The Intersection of Environment and EOR: How Carbon Capture is Changing Tertiary Recovery

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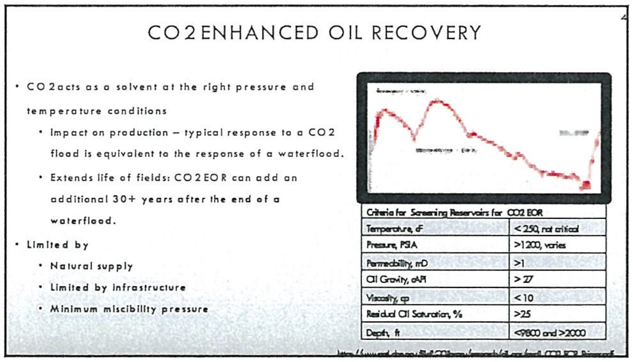
OUTLINE

1. A brief history of CO_2 Enhanced Oil Recovery (EOR)
2. Carbon Capture and Storage (CCS) vs utilization (CCUS)
3. Case Studies of Carbon capture and utilization for EOR
4. Southwest Partnership demonstration at Farnsworth unit
    a) Introduction to Farnsworth
    b) Characterization of the reservoir and seals
    c) Models and Simulation
    d) Monitoring, Verification and Accounting (carbon storage security)
5. Final thoughts and takeaways



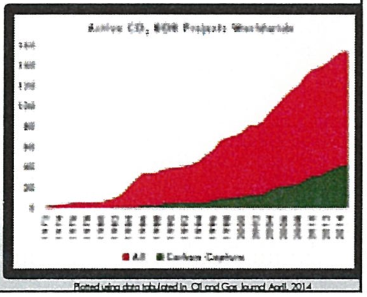
CO2ENHANCED OIL RECOVERY

- CO2acts as a solvent at the right pressure and temperature conditions
    - Impact on production – typical response to a CO2 flood is equivalent to the response of a waterflood.
    - Extends life of fields: CO2EOR can add an additional 30+ years after the end of a waterflood.
- Limited by
    - Natural supply
    - Limited by infrastructure
    - Minimum miscibility pressure

Criteria for Screening Reservoirs for CO2 EOR	
Temperature, oF	< 250, not critical
Pressure, PSIA	>1200, varies
Permeability, mD	>1
Oil Gravity, oAPI	> 27
Viscosity, cp	< 10
Residual Oil Saturation, %	>25
Depth, ft	<9800 and >2000

CO2EOR PROJECTS

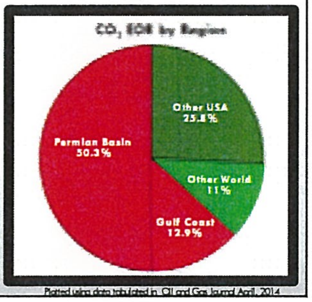
- First CO_2 EOR project started in 1972 at SACROC unit in Texas
- Since then 154 additional projects have been emplaced, initially in the Permian basin and Gulf coast areas of the United States
    - Availability of Natural CO_2
- Carbon capture has enabled additional projects in the USA and the World



Plotted using data tabulated in Oil and Gas Journal April, 2014

CARBON CAPTURE, (UTILIZATION) AND STORAGE

- Concerns over CO_2 in the atmosphere is prompting governments to investigate CCS/CCUS
- For large point sources (coal plants) looking at saline aquifers
- For smaller point sources use for EOR is growing due to:
    - Proximity to mature fields
    - Purity of CO_2
    - Existing oil field infrastructure



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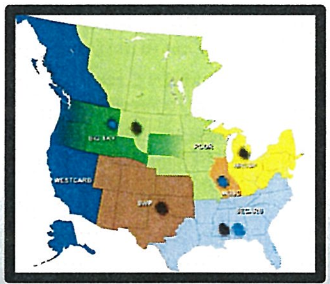
IMPLICATIONS OF ANTHROPOGENIC CO2 FOR EOR

- Governmental Impacts
    - Tax credits/carbon credits
    - Faster path to sequestration due to profit potential
- Impacts for Producing Companies:
    - Local supply: Sources near every oil field
    - Increased recovery: ~2/3 of all oil world-wide is stranded
    - Mitigate regulatory impacts
    - Market advantages
    - Public perception

USA CASE STUDIES FOR CCS

- US Department of Energy Regional Carbon Sequestration Partnerships
    - Seven regional partnerships
- Each demonstrating injection of at least 1,000,000 metric tons of CO_2
- Four projects are demonstrating storage in conjunction with EOR
- Developing "best practices" for utilizing captured CO_2



Modified from http://energy.gov/fe/science-innovation/carbon-capture-and-storage-research/regional-partnerships

FARNSWORTH UNIT

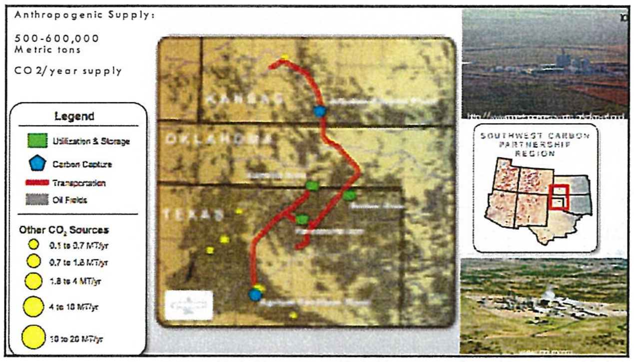
- Farnsworth field was discovered in 1955.
- Over 100 wells were completed by the year 1960.
  - Water injection for secondary recovery started in 1964.

Property	Value
Initial water saturation	31.4%
Initial reservoir pressure	2218 PSIA (Pbubble 2059)
API	36.7o
Original Oil in Place (OOIP)	120 MMSTB (60 MMSTB west-side)
Drive Mechanism	Solution Gas
Primary Recovery	11.2 MMSTB (9.3%)
Secondary Recovery	25.6 MMSTB (21.3%)

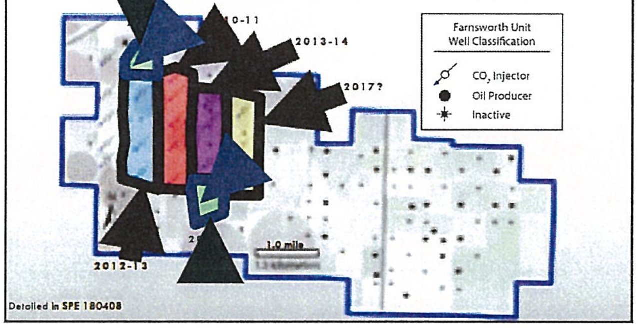
Anthropogenic Supply:

500-600,000
Metric tons

CO2/year supply



ACTIVE CURRENTLY PLANNED CO2 PATTERNS

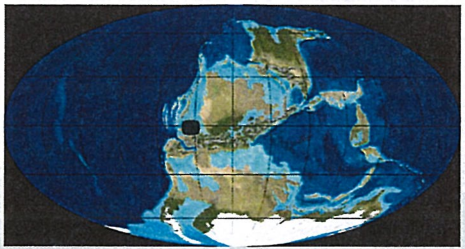


Detailed in SPE 180408

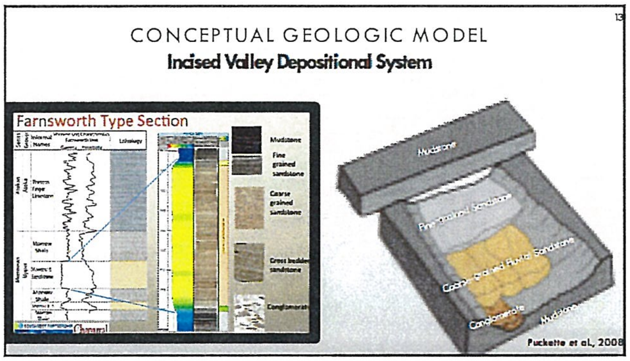
CHARACTERIZATION

- Goals are to better understand geology of storage system
- Deliver fine scale facies based

  models including hydraulic flow units to improve flow simulation



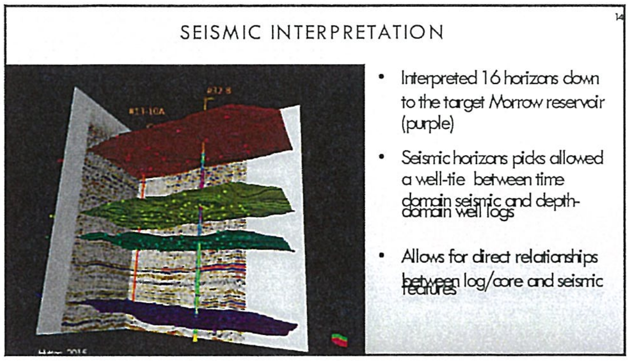
Ron Blakey - http://jan.ucc.nau.edu/rcb7/300moll.jpg



CONCEPTUAL GEOLOGIC MODEL

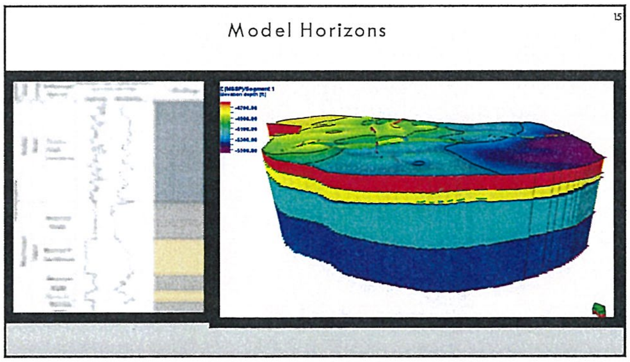
Incised Valley Depositional System

Puckette et al., 2008

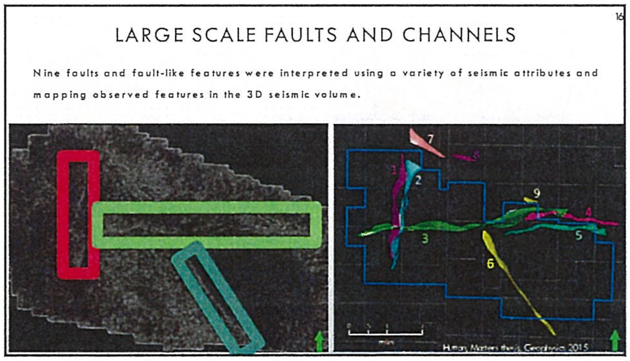


SEISMIC INTERPRETATION

- Interpreted 16 horizons down to the target Morrow reservoir (purple)
- Seismic horizons picks allowed a well-tie between time domain seismic and depth-domain well logs
- Allows for direct relationships between log/core and seismic features



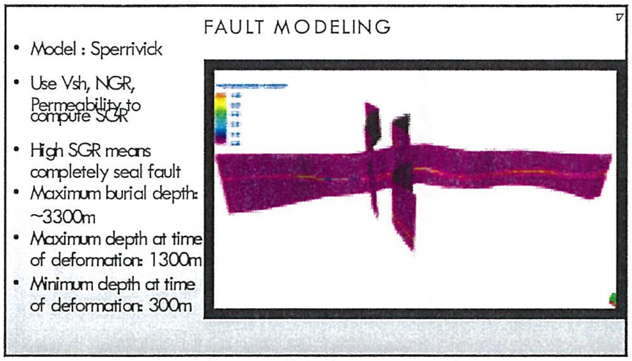
Model Horizons



LARGE SCALE FAULTS AND CHANNELS

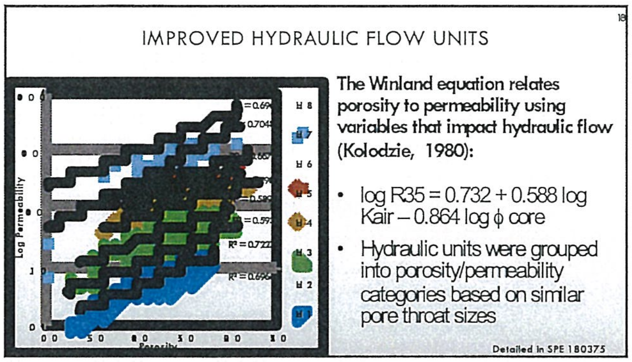
Nine faults and fault-like features were interpreted using a variety of seismic attributes and mapping observed features in the 3D seismic volume.

Hutton, Masters thesis, Geophysics 2015



FAULT MODELING

- Model : Sperrivick
- Use Vsh, NGR, Permeability to compute SGR
- High SGR means completely seal fault
- Maximum burial depth: ~3300m
- Maximum depth at time of deformation: 1300m
- Minimum depth at time of deformation: 300m

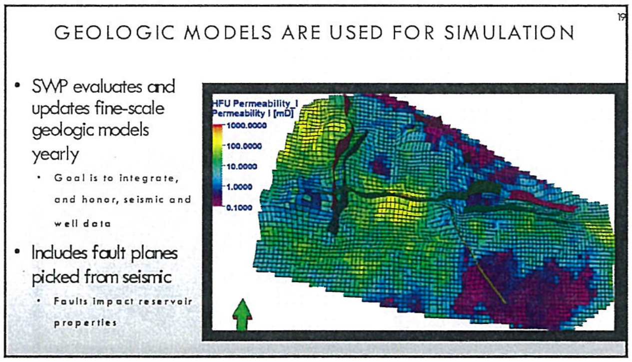


IMPROVED HYDRAULIC FLOW UNITS

The Winland equation relates porosity to permeability using variables that impact hydraulic flow (Kolodzie, 1980):

- log R35 = 0.732 + 0.588 log Kair – 0.864 log ϕ core
- Hydraulic units were grouped into porosity/permeability categories based on similar pore throat sizes

Detailed in SPE 180375



GEOLOGIC MODELS ARE USED FOR SIMULATION

- SWP evaluates and updates fine-scale geologic models yearly
  - Goal is to integrate, and honor, seismic and well data
- Includes fault planes picked from seismic
  - Faults impact reservoir properties

FWU FLUID ANALYSIS

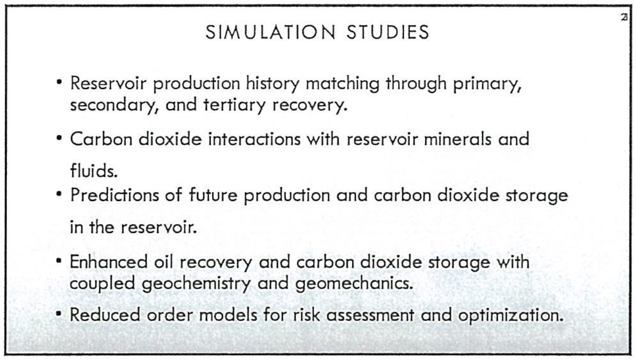
Data Available

- Fluid composition sampled @ 1956
- Experimental Data

- Saturation Pressure Experiment
- Constant Mass Expansion at 168 ° F
- Differential Liberation 1 at 168 ° F
- Multi Stage Separator Test

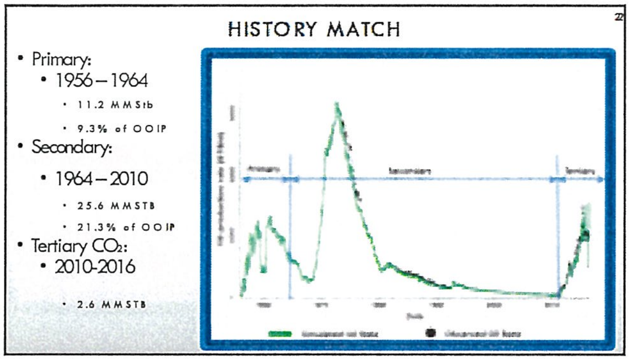
Tuning Process

- EOS equation - Peng Robinson
- Viscosity equation - Lohrenz-Bray-Clark correlation



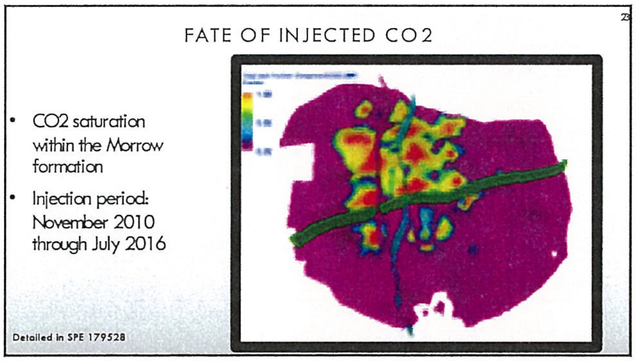
SIMULATION STUDIES

- Reservoir production history matching through primary, secondary, and tertiary recovery.
- Carbon dioxide interactions with reservoir minerals and fluids.
- Predictions of future production and carbon dioxide storage in the reservoir.
- Enhanced oil recovery and carbon dioxide storage with coupled geochemistry and geomechanics.
- Reduced order models for risk assessment and optimization.



HISTORY MATCH

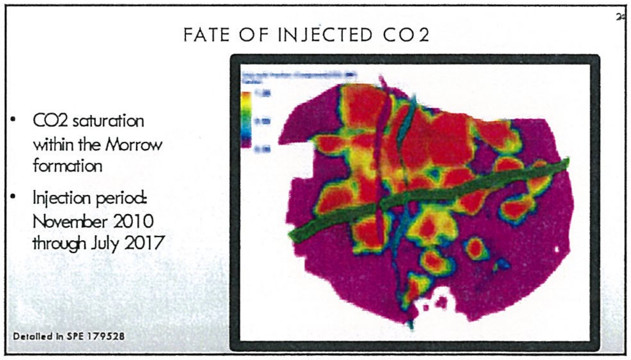
- Primary:
  - 1956 – 1964
    - 11.2 MMStb
    - 9.3% of OOIP
- Secondary:
  - 1964 – 2010
    - 25.6 MMSTB
    - 21.3% of OOIP
- Tertiary CO_2:
  - 2010-2016
    - 2.6 MMSTB



FATE OF INJECTED CO2

- CO2 saturation within the Morrow formation
- Injection period: November 2010 through July 2016

Detailed in SPE 179528



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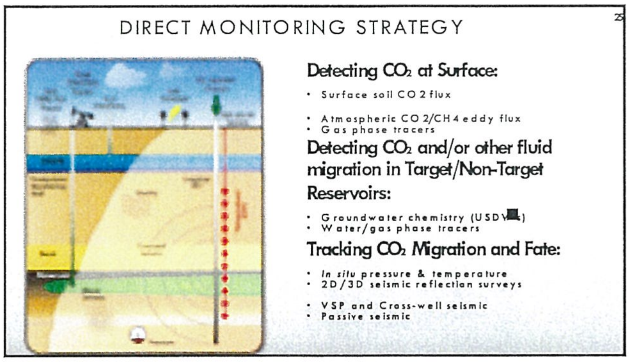


DIRECT MONITORING STRATEGY

Detecting CO_2 at Surface:

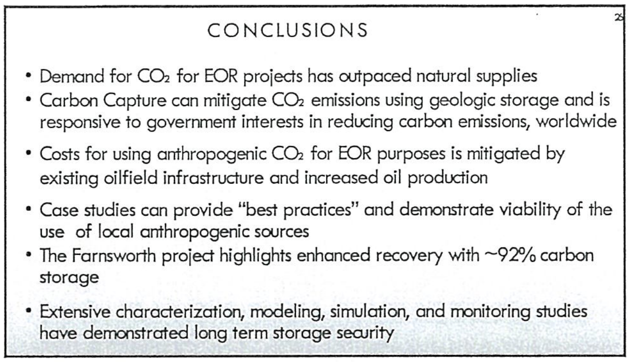
- Surface soil CO 2 flux
- Atmospheric CO 2/CH 4 eddy flux
- Gas phase tracers

Detecting CO_2 and/or other fluid migration in Target/Non-Target Reservoirs:

- Groundwater chemistry (USDV[redacted])
- Water/gas phase tracers

Tracking CO_2 Migration and Fate:

- *In situ* pressure & temperature
- 2D/3D seismic reflection surveys
- VSP and Cross-well seismic
- Passive seismic



CONCLUSIONS

- Demand for CO_2 for EOR projects has outpaced natural supplies
- Carbon Capture can mitigate CO_2 emissions using geologic storage and is responsive to government interests in reducing carbon emissions, worldwide
- Costs for using anthropogenic CO_2 for EOR purposes is mitigated by existing oilfield infrastructure and increased oil production
- Case studies can provide "best practices" and demonstrate viability of the use of local anthropogenic sources
- The Farnsworth project highlights enhanced recovery with ~92% carbon storage
- Extensive characterization, modeling, simulation, and monitoring studies have demonstrated long term storage security