CarbonSAFE Rocky Mountains Phase I:
Ensuring Safe Subsurface Storage of CO_2 in the Intermountain West

DE-FE0029280

Brian McPherson
University of Utah

U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
August 13-16, 2018

CarbonSAFE Rocky Mountains Phase I: Ensuring Safe Subsurface Storage of CO2 in the Intermountain West

DE-FE0029280

Acknowledgements:

U.S. Department of Energy

National Energy Technology Laboratory

All Partners:

Partners

The University of Utah

Sandia National Laboratories

USTAR

PacifiCorp

Utah DNR Utah Geological Survey

New Mexico Tech Science • Engineering • Research University

Los Alamos National Laboratory Est. 1943

Schlumberger

Outline

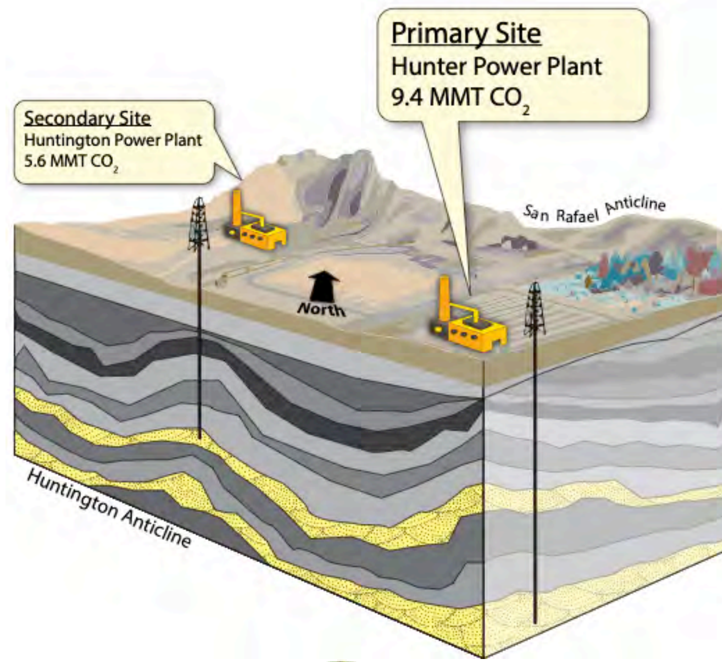
- Technical Status
  - CO_2 Management
  - Storage Complex
  - Model Development
  - Simulation
  - Non-Technical
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary
- Appendix

Technical Status

CO_2 Management: Source

Hunter Power Plant

- Originally commissioned in 1978 (Unit I).
- Owned & operated by PacifiCorp/Rocky Mountain Power.
- The Hunter Plant burns ~4.3 million short tons (2015) of Utah-sourced bituminous coal per year.
- The Hunter plant generates approximately 9.3 MMT (2015) of CO_2 from 3 Units.
- The typical flue gas flow rate ranges from 70-75 million wet standard cubic feet of flue gas per unit.



Constituent	CO_2	N_2	O_2	H_2O
Percentage (% by volume)	11-12%	70-75%	6%	11-12%

Typical Hunter Plant Flue Gas Composition.

Technical Status

CO_2 Management: Capture

Hunter Power Plant

- Capture assessment considered 3 amine-based Cases:
  - A full-scale system at 90% capture (Case 2)
    - served as basis for development of heat balances, mass balances, process flow diagrams, general arrangements, equipment sizing, capital costs;
  - The full-scale system inputs were adjusted for other capture facility design sizes:
    - Case 1: 65% capture
    - Case 3: 1,000 lb CO_2/MWhg (~48%)
- Technology assessed: Mitsubishi KM-CR Process® with KS-1™ solvent.

CO_2 Capture Facility Requirements and CO_2 Quality

Variable	Unit	Case 1 (65% Capture)	Case 2 (90% Capture)	Case 3 (1,000 lbs/MWl
CO_2 Capture	–	65%	90%	48% Capture
CO_2 Stream Purity	%	□ 95	□ 95	□ 95
CO_2 Product Temperature	°F	95	95	95
CO_2 Product Stream Pressure	psia	2,215	2,215	2,215
CO_2 Production	lb/hr	640,000	887,000	473,000
	ton/yr	2,159,700	2,991,500	1,595,200
Capture Island Size	MWe	370	511	273
	lb/hr	3,790,000	5,248,000	2,799,000
	acfm	1,137,000	1,574,000	840,000
	CO_2 lb/hr	712,000	985,000	526,000
CO_2 Emissions	lb/MWh	675	193	1,002
Aux Power*	MW	Compressor – 18 Process –33	Compressor – 25 Process – 46	Compressor – 1 Process –25
Steam	lb/hr	788,000	1,000,000	617,000
Raw Make Up Water	gpm	2,600	3,600	1,900
Demin Make Up Water	gpm	20	28	15

*Note: Aux power requirement listed is in addition to the existing plant aux power requirements.

Technical Status

CO_2 Management: Capture

Hunter Power Plant

- Capital cost for retrofitting Unit 3 in excess of $650 million;
- PacifiCorp is already working with small-scale testing of cryogenic processes for separating CO_2 from flue gas (Sustainable Energy Solutions, LLC);
- While much of the operating costs ($85M/year at 90% capture) could be offset by 45Q credits, additional outside sources of funding would be required for any capture retrofit.

Capital Cost Summary of CO_2 Capture Slipstream Systems

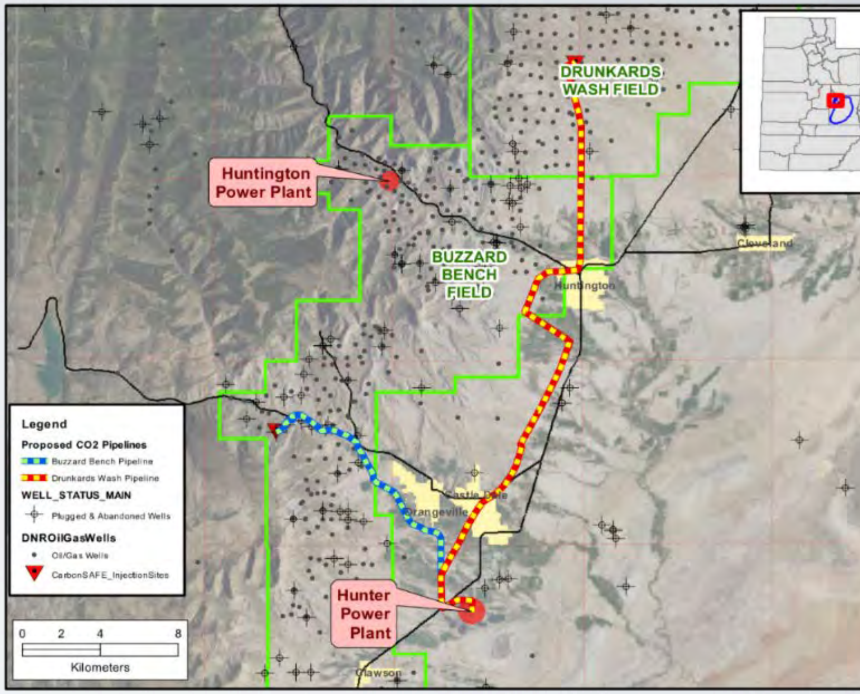
Description	Case 1 (65% Capture)	Case 2 (90% Capture)	Case 3 (1,000 lb/MWh$_g$)
BOP Scope			
Civil, Site Prep, and Structural	6,168,200	7,125,500	5,434,200
Architectural	4,812,000	5,850,000	4,016,100
Mechanical	15,945,200	18,867,300	13,704,900
Electrical and I&C	2,342,900	2,342,900	2,342,900
CO_2 Capture System (EPC)	470,000,000	610,000,000	380,000,000
Total Direct Capital Cost	**499,268,300**	**644,185,700**	**405,498,100**
Other Direct and Construction Indirect Costs (Excludes EPC)	6,221,000	7,266,000	5,420,000
Engineering (Excludes EPC)	3,549,000	4,145,000	3,092,000
Construction Management (Excludes EPC)	710,000	829,000	618,000
Startup/Commissioning (Excludes EPC)	366,000	427,000	318,000
Contingency (Excludes EPC)	8,022,000	9,370,000	6,989,000
Total Capital Investment	**518,136,300**	**666,222,700**	**421,935,100**

Technical Status

CO_2 Management: Transport

Hunter Plant: Injection Site(s)

- Assessment suggests on-site compression, yielding pipeline quality CO_2 stream (>99% purity) at 2,215 psia
- Two primary storage sites were considered:
  - Drunkards Wash Field
    (11.3 miles from Hunter Power Plant)
  - Buzzards Bench Field
    (22.9 miles from Hunter Power Plant)



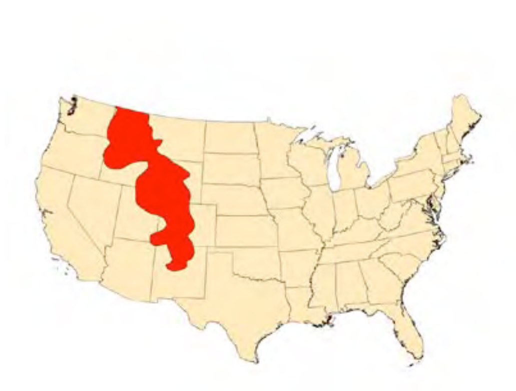
Parameters	Buzzard Bench	Drunkards Wash
Mass flow rate (ton/day)	5000	5000
Pipeline length (m)	18,158	36,593
Elevation gain (m)	218	293
Minimum p_1-p_2 (psi)	372	276
Mean velocity (m/s)	1.07-2.47	1.74-3.33
Pipeline diameter (inch)	7.2-10.9	6.2-8.6
Pipeline Cost ($)	3.7M	7.4M

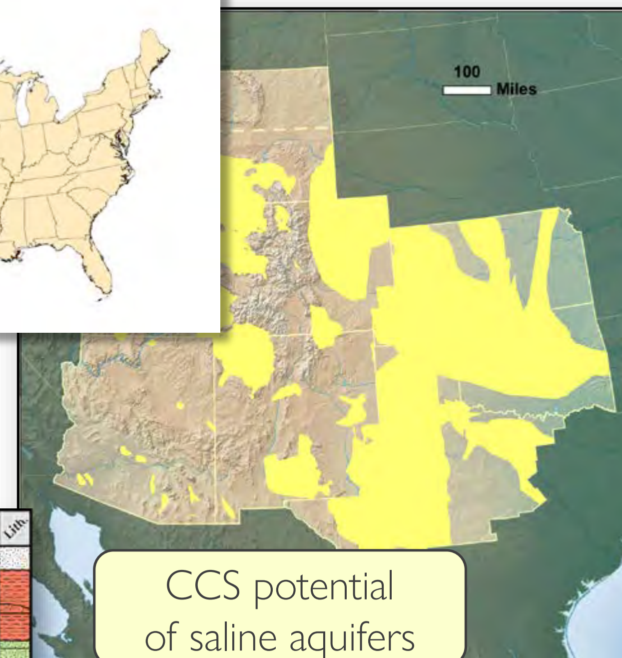
NATIONAL ENERGY TECHNOLOGY LABORATORY

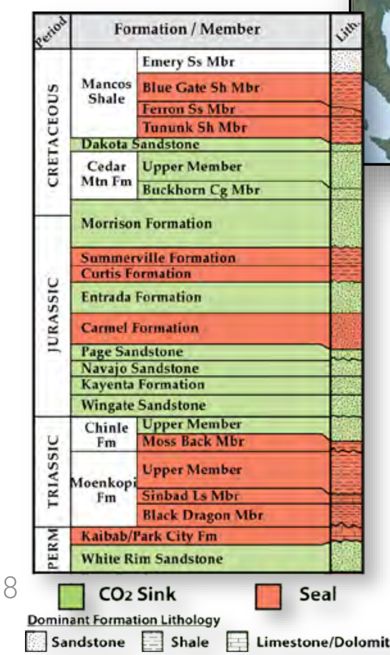
Technical Status

Storage Complex: Regional Setting

- Subsurface geology at Hunter is typical of Rocky Mountain region– deep sedimentary basins with high porosity and high permeability sandstones and thick seal units;
- The San Rafael Swell is surrounded by massive structural basins (Uintah Basin, Paradox Basin);
- Conservative estimates of CO_2 storage capacity within the southwestern US are several hundred billion metric tons;
- Most of the region's coal-fired power plants overlie reservoirs with sufficient CO_2 capacity to store in excess of 100 years worth of emissions.







Rocky Mountain CarbonSAFE

NATIONAL ENERGY TECHNOLOGY LABORATORY

Technical Status

Storage Complex: Site Selection

- Initial priority was Permian White Rim Sandstone directly below (~7,000 ft bgs) the Hunter Plant;
- However, geophysical logs and core samples of the White Rim Ss in the vicinity of Hunter Power Plant yield permeabilities <<1mD;
- The secondary reservoir, Navajo Sandstone, yields high porosity and permeability values, but requires transport of CO_2 tens of miles to the west and north to maintain supercritical.

Period	Formation / Member		Thickness (feet)	Depth (ft) @Hunter	Depth (ft) @Hntingtn
CRET	Mancos Shale	Blue Gate Sh Mbr	300-1300	0	0
CRET	Mancos Shale	Ferron Ss Mbr	20-110	3214	1892
CRET	Mancos Shale	Tununk Sh Mbr	400-650	3481	
CRET	Dakota Sandstone		150	4050	2690
CRET	Cedar Mtn Fm	Upper member	100-200		2790
CRET	Cedar Mtn Fm	Buckhorn Cg Mbr	230		2860
JURASSIC	Morrison Formation		450		3470
JURASSIC	Summerville Formation		55		3900
JURASSIC	Curtis Formation		1102		4415
JURASSIC	Entrada Formation		1090	5626	4610
JURASSIC	Carmel Formation		745	6375	5550
JURASSIC	Navajo Sandstone		105	7258	6767
JURASSIC	Kayenta Formation		370		
JURASSIC	Wingate Sandstone		265		
TRIASSIC	Chinle Formation		40	8534	8025
TRIASSIC	Moenkopi Fm	Upper member	380		
TRIASSIC	Moenkopi Fm	Sinbad Ls Mbr	155	9192	8650
TRIASSIC	Moenkopi Fm	Black Dragon Mbr	300		
PERM	Black Box Dolomite		300	9570	9088
PERM	White Rim Sandstone		300	>9570	9229
P	"Hermosa" Formation		450		10095
MISS	Madison Limestone		1200		

Seals
Secondary Reservoir
Primary Reservoir

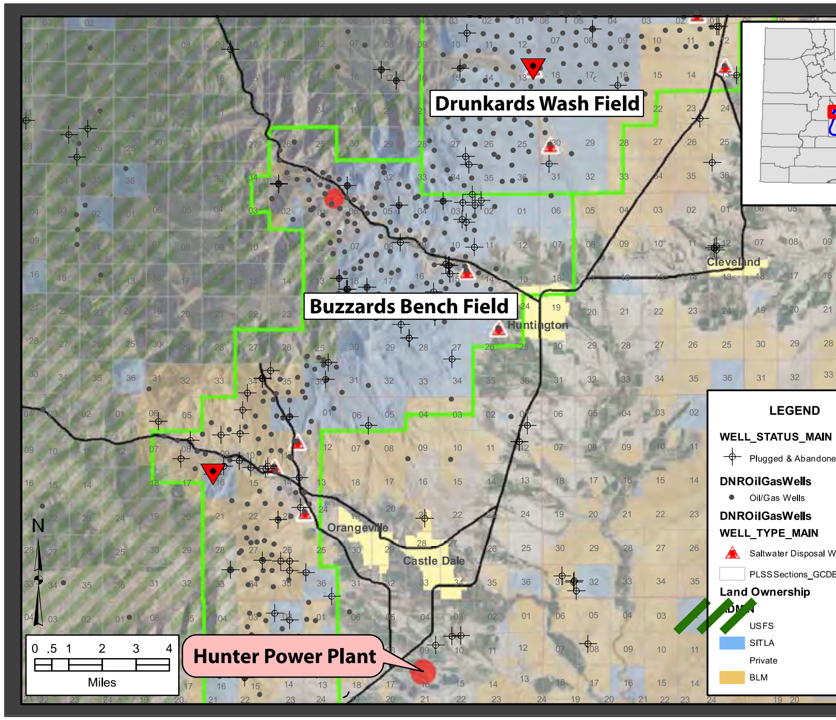
- General stratigraphy from Hintze (1992)
- Depths of individual formations from nearby well (API # 43-015-10900 (near Huntington) and API# 43-015-XXXXX (near Hunter))

Technical Status

Storage Complex: Site Selection

Buzzards Bench & Drunkards Wash

- methane production operated by XTO Energy and ConocoPhillips;
- Methane (and brine) produced from shallow Ferron sandstone/coal (CBM), utilizes vast surface infrastructure (wells, pipelines, ROWs).
- Saltwater is disposed in the Navajo Ss, yielding significant reservoir properties (porosity, permeability, injectivity, etc).
- Both sites are down-dip from the Hunter Power Plant, where potential CO_2 reservoirs are sufficiently deep.



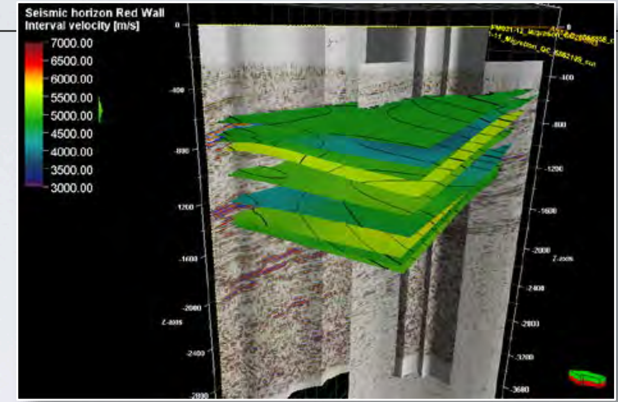
Period	Formation / Member		Thickness (feet)	Depth (ft) @Hunter	Depth (ft) @Hntingtn	Lith.
CRET	Mancos Shale	Blue Gate Sh Mbr	300-1300	0	0	
		Ferron Ss Mbr	70-110	3214	1892	
		Tununk Sh Mbr	400-650	3481		
	Dakota Sandstone		150	4050	2690	
	Cedar Mtn Fm	Upper member	100-200		2790	
		Buckhorn Cg Mbr	230		2860	
JURASSIC	Morrison Formation		450		3470	
	Summerville Formation		55		3900	
	Curtis Formation		1102		4415	
	Entrada Formation		1090	5626	4610	
	Carmel Formation		745	6375	5550	
	Navajo Sandstone		105	7258	6767	
	Kayenta Formation		370			
	Wingate Sandstone		265			
TRIASSIC	Chinle Formation		40	8534	8025	
	Moenkopi Fm	Upper member	380			
		Sinbad Ls Mbr	155	9192	8650	
		Black Dragon Mbr	300			
PERM	Black Box Dolomite		300	9570	9088	
	White Rim Sandstone		300	>9570	9229	

Seals
Secondary

Rocky Mountain CarbonSAFE

NATIONAL ENERGY TECHNOLOGY LABORATORY

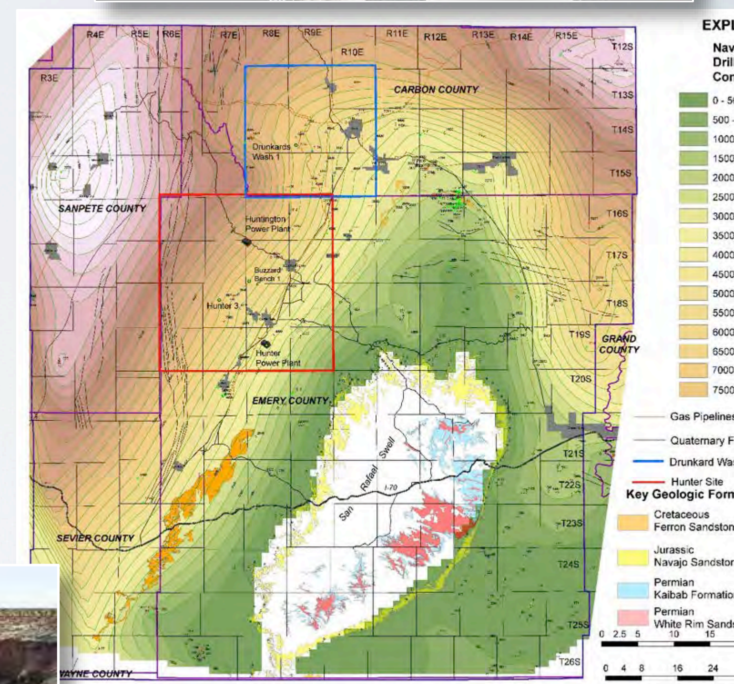
Technical Status



Storage Complex

Site Geologic Characterization

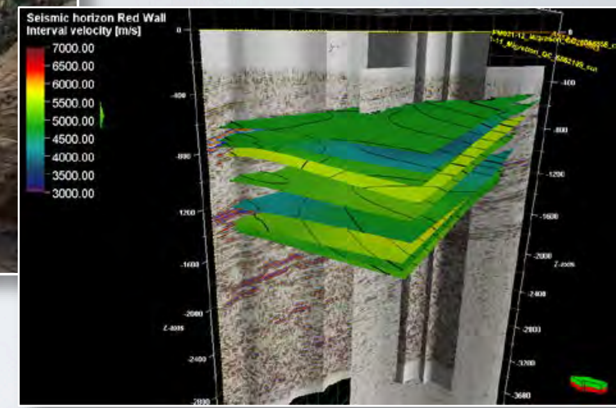
- Navajo Sandstone (primary reservoir), Kayenta and Wingate sandstones (reservoirs); seal units.
  - Surface and Subsurface mapping
  - Geophysical log interpretation
  - Core/plug analysis (P&P, rel perm, capillary pressure)
  - Produced & groundwater analysis
  - Seismic characterization (legacy 2D)
  - Petrography
  - Seal analysis



Rocky Mountain CarbonSAFE

NATIONAL ENERGY TECHNOLOGY LABORATORY

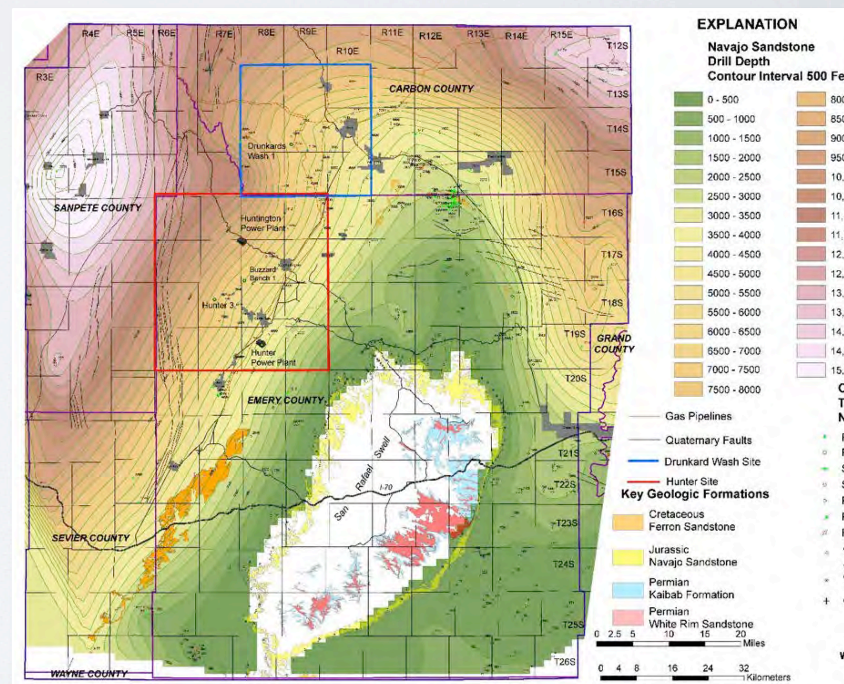
Technical Status



Storage Complex

Primary Reservoir

- Navajo Sandstone
  - Sufficiently deep: >6000 ft
  - Thickness: ~420 ft
  - Thick overlying seal units
  - High porosity: 12-20%
  - High permeability: 17 – 640 mD
  - >>50 million metric tons CO_2 storage capacity

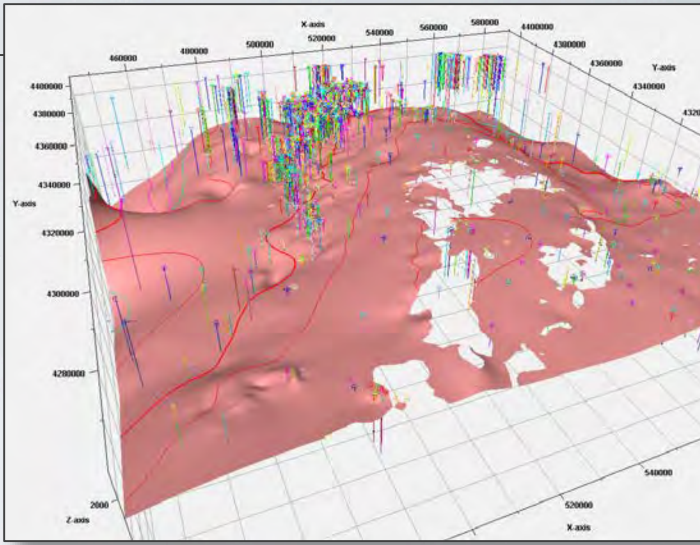


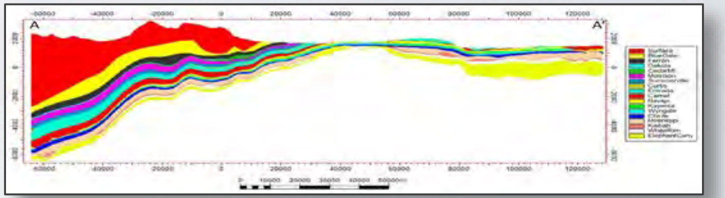
Rocky Mountain CarbonSAFE

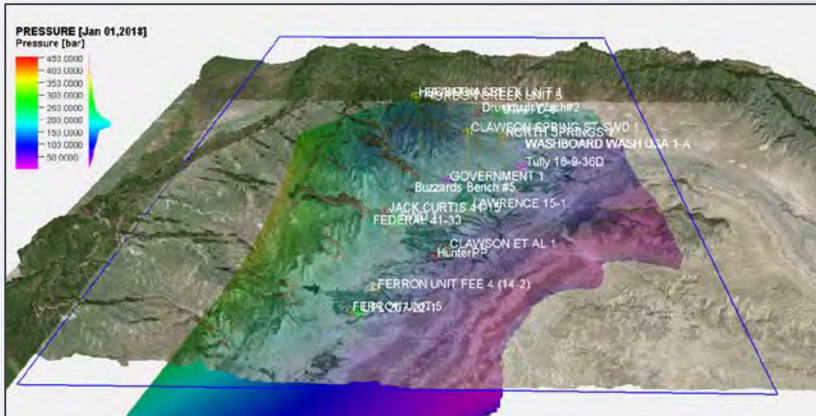
Technical Status

Model Development

- Geologic characterization data used to develop and refine 3D reservoir model.
  - Model domain: 44 miles (N-S) by 62 miles (E-W)
  - includes the Carmel formation (overlying seal unit), the Navajo Sandstone (primary reservoir), the Kayenta Formation (secondary reservoir), the Wingate Sandstone (tertiary reservoir), and the Chinle Formation (underlying sealing unit).
  - The model contains 1,053,864 active cells in the flow domain.







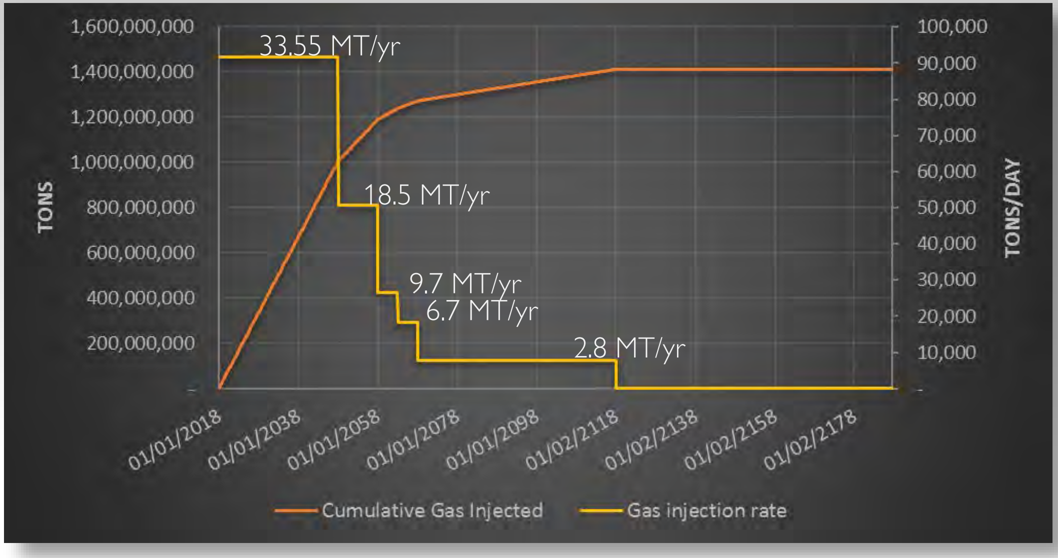
Rocky Mountain CarbonSAFE

Technical Status

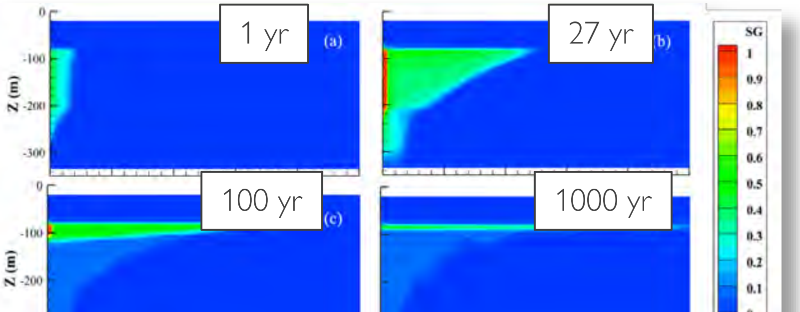
Simulation

- CO_2 injectivity
- Pressure distribution
- CO_2 capacity (>1300 MMT)
- CO_2 plume migration forecasts
- Relative permeability and capillary pressure evaluated
- Reactive transport analysis
- Area of Review
- Risk forecasts
- NRAP methods

CO_2 Injection Rate & Cumulative Injection



CO_2 saturation in gas phase



Total Mass CO_2 Injected [tons]	1,412,952,644
Total Mass Mobile Spercritical CO_2 [tons]	968,277,893
Total Mass Trapped Supercritical CO_2 [tons]	70,192,604
Total Mass Dissolved CO_2 [tons]	357,107,434

*all data is for the end of the simulation time (1000 yrs)

NATIONAL ENERGY TECHNOLOGY LABORATORY

Technical Status

Non-Technical

- Legal & Regulatory
  - EPA Class VI – The Utah Department of Environmental Quality performed an analysis of and summarized all Class VI requirements with particular emphasis on site characterization, modeling and simulation, and Area of Review and Corrective Action Plan.
    - The State of Utah would not seek primacy for Class VI applications.
  - Surface ownership
    - Federal, State (SITLA) and Private; may be leased similar to oil/gas industry.
  - Pore-space ownership
    - Generally matches surface ownership, but is complex because Utah has not adopted legislation defining pore space ownership, and no case law from Utah directly addresses ownership in the CCS context.
  - Rights-of-Way
    - Private: lease, outright conveyance (deed or similar)
    - Federal: may be prolonged as no precedent has been set for a CCS project.
  - Endangered Species
    - Greater Sage Grouse inhabits the complex and would require accommodation

Technical Status

Non-Technical

- Liability
  - Transport Regulation (Pipeline) dictating design, construction, inspection, testing, operation, maintenance, corrosion control and reporting;
  - CO_2 Storage Liability: no precedent, but may follow natural gas storage rules;
  - Financial Risk and Long-Term Liability;
- Economic
  - Capital costs for CO_2 capture
  - Offsets: 45Q, EOR
- Stakeholder Assessment
  - Public: central Utah is a large coal-producing area; public acceptance is high
  - Environmental organizations: Drunkard's Wash and Buzzard's Bench are active gas fields, already subjected to NGO vetting to some extent
  - Industry: generally tepid; owing to uncertainty in market
  - State: generally tepid, owing to uncertainty in Federal and market commitments

Accomplishments to Date

- Assembled team with capacity to undertake additional CCS opportunities in the Rocky Mountain region;
- Primary and secondary CO_2 sources and transport requirements determined;
- Geologic characterization of primary and secondary sites complete;
- Generation of 3D reservoir model complete;
- Simulations to evaluate injectivity, capacity, permanence complete;
- Risk registry created with subsequent risk analyses complete;
- EPA Class VI regulations evaluated and communicated to necessary groups (site characterization, simulation, AoR) for required action;
- Surface and subsurface ownership defined;
- CCS Complex Scenario Development evaluated using saline aquifers, local EOR/EOG options, and regional pipeline requirements.

Lessons Learned

- Outcrop data of geologic reservoirs are "no match" for subsurface data (logs, core);
  - All outcrop data suggest the White Rim Ss is a highly suitable CO_2 reservoir until local wells yielded low porosity/permeability values;
- Despite the vast geologic sinks in the region, successful CCS is hindered by the high cost of CO_2 capture;
- The State of Utah has little to no regulatory framework in place for CCS projects; while this creates uncertainty at project onset, it may also allow for opportunities to adapt effectively to any new regulations;
- Uncertainty in federal CO_2/GHG policy results in lack of commitment from industry and public for CCS projects.

Synergy Opportunities

- Augmented analyses performed by the Southwest Regional Carbon Partnership (SWP), including CO_2 capacity assessments;
- Developed collaborative partnership with PacifiCorp and Rocky Mountain Power, which own/operate several power plants in the Rocky Mountain region.

Project Summary

- Established team and collaborative relationship with key stakeholder (PacifiCorp) with strong position for future CCS opportunities;
- Identified and quantified most opportune CO_2 source options (Hunter power plant);
- Identified and characterized subsurface geology at multiple sites within the complex capable of commercial storage (50+ million tonnes of CO_2);
- Evaluated regulatory challenges, including comprehensive analysis of EPA Class VI requirements;
- Developed scenarios to promote CO_2 storage complex in central Rocky Mountain region.

Appendix

- These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

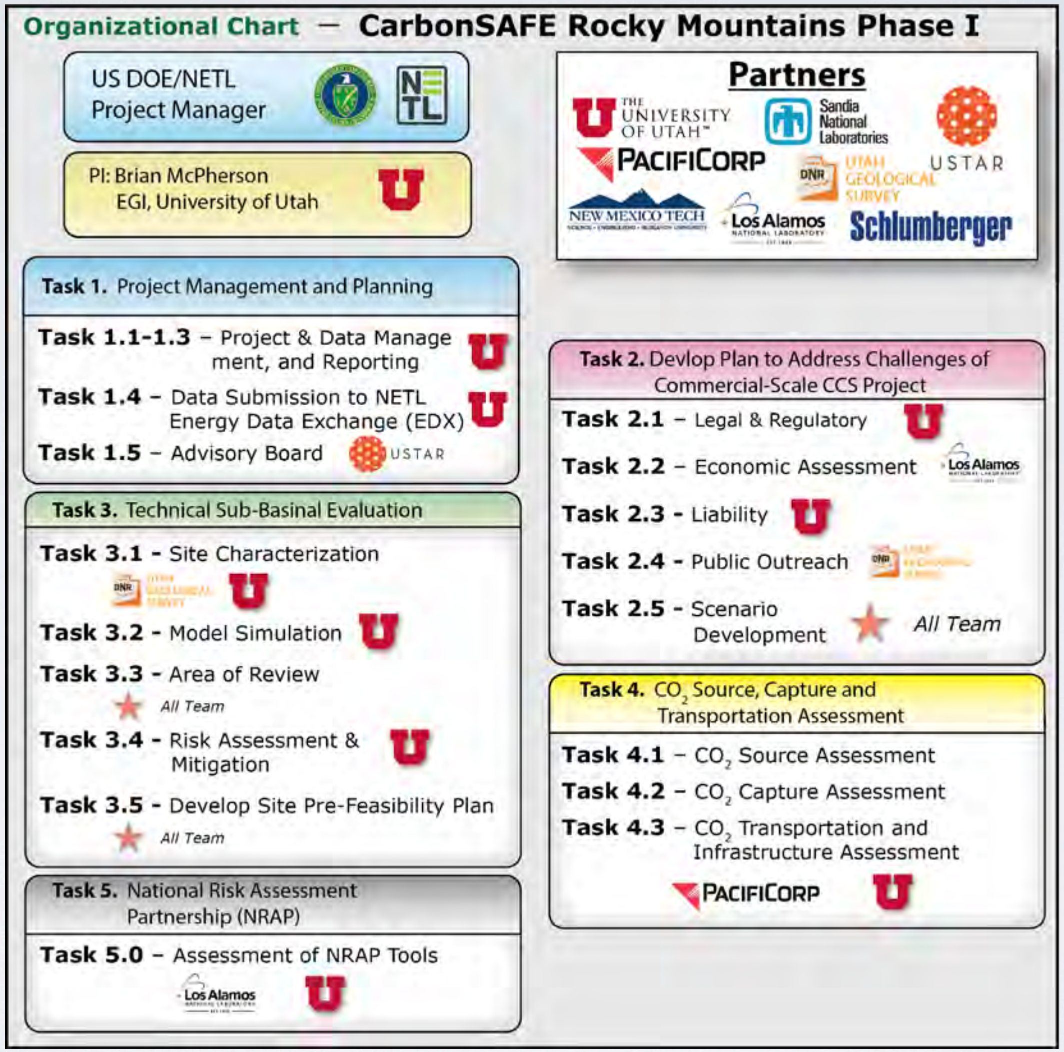
- Compare and contrast the range of possible injection sites and storage reservoirs in a stacked saline aquifer system
- Identify minimum risk, maximum storage efficiency, and minimum cost, conducive to a storage complex capable of accepting 50+ million tonnes of CO_2.
- Multiple practical storage (injection) sites will be identified and compared using a state-of-the-art systems analysis of competing costs as well as regulatory and technical requirements
- BENEFITS STATEMENT: The primary outcome is a proof-of-feasibility for commercial-scale CCS for an existing, operating coal-fired power plant in the western USA. Another benefit of this proposed project is a template plan for existing and future coal-fired and natural-gas-fired plants in the Rocky Mountain states, with PacifiCorp's Hunter Plant in central Utah as the representative example of a typical generating station in the Rocky Mountain west. The project leveraged and built upon work previously performed by Southwest Partnership on Carbon Sequestration (SWP) projects to comprehensively characterize reservoir and seal geology.

Project Overview

Goals and Objectives

- The primary objective is to identify the conditions and attributes that will facilitate feasible and practical commercial-scale CCS. Objectives include identification and quantification of technical requirements as well as attributes maximizing economic feasibility and public acceptability of an eventual storage project, achieved through high-level technical evaluation of a proposed storage complex with multiple storage site options and CO_2 source(s). The primary outcome of the project will be a template for existing and future coal-fired and natural-gas-fired plants in the Rocky Mountains states, with PacifiCorp's Hunter Plant in central Utah exemplifying a typical generating station in the Rocky Mountains west.
- The success criteria are 1) the identification of a ready source of anthropogenic source of CO_2, sufficient for "acceptable" capture and transport to a 2) comprehensively characterized geologic site/reservoir capable of storing 50+ million tonnes of CO_2 within a 30 year timeframe, while 3) overcoming any non-technical challenges that might otherwise make a large-scale CO_2 storage complex unfeasible.

Organization Chart



Organization Chart

Team Member	Role
PacifiCorp	Plant Operator and Power Sector Requirements
Utah Geological Survey	Geologic Characterization
New Mexico Tech	Seismic and Geologic Characterization
Los Alamos National Lab	Systems Analysis (Economic-Technical)
Sandia National Lab	Caprock Characterization
Schlumberger Carbon Services	Injection/Monitoring Well Design and Risk Assessment
University of Utah	Project Management, Simulation and Risk Assessment
University of Utah Law School	Legal and Other Policy Requirements
Utah Department of Env. Quality	UIC and Other Permitting Requirements
Stakeholder Advisory Board (Under Assembly)	Advice on Non-technical CCS Requirements and Public Relations

Gantt Chart

Rocky Mountain CarbonSAFE

NATIONAL ENERGY TECHNOLOGY LABORATORY

Bibliography

Middleton, R., and Yaw, S., 2018, The cost of getting CCS wrong: Uncertainty, infrastructure design, and stranded CO_2. International Journal of Greenhouse Gas Control, v. 70, p. 1-11, available at: https://doi.org/10.1016/j.ijggc.2017.12.011.