Southwest Regional Partnership on Carbon Sequestration

SWP Phase 3 Deployment Project: Overview and Summary

Brian McPherson and Reid Grigg

Southwest Carbon Partnership

RCSP Annual Review Meeting

October 5-7, 2010

Pittsburgh, PA

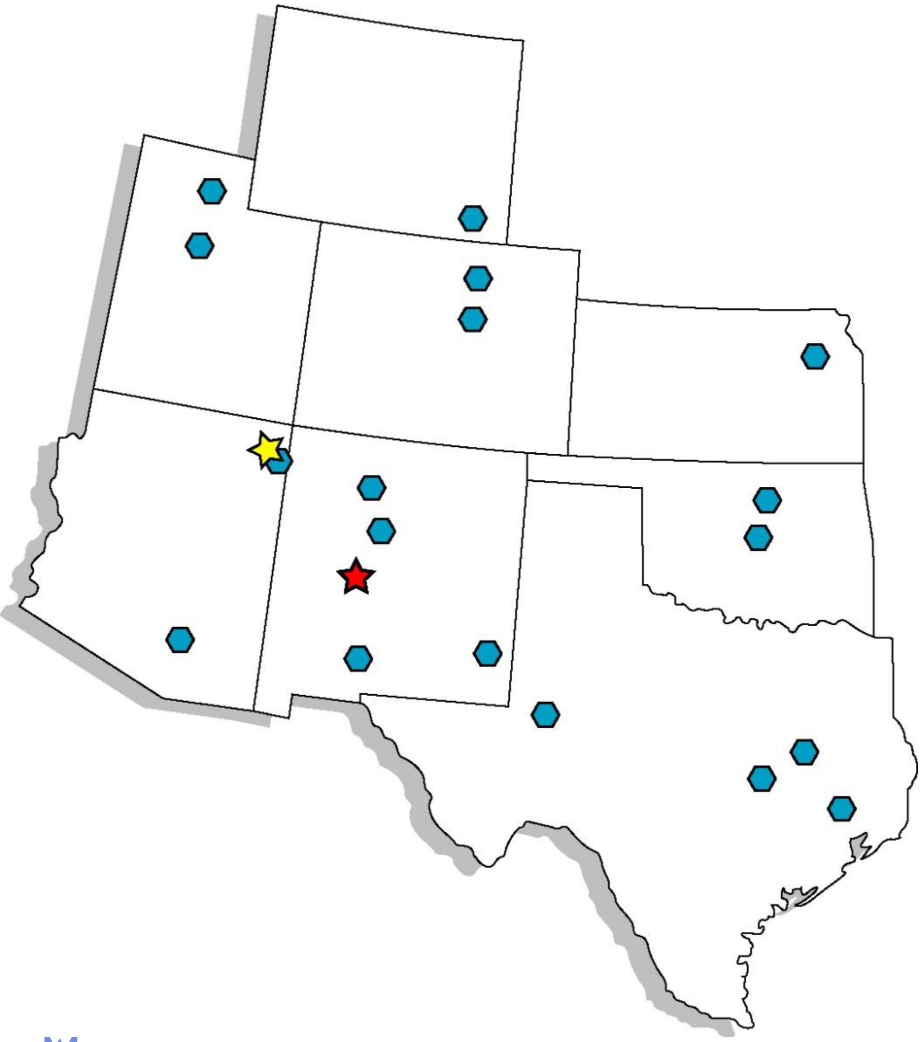
Acknowledgements

- Many thanks to the U.S. Department of Energy and NETL for supporting this project

- We express our gratitude also to our many industry partners, who have committed a great deal of time, funding and other general support for these projects

- The work presented today is co-authored by all partners in the Southwest Partnership

Southwest Regional Partnership

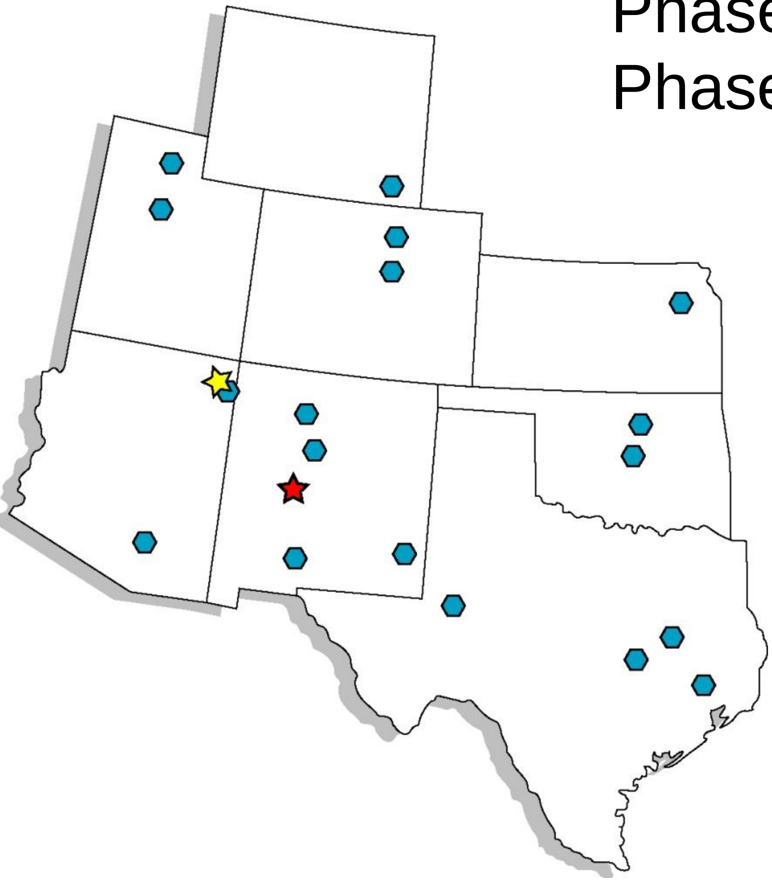


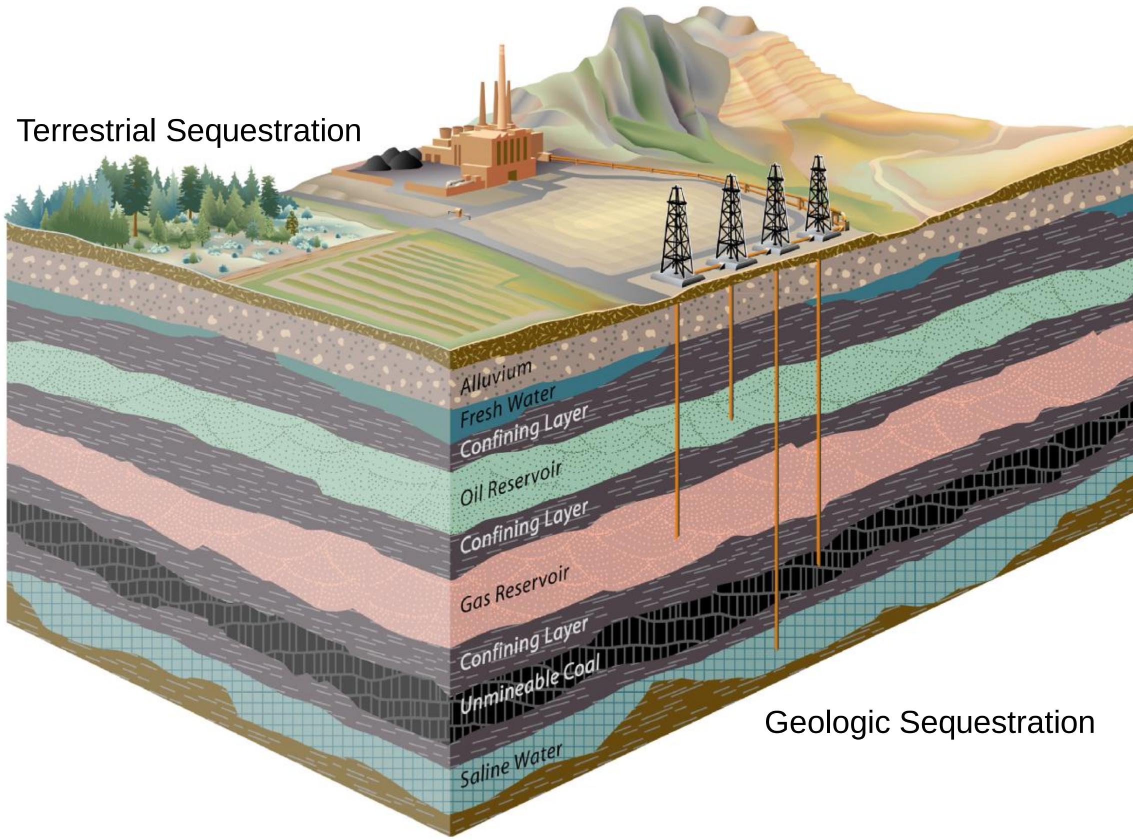
In all partner states:
- major universities
- geologic survey
- other state agencies
- over 50 partners

as well as
- Western Governors Association
- five major utilities
- seven energy companies
- three federal agencies
- the Navajo Nation
- many other critical partners

Southwest Regional Partnership

Phase I: Characterization (2003 – 2005)
Phase 2: Validation Testing (2005 – 2009)
Phase 3: Deployment



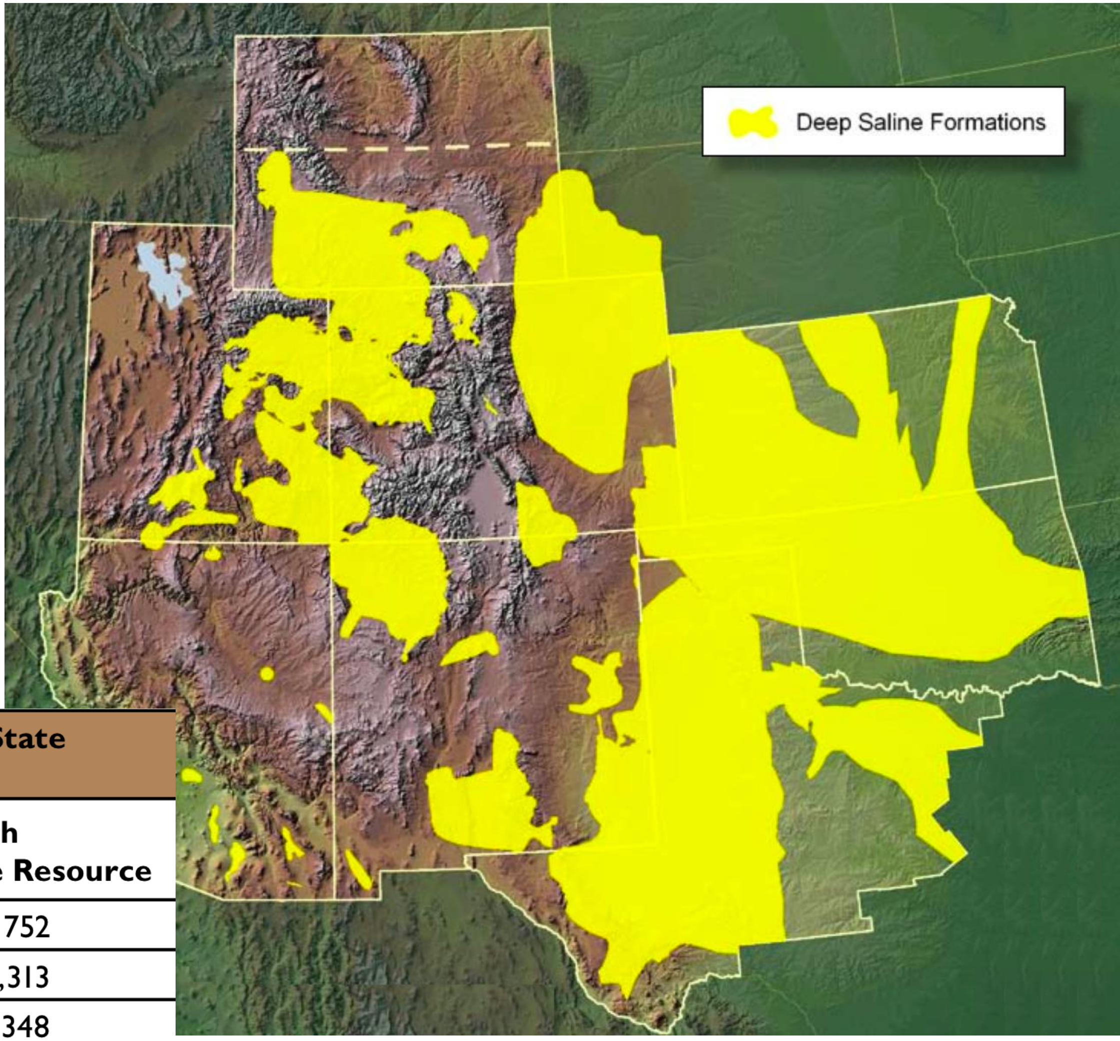


Presentation Outline

- **Summary of SWP Phase I**
- Summary of Phase 2 Activities
- Regional Context of Phase 2 Tests
- Overview of Phase 3 Deployment Project
- Phase 3 Deployment Design
- Alternative Phase 3 Site
- Summary Goals

Phase I Results: Source/Sink Inventory

Southwestern U.S. Atlas (Inventory) of Sources and Sinks

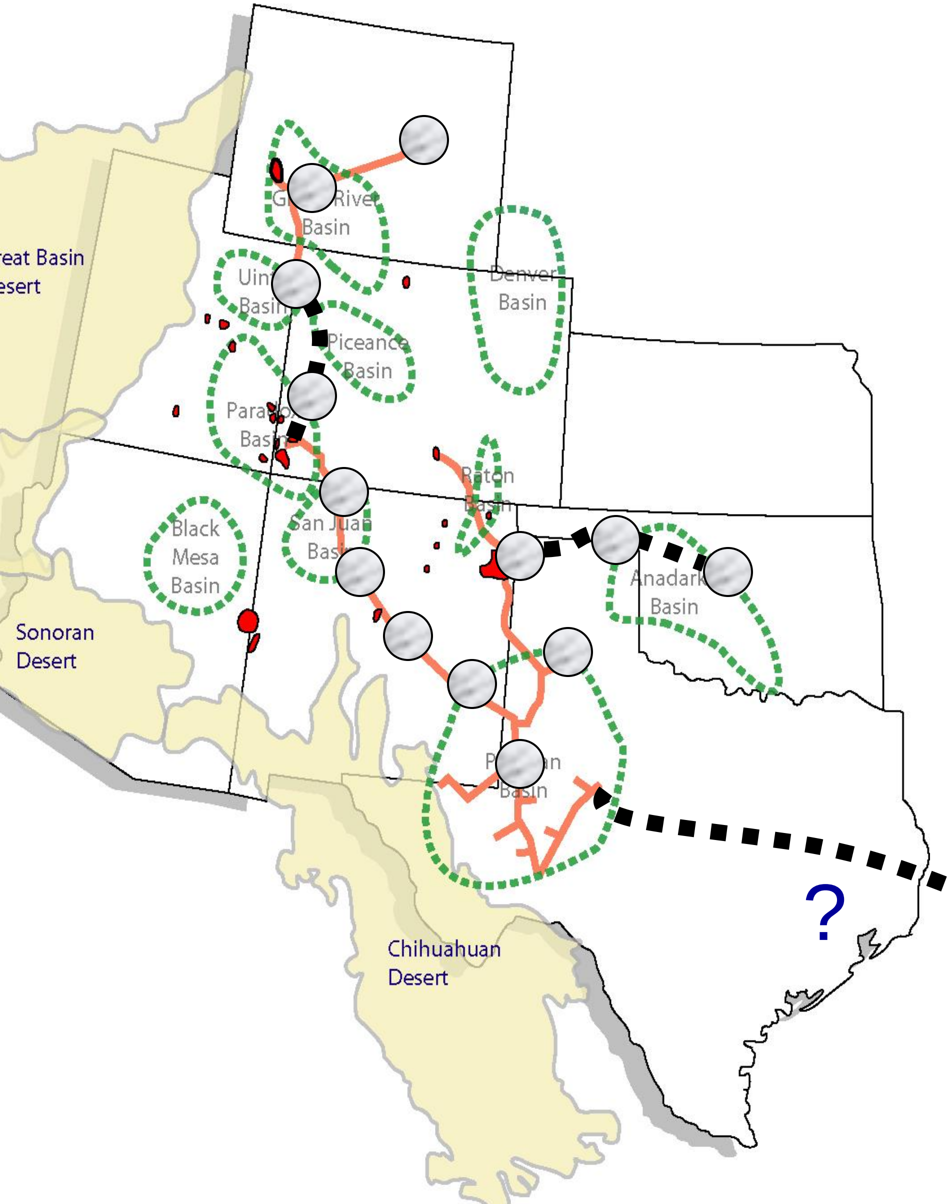


Saline Formation CO_2 Storage Resource by State (million metric tons)		
State	Low CO_2 Storage Resource	High CO_2 Storage Resource
Arizona	199	752
Colorado	18,828	75,313
Nebraska	87	348
New Mexico	33,054	132,215
Texas	11,700	46,800
Utah	24,934	99,305
Wyoming	4,909	19,636

Presentation Outline

- Summary of SWP Phase I
- **Summary of Phase 2 Activities**
- Regional Context of Phase 2 Tests
- Overview of Phase 3 Deployment Project
- Phase 3 Deployment Design
- Alternative Phase 3 Site
- Summary Goals

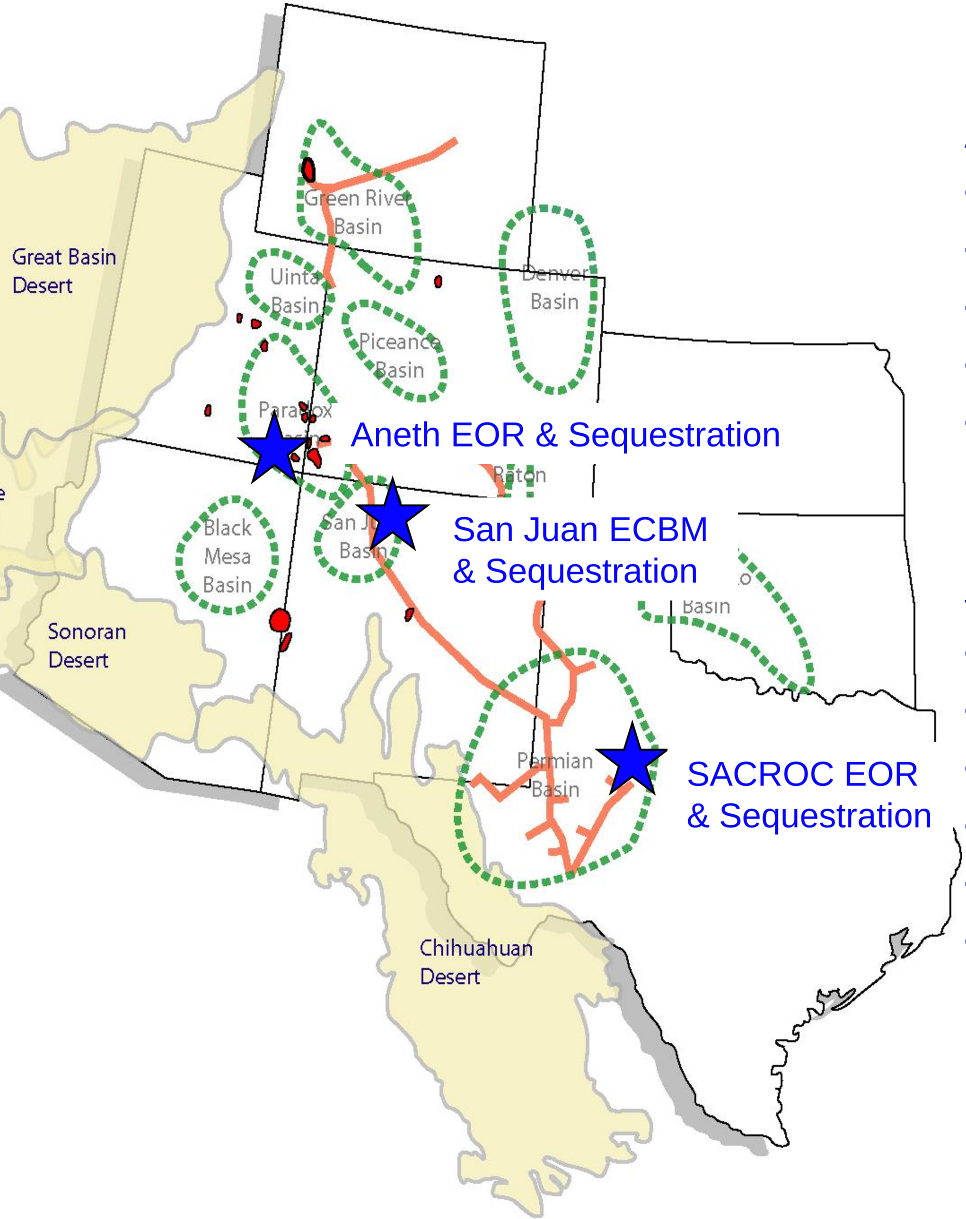
Southwest Phase 2 "Concept"



"String of Pearls"

Phase 2 tests intended to demonstrate short-term strategy: ***sequester along pipelines***

SWP Phase 2 Projects Summary



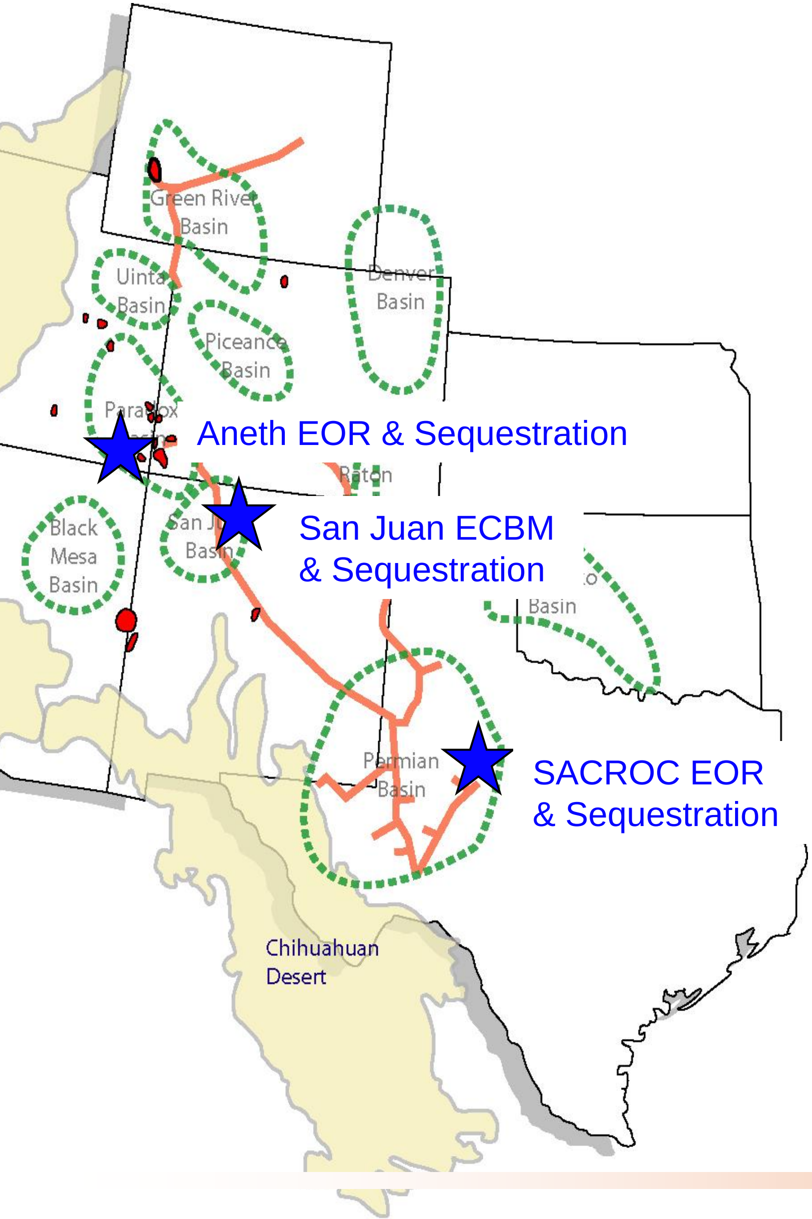
Aneth EOR & Sequestration:

- Injection began Aug 2007 - ongoing
- 292,300 tons total in SWP wells
- Successful seismic imaging
- Successful tracer monitoring
- Successful concomitant EOR with net CO_2 storage

San Juan ECBM & Sequestration

- Injection July 2008 - July 2009
- 18,400 tons in SWP injection well
- Successful vertical seismic profiling,
- Successful tiltmeter deployment
- Successful tracer testing
- Successful methane recovery with CCS

SWP Phase 2 Projects Summary



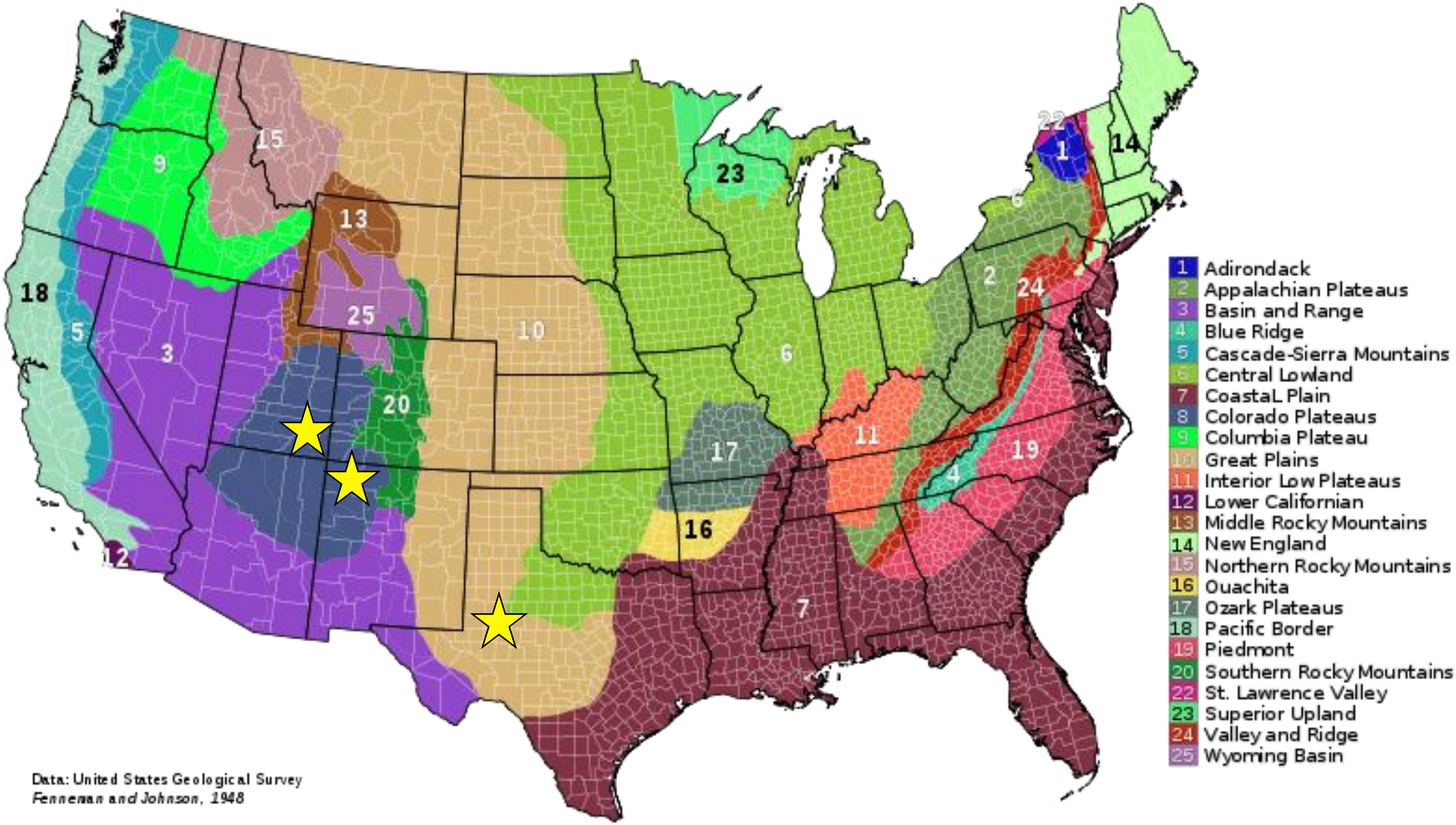
SACROC EOR & Sequestration:
- Injection began Oct 2008 and is ongoing
- Approximate 350,000 tons/year rate
- 4-D seismic imaging analysis ongoing
- Groundwater impacts methods
- Post-audit of trapping mechanisms and their relative roles, following 35 years of CO_2 injection for EOR
- Successful concomitant EOR and CCS
- Ongoing risk assessment suggests negligible CCS risks at this site

Terrestrial Sequestration:
- final analysis suggests that 1 to 5 power plants' worth of emissions can be offset by altered land management
- successful local-scale terrestrial pilot with San Juan Basin ECBM injection

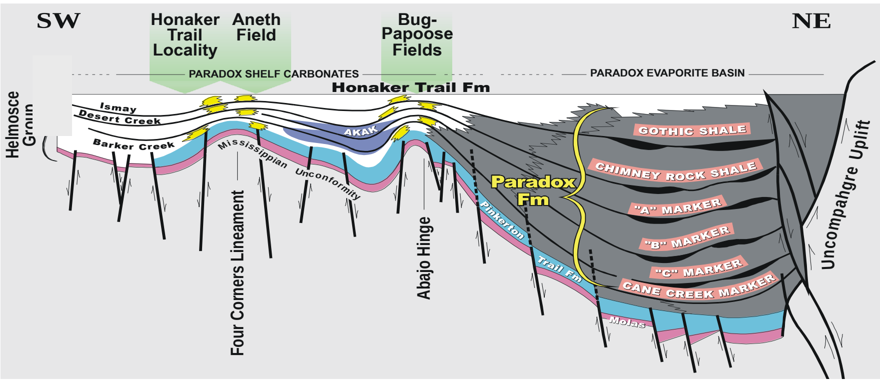
Presentation Outline

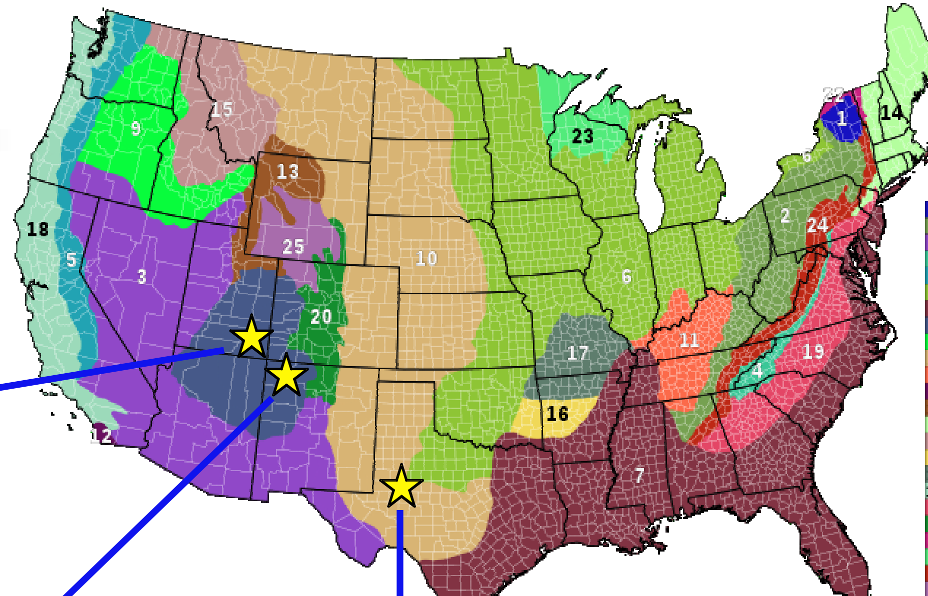
- Summary of SWP Phase I
- Summary of Phase 2 Activities
- **Regional Context of Phase 2 Tests**
- Overview of Phase 3 Deployment Project
- Phase 3 Deployment Design
- Alternative Phase 3 Site
- Summary Goals

Regional Context of Phase 2 Tests

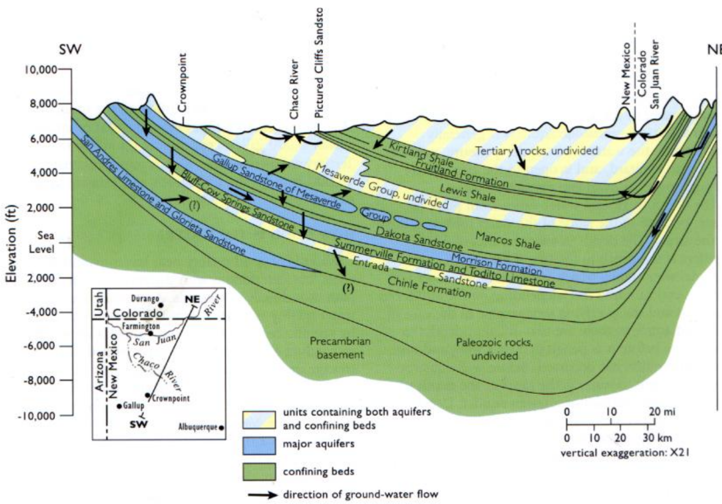


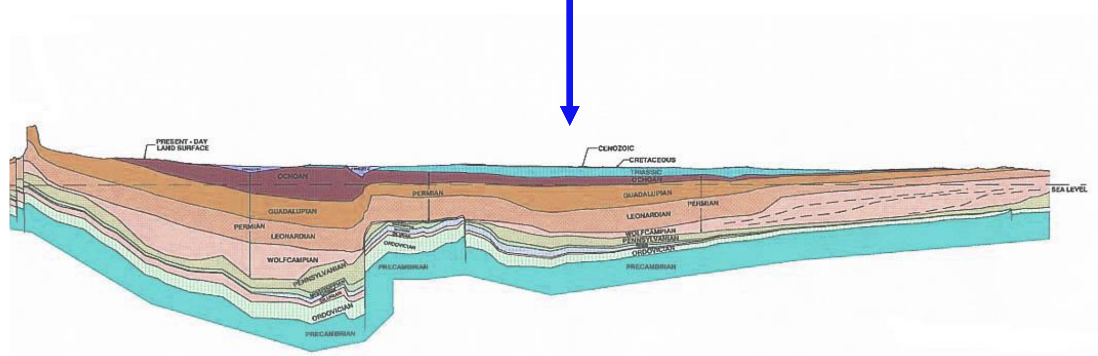
Regional Context



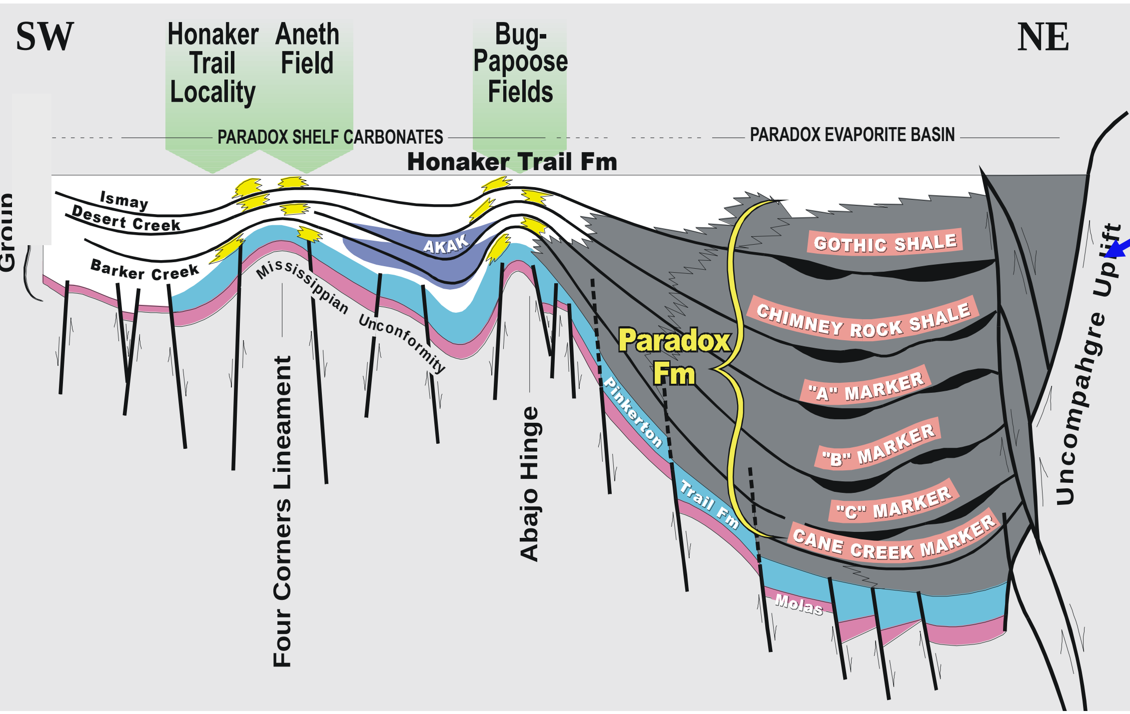


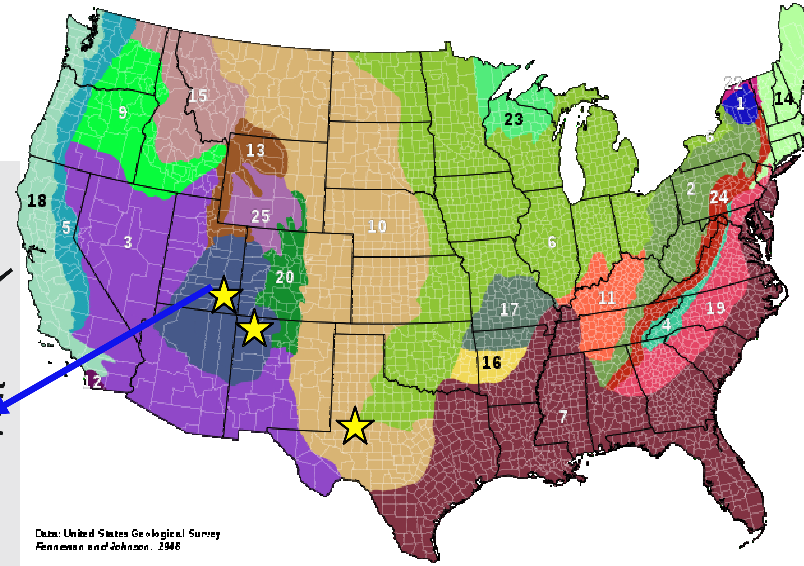
Data: United States Geological Survey
Fenneman and Johnson, 1946





Regional Context





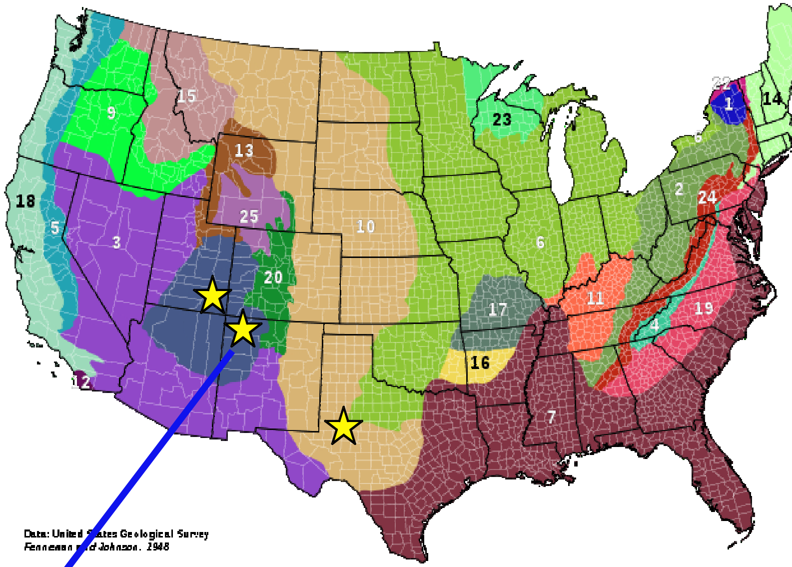
Aneth test site:

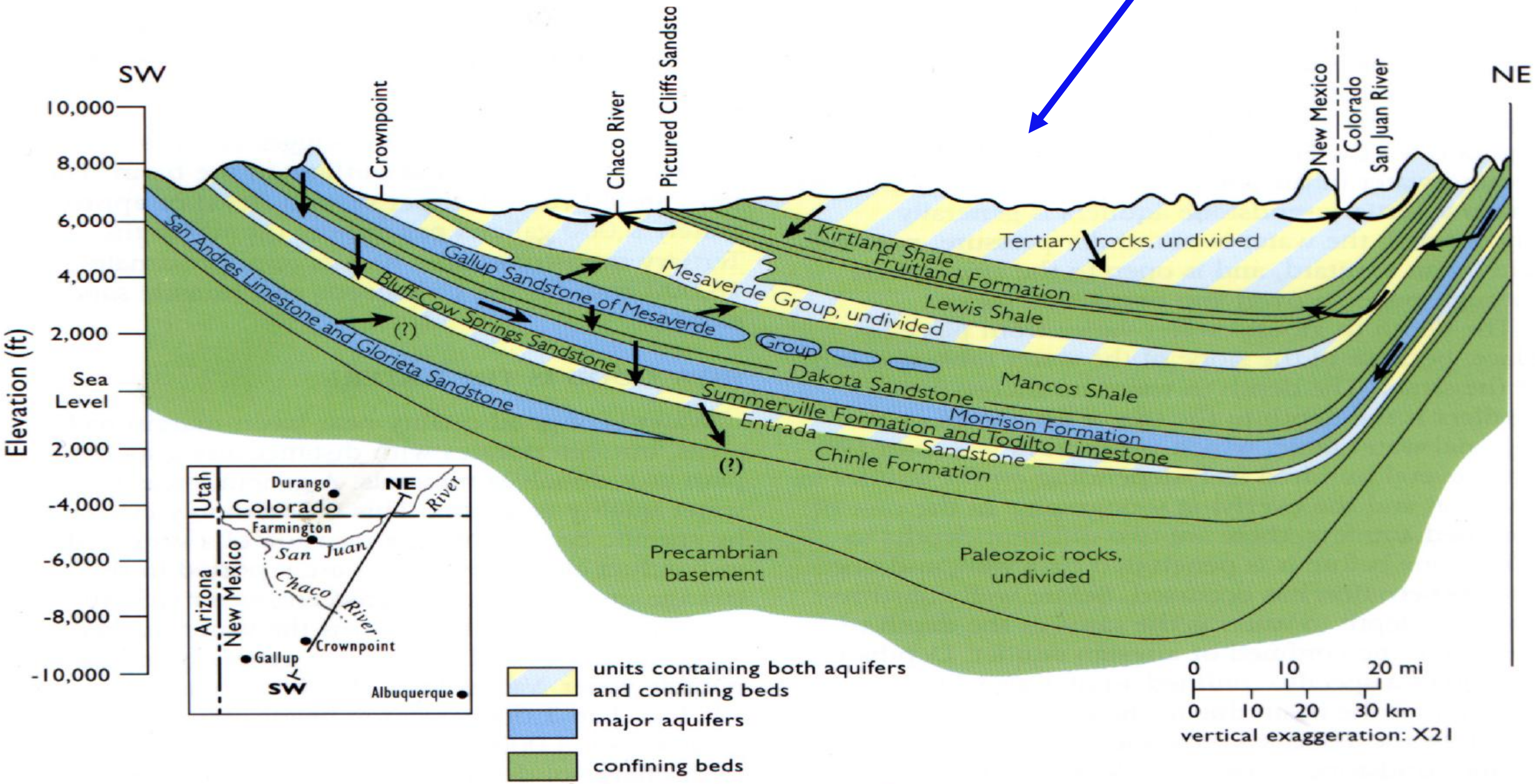
- Colorado Plateau province
- Pennsylvanian-age formations
- Carbonates
- EOR with Sequestration

Regional Context

San Juan test site:

- Colorado Plateau province
- Cretaceous-age formations
- Coal, SS, Shale
- ECBM with Sequestration

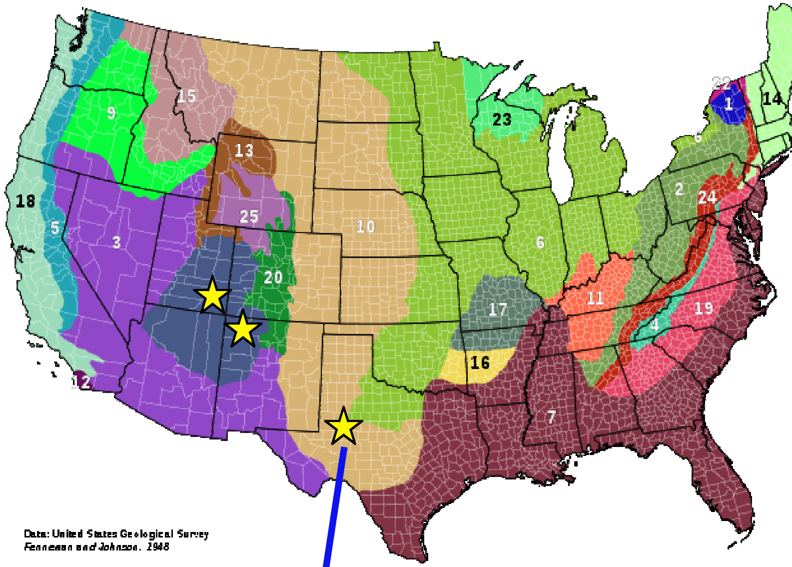


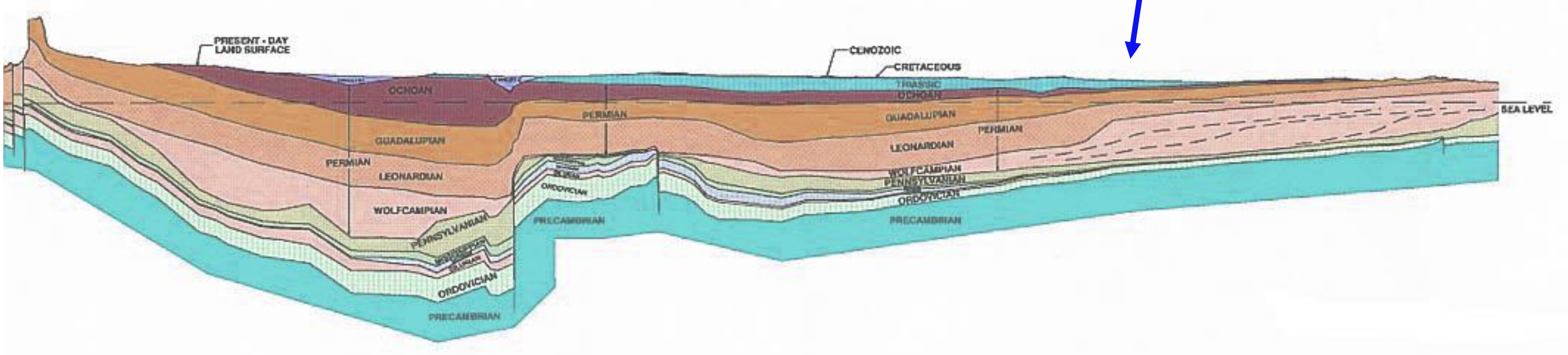


Regional Context

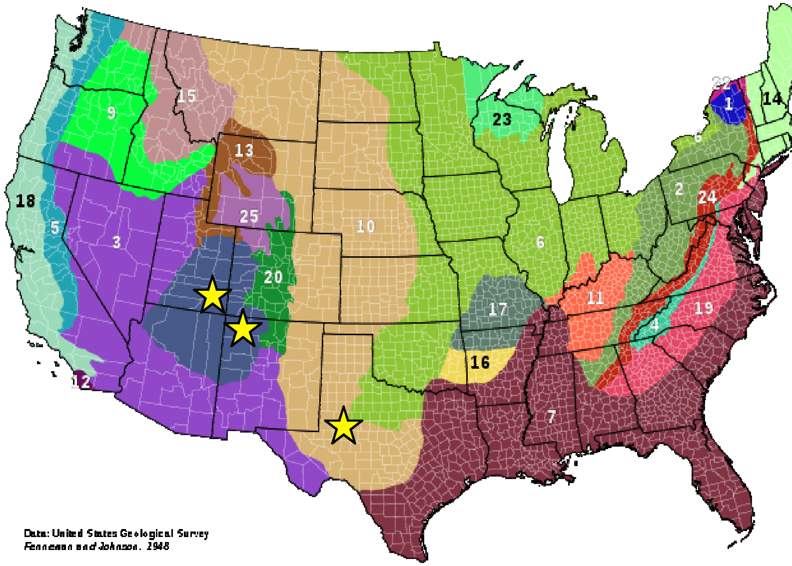
SACROC test site:

- Great Plains province
- Pennsylvanian-age formations
- Carbonates
- EOR with Sequestration



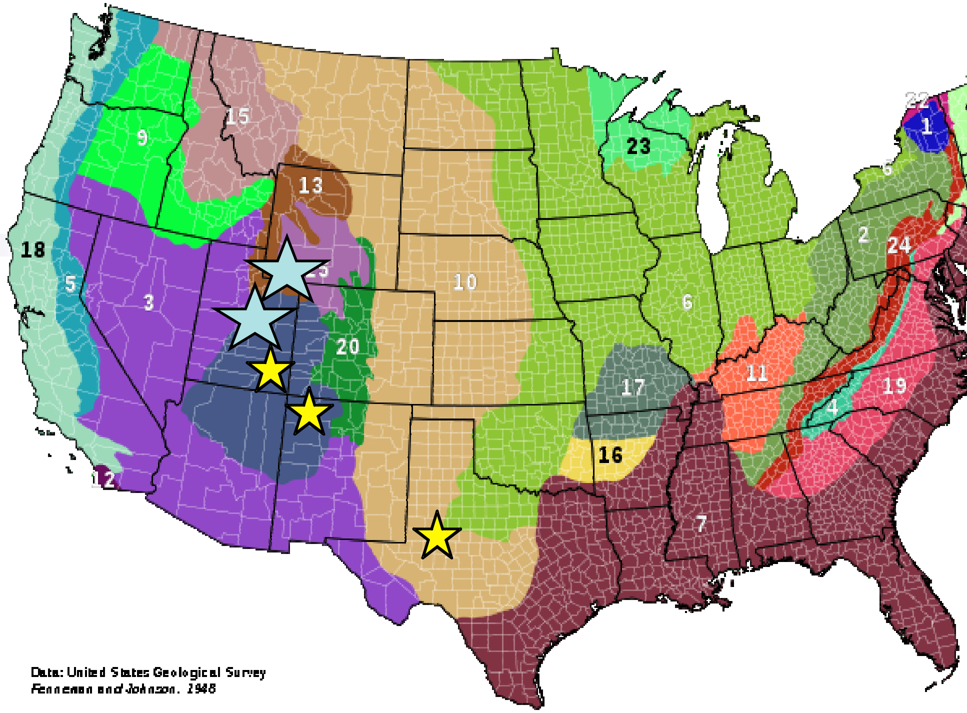


Regional Context



So, what might be most appropriate for Phase 3 deployment?

Regional Context



Data: United States Geological Survey
Fenneman and Johnson, 1946

So, what might be most appropriate for Phase 3 deployment?

- **deep saline - <u>more capacity</u>**
- **Jurassic and older sandstones - <u>more SS options</u>**
- **Colorado Plateau / Rocky Mtns - <u>more power plants</u>**

Presentation Outline

- Summary of SWP Phase I
- Summary of Phase 2 Activities
- Regional Context of Phase 2 Tests
- **Overview of Phase 3 Deployment Project**
- Phase 3 Deployment Design
- Alternative Phase 3 Site
- Summary Goals

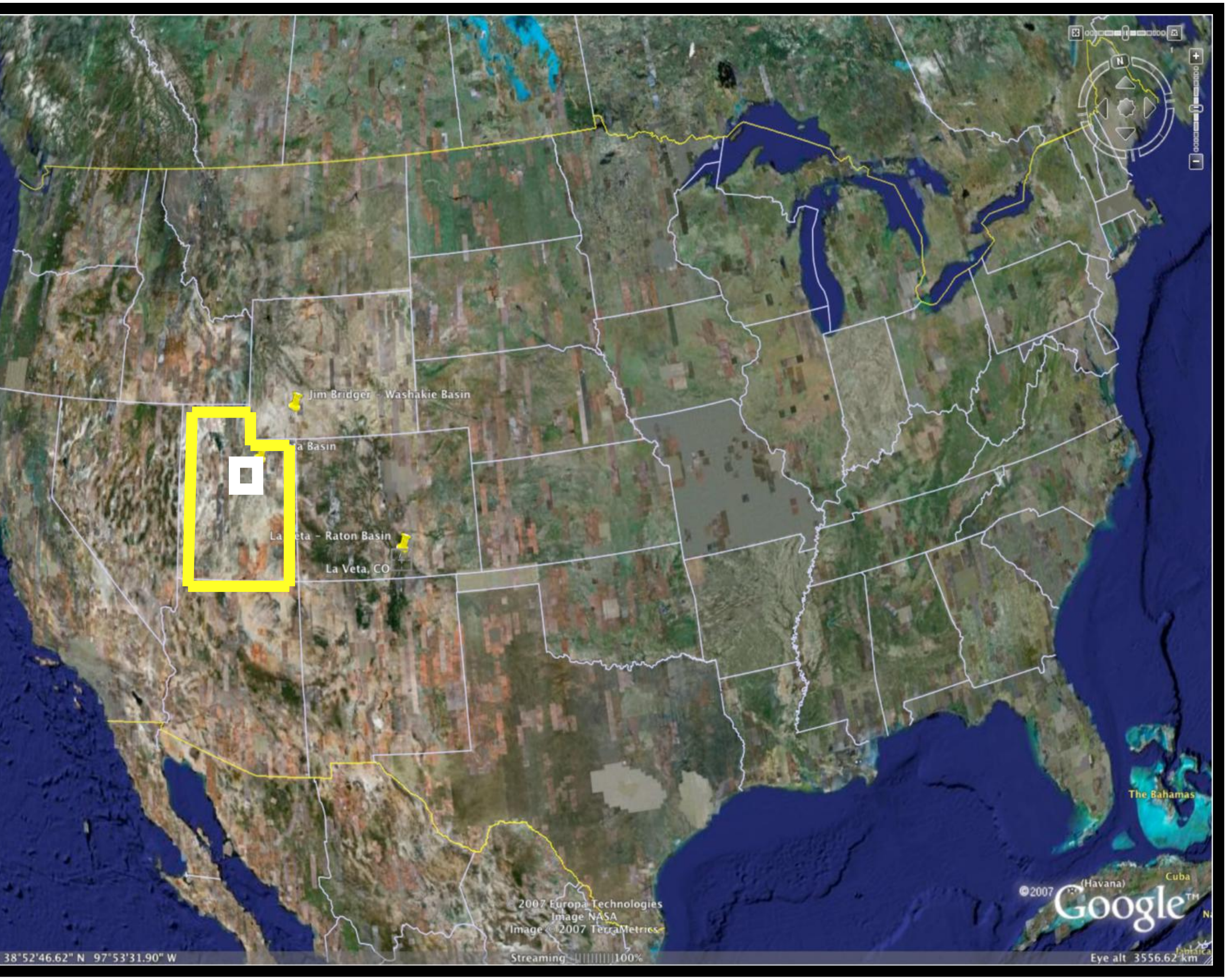
SWP Phase 3 - What and Why

- **What is the SWP and its partners planning for 2010?**
  - 1,000,000 tons per year for multiple years
  - "blueprint" for future commercial sequestration
- **Why are we conducting this testing?**
  - many deep saline formations common to all basins
  - deep Jurassic- and older "clean" sandstones in all states
  - representative commercial sites
- **How are we carrying out this testing?**
  - Close collaboration among Partnership and industry
  - Concerted coordination with regulatory agencies

SWP Phase 3 - What and Why

- Validate Geologic Storage
  - Injectivity
  - Capacity
  - Permanence
- Develop Monitoring Methodologies
  - Areal Extent of Plume
- Develop from Experience
  - Risk Assessment Strategies
  - Best Practices for Industry
- Support Regulatory Development
- Engage in Public Outreach and Education

Wasatch Plateau Project

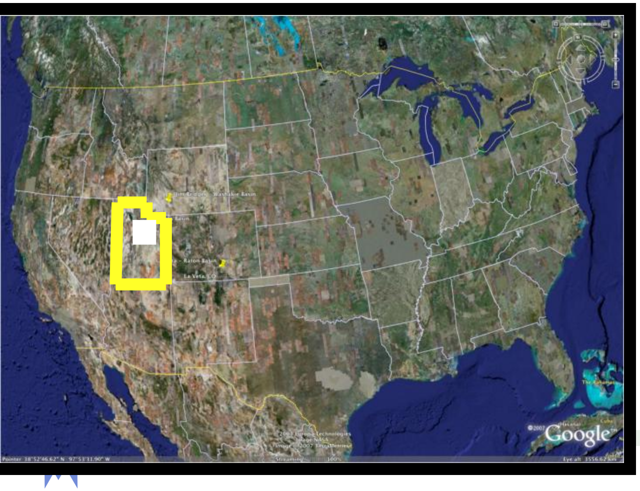


Commercial-Scale Project Location:
Wasatch Plateau, Utah
CO_2 Source = White Rim Formation (natural)

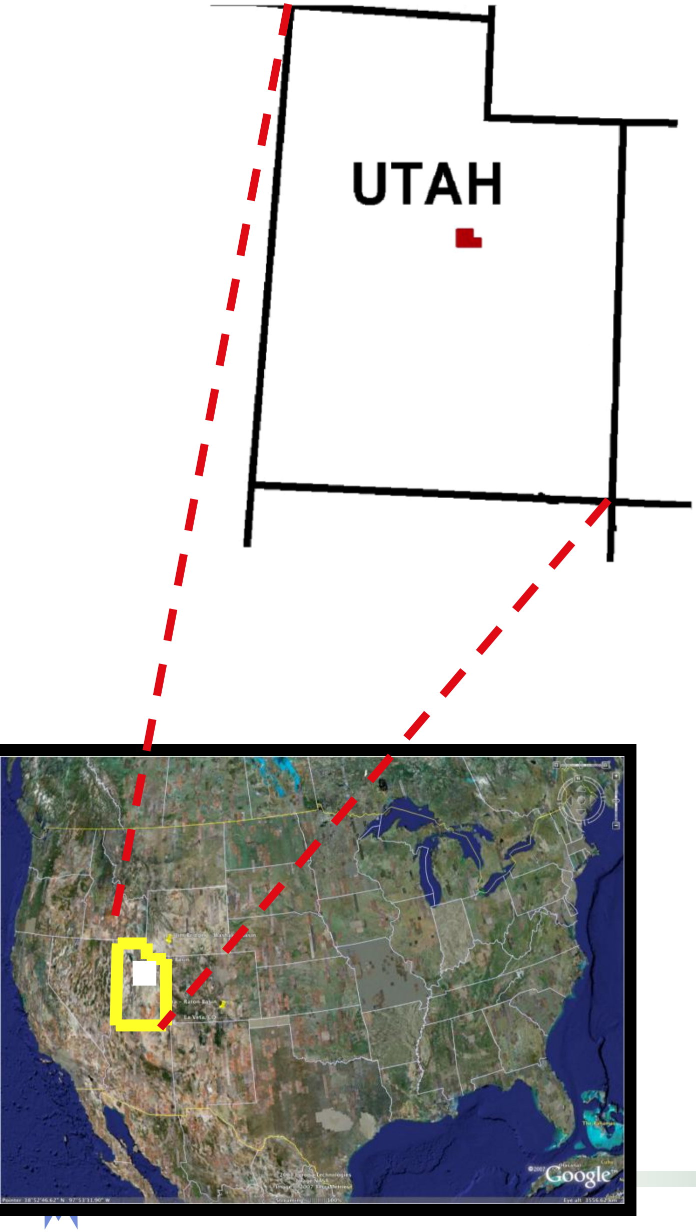
Details:

- Gordon Creek Field (active gas field)
- 2,900,000 tons minimum
- 3 year injection minimum
- focus on transferability of results (site-to-site)
- target injection start date: **2011**

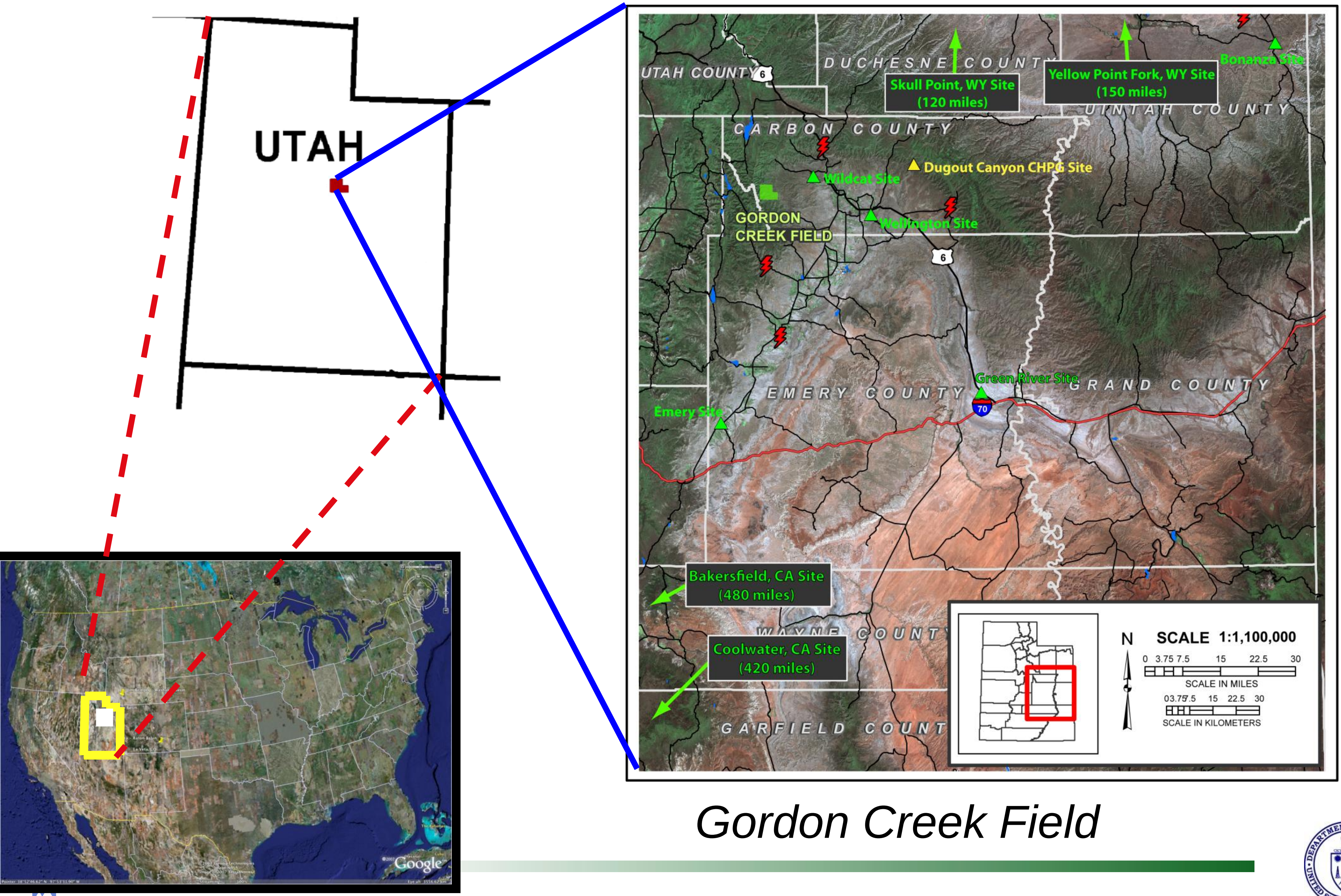
Wasatch Plateau Project



Wasatch Plateau Project

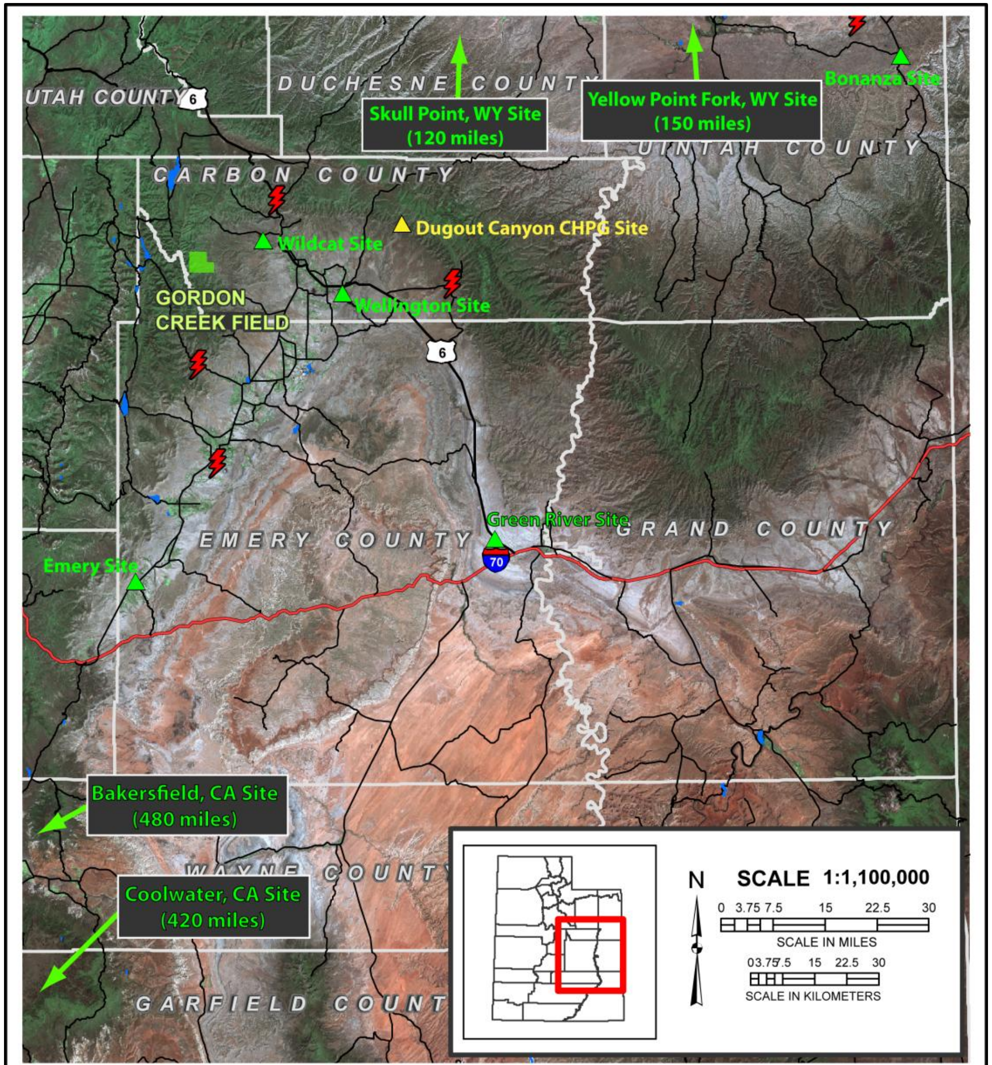


Wasatch Plateau Project: Location



Gordon Creek Field

Wasatch Plateau Project: Location and Geology



"Ring of Power"

Period	Symb *	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250	3115	
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300	4000	
	Kd	Dakota Sandstone		0-30	4025	
	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
	Js	Summerville Formation		120-180	5895	
	Jct	Curtis Formation		140-180	6275	
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700	7650	
	Jc	Page Sandstone		<70		
	Jgc	Navajo Sandstone		150-300	8400	
		Kayenta Formation		120-200	8750	
		Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700	9520	
	Trms		Sinbad Ls Mbr	50	10460	
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
	Pwr	White Rim Sandstone		500-700	11135	

CO_2 Source
CO_2 Sink
Methane Producer
Seal

Stacked System

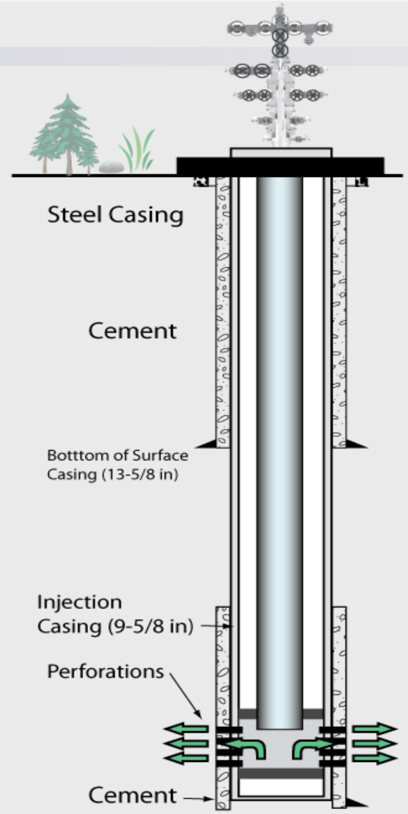
Wasatch Plateau Project: Storage Formations

Period	Symb†	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
CRET	Km	Mancos Shale	Blue Gate Sh Mbr	<250	3115	
CRET	Km	Mancos Shale	Ferron Ss Mbr	10-110	3250	
CRET	Km	Mancos Shale	Tununk Sh Mbr	200-300	4000	
CRET	Kd	Dakota Sandstone		0-30	4025	
CRET	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
CRET	Kcm	Cedar Mtn Fm	Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
JURASSIC	Js	Summerville Formation		120-180	5895	
JURASSIC	Jct	Curtis Formation		140-180	6275	
JURASSIC	Je	Entrada Formation		150-950	6585	
JURASSIC	Jc	Carmel Formation		300-700	7650	
JURASSIC	Jc	Page Sandstone		<70		
JURASSIC	Jgc	Navajo Sandstone		150-300	8400	
JURASSIC	Jgc	Kayenta Formation		120-200	8750	
JURASSIC	Jgc	Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
TRIASSIC	Trc	Chinle Fm	Moss Back Mbr	20-60		
TRIASSIC	Trmt	Moenkopi Fm	Upper member	550-700	9520	
TRIASSIC	Trms	Moenkopi Fm	Sinbad Ls Mbr	50	10460	
TRIASSIC	Trmbd	Moenkopi Fm	Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
PERM	Pwr	White Rim Sandstone		500-700	11135	

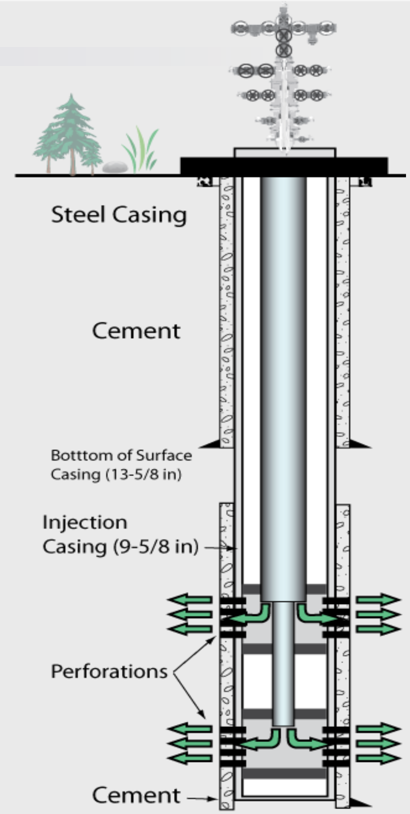
- Blue: CO_2 Source
- Yellow: Methane Producer
- Green: CO_2 Sink
- Red: Seal

† Geologic symbols for correlation to units in Morgan (2007)

Modified from Hintze (1992)



Single zone Injection (Navajo Fm):



Dual zone Injection (Entrada & Navajo Fm)

Multiple-Zone Injection and Storage Assessment

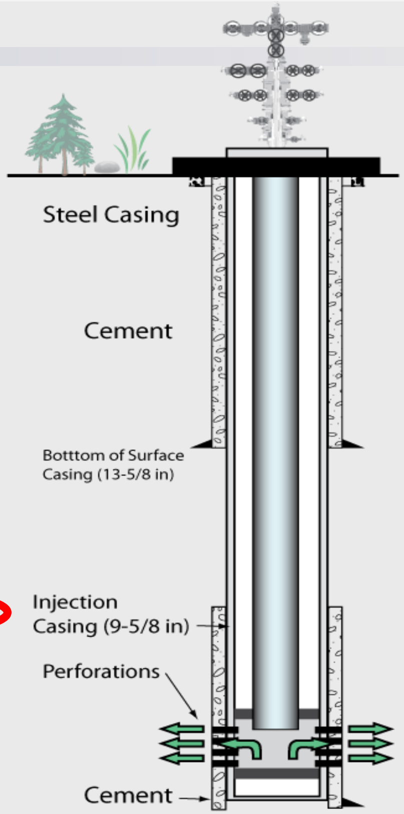
Wasatch Plateau Project: Storage Formations

Period	Symb†	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250	3115	
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300	4000	
	Kd	Dakota Sandstone		0-30	4025	
	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
	Js	Summerville Formation		120-180	5895	
	Jct	Curtis Formation		140-180	6275	
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700	7650	
	Jc	Page Sandstone		<70		
	Jgc	Navajo Sandstone		150-300	8400	
		Kayenta Formation		120-200	8750	
		Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700	9520	
	Trms		Sinbad Ls Mbr	50	10460	
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
	Pwr	White Rim Sandstone		500-700	11135	

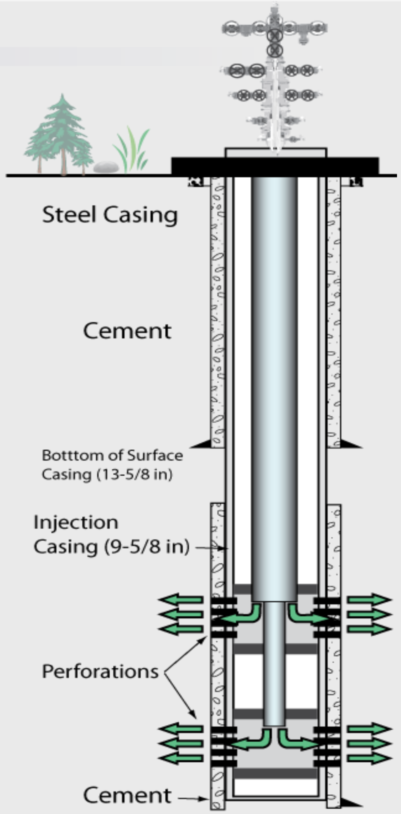
CO_2 Source — CO_2 Sink — Methane Producer — Seal

† Geologic symbols for correlation to units in Morgan (2007)

Modified from Hintze (1992)



Single zone Injection (Navajo Fm):



Dual zone Injection (Entrada & Navajo Fm)

Multiple-Zone Injection and Storage Assessment

NETL

Wasatch Plateau Project: CO_2 Source

Period	Symb	Formation	Member	Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250	3115	
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300	4000	
	Kd	Dakota Sandstone		0-30	4025	
	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
	Js	Summerville Formation		120-180	5895	
	Jct	Curtis Formation		140-180	6275	
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700	7650	
	Jc	Page Sandstone		<70		
	Jgc	Navajo Sandstone		150-300	8400	
		Kayenta Formation		120-200	8750	
		Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700	9520	
	Trms		Sinbad Ls Mbr	50	10460	
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
	Pwr	White Rim Sandstone		500-700	11135	

Legend:
- Blue: CO_2 Source
- Green: CO_2 Sink
- Yellow: Methane Producer
- Red: Seal

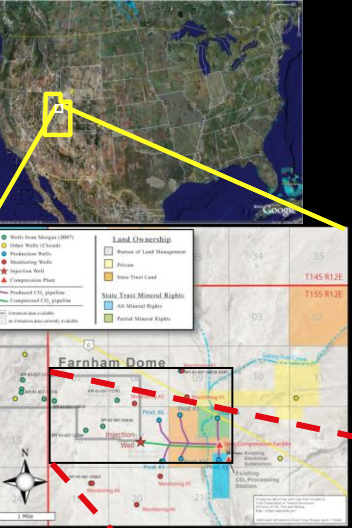
Natural CO_2 Reservoir

Advantages:

- FREE
- *(Ahem…cost of production)*

- still facilitates goals:
  - MVA efficacy
  - injectivity design
  - risk asssessment
  - mitigation design
  - water management

Wasatch Plateau, Utah: Baseline Modeling for MVA



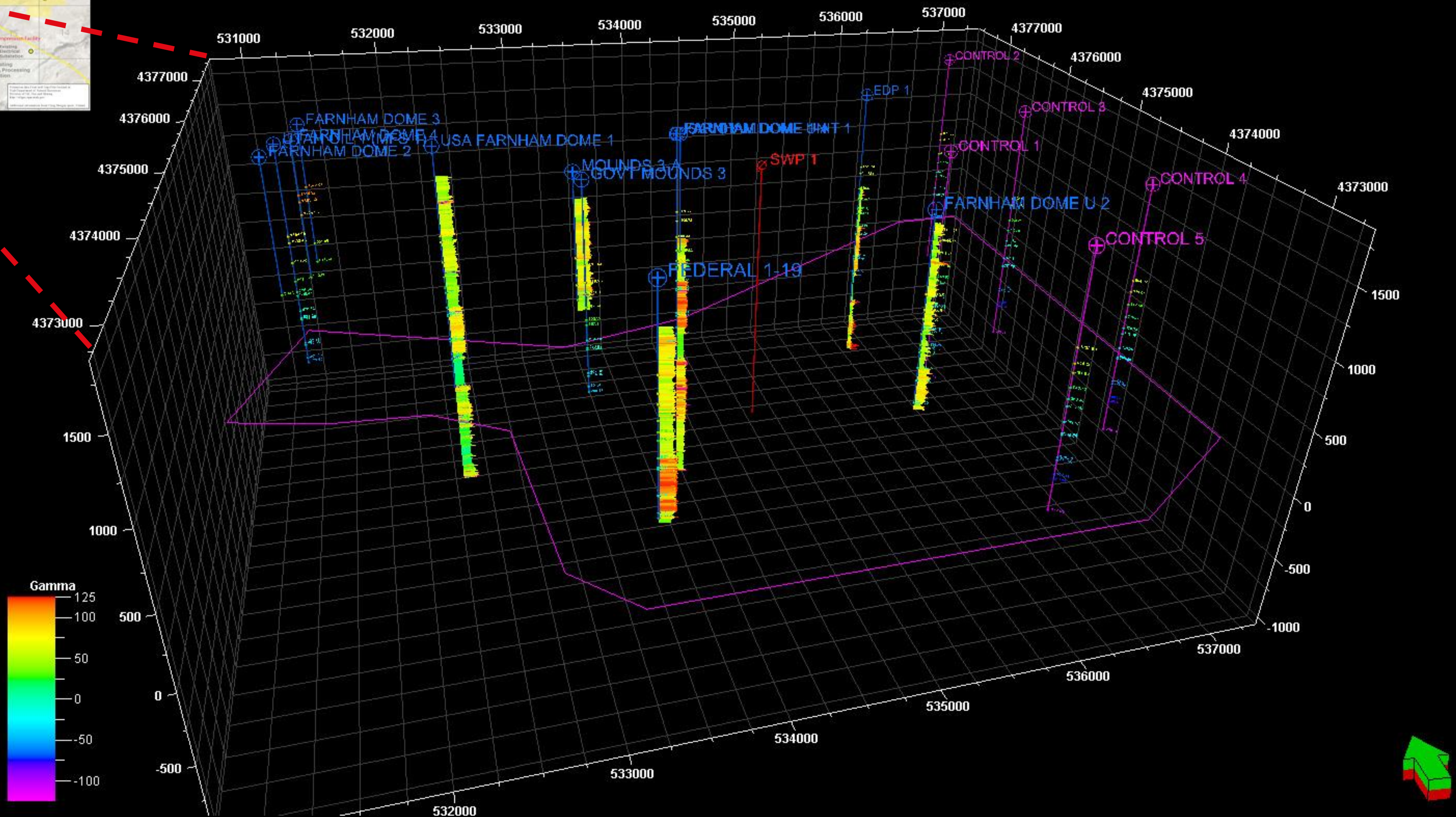
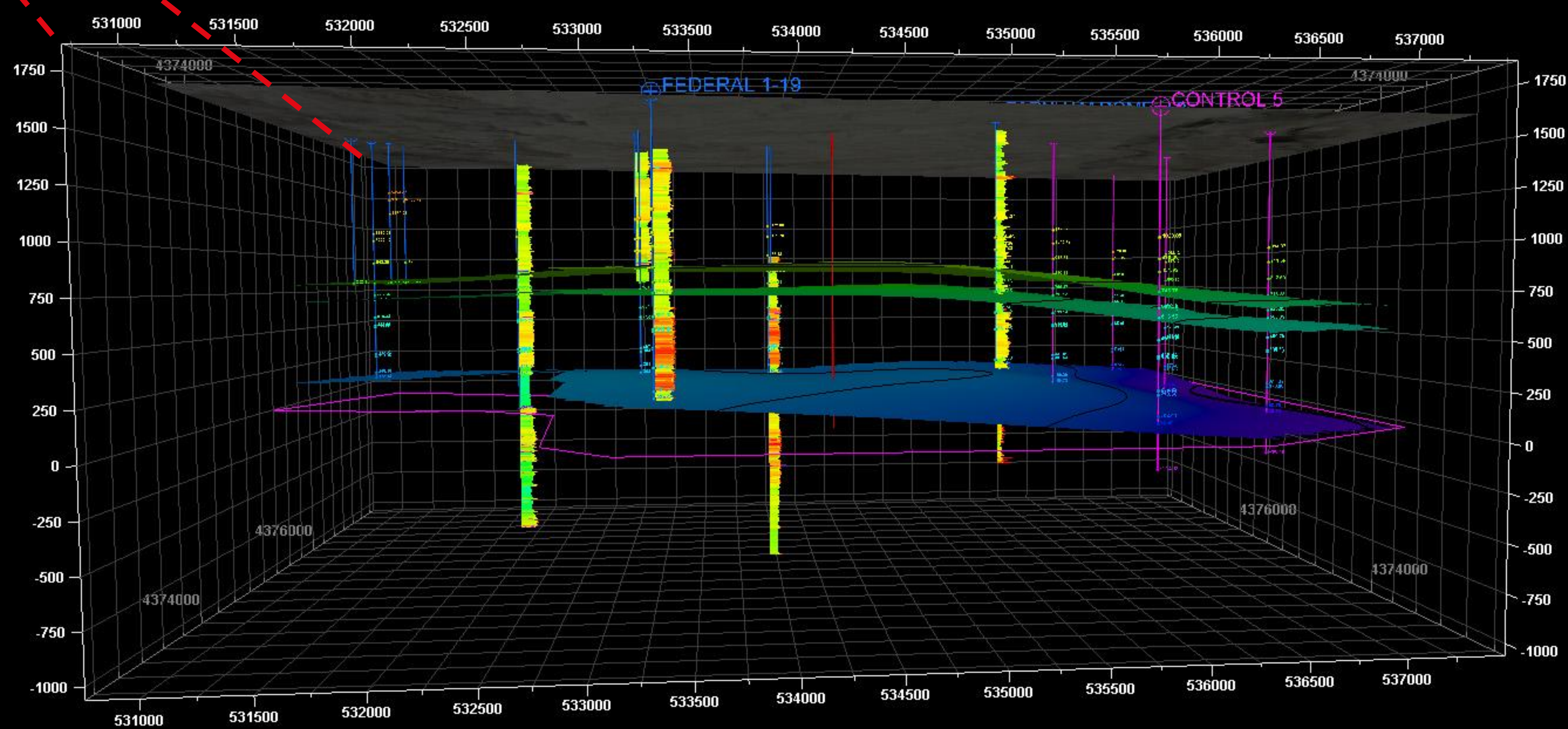
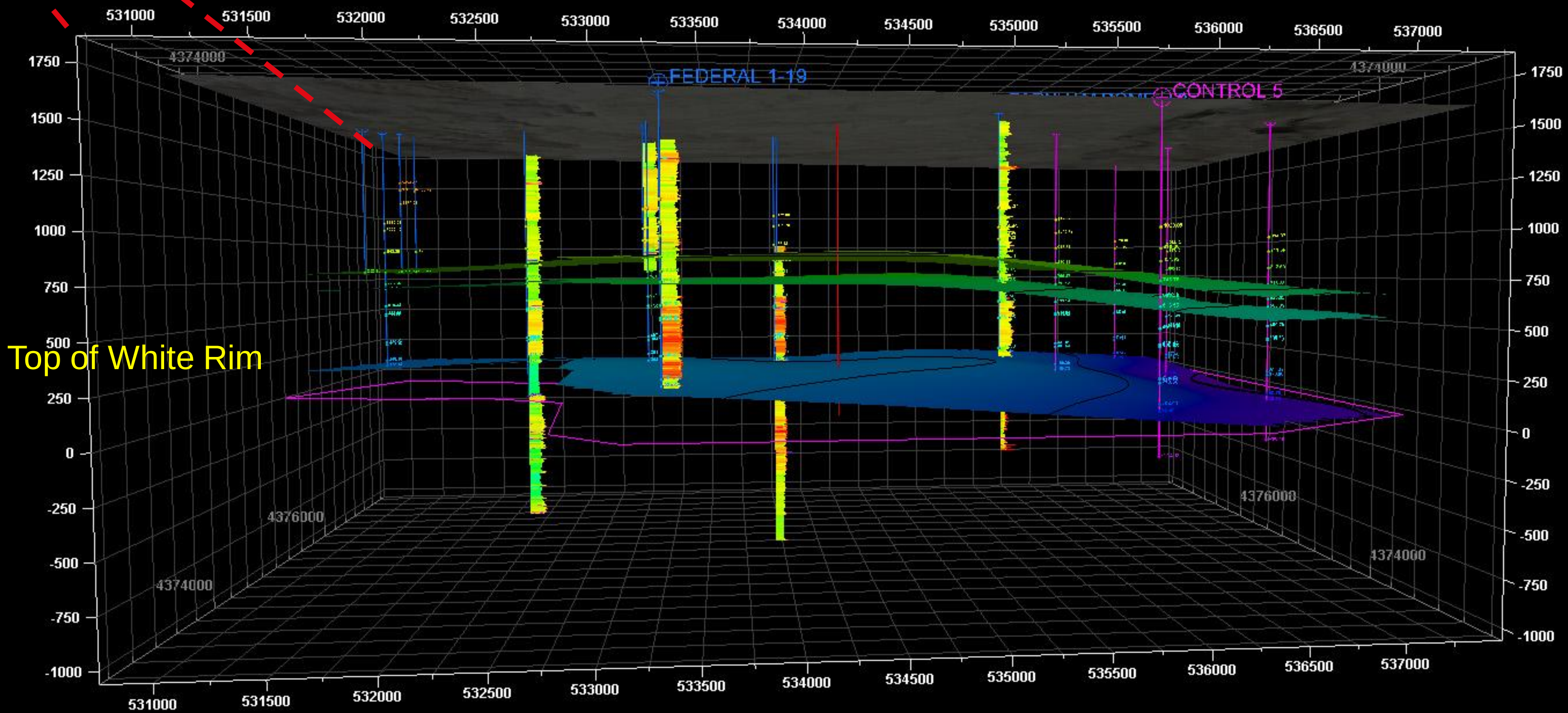


Figure by Si-Yong Lee

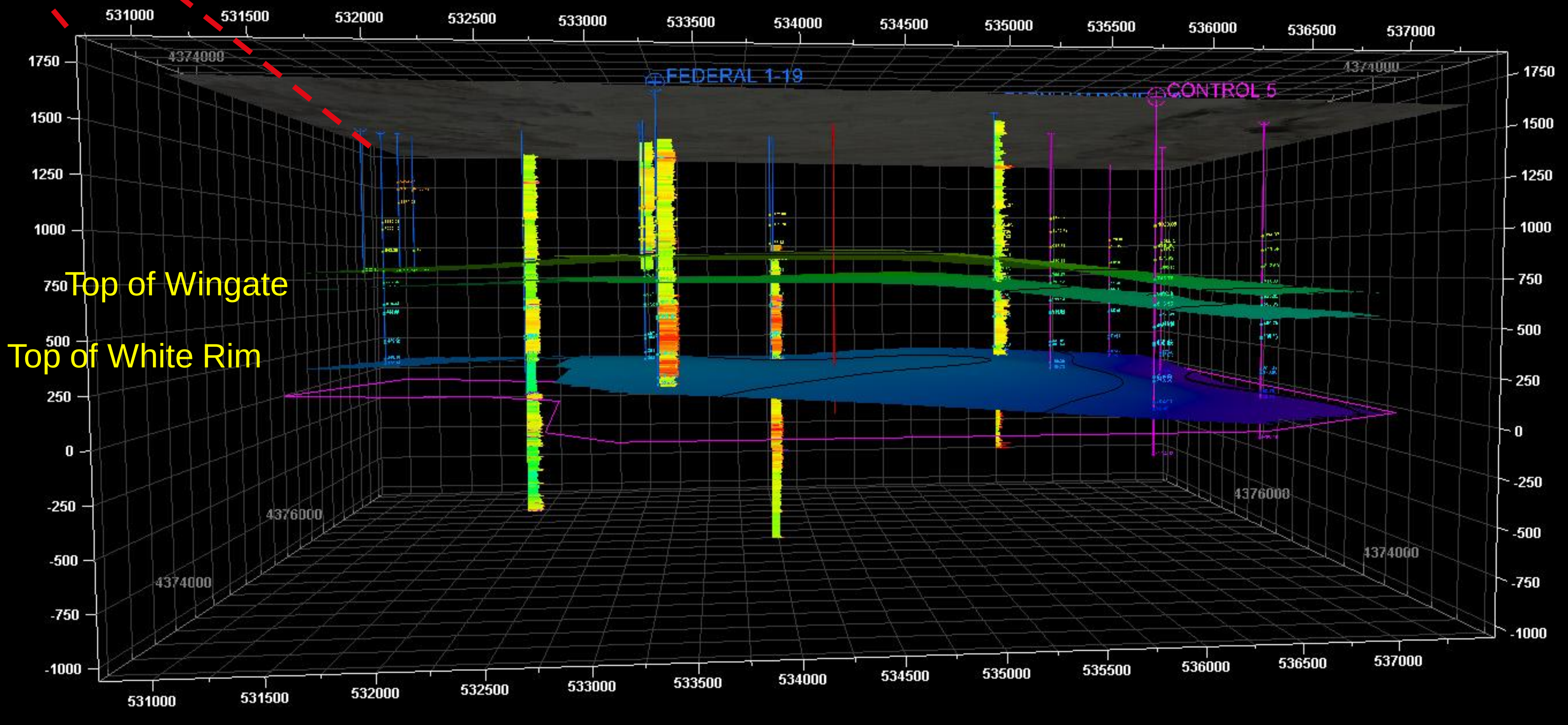
Wasatch Plateau, Utah: Baseline Modeling for MVA



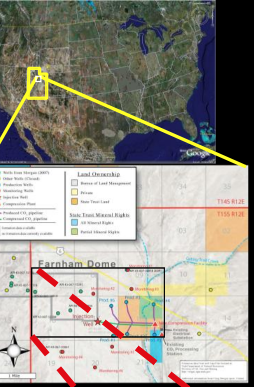
Wasatch Plateau, Utah: Baseline Modeling for MVA

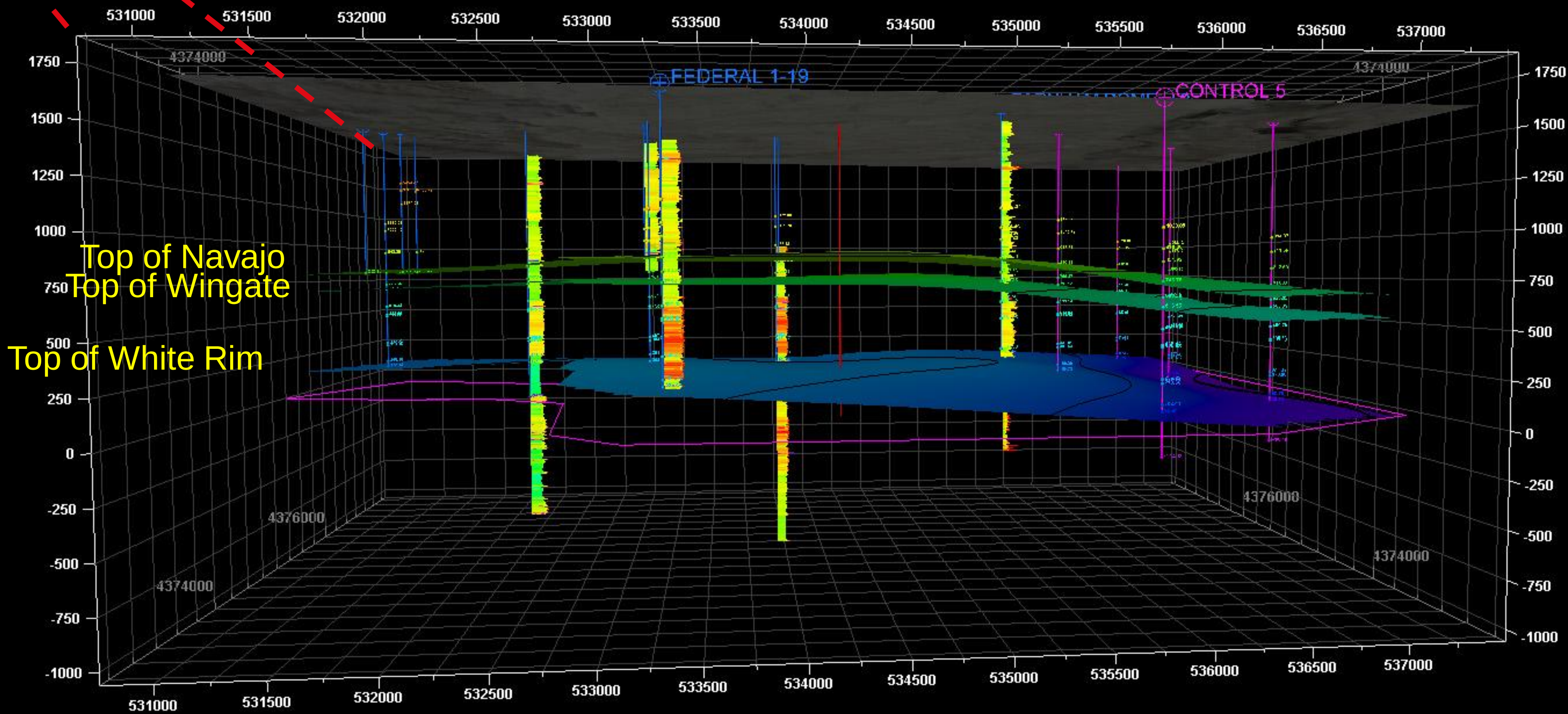


Wasatch Plateau, Utah: Baseline Modeling for MVA



Wasatch Plateau, Utah: Baseline Modeling for MVA





Wasatch Plateau, Utah: Baseline Modeling for MVA

5 Mile Radius

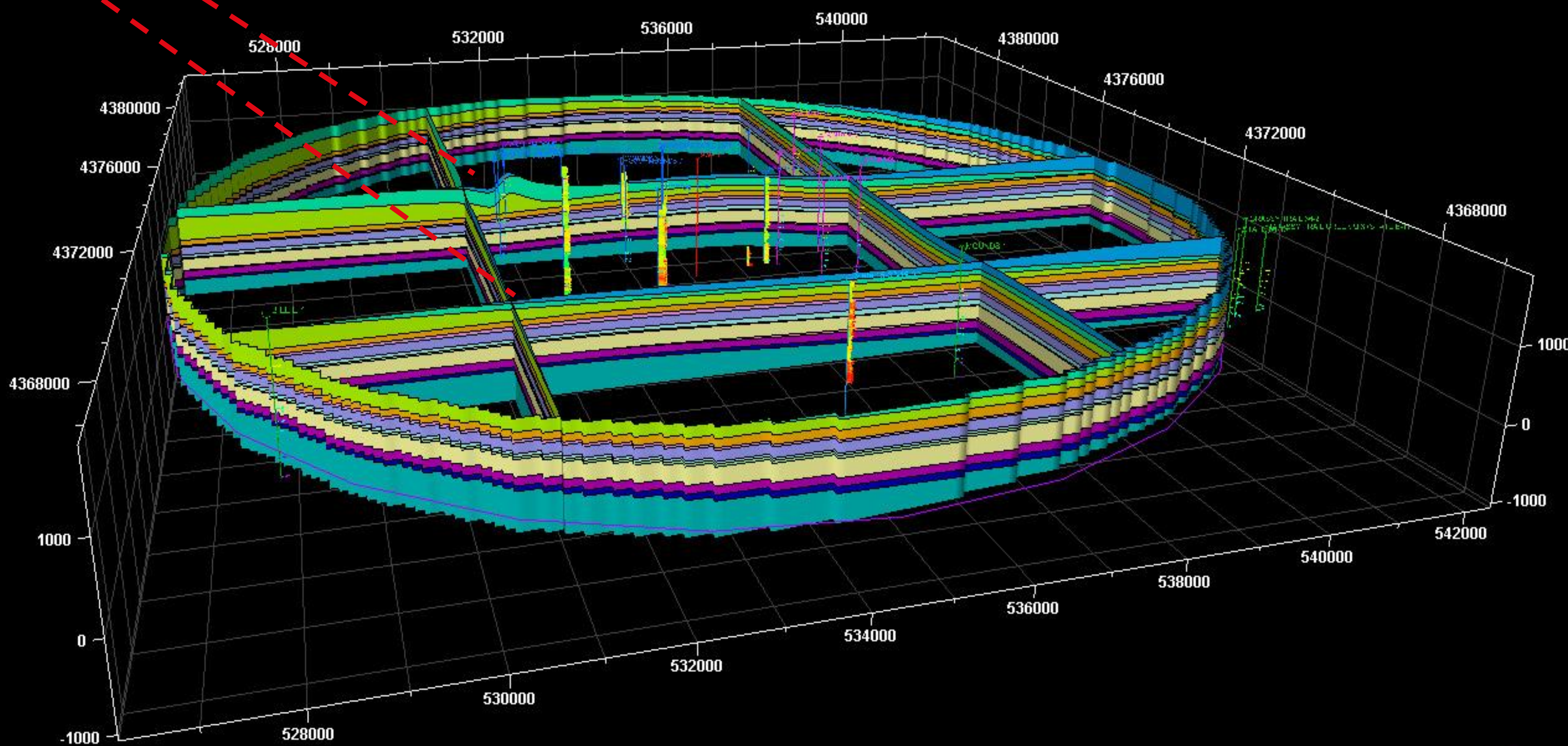
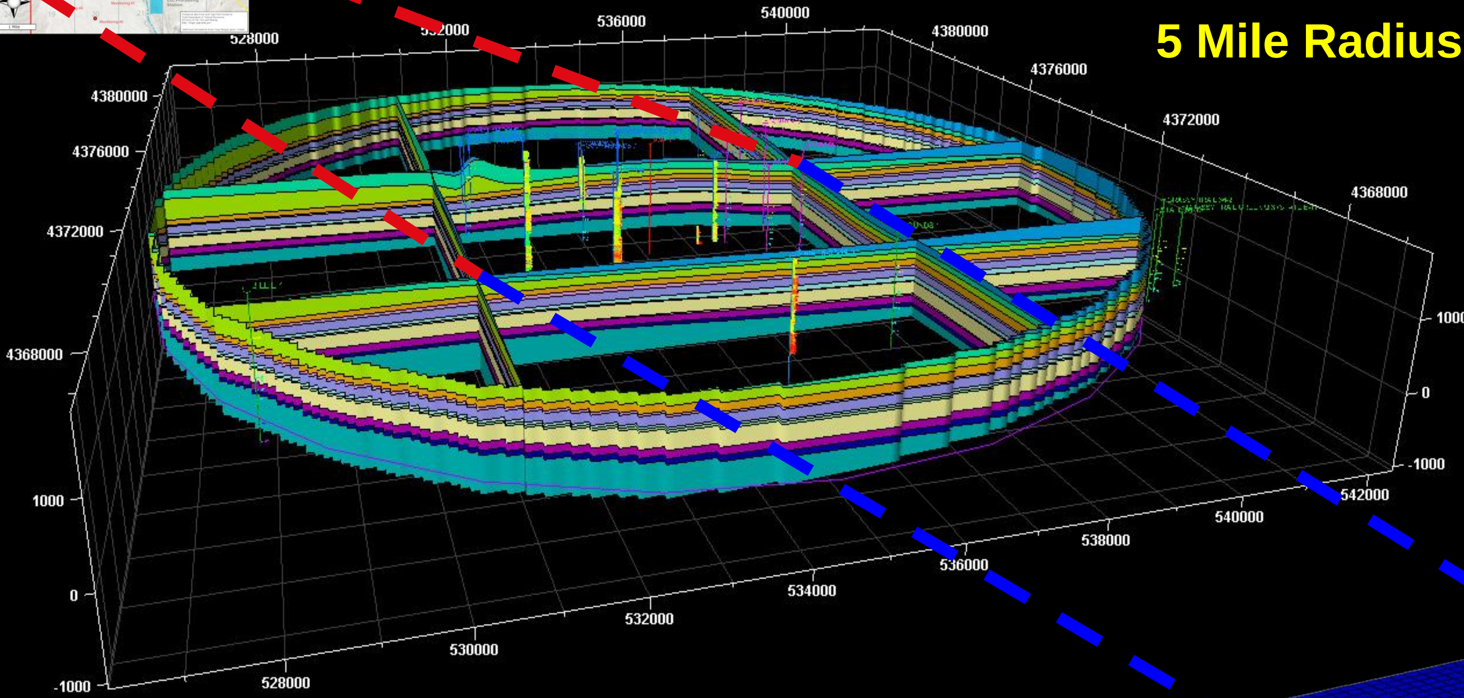
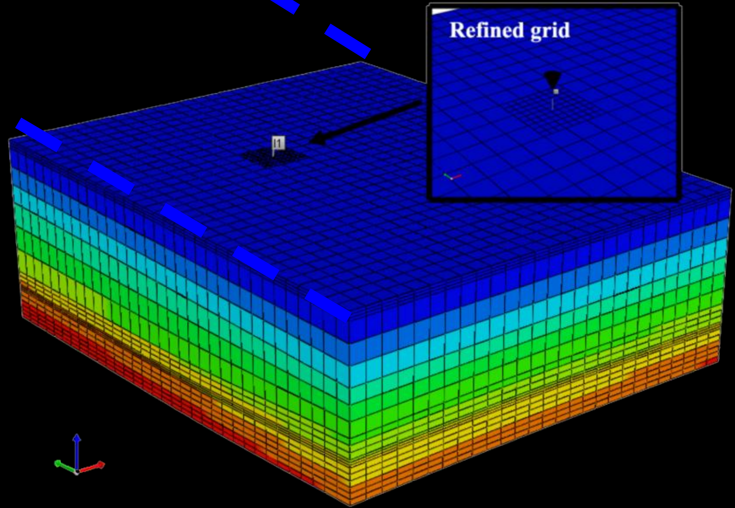


Figure by Si-Yong Lee

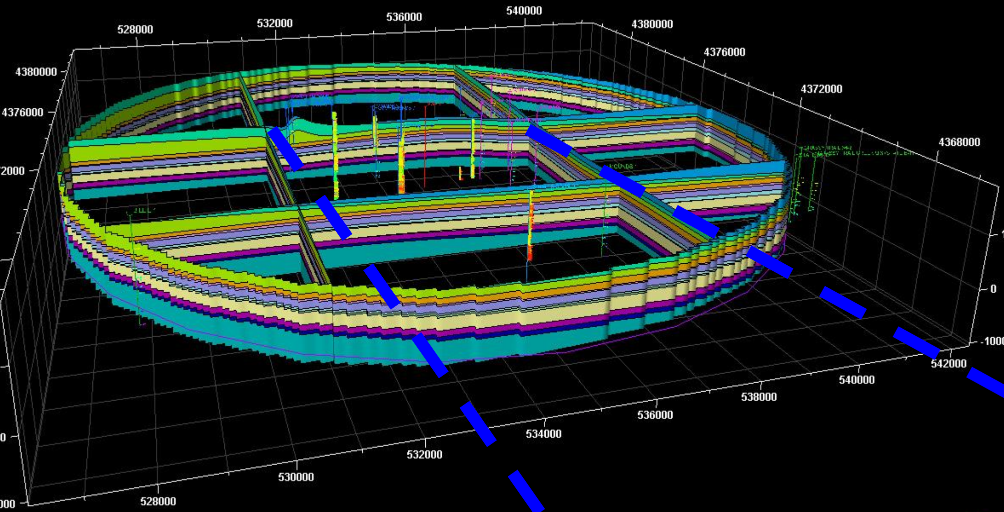
Wasatch Plateau, Utah: Baseline Modeling for MVA

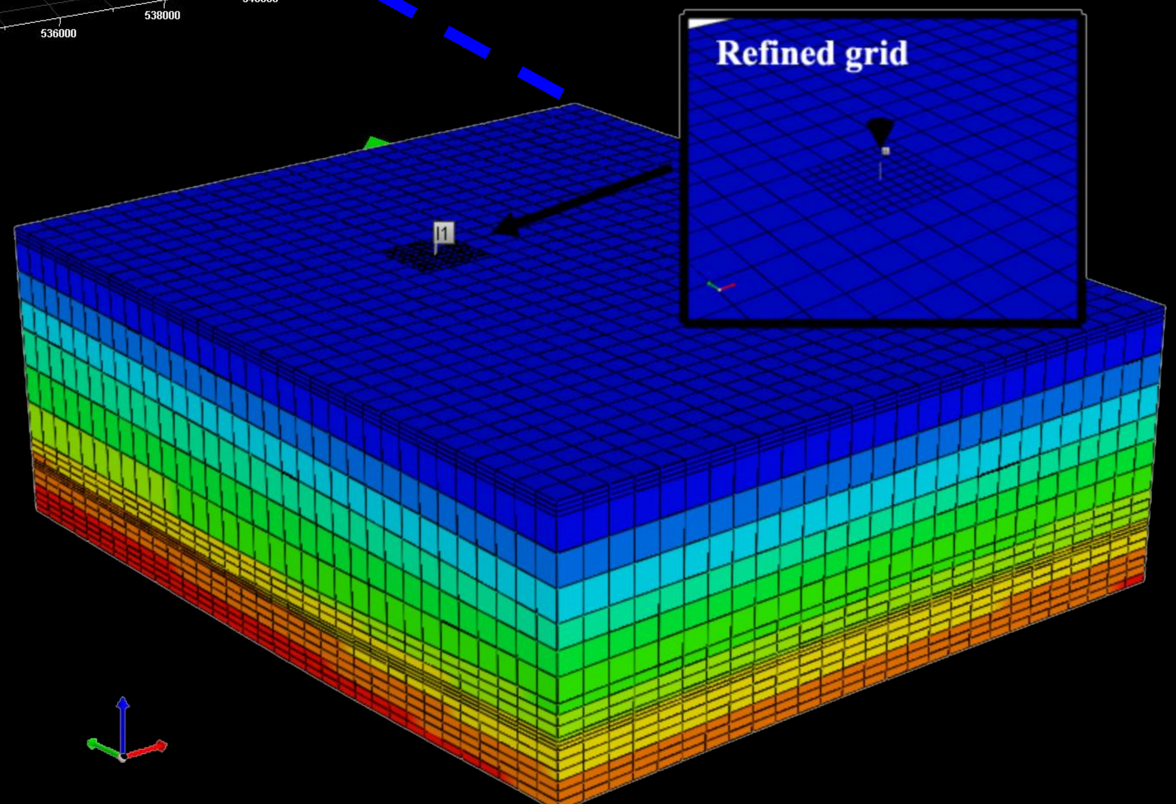




Wasatch Plateau, Utah: Baseline Modeling for MVA

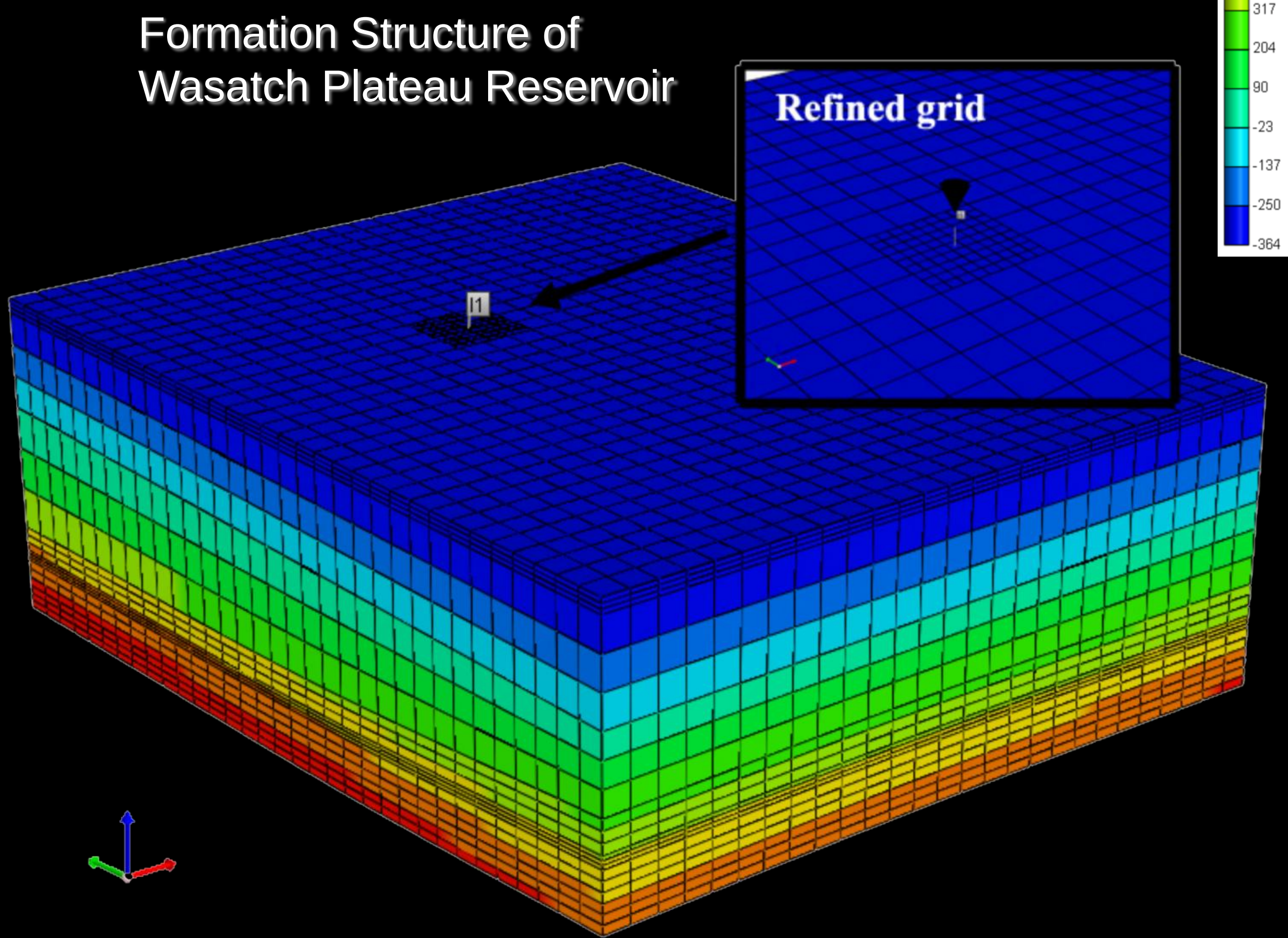
5 Mile Radius





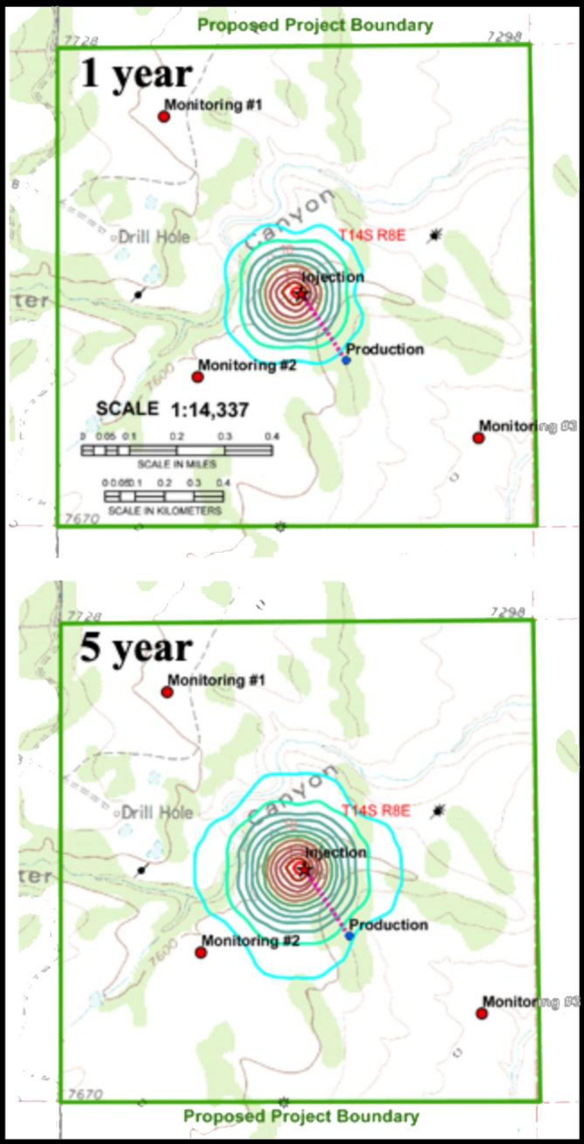
Wasatch Plateau Project

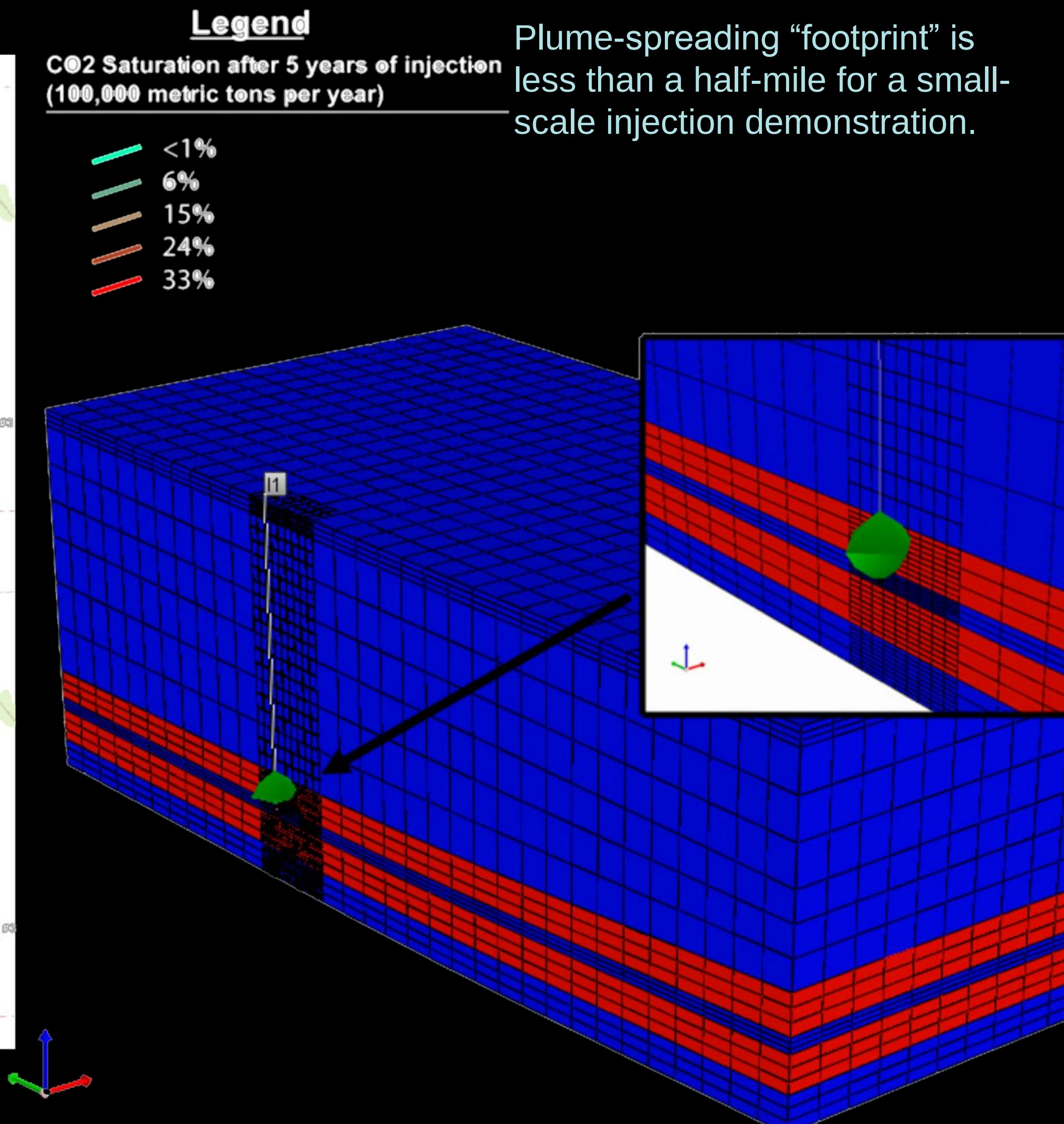
Well logs used to construct initial general model of Wasatch Plateau site



Wasatch Plateau Project

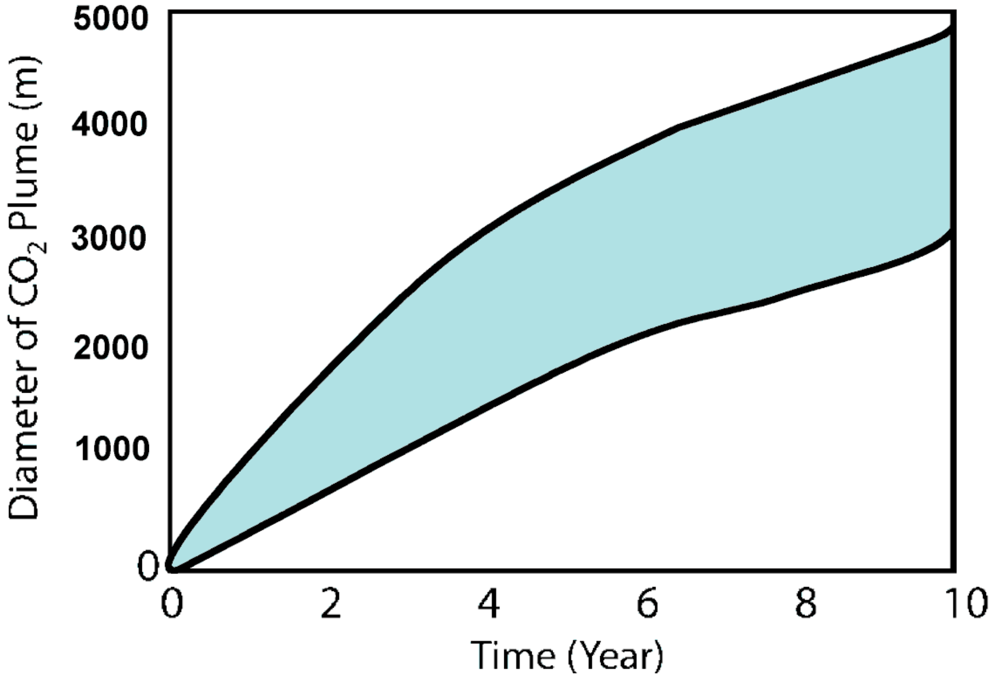
Plume-spreading “footprint” is less than a half-mile for a small-scale injection demonstration.





Wasatch Plateau Project

10-year Injection of 2M tons/year



- Wasatch Plateau, Utah

  Initial modeling of capacity and stability

- Additional data anticipated…
  - Core from target and seal formations
  - Accurate logs from injection well
  - High Resolution 3D seismic

Presentation Outline

- Summary of SWP Phase I
- Summary of Phase 2 Activities
- Regional Context of Phase 2 Tests
- Overview of Phase 3 Deployment Project
- **Phase 3 Deployment Design**
- Alternative Phase 3 Site
- Summary Goals

Wasatch Plateau Project: Deployment Design

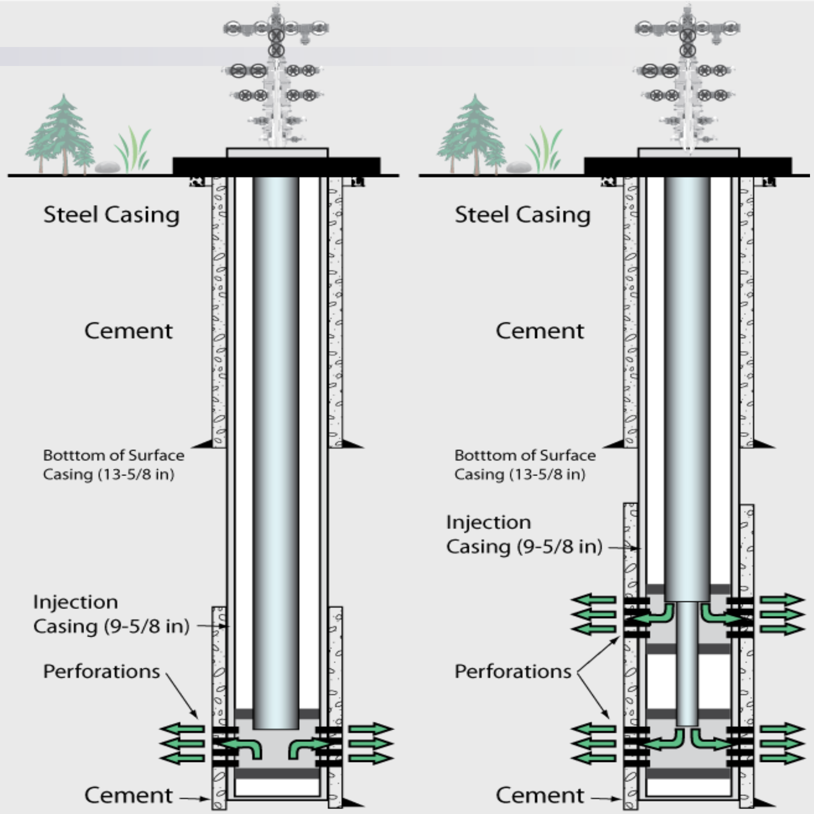
Period	Symb†	Formation	Member	Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250	3115	
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300	4000	
	Kd	Dakota Sandstone		0-30	4025	
	Kcm	Cedar Mtn Fm	Upper member	150-750	4120	
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±	4460	
	Js	Summerville Formation		120-180	5895	
	Jct	Curtis Formation		140-180	6275	
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700	7650	
	Jc	Page Sandstone		<70		
	Jgc	Navajo Sandstone		150-300	8400	
		Kayenta Formation		120-200	8750	
		Wingate Sandstone		300-400	8885	
TRIASSIC	Trc	Chinle Fm	Upper member	200-300	9225	
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700	9520	
	Trms		Sinbad Ls Mbr	50	10460	
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170	10890	
	Pwr	White Rim Sandstone		500-700	11135	

CO_2 Source — CO_2 Sink

Methane Producer — Seal

† Geologic symbols for correlation to units in Morgan (2007)

Modified from Hintze (1992)



Single zone Injection (Navajo Fm):

Dual zone Injection (Entrada & Navajo Fm)

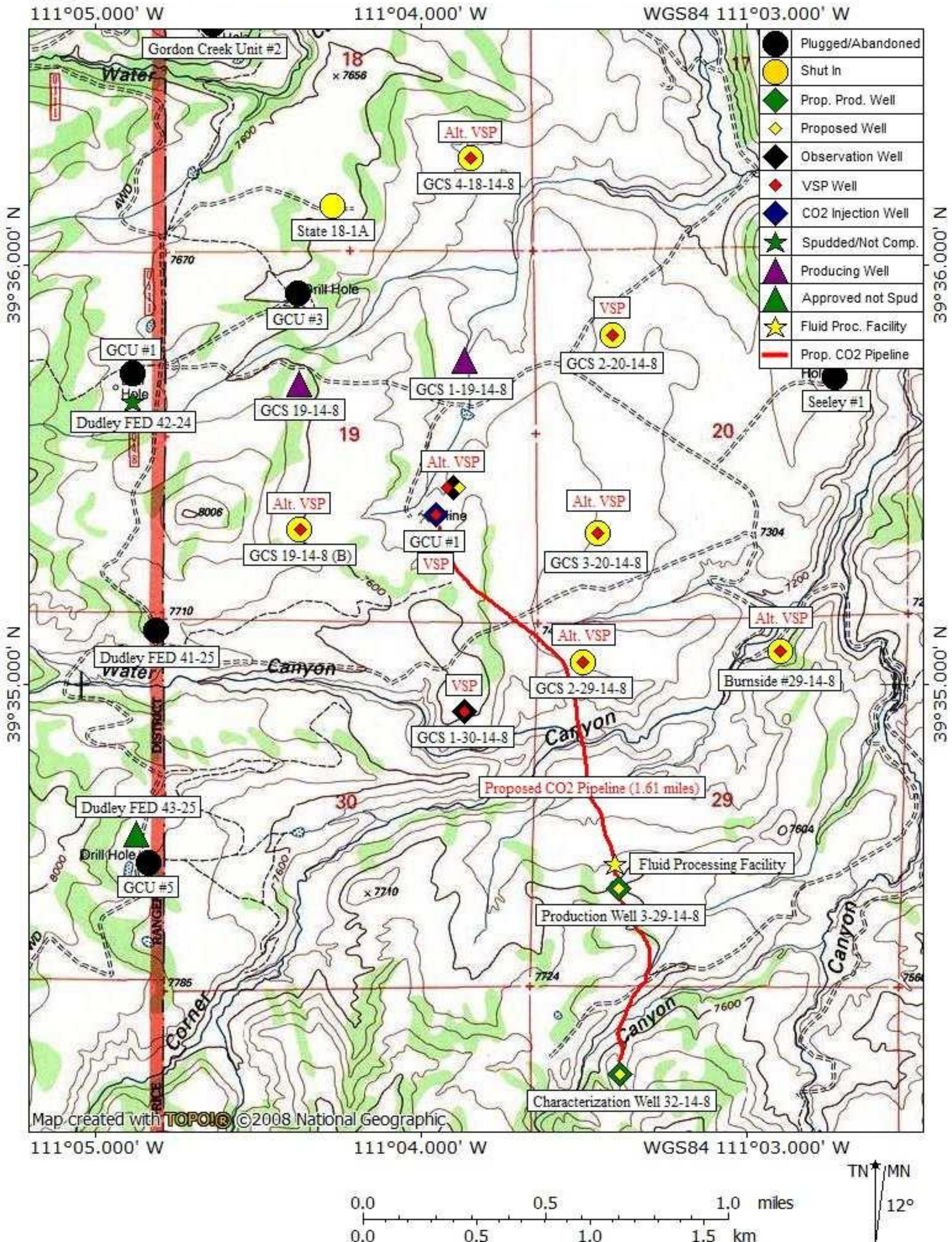
Multiple-Zone Injection and Storage Assessment

Phase III Deployment Design

	NAVAJO	CARMEL	ENTRADA	CURTIS / SUMMERVILLE
FUNCTION	1 Reservoir	1 Seal	2 Reservoir	2 Seal
Storage Capacity/1.0 mi^2 (million tons) 0.01 to 0.05 efficiency	0.24 - 1.22	NA	NA	NA
Depth (m)	8400	7650	6585	5895
Thickness (m)	350	650	1065	690
Temperature (*C)	149	144	131	127
Pressure (Mpa)	4050	3600	3050	2750
~Permeability (mD)	10	0.001	5	0.001
~Porosity	10%	2%	10%	2%
Lithology	Eolian Sandstone	Interbedded limestone, shale, siltstone, sandstone, evaporites	Eolian Sandstone	Interbedded shale, siltstone, sandstone
Mineralogy/ Chemical Composition	quartz with feldspar and minor clay	Silicates (quartz, feldspar) carbonates, phosphorites (carbonate-fluorapatite) and sulfides	quartz with feldspar and minor clay	illite, chloaite, quartz, calcite, dolomite, plagioclase, authigenic pyrite and trace amounts of other minerals

NA = Not Applicable

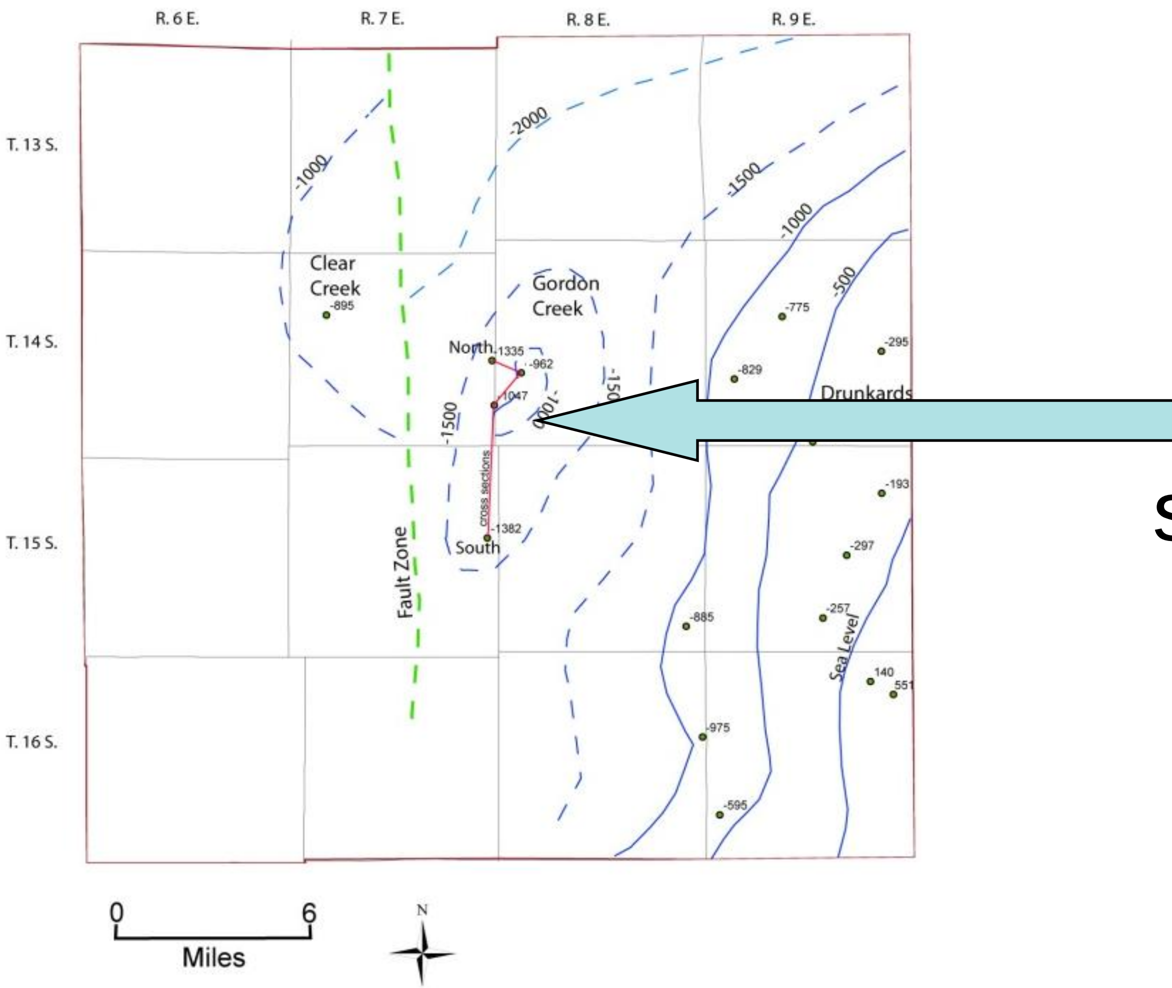
Phase III Deployment Design



Initial Field Engineering Design:

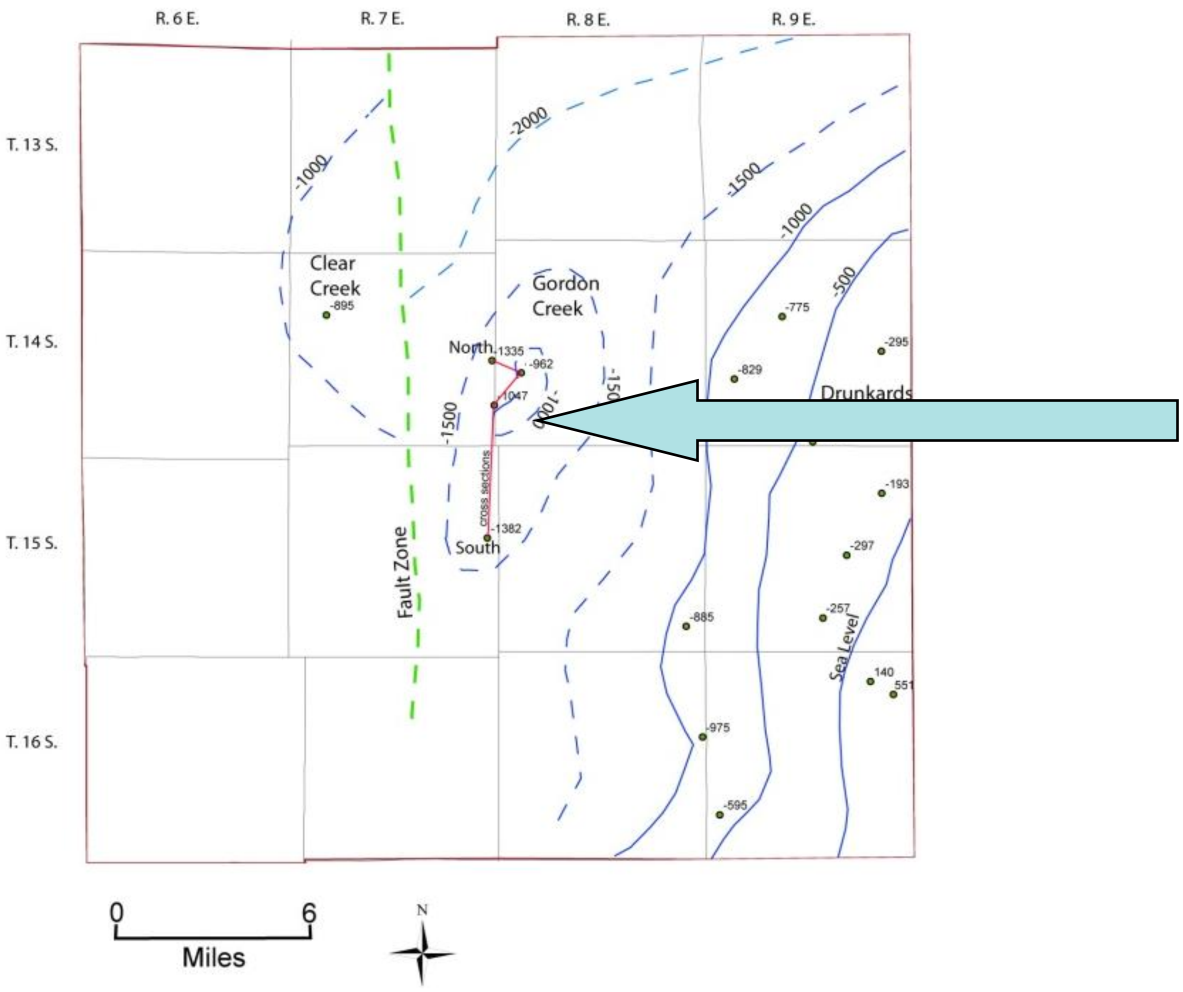
Site map including existing and projected wells, CO_2 pipeline, and CO_2 processing facilities.

Phase III Deployment Design



Some uncertainty regarding structural high at center of the field

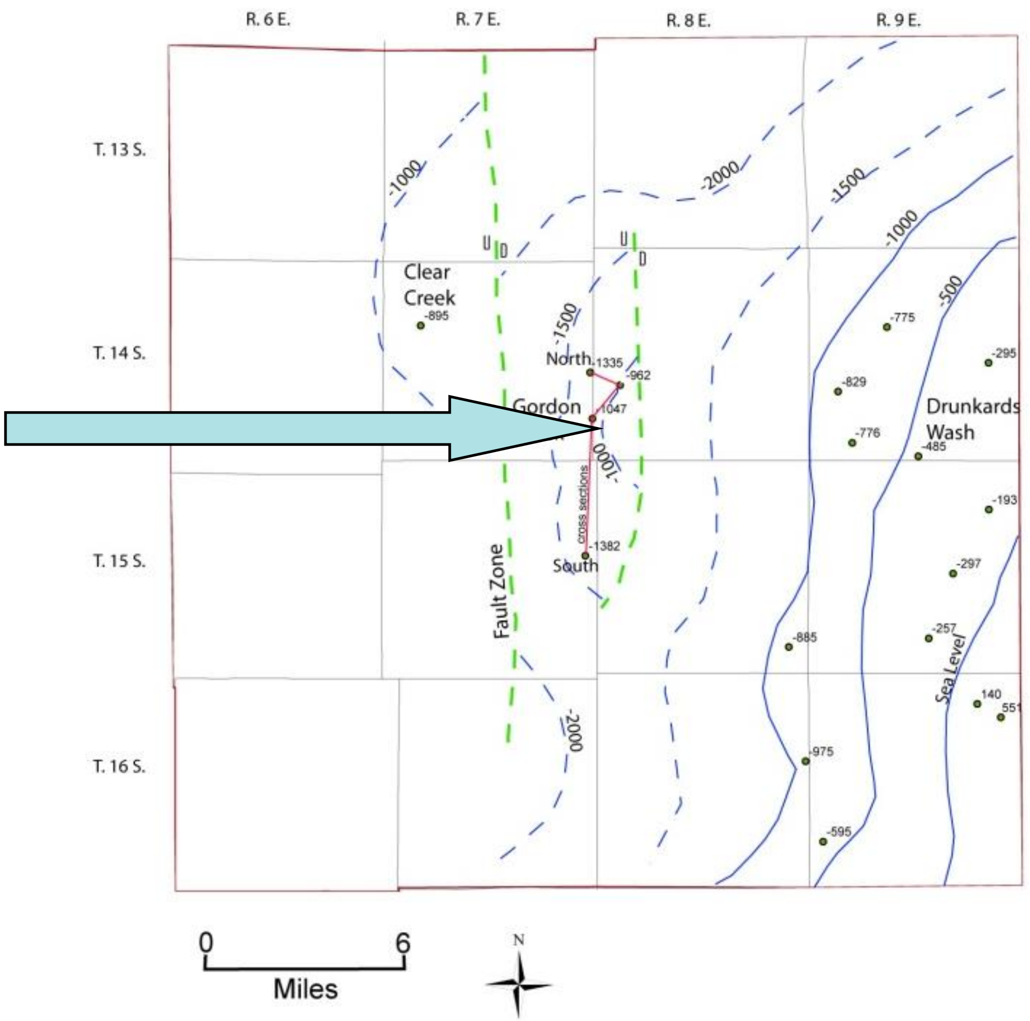
Phase III Deployment Design



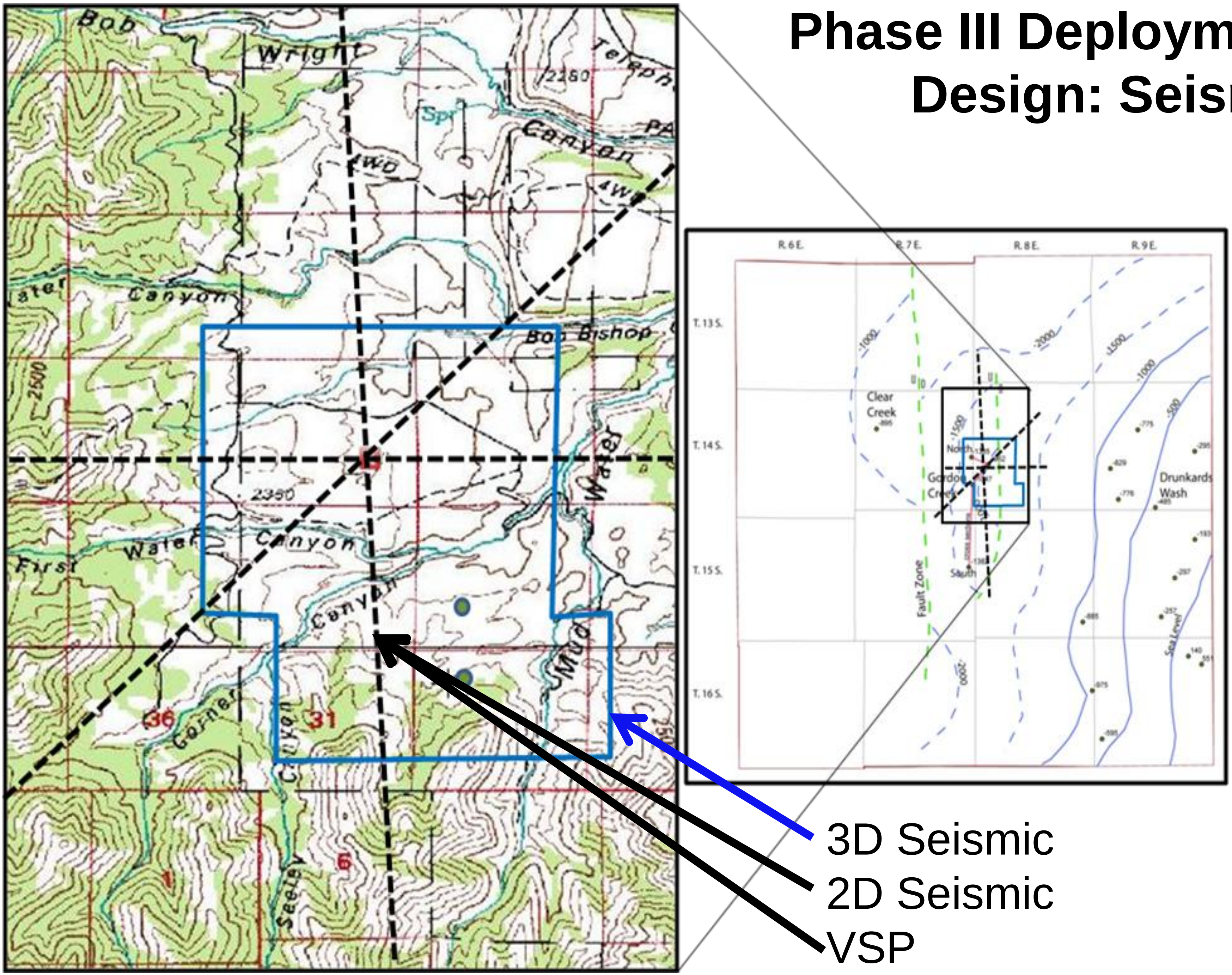
(1) Interpreted as an anticline

Phase III Deployment Design

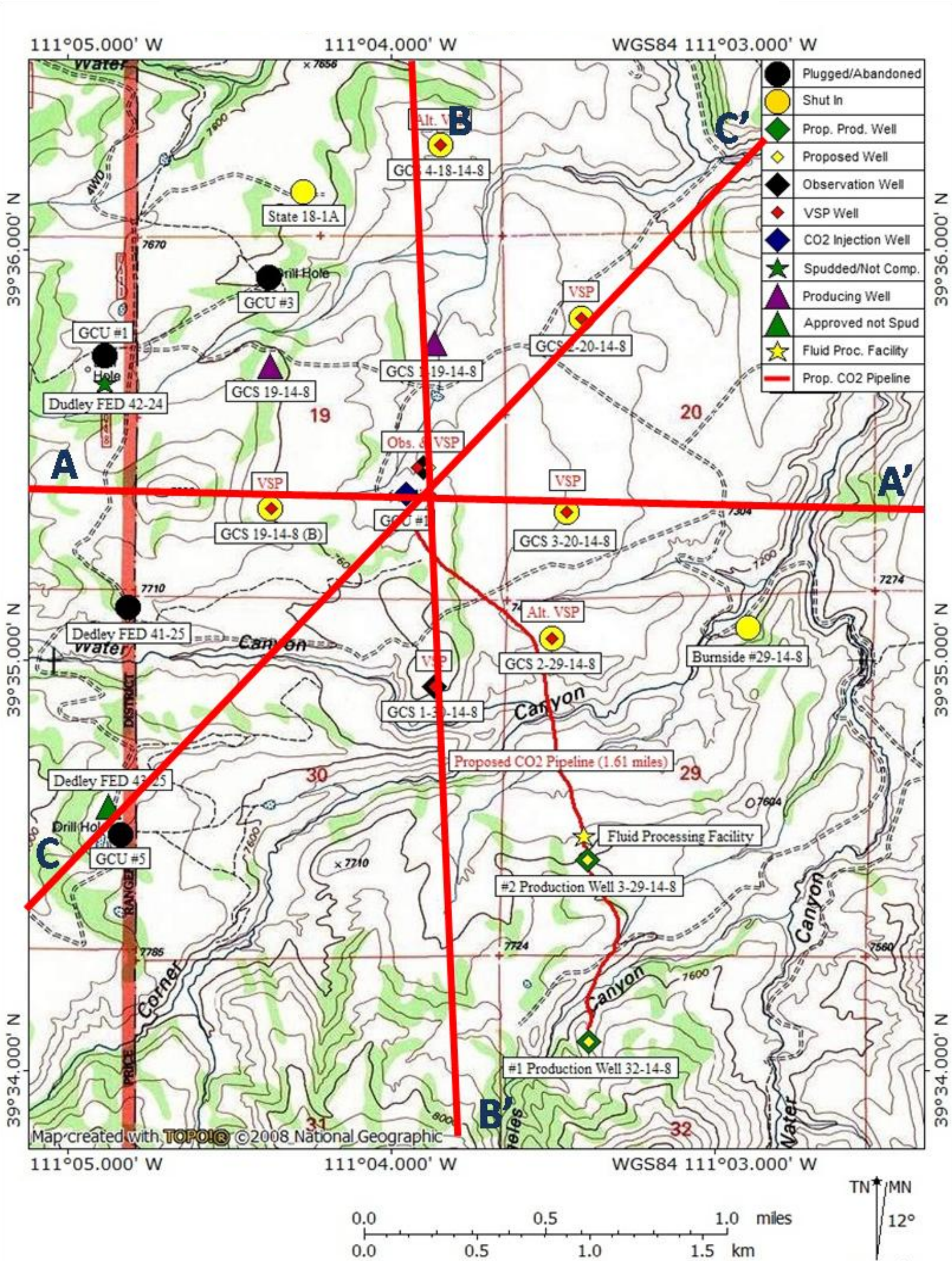
(2) But it is also possible that a small fault lies adjacent to the apex

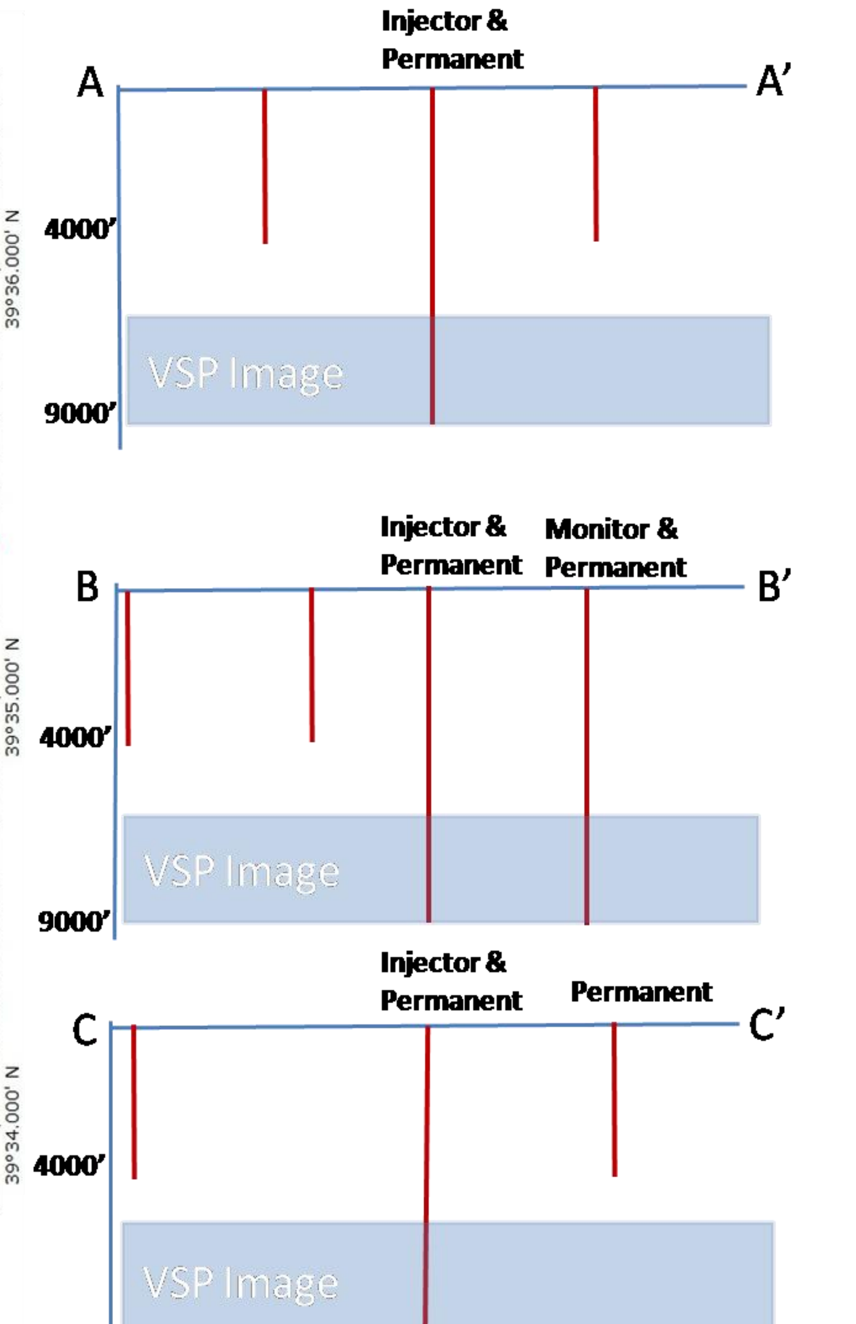


Phase III Deployment Design: Seismic



Initial Monitoring Plans: VSP Site Map



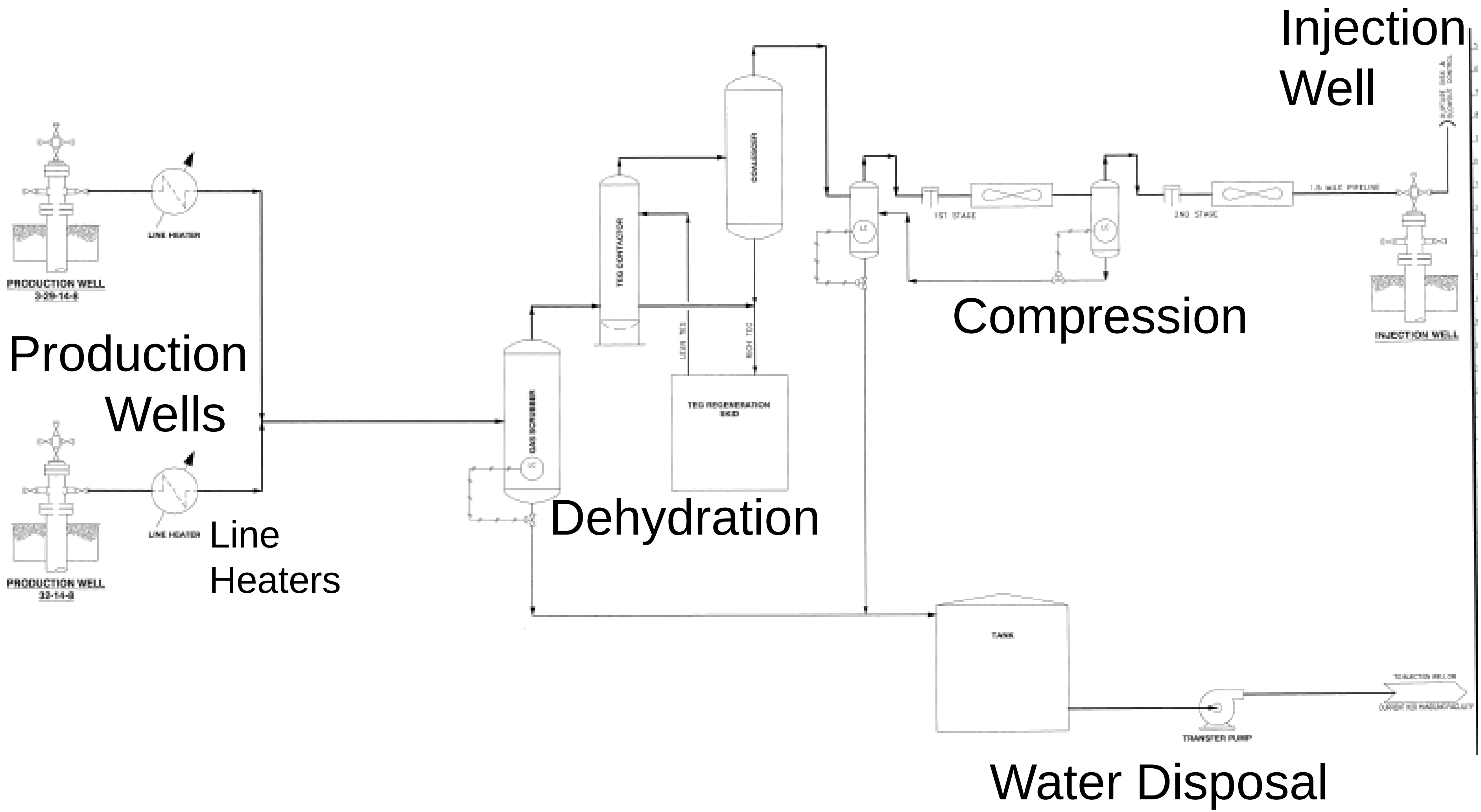


Phase III Deployment Design: Surface Facilities

Material and Equipment

Component	Size / Description	Quantity	
Production Wells	piping, valves, instrumentation; pressure cntl.	2	ea
Flowlines (installed)	transfer lines from wellhead to comp. facility	3,500	ft
Line Heater	produced gas line heater near the wellhead	2	ea
Fuel Gas Distribution System	fuel gas to facility and production well sites	15,840	ft
Inlet Gas Scrubber	2 phase vertical; ~700psi MAWP	1	ea
Dehydration	50 MMSCFD dehy to < 40lb of H2O / MMSCF	1	ea
Coalescing Filter	sized to handle 50 MMSCFD of CO2	1	ea
Compression (skidded units)	25 MMSCFD - 2700 hp; 350psi to 1650psi	5,400	hp
Instrument Air	inst. air pkg; engine start air & instrumentation	1	ea
Power Upgrade (unknown)	480V power to new compression facility	1	tot
Miscellaneous Valves	CVs, SDVs, manual valves (comp. facility)	1	tot
Pipe, Fittings, Flanges, etc..	mechanical construction mtls. (comp. facility)	1	tot
Foundations & Structures	civil construction mtls. (comp. facility)	1	tot
Controls Devices	PLC, transmitters, etc… (comp. facility)	1	tot
Conduit, Cable, etc…	power & ctls. construction mtls. (comp. facility)	1	tot
CO2 Injection Line (installed)	6" SCH 80 CS; dry CO2 to injection well	7,920	ft
Water Injection Line (installed)	produced liquids to inj. well or existing facility	7,920	ft
Injection Well	valves and instrumentation; injection control	1	ea

Phase III Deployment Design: Surface Facilities



Phase III Deployment Design: Surface Facilities

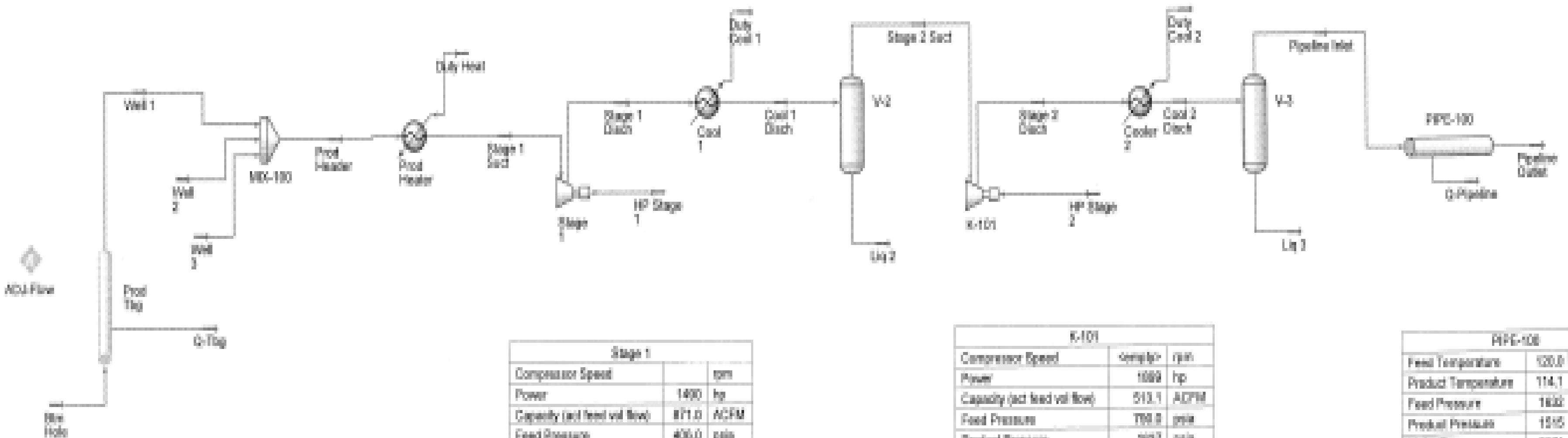
Gas Composition

Component	Mole %
CO2	98.85
C1	0.14
H2S (ppm)	n/a
C2+	n/a
N2	1.03
O2	0.01
Specific Gravity	1.512

Phase III Deployment Design: Surface Facilities

2-3 Stage Compression

200-400 psia production
1800-2000 psia injection



Stage 1		
Compressor Speed		rpm
Power	1490	hp
Capacity (act feed vol flow)	871.0	ACFM
Feed Pressure	406.0	psia
Product Pressure	795.0	psia
Product Temperature	136.9	F
Surge Flow Rate		ACFM

K-101		
Compressor Speed	<empty>	rpm
Power	1089	hp
Capacity (act feed vol flow)	513.1	ACFM
Feed Pressure	789.8	psia
Product Pressure	1937	psia
Product Temperature	246.0	F
Surge Flow Rate	<empty>	ACFM

PIPE-100		
Feed Temperature	120.0	F
Product Temperature	114.1	F
Feed Pressure	1932	psia
Product Pressure	1515	psia
Molar Flow	5271	lbmole/hr

Phase III Deployment Design: MVA

Surface and near-surface gas flux monitoring

Monitoring	Objectives	Equipment
Soil gas flux (CH_4, CO_2, O_2, N_2, hydrocarbons) Nobel gas analysis Isotope analysis	➢ CO_2 leakage; ➢ Measure compositional and isotopic fluxes; ➢ Measure the total concentration of CO_2 and the vertical flux of isotopes with precision high enough to resolve diurnal variations caused by natural sources and isotopic shifts between natural and fossil sources; ➢ Thief zone monitoring	▪ Gas chromatograph (GC); ▪ Picarro isotope analyzer for gas isotope analysis; ▪ The Aerodyne Research Inc. (ARI) CO_2 instrument, Sandia National Laboraotry)

Phase III Deployment Design: MVA

Shallow groundwater quality monitoring wells

□ Existing wells □ New drilling wells	➢ CO_2 leakage ➢ Identification of ground water contamination	▪ Ion chromatograph (IC) ▪ Inductively coupled plasma - mass spectrometer (ICPMS)

Phase III Deployment Design: MVA

Monitoring well

Downhole P,T monitoring □ Chemical sensor (pH) □ Downhole water sampling □ Tracers	➢ CO_2 plume tracking ➢ Impact of CO_2 injection on receiving aquifer	▪ Pressure, temperature sensor ▪ Chemical sensor ▪ Ion chromatograph (IC) ▪ Inductively coupled plasma - mass spectrometer (ICPMS) ▪ Total organic carbon analyzer (TOC) ▪ Total inorganic carbon (?) ▪ Picarro isotope analyzer

Phase III Deployment Design: MVA

Methane producing wells

□ Isotope analysis of CH_4 and CO_2 □ Compositional analysis of produced gases	➢ Caprock integrity ➢ Leakage; use isotopic mixing methods to characterize mixing and transport processes in the reservoir	▪ Picarro isotope analyzer in the field

Phase III Deployment Design: MVA

CO_2 production well

□ Isotope analysis □ Downhole P,T monitoring at different formations □ Wellhead pressure	➢ CO_2 source analysis ➢ CO_2 supply ➢ CO_2 plume tracking	▪ Picarro isotope analyzer

Phase III Deployment Design: MVA

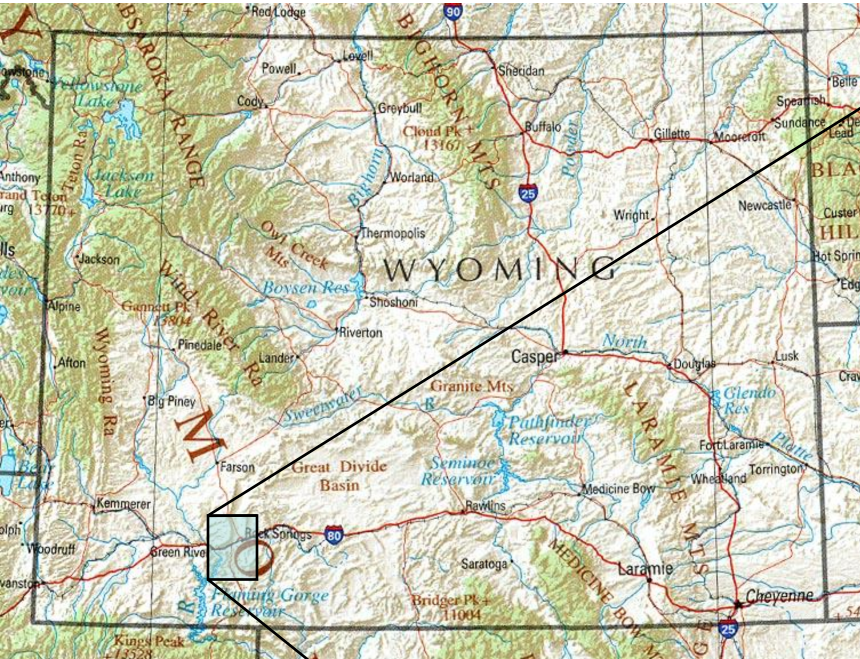
Injection well

□ Downhole P,T monitoring □ Wellhead pressure □ Injection volume/rate □ Pump testing	➢ Injectivity monitoring ➢ Operating adjustment ➢ Reservoir diagnostics to characterize boundary conditions; obtain permeability	▪ Pressure sensor ▪ Temperature sensor ▪ Pressure gauge ▪ Flow meter

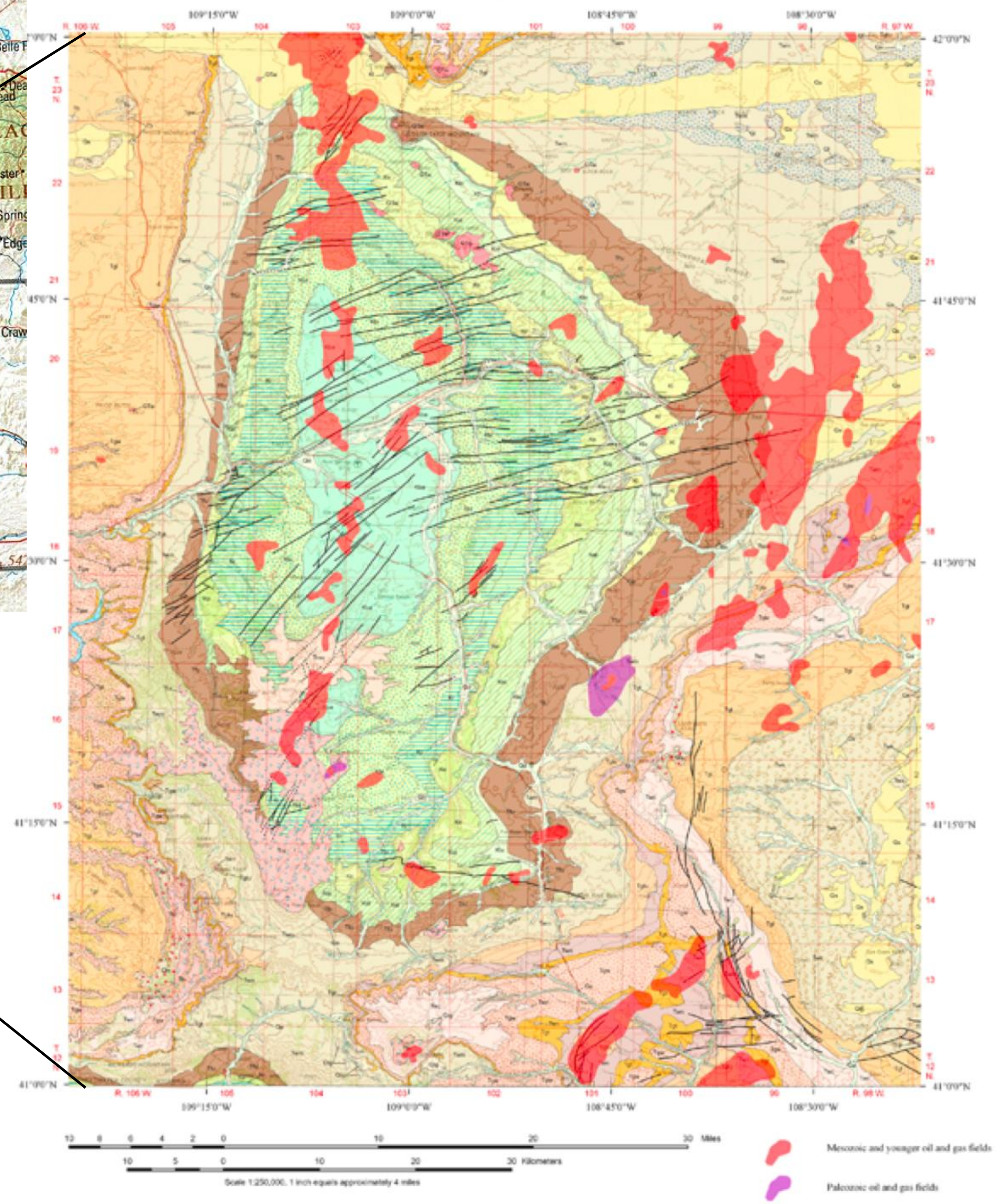
Presentation Outline

- Summary of SWP Phase I
- Summary of Phase 2 Activities
- Regional Context of Phase 2 Tests
- Overview of Phase 3 Deployment Project
- Phase 3 Deployment Design
- **Alternative Phase 3 Site**
- Summary Goals

Alternative Site: Rock Springs Uplift



GEOLOGIC MAP AND OIL AND GAS FIELDS OF THE ROCK SPRINGS UPLIFT AREA, SWEETWATER COUNTY, SOUTHWESTERN WYOMING

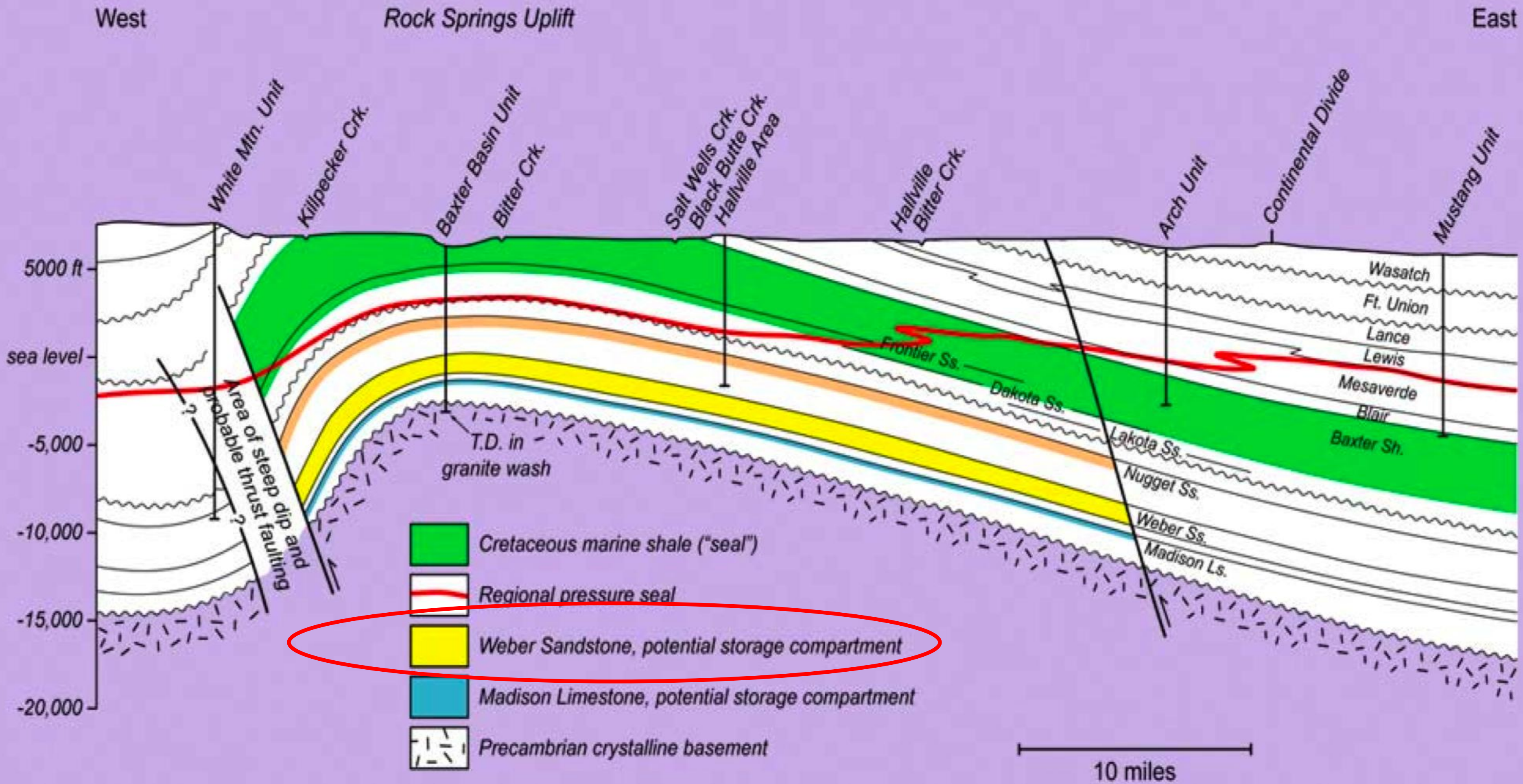


Key Aspects:

- 2,900,000 tons minimum
- 3 year injection minimum
- focus on transferability of results (site-to-site)
- target injection start date: 2011

Geologic Map by WGS

Rock Springs Option



Injection Targets: Jurassic Entrada / Navajo
and Pennsylvanian Weber (White Rim)

Figure by Ron Surdam

Rock Springs Uplift, Wyoming

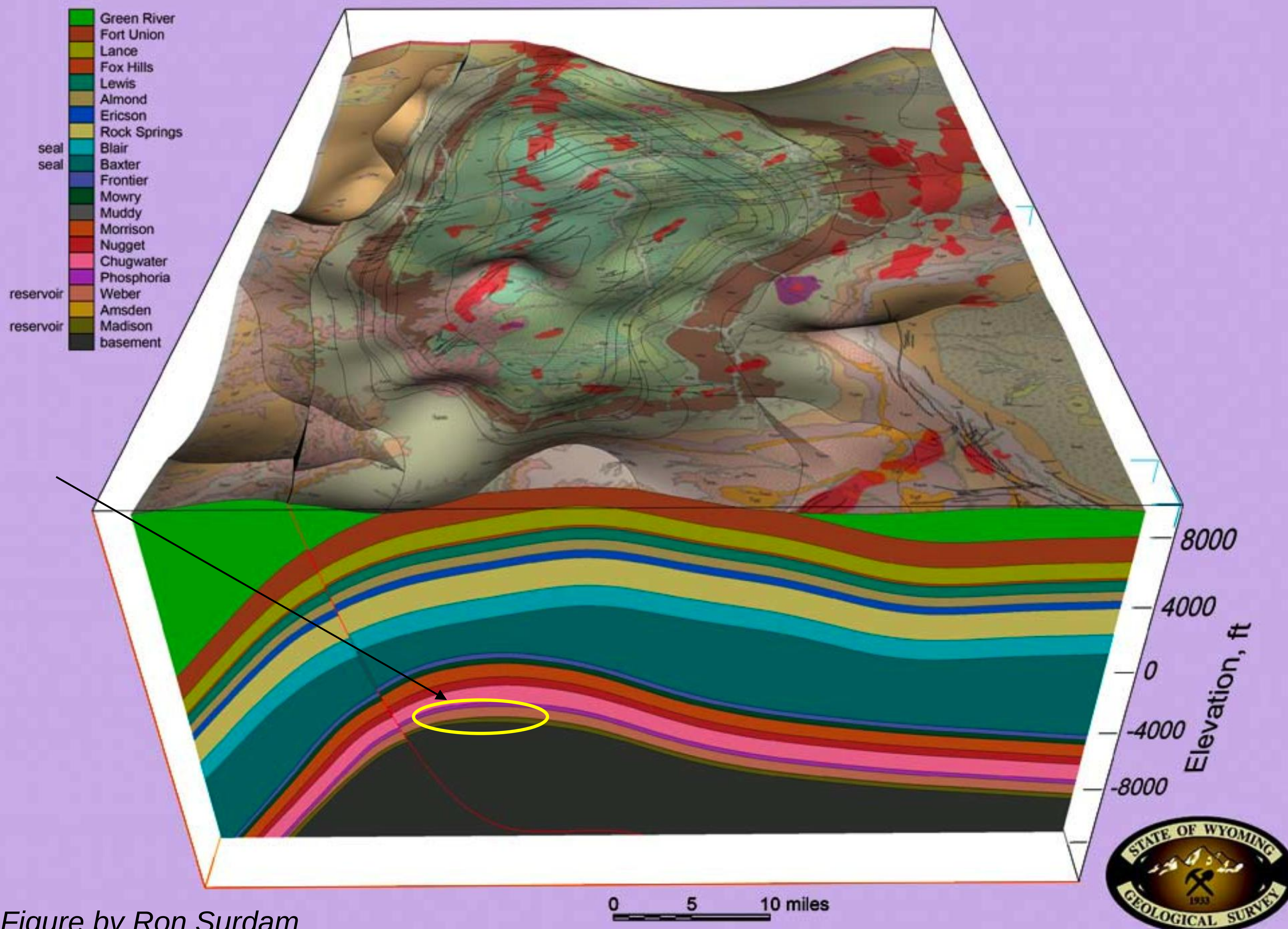
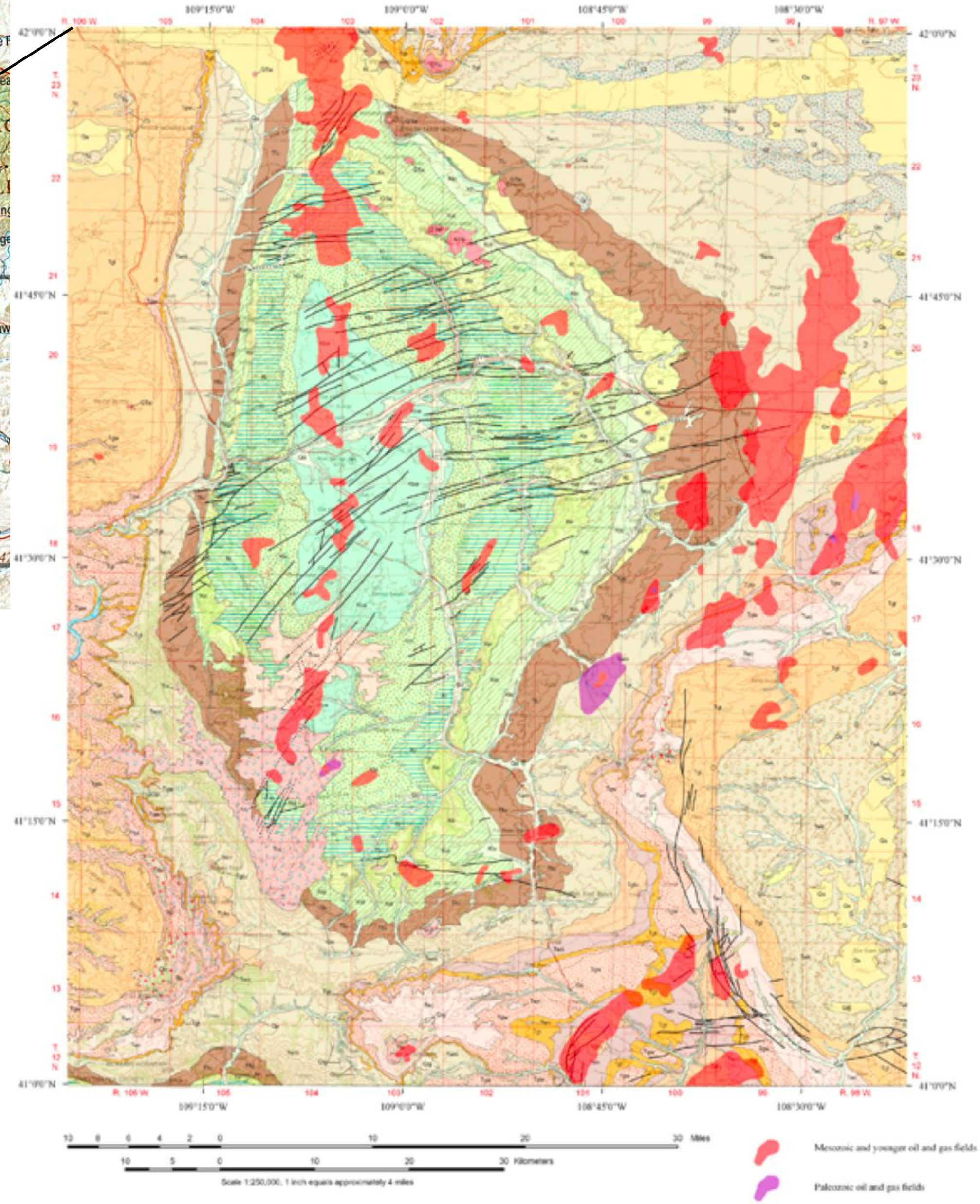


Figure by Ron Surdam

Alternative Site: Rock Springs Uplift

GEOLOGIC MAP AND OIL AND GAS FIELDS OF THE ROCK SPRINGS UPLIFT AREA, SWEETWATER COUNTY, SOUTHWESTERN WYOMING



How does this alternative site compare to the Wasatch Plateau site?

Comparison of Primary & Alternative Site

Period	Symb.	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250		
			Ferron Ss Mbr	10-110	**3250**	
			Tununk Sh Mbr	200-300		
	Kd	Dakota Sandstone		0-30		
	Kcm	Cedar Mtn Fm	Upper member	150-750		
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±		
	Js	Summerville Formation		120-180		
	Jct	Curtis Formation		140-180		
	Je	Entrada Formation		150-950	**6585**	
	Jc	Carmel Formation		300-700		
	Jc	Page Sandstone		<70		
	Jgc	Navajo/Nugget Sandstone		150-300	**9000**	
		Kayenta Formation		120-200		
		Wingate Sandstone		300-400		
TRIASSIC	Trc	Chinle Fm	Upper member	200-300		
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700		
	Trms		Sinbad Ls Mbr	50		
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170		
	Pwr	White Rim/Weber Sandstone		500-700	**11000**	

Period	Formation / Member		Thick-ness (ft)	Depth (feet)	Rock Type
CRETACEOUS	Lance Formation		500-1000		
	Fox Hills Formation Lewis Shale		1000-2000		
	Mesaverde Group	Almond Formation Ericson Formation Rock Springs Formation Blair Formation	4000-4500		
	Baxter-Hilliard Shale Ash Creek Shale Niobrara Formation		3200-3700		
	Frontier Formation		150-900		
	Mowry Shale		100-300		
	Muddy Sandstone / Thermopolis Shale		100		
	Dakota Sandstone		100		
JURASSIC	Morrison Formation		300-500		
	Curtis Formation Entrada Sandstone		100-200	9100	
	Twin Creek Limestone Gypsum Spring Formation		100		
JURASSIC / TRIASSIC	Navajo / Nugget Sandstone		400-600	9300	
TRIASSIC	Chugwater Group Thaynes Formation Crow Mountain Sandstone		100-200		
	Dinwoody Formation		0-100		
PERM	Phosphoria Formation		100-300	11000	
PENN	White Rim / Weber Sandstone		700-900	11810	
	Morgan Formation		300-500		
MISS	Madison Limestone			13000	

CO_2 Source

CO_2 Sink

Methane Producer

Seal

Comparison of Primary & Alternative Site

Period	Symb	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250		
			Ferron Ss Mbr	10-110	3250	
			Tununk Sh Mbr	200-300		
	Kd	Dakota Sandstone		0-30		
	Kcm	Cedar Mtn Fm	Upper member	150-750		
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±		
	Js	Summerville Formation		120-180		
	Jct	Curtis Formation		140-180		
	Je	Entrada Formation		150-950	6585	
	Jc	Carmel Formation		300-700		
	Jc	Page Sandstone		<70		
	Jgc	Navajo/Nugget Sandstone		150-300		
		Kayenta Formation		120-200		
		Wingate Sandstone		300-400		
TRIASSIC	Trc	Chinle Fm	Upper member	200-300		
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700		
	Trms		Sinbad Ls Mbr	50		
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170		
	Pwr	White Rim/Weber Sandstone		500-700	11000	

9000’

Period	Formation / Member		Thick-ness (ft)	Depth (feet)	Rock Type
CRETACEOUS	Lance Formation		500-1000		
	Fox Hills Formation Lewis Shale		1000-2000		
	Mesaverde Group	Almond Formation Ericson Formation Rock Springs Formation Blair Formation	4000-4500		
	Baxter-Hilliard Shale Ash Creek Shale Niobrara Formation		3200-3700		
	Frontier Formation		150-900		
	Mowry Shale		100-300		
	Muddy Sandstone / Thermopolis Shale		100		
	Dakota Sandstone		100		
JURASSIC	Morrison Formation		300-500		
	Curtis Formation				
	Entrada Sandstone		100-200	9100	
	Twin Creek Limestone Gypsum Spring Formation		100		
TRIASSIC	Navajo / Nugget Sandstone		400-		
	Chugwater Group Thaynes Formation Crow Mountain Sandstone		100-200		
	Dinwoody Formation		0-100		
PERM	Phosphoria Formation		100-300	11000	
PENN	White Rim / Weber Sandstone		700-900	11810	
	Morgan Formation		300-500		
MISS	Madison Limestone			13000	

9300’

- CO_2 Source
- CO_2 Sink
- Methane Producer
- Seal

Comparison of Primary & Alternative Site

Period	Symb	Formation / Member		Thickness (feet)	Depth (feet)*	Lith.
CRET	Km	Mancos Shale	Emery Ss Mbr		0	
			Blue Gate Sh Mbr	<250		
			Ferron Ss Mbr	10-110	**3250**	
			Tununk Sh Mbr	200-300		
	Kd	Dakota Sandstone		0-30		
	Kcm	Cedar Mtn Fm	Upper member	150-750		
			Buckhorn Cg Mbr	0-50		
JURASSIC	Jm	Morrison Formation		800±		
	Js	Summerville Formation		120-180		
	Jct	Curtis Formation		140-180		
	Je	Entrada Formation		150-950	**6585**	
	Jc	Carmel Formation		300-700		
	Jc	Page Sandstone		<70		
	Jgc	Navajo/Nugget Sandstone		150-30[illegible]		
		Kayenta Formation		120-2[illegible]		
		Wingate Sandstone		300-400		
TRIASSIC	Trc	Chinle Fm	Upper member	200-300		
			Moss Back Mbr	20-60		
	Trmt	Moenkopi Fm	Upper member	550-700		
	Trms		Sinbad Ls Mbr	50		
	Trmbd		Black Dragon Mbr	250-350		
PERM	Ppc	Kaibab/Park City Fm		170		
	Pwr	White Rim/Weber Sandstone		500-7[illegible]		

9000’

11000’

source

Period	Formation / Member		Thickness (ft)	Depth (feet)	Rock Type
CRETACEOUS	Lance Formation		500-1000		
	Fox Hills Formation Lewis Shale		1000-2000		
	Mesaverde Group	Almond Formation Ericson Formation Rock Springs Formation Blair Formation	4000-4500		
	Baxter-Hilliard Shale Ash Creek Shale Niobrara Formation		3200-3700		
	Frontier Formation		150-900		
	Mowry Shale		100-300		
	Muddy Sandstone / Thermopolis Shale		100		
	Dakota Sandstone		100		
JURASSIC	Morrison Formation		300-500		
	Curtis Formation				
	Entrada Sandstone		100-200	9100	
	Twin Creek Limestone Gypsum Spring Formation		100		
TRIASSIC	Navajo / Nugget Sandstone		40[illegible]		
	Chugwater Group Thaynes Formation Crow Mountain Sandstone		100-200		
	Dinwoody Formation		0-100		
PERM	Phosphoria Formation		[illegible]	[illegible]	
PENN	White Rim / Weber Sandstone				
	Morgan Formation				
MISS	Madison Limestone			13000	

9300’

11800’

sink

CO_2 Source

Methane Producer

CO_2 Sink

Seal

Comparison of Primary & Alternative Site

General Comparison of Options

Identical (or very similar) attributes:

(1) stratigraphy and lithologies
(2) structural geology
(3) same MVA design
(4) same project engineering design

Differing attributes:

(1) **CO_2 sources**
- natural CO_2 at Wasatch Plateau
- natural and anthropogenic sources at Rock Springs

(2) **liability**
- short-term liability defined for Wyoming
- **long-term liability options not definitive in WY or UT, but path forward is becoming clear**

Presentation Outline

- Summary of SWP Phase I
- Summary of Phase 2 Activities
- Regional Context of Phase 2 Tests
- Overview of Phase 3 Deployment Project
- Phase 3 Deployment Design
- Alternative Phase 3 Site
- **Summary Goals**

Summary Goals

Phase 3 Summary:

- 1,000,000 tons per year for multiple years
- MVA efficacy
- Risk assessment efficacy
- Mitigation / reservoir engineering design
- Water management
- "blueprint" for future commercial sequestration

Greatest Obstacle:

Long-term liability options not definitive in WY or UT, but path forward is becoming clear

Phase 2 Lessons Learned?

Too many specific lessons to list. A specific sub-list, for sake of example, focuses on microseismicity:

- Microseismicity - both natural and induced - occurs just about everywhere

- Most seismic/microseismic events are associated with:
- pre-existing faults
- low permeability zones

(3) Microseismicity can aid in identifying geologic features like “critically-stressed” faults

(4) Induced seismicity can be controlled through effective reservoir/injection engineering

(5) Careful and effective site characterization and selection are keys to successful microseismicity management

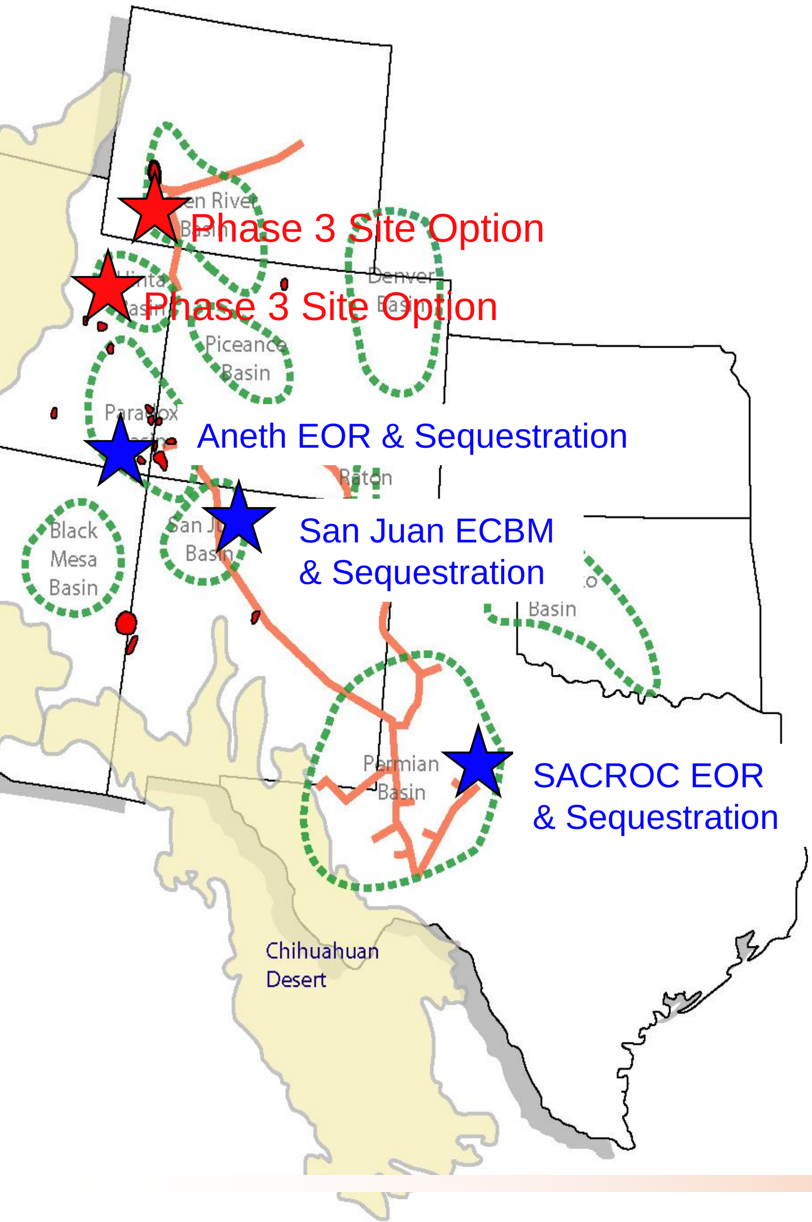
Some "Big Picture" Lessons Learned

- **Oil/gas fields can play an important role in deep saline sequestration**

- **In all cases, it is difficult to predict geomechanical processes**

- **In all cases, it is difficult to predict induced or triggered seismicity**

- **CO_2 Diffusivity $\neq$ Hydraulic Diffusivity**



Phase 3 Site Option
Phase 3 Site Option
Piceance Basin
Denver Basin
Paradox
Aneth EOR & Sequestration
Raton
Black Mesa Basin
San Juan ECBM
& Sequestration
Basin
Permian Basin
SACROC EOR
& Sequestration
Chihuahuan Desert