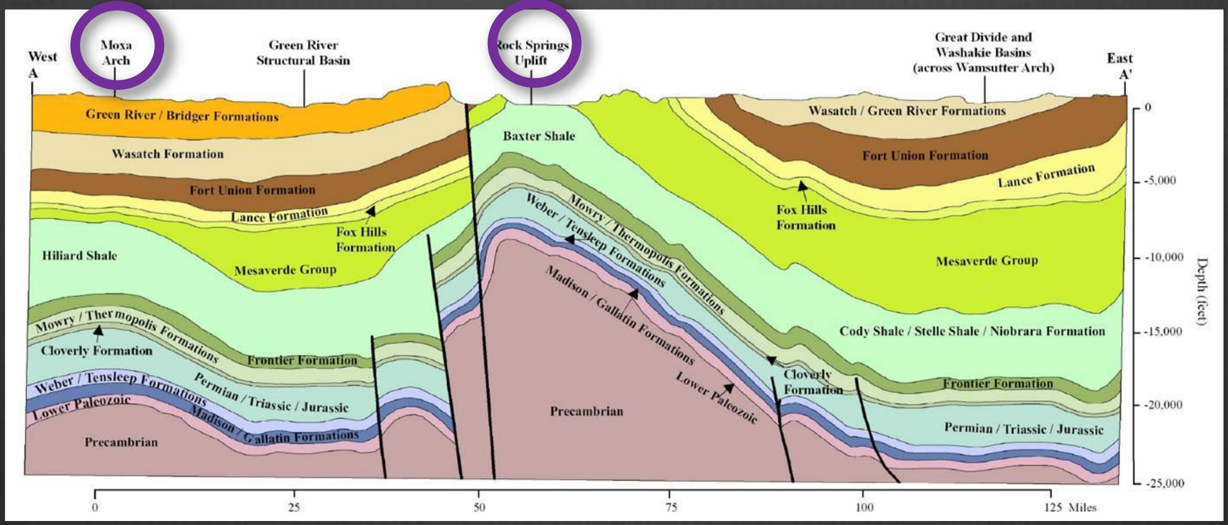


Modified stratigraphic column of the Rock Springs Uplift identifying possible confining layers and CO_2 target reservoirs. Modified from Love, Christiansen, and VerPloeg, 1993.

Carbon capture potential in southwest Wyoming



WSGS, UW, State, and DOE-funded research identified two high-capacity sites in southwest Wyoming: *Rock Springs Uplift* and *Moxa Arch*



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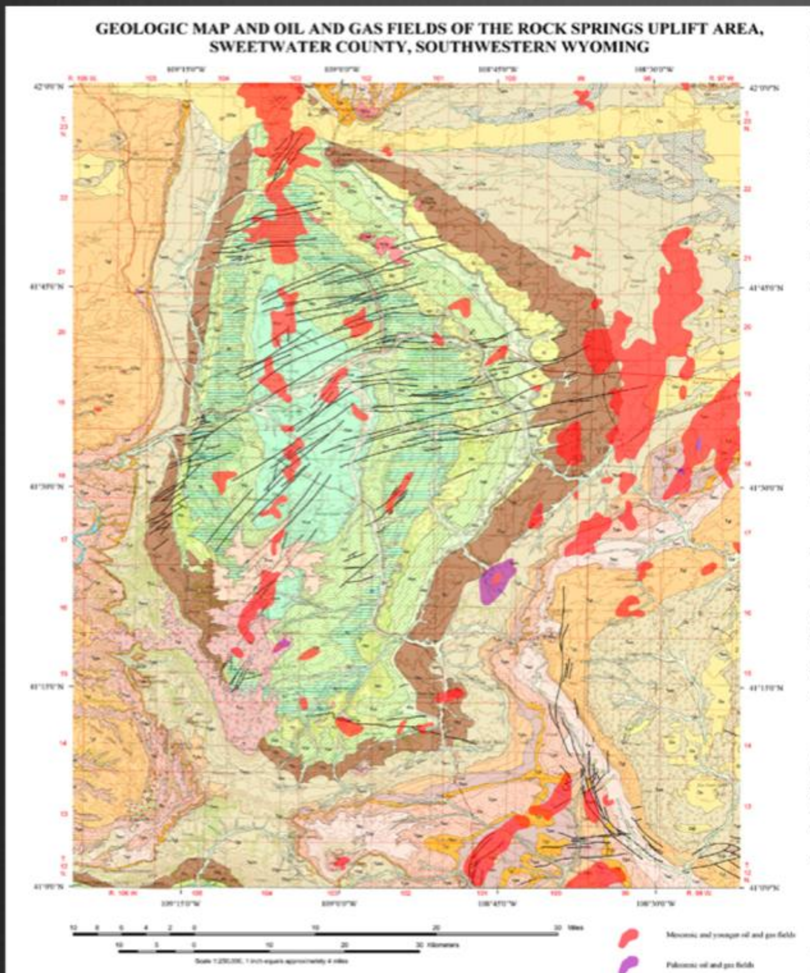
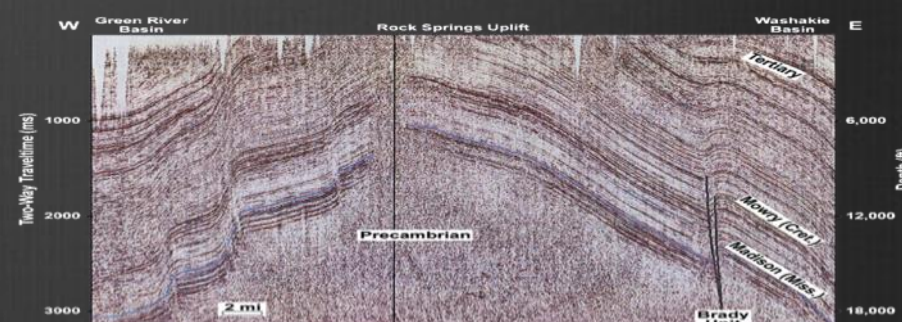
The Rock Springs Uplift: an outstanding geological CO_2 storage site in SW Wyoming



- Thick saline aquifer sequence overlain by thick sealing lithologies (8000 feet vertical separation between CO_2 storage reservoirs and fresh water aquifers)
- Doubly-plunging anticline characterized by more than 10,000 feet of closed structural relief
- Huge area (50 x 35 miles)
- Required reservoir conditions, including, but not limited to fluid chemistry, porosity (pore space), fluid-flow characteristics, temperature and pressure (i.e., regional burial history)



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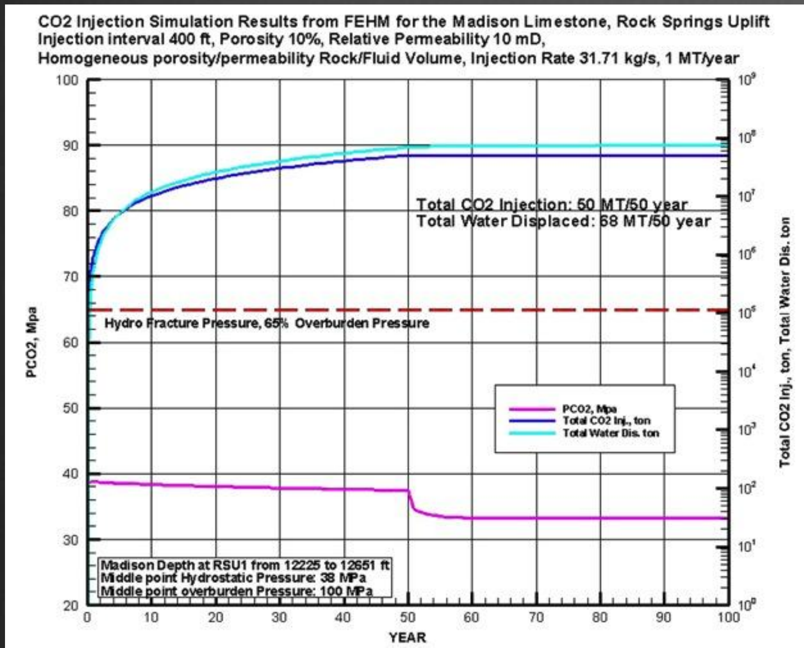
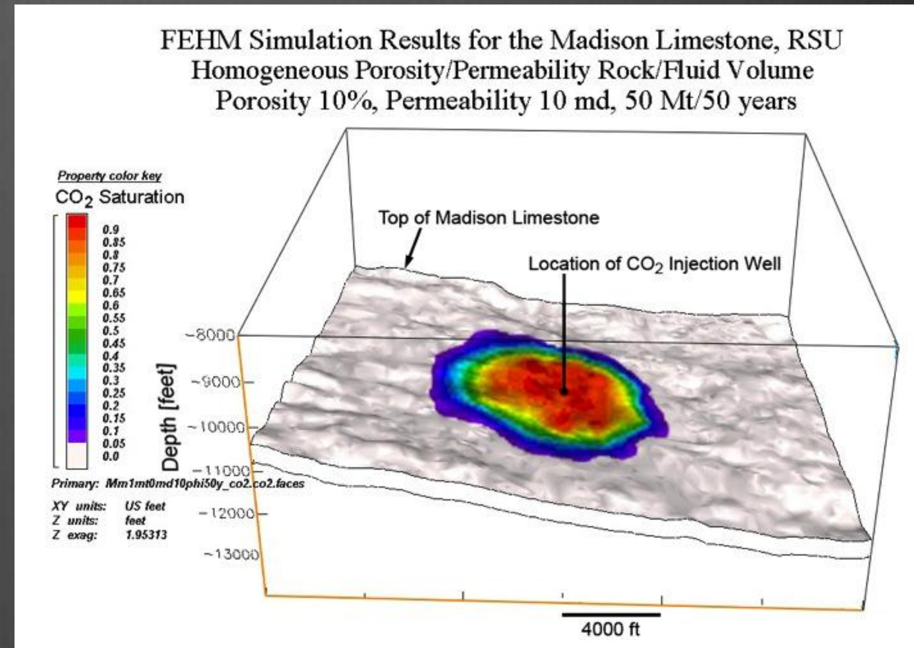
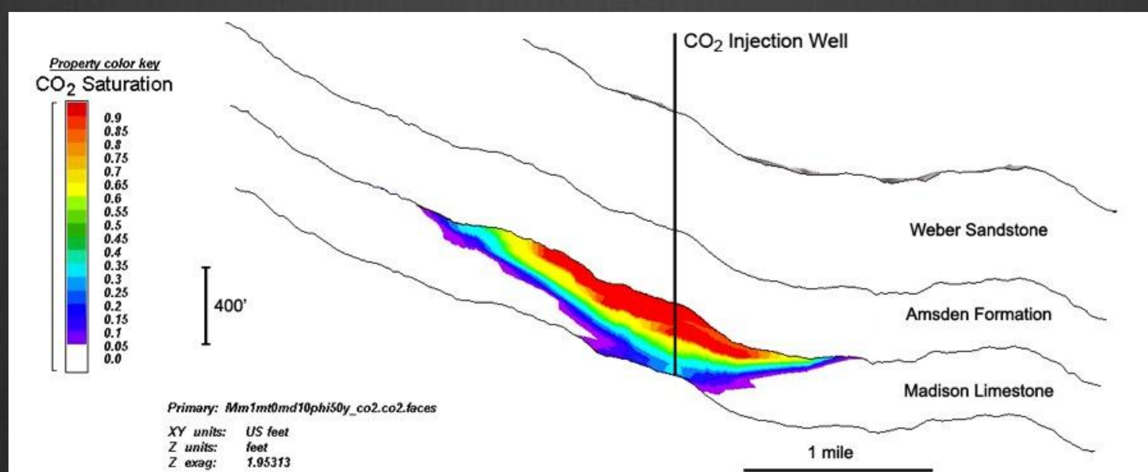

CO2 Injection Simulation Results from FEHM for the Madison Limestone, Rock Springs Uplift
Injection interval 400 ft, Porosity 10%, Relative Permeability 10 mD,
Homogeneous porosity/permeability Rock/Fluid Volume, Injection Rate 31.71 kg/s, 1 MT/year
Total CO2 Injection: 50 MT/50 year
Total Water Displaced: 68 MT/50 year
Hydro Fracture Pressure, 65% Overburden Pressure
PCO2, Mpa
Total CO2 Inj., ton
Total Water Dis. ton
Madison Depth at RSU1 from 12225 to 12651 ft
Middle point Hydrostatic Pressure: 38 MPa
Middle point overburden Pressure: 100 MPa
PCO2, Mpa
Total CO2 Inj., ton, Total Water Dis. ton
YEAR


FEHM Simulation Results for the Madison Limestone, RSU
Homogeneous Porosity/Permeability Rock/Fluid Volume
Porosity 10%, Permeability 10 md, 50 Mt/50 years
Property color key
CO_2 Saturation
Top of Madison Limestone
Location of CO_2 Injection Well
Depth [feet]
Primary: Mm1mt0md10phi50y_co2.co2.faces
XY units: US feet
Z units: feet
Z exag: 1.95313
4000 ft

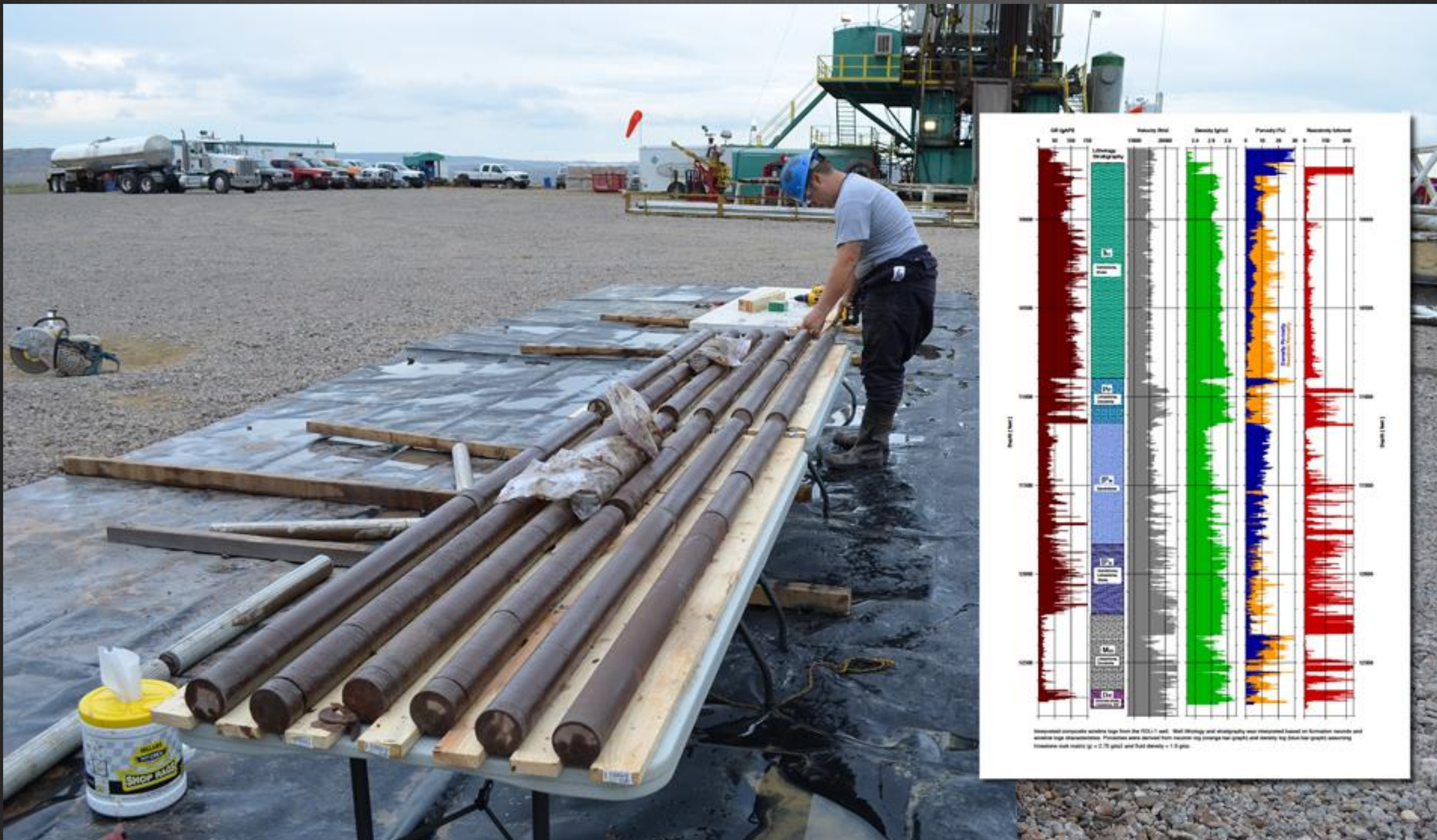

Property color key
CO_2 Saturation
CO_2 Injection Well
Weber Sandstone
Amsden Formation
Madison Limestone
400'
Primary: Mm1mt0md10phi50y_co2.co2.faces
XY units: US feet
Z units: feet
Z exag: 1.95313
1 mile

Risk reduction

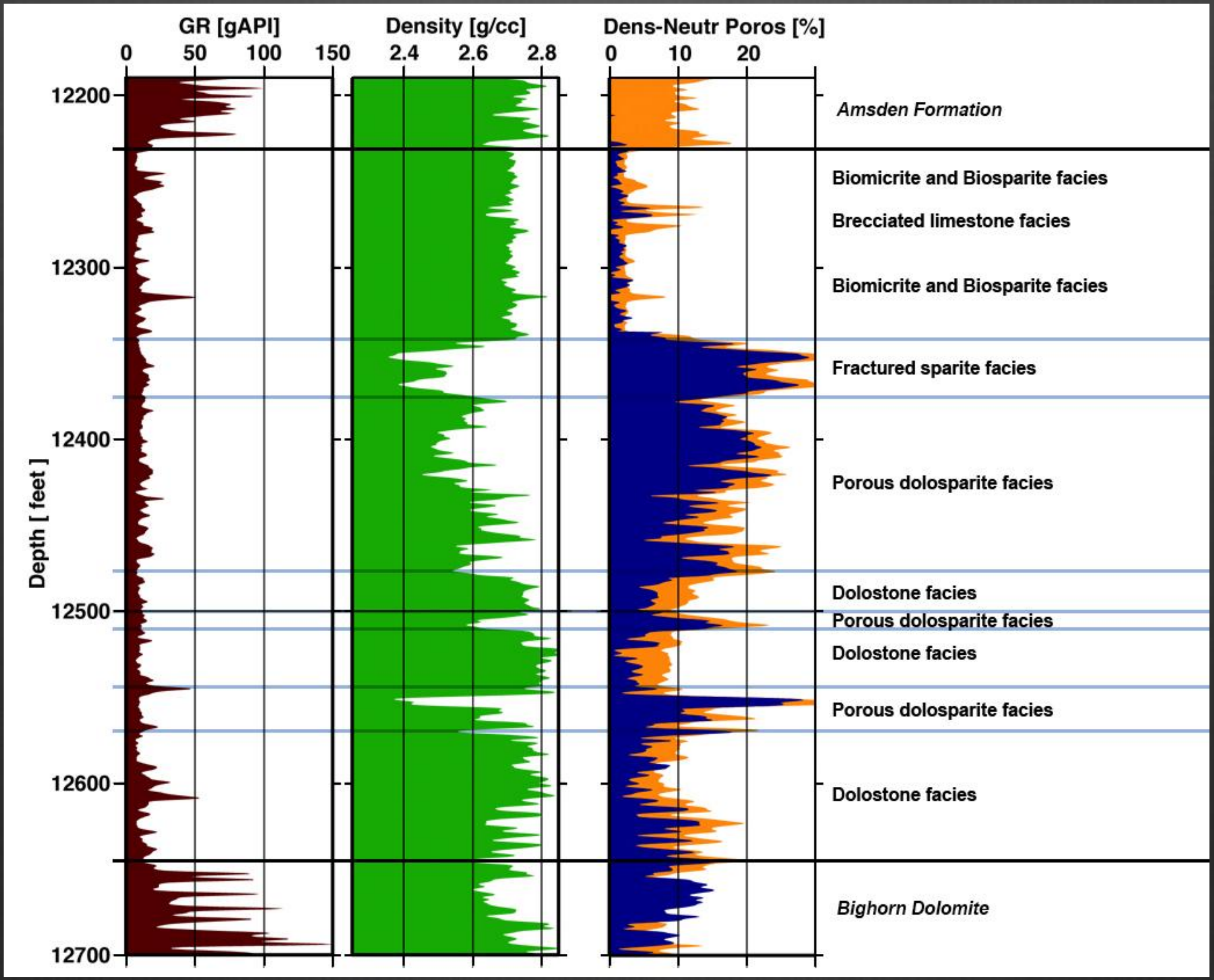
The greatest uncertainty in numerically simulating CO_2 sequestration processes is characterizing geological heterogeneity in three dimensions. This uncertainty is being substantially reduced by integrating 3-D seismic techniques with stratigraphic test well observations.

3-D seismic survey, Madison amplitude volume

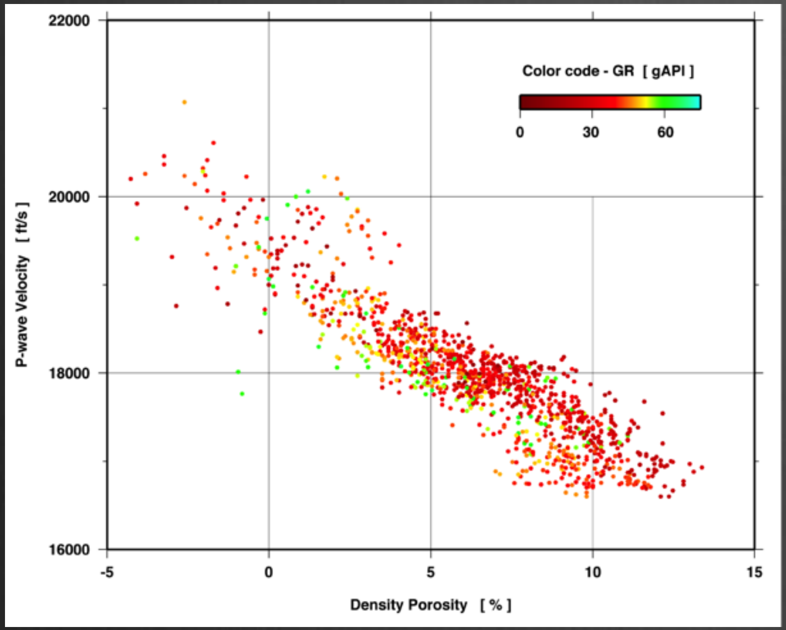
Interpretation of log suite/core



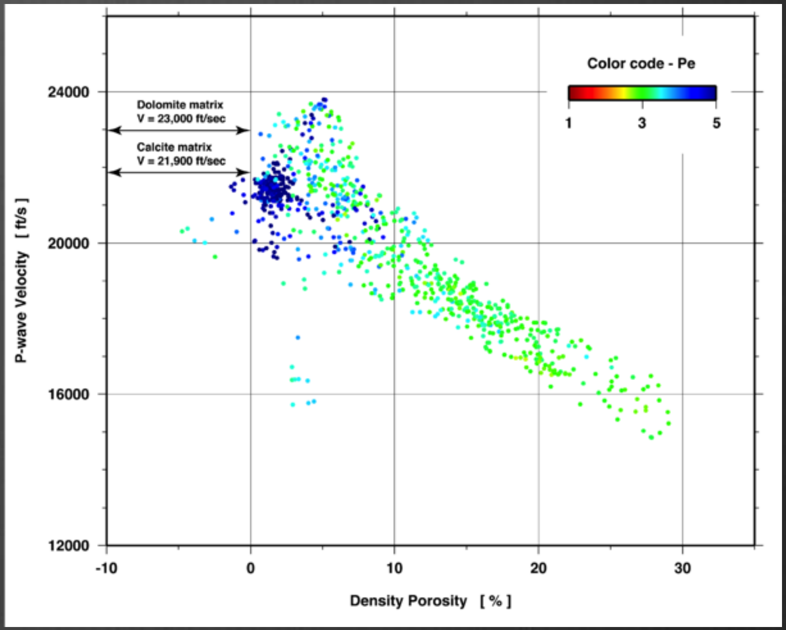
RSU-1 well: Madison Limestone Formation lithofacies zones



Sonic p-wave velocity vs. density porosity

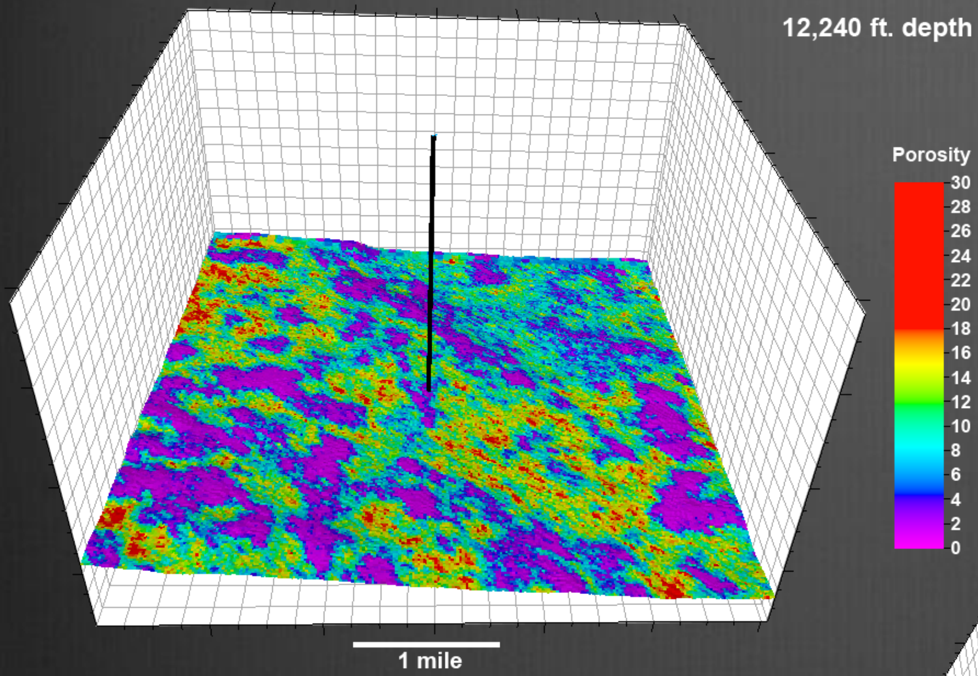


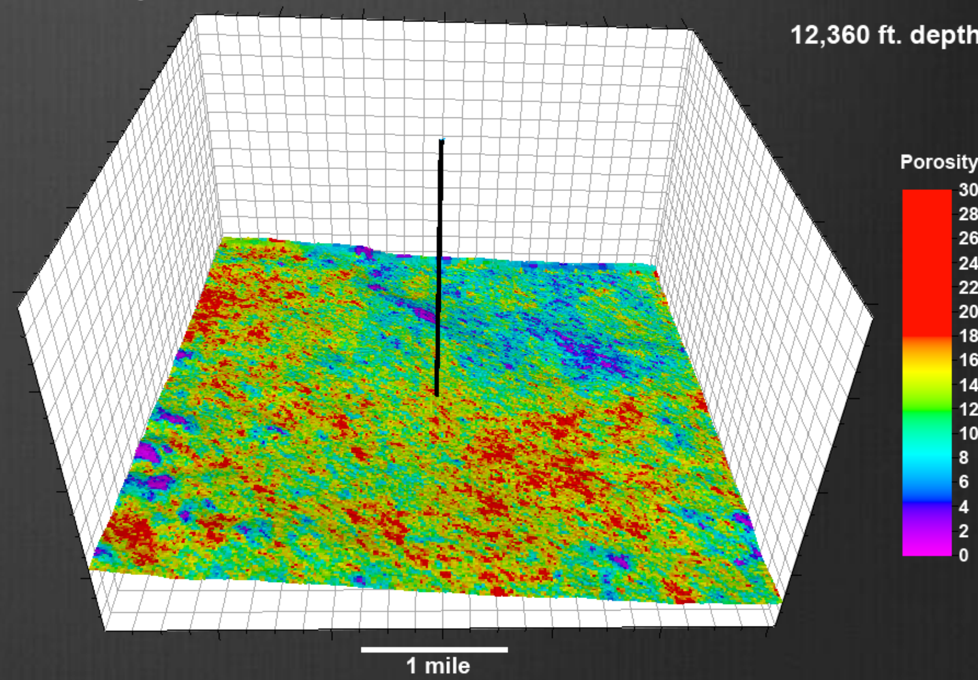
Weber Sandstone



Madison Limestone

Madison Limestone





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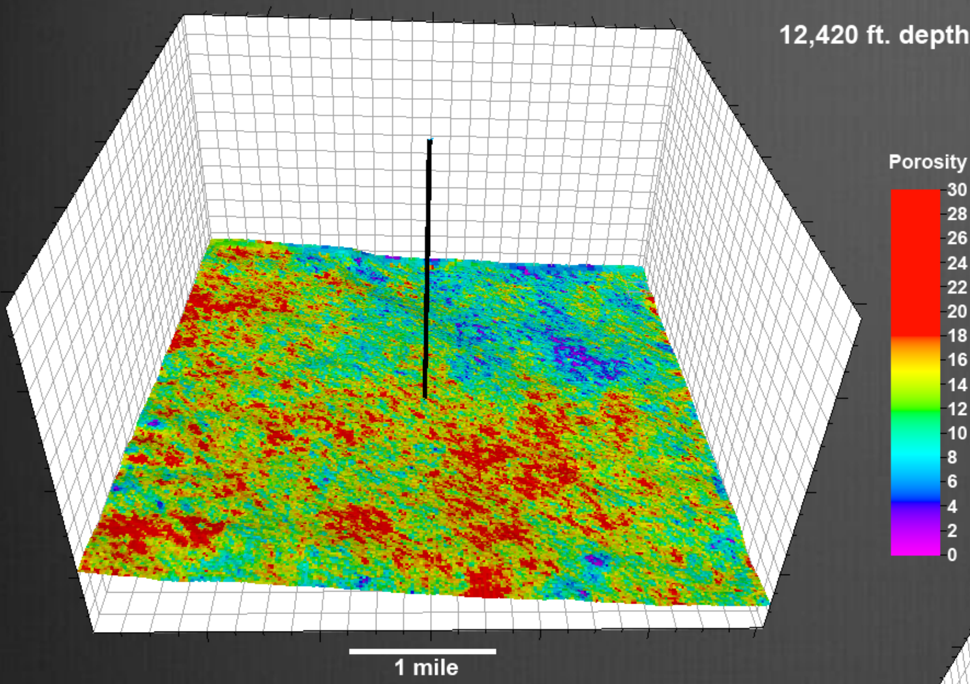
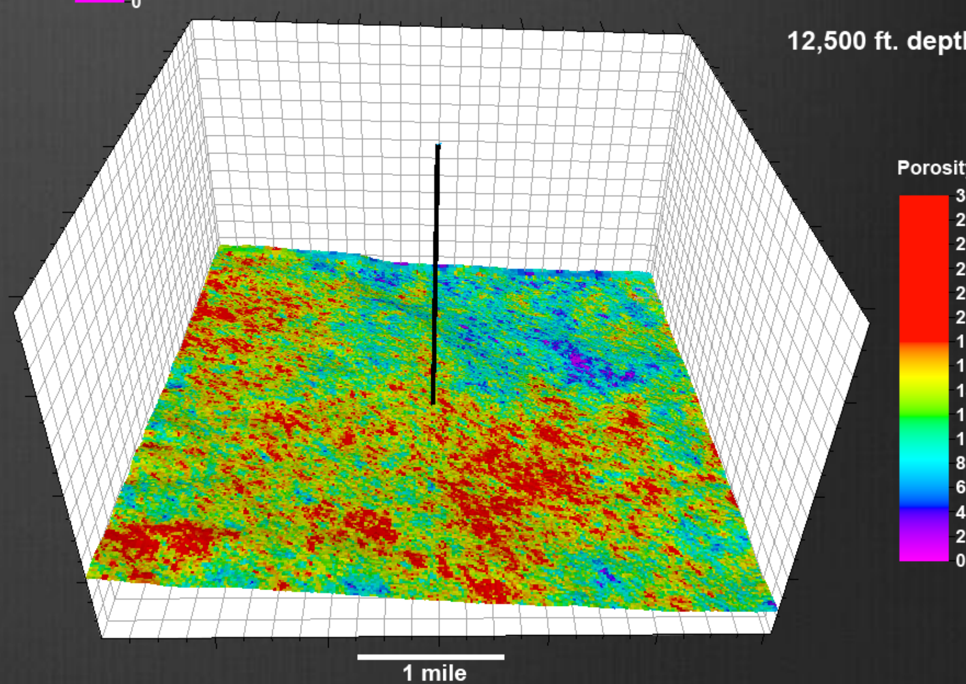
Madison Limestone





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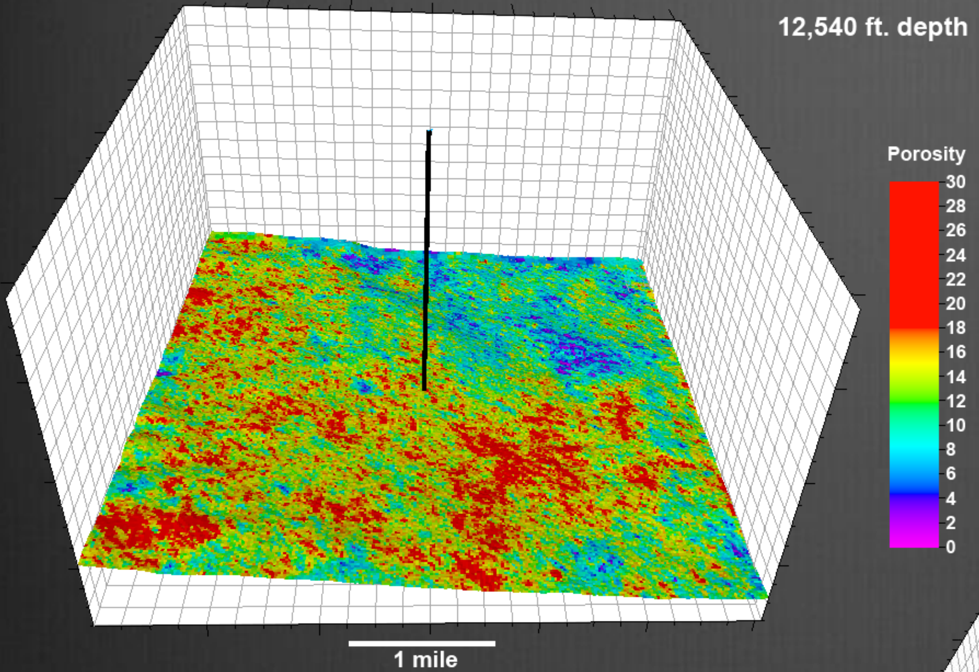
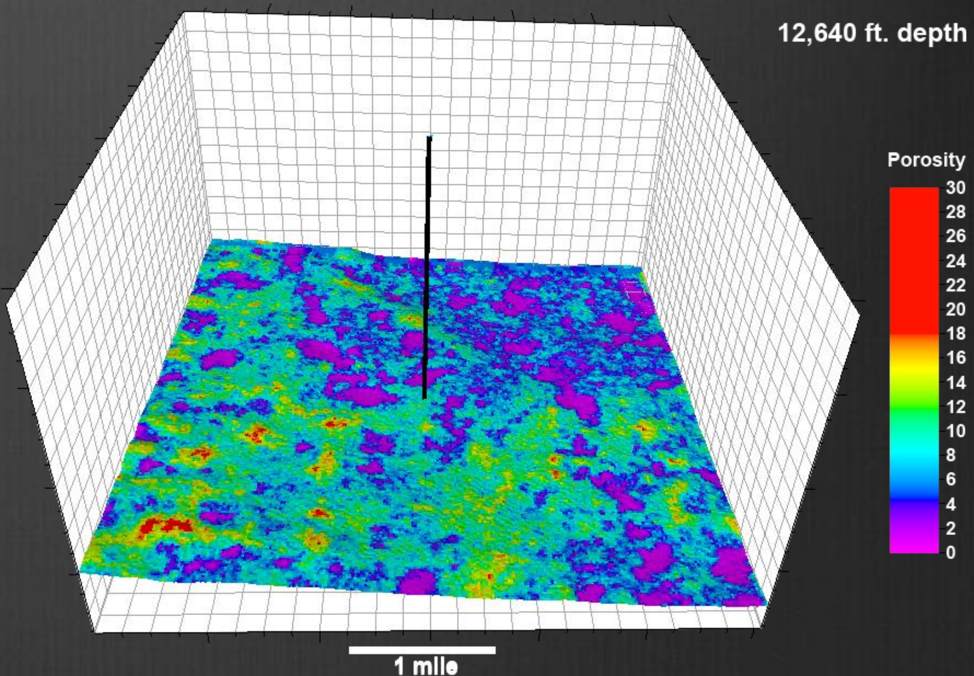
Madison Limestone





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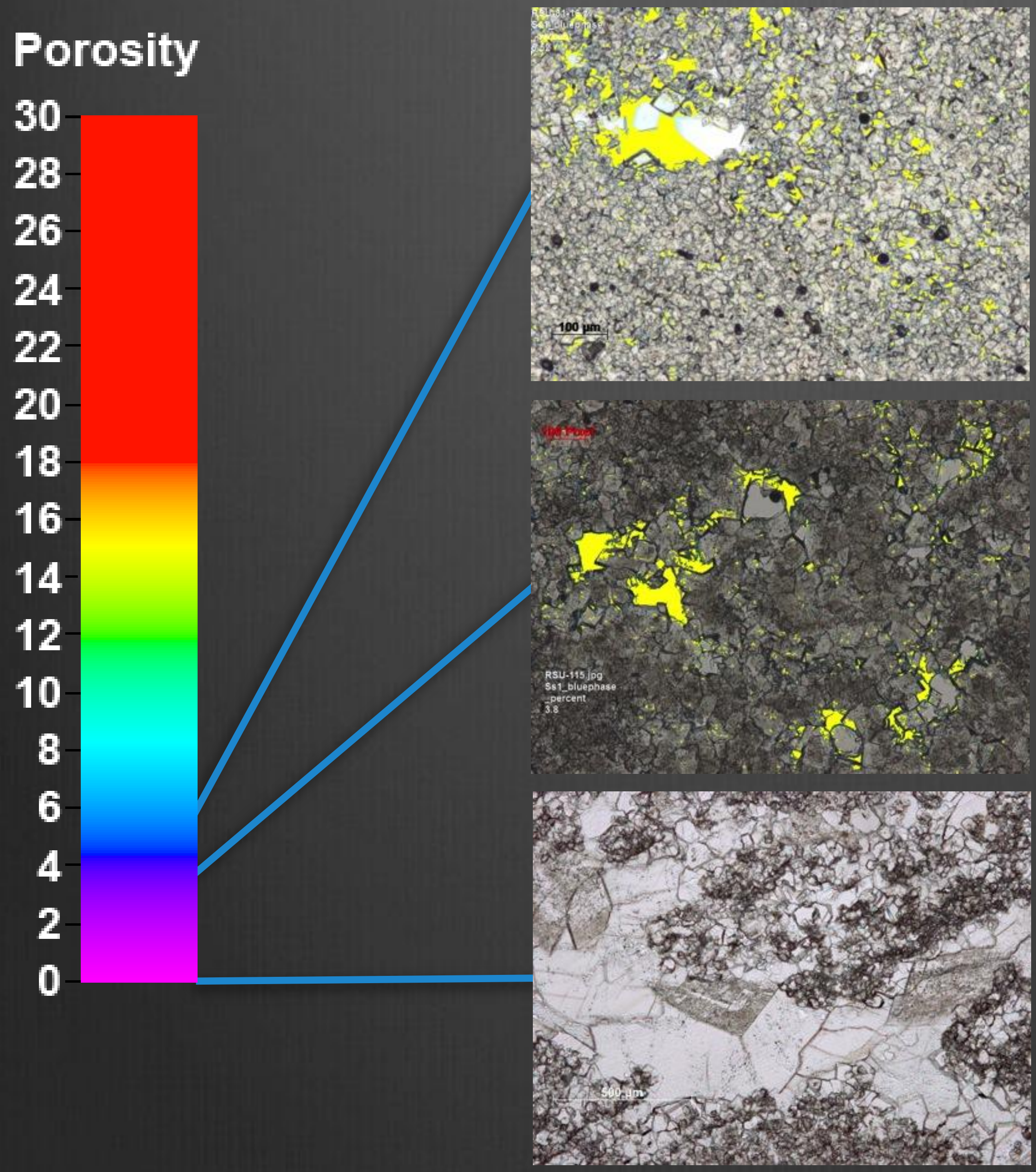
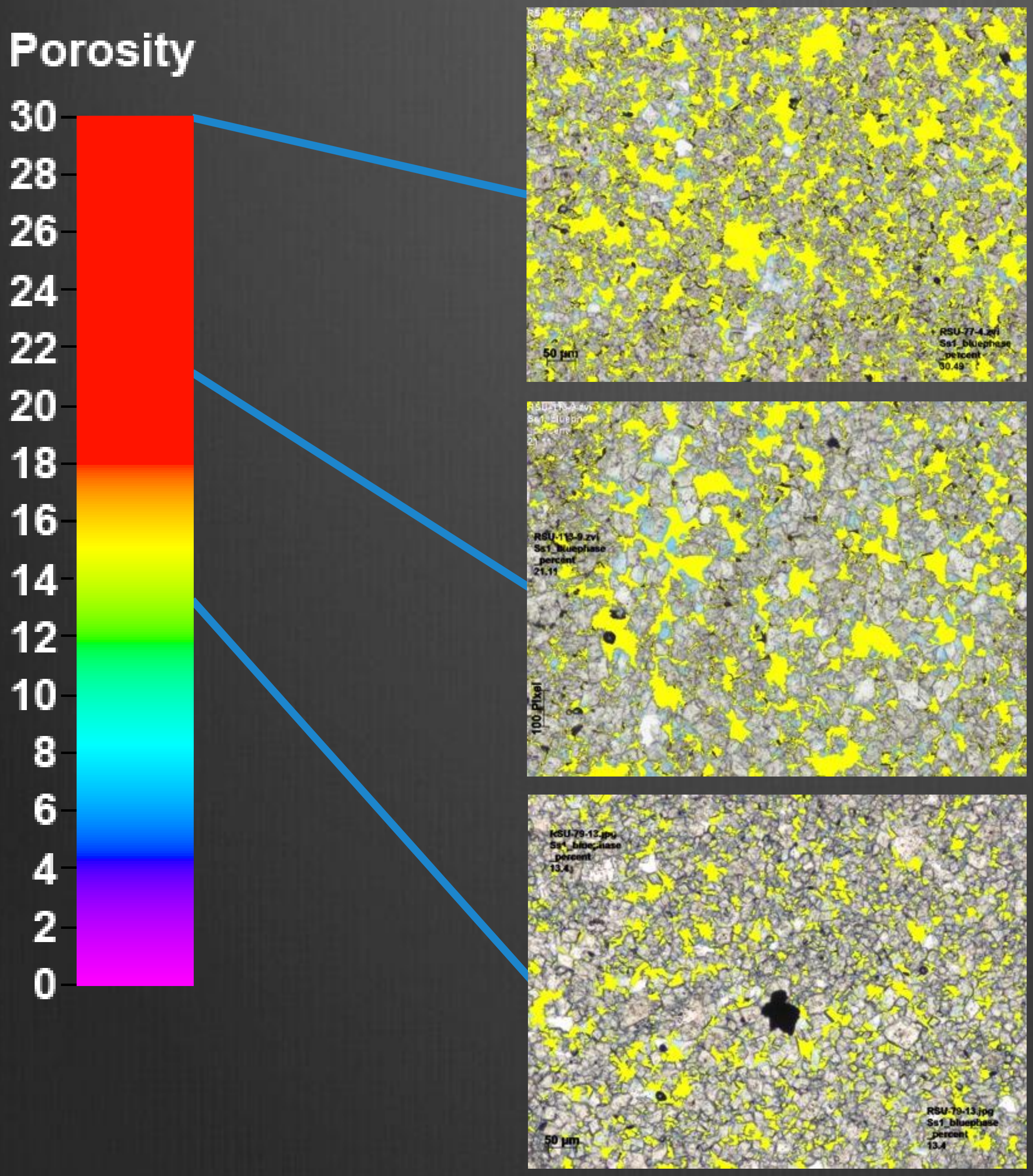


RSU-81
12,356.8 ft. depth
Madison Limestone
Porosity 5.5%

RSU-115
12,519.6 ft. depth
Madison Limestone
Porosity 3.8%

RSU-65
12,336.9 ft. depth
Madison Limestone
Porosity 0%



RSU-77
12,353.3 ft. depth
Madison Limestone
Porosity 30.5%

RSU-113
12,512.0 ft. depth
Madison Limestone
Porosity 21.1%

RSU-79
12,354.8 ft. depth
Madison Limestone
Porosity 13.4%

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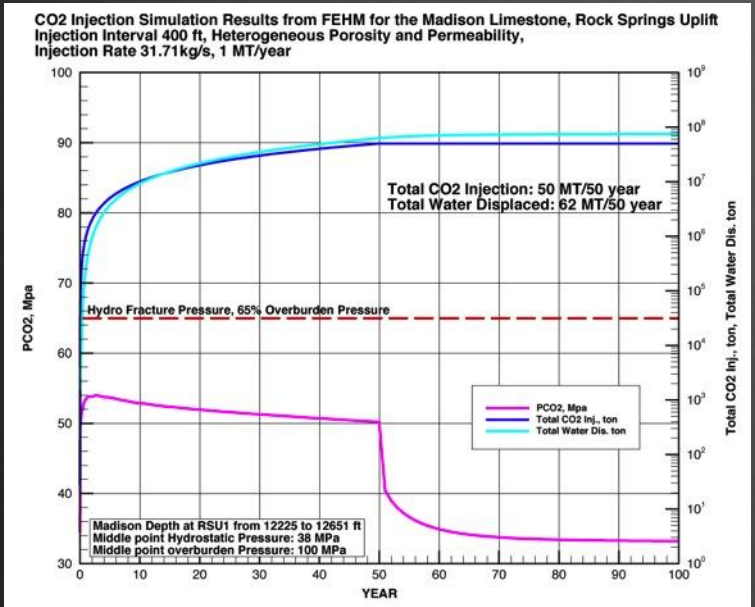
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Injection Interval 400 ft, Heterogeneous Porosity and Permeability,
Injection Rate 31.71kg/s, 1 MT/year
Total CO2 Injection: 50 MT/50 year
Total Water Displaced: 62 MT/50 year
Hydro Fracture Pressure, 65% Overburden Pressure
PCO2, Mpa
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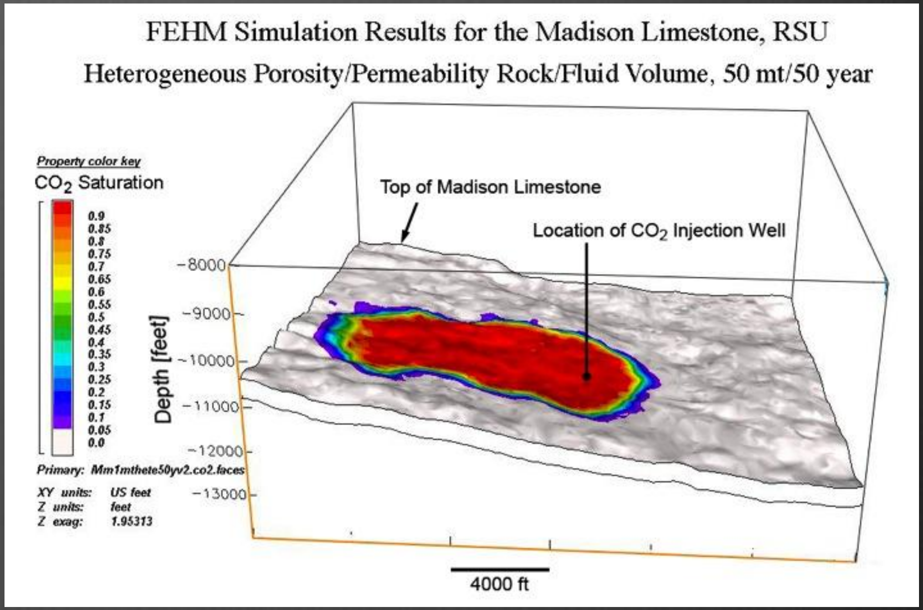
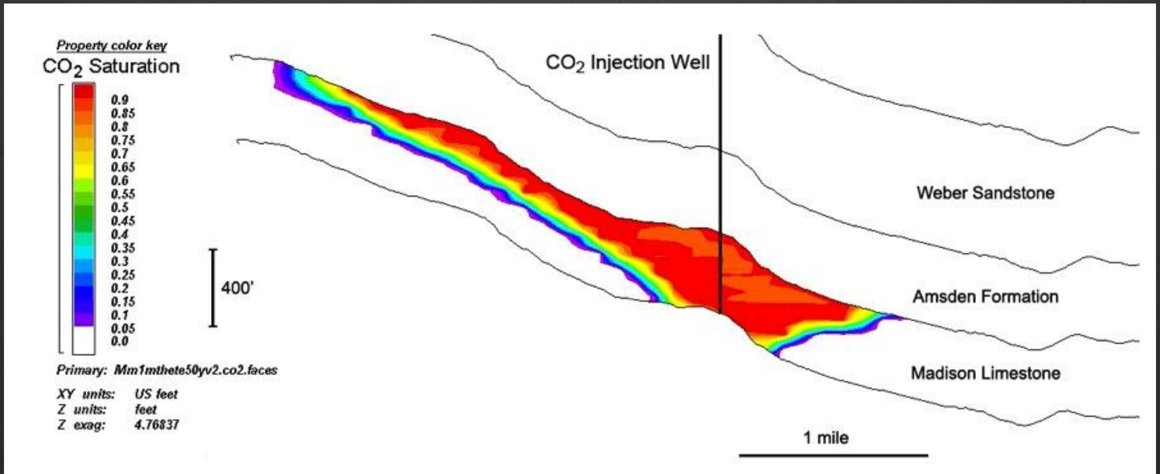
PCO2, Mpa
YEAR
Total CO2 Inj., ton, Total Water Dis. ton


FEHM Simulation Results for the Madison Limestone, RSU
Heterogeneous Porosity/Permeability Rock/Fluid Volume, 50 mt/50 year
Property color key
CO_2 Saturation
Top of Madison Limestone
Location of CO_2 Injection Well
Depth [feet]
Primary: Mm1mthete50yv2.co2.faces
XY units: US feet
Z units: feet
Z exag: 1.95313
4000 ft


Property color key
CO_2 Saturation
CO_2 Injection Well
Weber Sandstone
Amsden Formation
Madison Limestone
400'
Primary: Mm1mthete50yv2.co2.faces
XY units: US feet
Z units: feet
Z exag: 4.76837
1 mile

Future uncertainty reduction at the RSU gas storage site

Results from the following tests, analyses, and experiments will be integrated into the numerical simulations/performance assessments of the Weber/Tensleep and Madison reservoir intervals, overlying confining layers, and the RSU storage site:

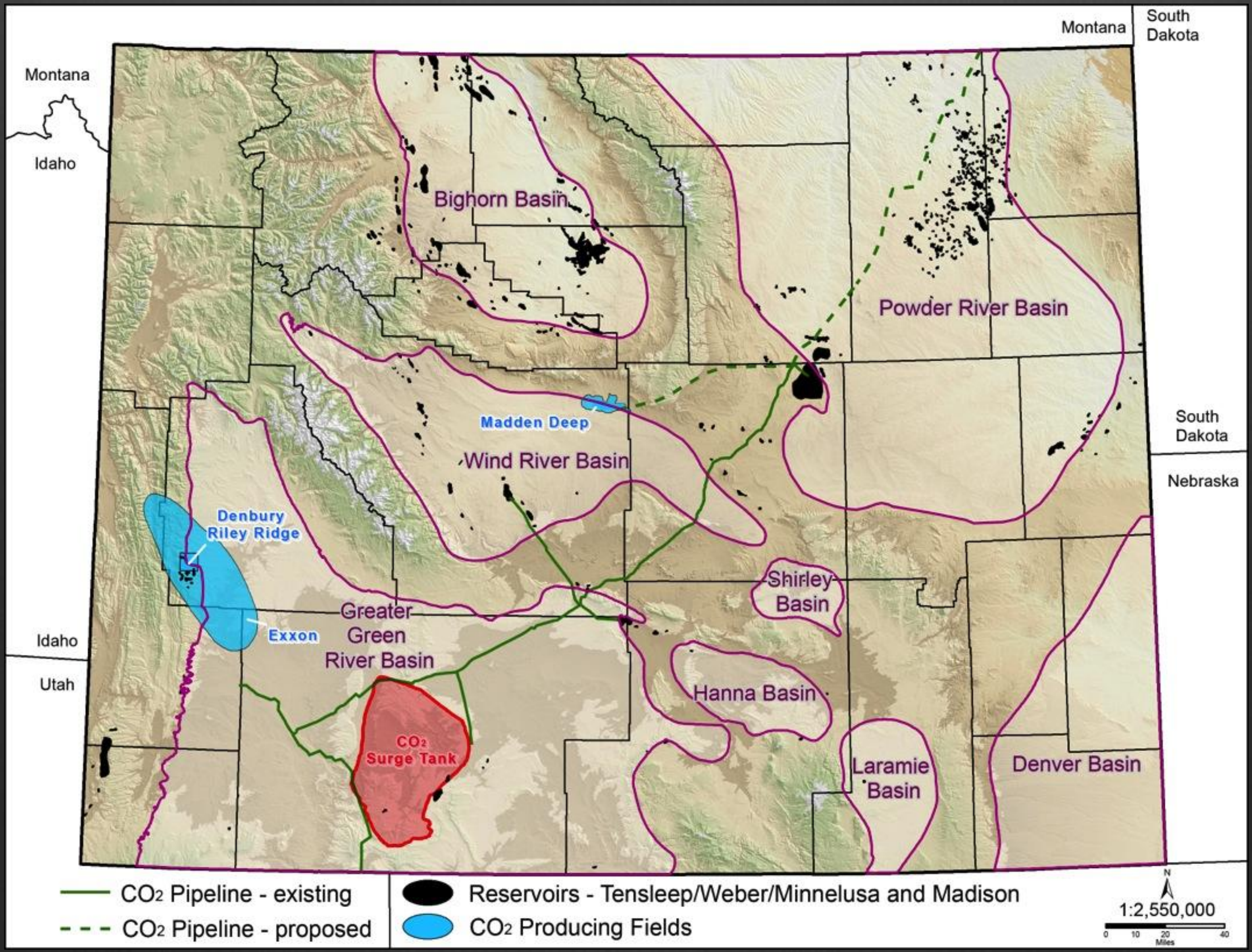
- Petrographic examinations
- Organic geochemical evaluations
- Geomechanical tests
- Porosity/permeability determinations (including capillary properties)
- Whole rock and isotopic analyses
- Rock/fluid reaction experiments

In addition, the RSU stratigraphic test well will be re-entered and drill stem tests and injectivity tests will be performed on the reservoir intervals. The availability and integration of this information should further reduce uncertainty associated with the characterization of the RSU as a gas storage site.

The WY-CUSP program

The ultimate goal of the WY-CUSP program is to deliver a certified commercial CO_2 storage site that could be used as a surge tank for CO_2 utilization.

Tensleep and Madison oil and gas fields in Wyoming: 2 – 4 billion barrels of stranded oil



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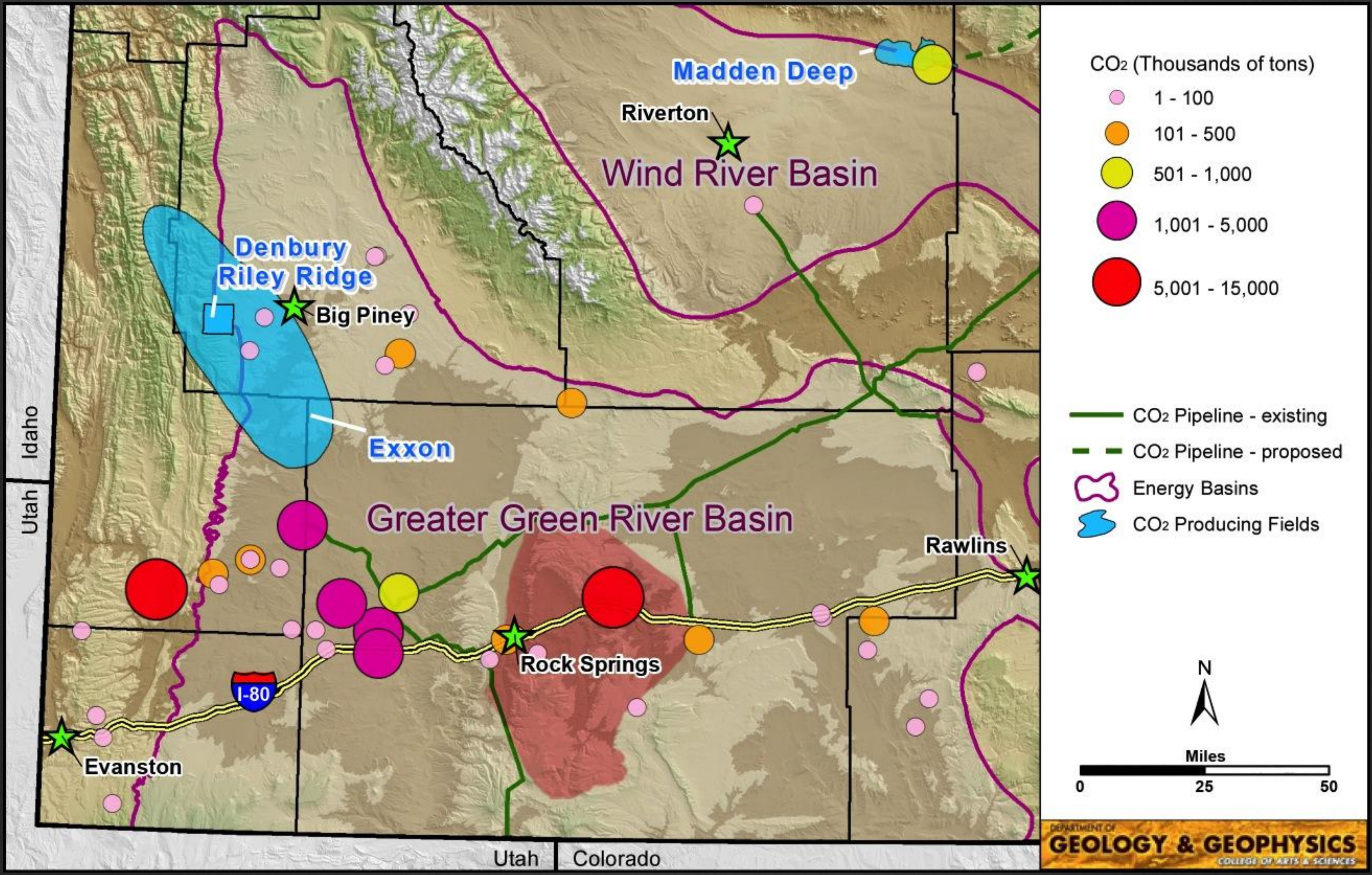
Major sources of CO_2 in SW Wyoming



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Wyoming CO_2 EOR (cont.)

CO_2 available to Wyoming starting in 2015

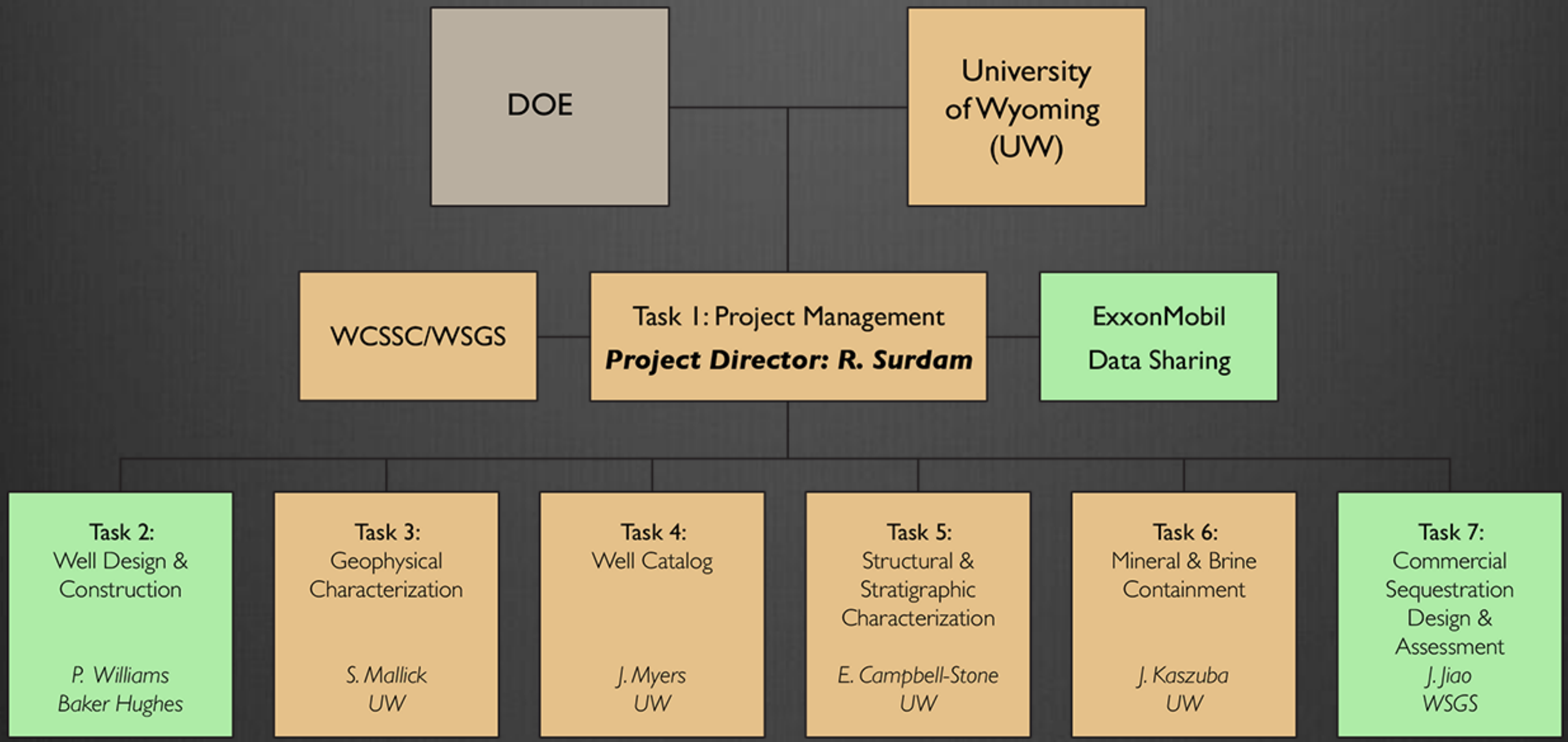
- 500 mmcf/day

How long will it take to recover Wyoming's stranded oil with potentially available CO_2?

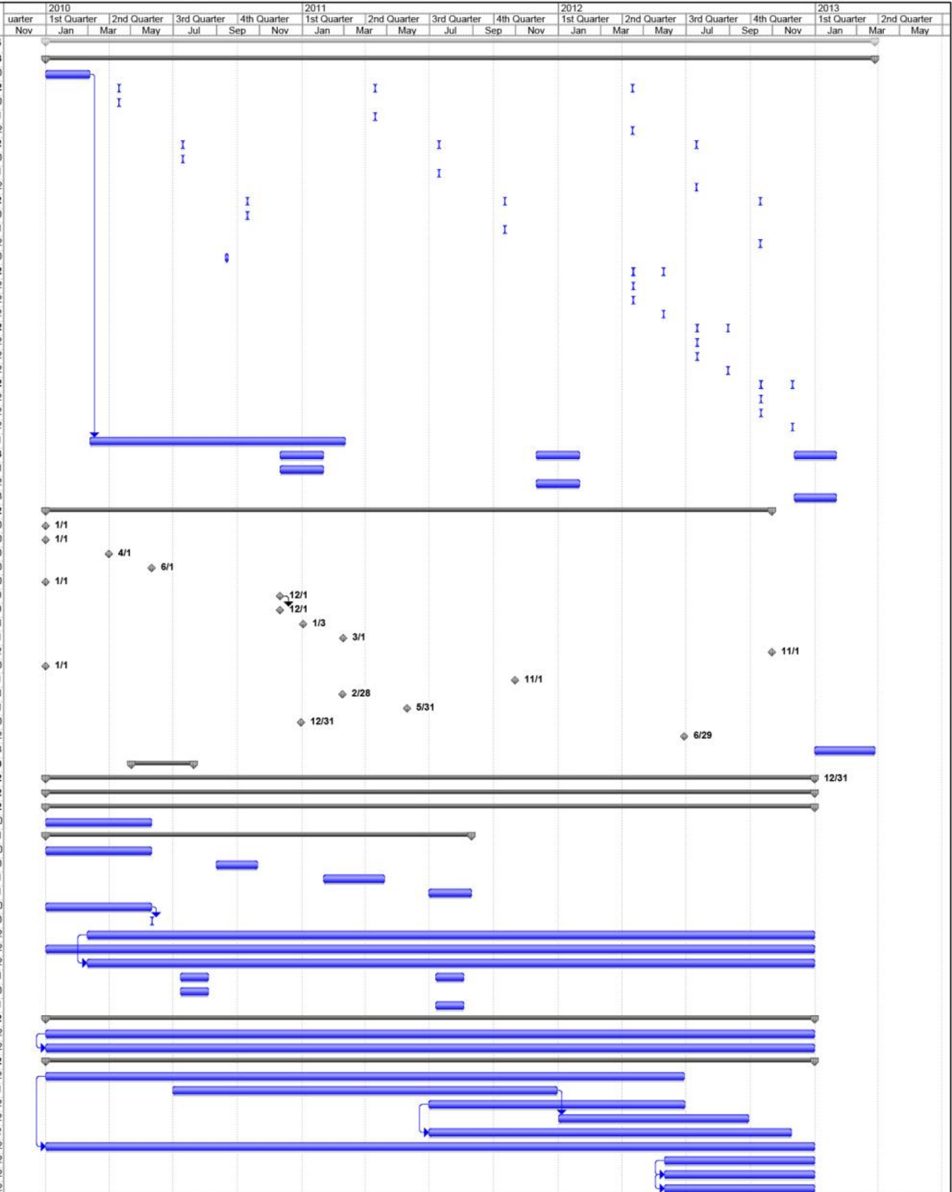
- 110 years to recover the 2 billion barrels of pay zone oil
- 220 to 440 years to recover the 4 to 8 billion barrels of oil in both the pay zone and the residual oil zone

If the 1.2 bcf of anthropogenic CO_2 generated annually in Wyoming was captured and utilized, 2 billion barrels of stranded oil could be recovered in 17 years.

Appendix


DOE
University of Wyoming (UW)
WCSSC/WSGS
Task 1: Project Management
Project Director: R. Surdam
ExxonMobil Data Sharing
Task 2: Well Design & Construction
P. Williams Baker Hughes
Task 3: Geophysical Characterization
S. Mallick UW
Task 4: Well Catalog
J. Myers UW
Task 5: Structural & Stratigraphic Characterization
E. Campbell-Stone UW
Task 6: Mineral & Brine Containment
J. Kaszuba UW
Task 7: Commercial Sequestration Design & Assessment
J. Jiao WSGS

ID	Task Name	Duration	Start	Finish
0	**FOA_033**	**844 days**	**Fri Jan 1, '10**	**Wed Mar 27, '13**
1	**1 Project Management and Planning**	**844 days**	**Fri Jan 1, '10**	**Wed Mar 27, '13**
2	1.1 Hire Project Manager	45 days	Fri Jan 1, '10	Thu Mar 4, '10
3	**1.2 First quarter meeting**	**523 days**	**Thu Apr 15, '10**	**Mon Apr 16, '12**
4	1.2.1 First quarter meeting 1	1 day	Thu Apr 15, '10	Thu Apr 15, '10
5	1.2.2 First quarter meeting 2	1 day	Fri Apr 15, '11	Fri Apr 15, '11
6	1.2.3 First quarter meeting 3	1 day	Mon Apr 16, '12	Mon Apr 16, '12
7	**1.3 Second quarter meeting**	**523 days**	**Thu Jul 15, '10**	**Mon Jul 16, '12**
8	1.3.1 Second quarter meeting 1	1 day	Thu Jul 15, '10	Thu Jul 15, '10
9	1.3.2 Second quarter meeting 2	1 day	Fri Jul 15, '11	Fri Jul 15, '11
10	1.3.3 Second quarter meeting 3	1 day	Mon Jul 16, '12	Mon Jul 16, '12
11	**1.4 Third quarter meeting**	**522 days**	**Fri Oct 15, '10**	**Mon Oct 15, '12**
12	1.4.1 Third quarter meeting 1	1 day	Fri Oct 15, '10	Fri Oct 15, '10
13	1.4.2 Third quarter meeting 2	1 day	Mon Oct 17, '11	Mon Oct 17, '11
14	1.4.3 Third quarter meeting 3	1 day	Mon Oct 15, '12	Mon Oct 15, '12
15	1.5 Annual briefing at NETL	4 days	Tue Sep 14, '10	Fri Sep 17, '10
16	**1.6 First quarter report submittal**	**32 days**	**Tue Apr 17, '12**	**Wed May 30, '12**
17	1.6.1 First quarter report submittal 1	1 day	Tue Apr 17, '12	Tue Apr 17, '12
18	1.6.2 First quarter report submittal 2	1 day	Tue Apr 17, '12	Tue Apr 17, '12
19	1.6.3 First quarter report submittal 3	1 day	Wed May 30, '12	Wed May 30, '12
20	**1.7 Second quarter report submittal**	**33 days**	**Tue Jul 17, '12**	**Thu Aug 30, '12**
21	1.7.1 Second quarter report submittal 1	1 day	Tue Jul 17, '12	Tue Jul 17, '12
22	1.7.2 Second quarter report submittal 2	1 day	Tue Jul 17, '12	Tue Jul 17, '12
23	1.7.3 Second quarter report submittal 3	1 day	Thu Aug 30, '12	Thu Aug 30, '12
24	**1.8 Third quarter report submittal**	**34 days**	**Tue Oct 16, '12**	**Fri Nov 30, '12**
25	1.8.1 Third quarter report submittal 1	1 day	Tue Oct 16, '12	Tue Oct 16, '12
26	1.8.2 Third quarter report submittal 2	1 day	Tue Oct 16, '12	Tue Oct 16, '12
27	1.8.3 Third quarter report submittal 3	1 day	Fri Nov 30, '12	Fri Nov 30, '12
28	1.9 Project Management	260 days	Fri Mar 5, '10	Thu Mar 3, '11
29	**1.10 Coordination with NATCARB database & technical working groups**	**567 days**	**Wed Dec 1, '10**	**Thu Jan 31, '13**
30	1.10.1 Coordination with NATCARB database & technical working groups 1	44 days	Wed Dec 1, '10	Mon Jan 31, '11
31	1.10.2 Coordination with NATCARB database & technical working groups 2	44 days	Thu Dec 1, '11	Tue Jan 31, '12
32	1.10.3 Coordination with NATCARB database & technical working groups 3	44 days	Mon Dec 3, '12	Thu Jan 31, '13
33	**1.11 Milestone Tracking**	**739 days**	**Fri Jan 1, '10**	**Thu Nov 1, '12**
34	1.11.1 Updated Project Management Plan	0 days	Fri Jan 1, '10	Fri Jan 1, '10
35	1.11.2 Document Links betweeen project and RCSP & NATCARB	0 days	Fri Jan 1, '10	Fri Jan 1, '10
36	1.11.3 Submit Site Characterization Plan	0 days	Thu Apr 1, '10	Thu Apr 1, '10
37	1.11.4 Notification to Project Manager that reservoir data collection has been initiated	0 days	Tue Jun 1, '10	Tue Jun 1, '10
38	1.11.5 Notification to Project Manager that subcontractors have been identified for drilling/field service operations	0 days	Fri Jan 1, '10	Fri Jan 1, '10
39	1.11.6 Notification to Project Manager that activities to populate database with geologic characterization data has begun	0 days	Wed Dec 1, '10	Wed Dec 1, '10
40	1.11.7 Notification to Project Manager that characterization wells have been drilled	0 days	Wed Dec 1, '10	Wed Dec 1, '10
41	1.11.8 Notification to Project Manager that well logging has been completed	0 days	Mon Jan 3, '11	Mon Jan 3, '11
42	1.11.9 Annual Progress Report submitted	0 days	Tue Mar 1, '11	Tue Mar 1, '11
43	1.11.10 Notification to Project Manager that activities on the lessons learned document on site characterization have been initiated	0 days	Thu Nov 1, '12	Thu Nov 1, '12
44	1.11.11 Finalize well design and budget	0 days	Fri Jan 1, '10	Fri Jan 1, '10
45	1.11.12 Complete 3-D/3-C & EM inversion on synthetic data	0 days	Tue Nov 1, '11	Tue Nov 1, '11
46	1.11.13 Catalog boreholes in probable area of review (AOR)	0 days	Mon Feb 28, '11	Mon Feb 28, '11
47	1.11.14 Complete core descriptions	0 days	Tue May 31, '11	Tue May 31, '11
48	1.11.15 Complete analysis of formation fluid samples	0 days	Fri Dec 31, '10	Fri Dec 31, '10
49	1.11.16 Complete 3D geologic model	0 days	Fri Jun 29, '12	Fri Jun 29, '12
50	**1.12 Submit final report to DOE**	62 days	Tue Jan 1, '13	Wed Mar 27, '13
51	**2 Design & construction of well-Rock Spring Uplift**	**65 days**	**Mon May 3, '10**	**Fri Jul 30, '10**
54	**3 Geophysical characterization of geologic formations: Southwest WY**	**782 days**	**Fri Jan 1, '10**	**Mon Dec 31, '12**
62	**4 Development of well catalog & borehole risk assessment: Southwest WY**	**782 days**	**Fri Jan 1, '10**	**Mon Dec 31, '12**
81	**5 Structural & stratigraphic characterization of geologic formationns: Southwest WY**	**782 days**	**Fri Jan 1, '10**	**Mon Dec 31, '12**
82	5.1 Compile available data for Rock Springs Uplift	107 days	Fri Jan 1, '10	Mon May 31, '10
83	**5.2 Conduct core analysis in Denver, CO**	**433 days**	**Fri Jan 1, '10**	**Tue Aug 30, '11**
84	5.2.1 Conduct Core analysis	107 days	Fri Jan 1, '10	Mon May 31, '10
85	5.2.2 Conduct core analysis	43 days	Wed Sep 1, '10	Fri Oct 29, '10
86	5.2.3 Conduct core analysis	63 days	Tue Feb 1, '11	Thu Apr 28, '11
87	5.2.4 Conduct core analysis	43 days	Fri Jul 1, '11	Tue Aug 30, '11
88	5.3 Recuit Undergrad	107 days	Fri Jan 1, '10	Mon May 31, '10
89	5.4 Undergrad on board	1 day	Tue Jun 1, '10	Tue Jun 1, '10
90	5.5 Determine reservoir/seal stratigraphy & thickness on Rock Springs Uplift & Moxa Arch	741 days	Mon Mar 1, '10	Mon Dec 31, '12
91	5.6 Conduct structural analysis	782 days	Fri Jan 1, '10	Mon Dec 31, '12
92	5.7 Study/determine fault seals	741 days	Mon Mar 1, '10	Mon Dec 31, '12
93	**5.8 Conduct Field Work**	**290 days**	**Mon Jul 12, '10**	**Fri Aug 19, '11**
94	5.8.1 Conduct Field Work 1	30 days	Mon Jul 12, '10	Fri Aug 20, '10
95	5.8.2 Conduct Field Work 2	30 days	Mon Jul 11, '11	Fri Aug 19, '11
96	**6 Laboratory measurement of containment-mineralization and brine**	**782 days**	**Fri Jan 1, '10**	**Mon Dec 31, '12**
97	6.1 Research containment - mineralization	782 days	Fri Jan 1, '10	Mon Dec 31, '12
98	6.2 Research containment - brine	782 days	Fri Jan 1, '10	Mon Dec 31, '12
99	**7 Design commercial-scale sequestration project & complete performance risk assessment**	**782 days**	**Fri Jan 1, '10**	**Mon Dec 31, '12**
100	7.1 Construct a comprehensive petrophysical database	650 days	Fri Jan 1, '10	Thu Jun 28, '12
101	7.2 Three dimensional seismic processing, data analysis, & interpretation	392 days	Thu Jul 1, '10	Fri Dec 30, '11
102	7.3 Construct a detailed 3-D geological structural model	261 days	Fri Jul 1, '11	Fri Jun 29, '12
103	7.4 Generate a 3-D rock/fluid parameter grid	195 days	Mon Jan 2, '12	Fri Sep 28, '12
104	7.5 Conduct CO2 injection numerical simulations	369 days	Fri Jul 1, '11	Wed Nov 28, '12
105	7.6 Complete the geological CO2 sequestration performance assessment	782 days	Fri Jan 1, '10	Mon Dec 31, '12
106	7.7 Design of Water Production Scenarios	152 days	Fri Jun 1, '12	Mon Dec 31, '12
107	7.8 Determination of Water Treatment Options and Facilities	152 days	Fri Jun 1, '12	Mon Dec 31, '12
108	7.9 Determination of Beneficial uses of produced water	152 days	Fri Jun 1, '12	Mon Dec 31, '12



Project: FOA_033
Date: Thu Jul 30, '09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

Bibliography of recent work

Surdam, R.C., Jiao, Z., Ganshin, Y., Bentley, R., and Garcia-Gonzalez, M., 2012, Documented subsurface three-dimensional geological heterogeneity in the Weber/Tensleep sandstones and Madison carbonates: Wyoming's highest-priority CO_2/hydrocarbon storage and production reservoirs: presented at the American Association of Petroleum Geologists annual meeting in Long Beach, CA, April 2012.

Surdam, R., Jiao, Z., Ganshin, Y., Bentley, R., Quillinan, S., McLaughlin, J., and Deng, H., 2012, The Rock Springs Uplift: An outstanding geological CO_2 storage site: presented at the 2012 meeting of the Rocky Mountain Section of the Geological Society of America in Albuquerque, NM, May 2012.

Surdam, R., Jiao, Z., Ganshin, Y., Zhou, L., Wang, Y., Luo, T., Stauffer, P., and Deng, H., 2012, Reservoir simulation of CO_2 storage on the Rock Springs Uplift based on a robust database and an accurate model of geological heterogeneity: presented at the Third International Advanced Coal Technology Conference, in Xian, China, June 2012.

Surdam, R.C., Dahl, S., Hurless, R., Jiao, Z., Ganshin, Y., Bentley, R., and Garcia-Gonzalez, M., 2012, The Rock Springs Uplift: A premier CO_2 storage site in Wyoming *in* Proceedings of the Carbon Management Technology Conference, 2012: Society of Petroleum Engineers, CD-ROM available at http://store.spe.org/2012-Carbon-Management-Technology-Conference-P636.aspx.