CO_2 for Enhanced Oil Recovery (EOR)

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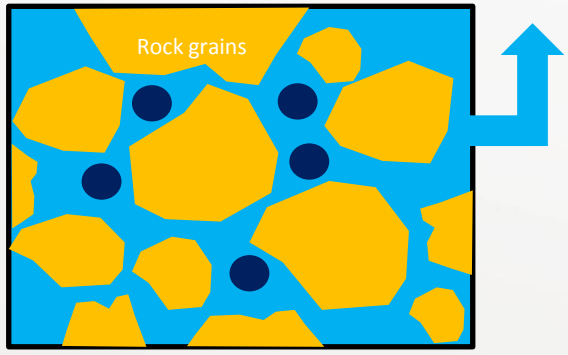
Talk Outline

- Enhanced oil recovery (EOR) is the major use of CO_2
- Potential for expansion of this use
  - Sources of CO_2 – traditional and evolving
  - US and global potential markets for CO_2 for EOR
- CO_2 EOR as part of carbon capture use and storage (CCUS)
  - Case studies
  - Monitoring storage and accounting as part of CCUS

Use of CO_2 for enhanced oil recovery (EOR) process

Residual oil will not move to production wells

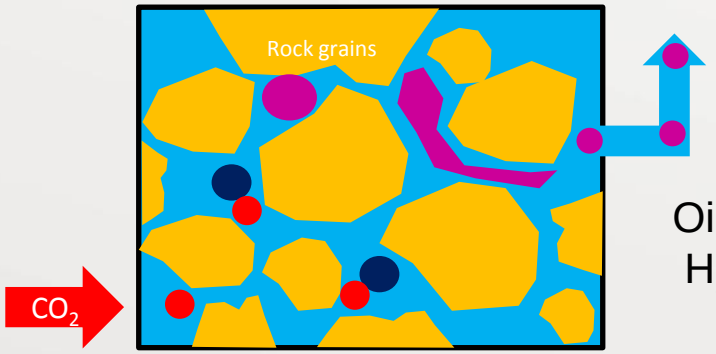


30% Remaining oil is residual, immobile

At reservoir pressure, CO_2 is miscible with oil

- Viscosity decrease
- Volume increase

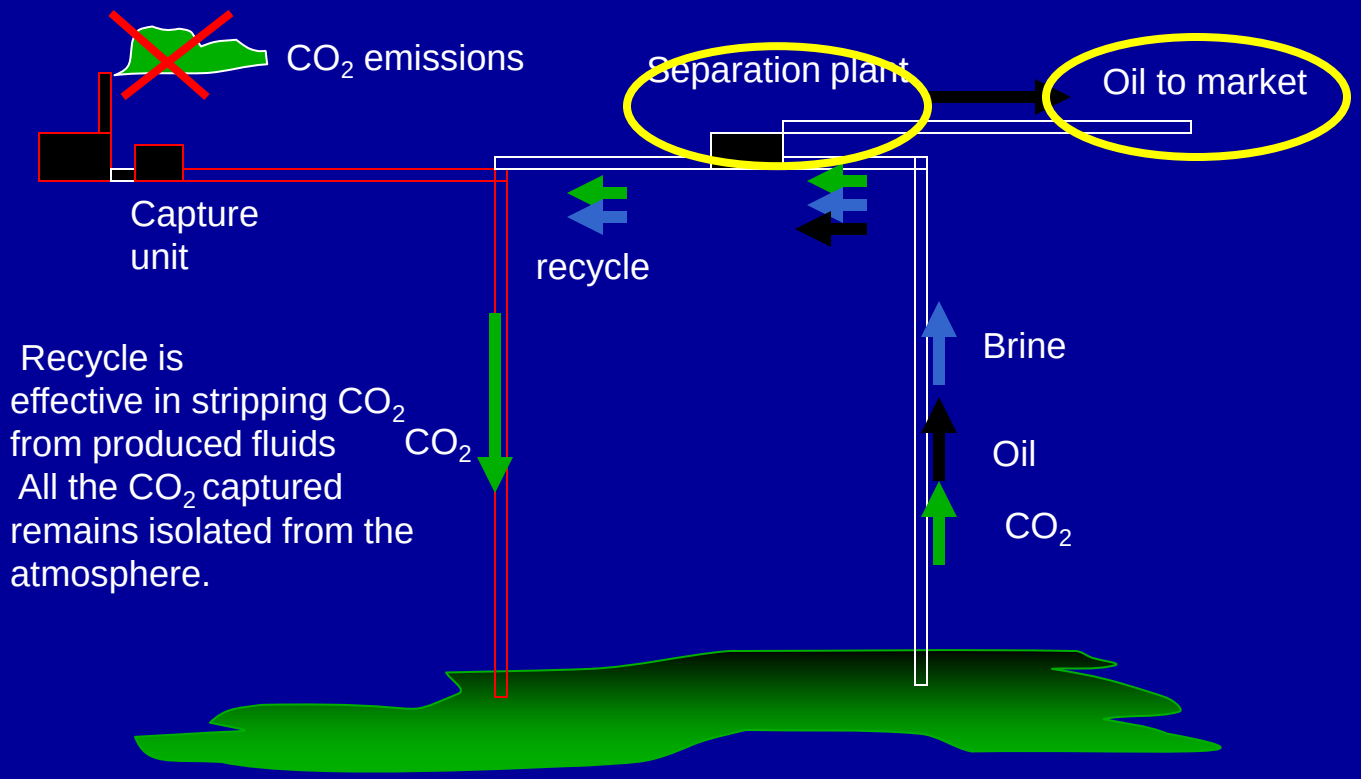
Oil-CO_2 phase can migrate to production wells



Oil, CO_2, and H_2O produced

Note: Many other EOR techniques compete with CO_2

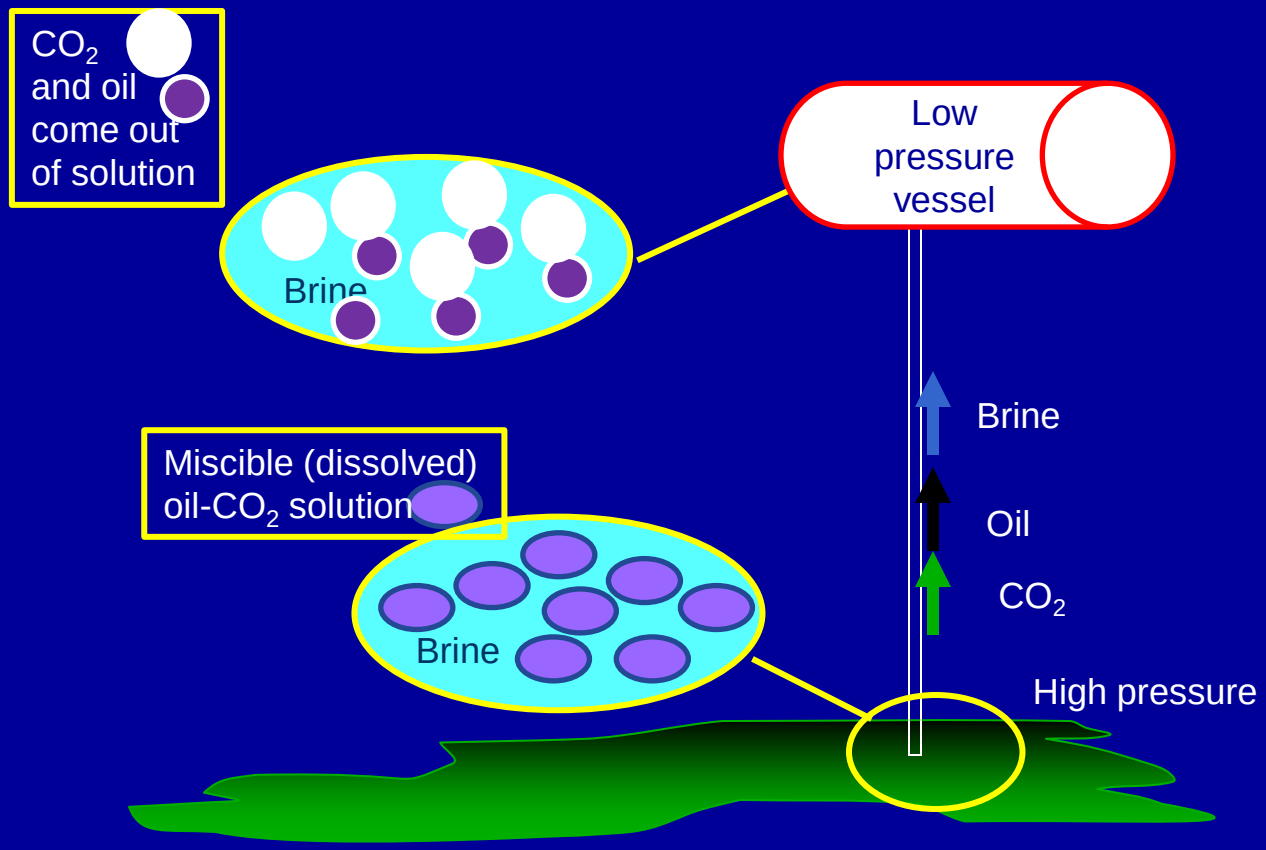
CO_2 EOR is a Closed Loop System



Recycle is effective in stripping CO_2 from produced fluids

All the CO_2 captured remains isolated from the atmosphere.

Overview of CO_2 Recycle



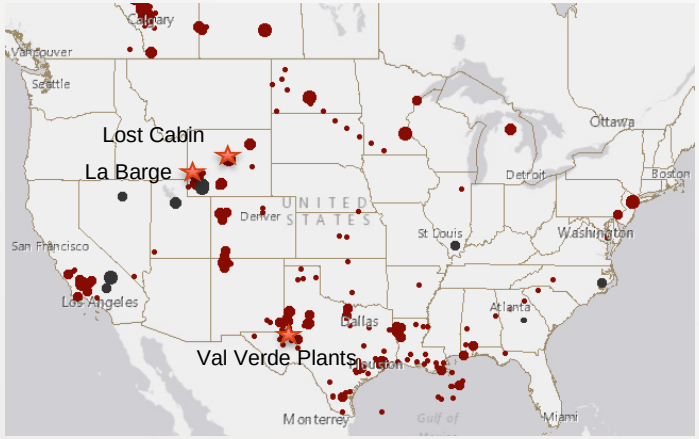
Captured CO_2

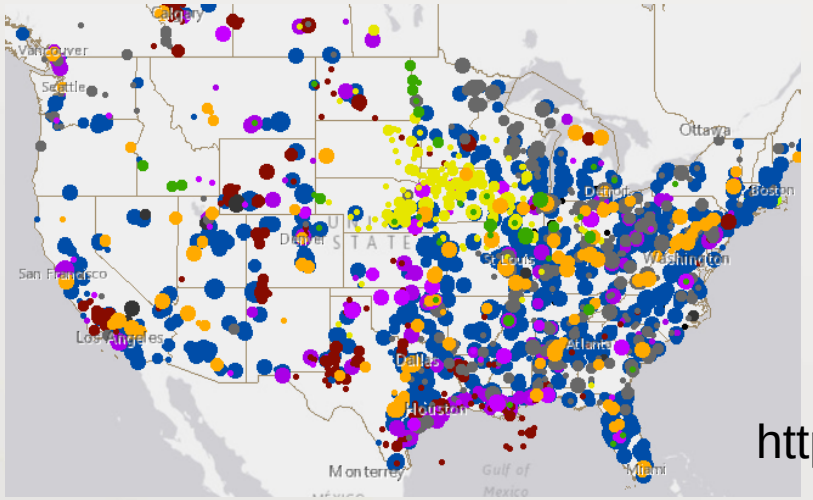
- From combustion
  - Pre-combustion
  - Oxyfired
  - Post combustion
- From industrial processes
  - Hydrogen separation from methane
  - Ethylene production etc.
  - Fertilizer
  - Cement manufacture
  - Steel
- Ethanol production

Distribution of US CO_2 Stationary Point Sources

Geologic “natural” accumulations

Oil, and gas and mining sources



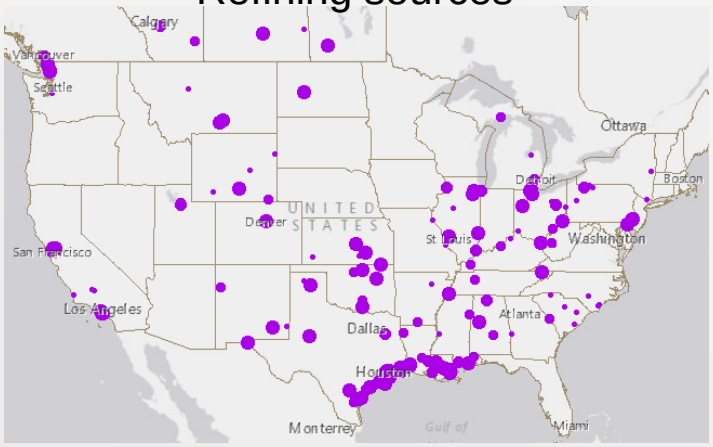


- Cement Plant
- Ethanol Plants
- Fertilizer
- Industrial
- Mining
- Petroleum & Natural Gas
- Refineries/Chemicals
- Electricity Generation
- Waste Management
- Unclassified

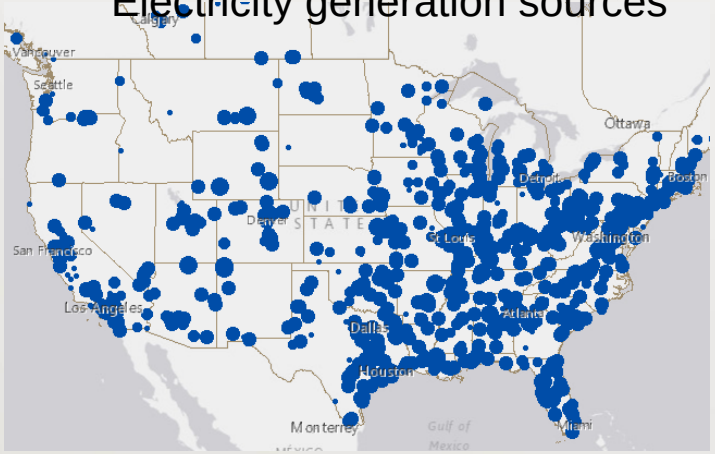
http://www.natcarbviewer.com/

Distribution of US CO_2 Stationary Point Sources

Refining sources



Electricity generation sources



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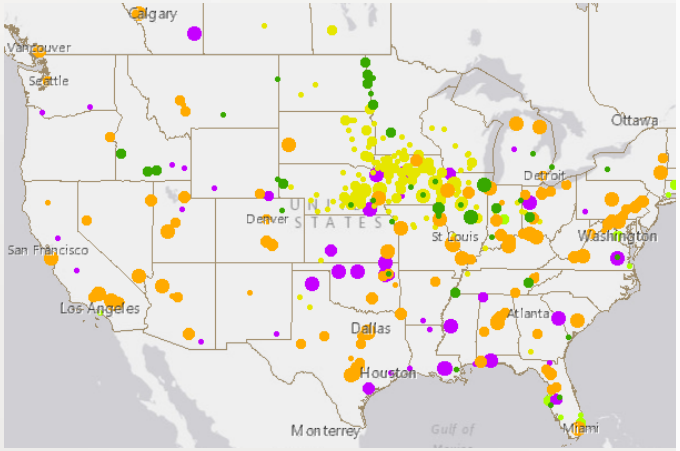

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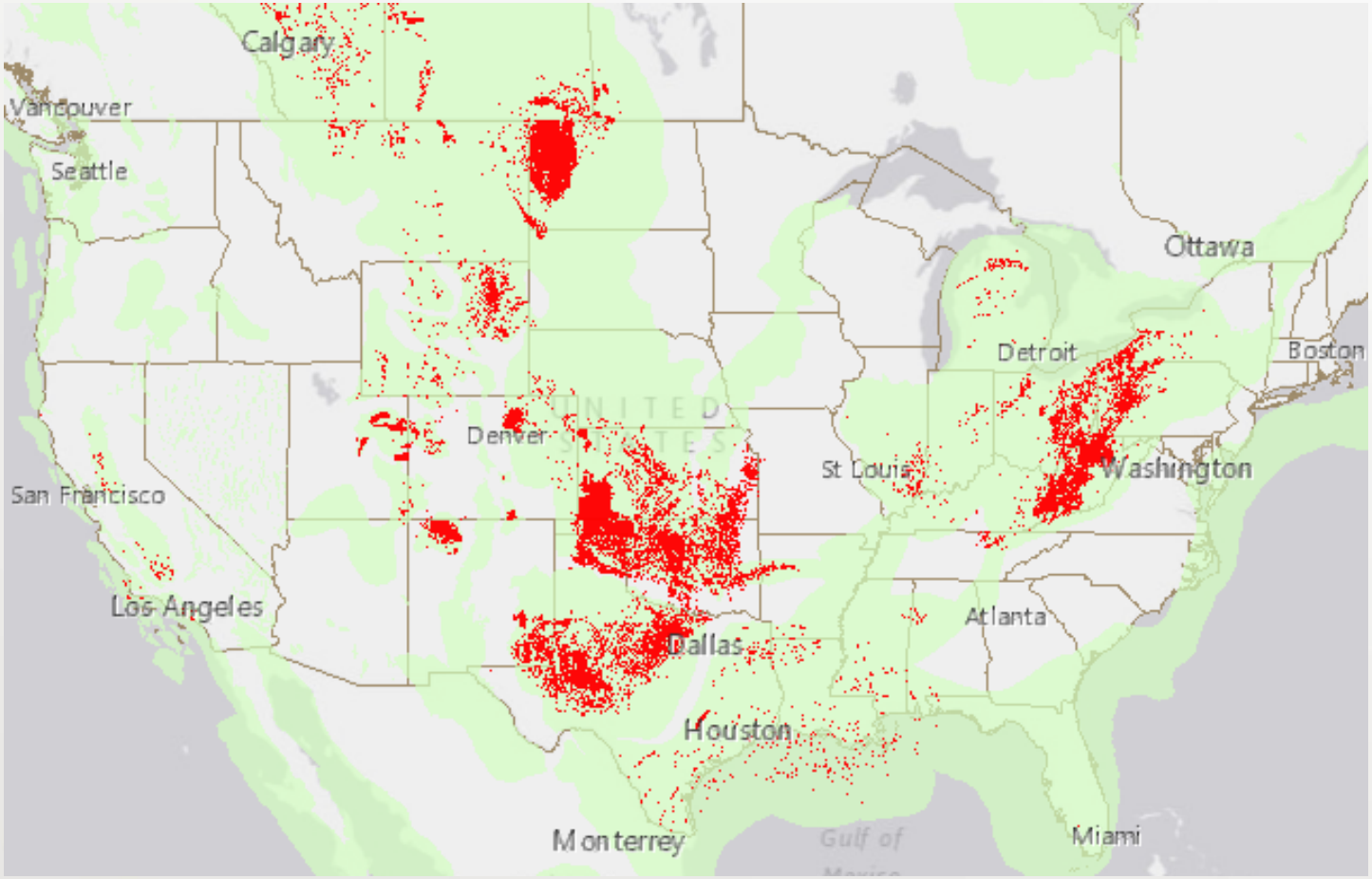
Marketing CO_2 for EOR

- Accessible oil resource
  - Geotechnical issues – miscibility, sweep
- Economically viable
  - Capital costs: CO_2, pipeline, separation facility,
  - Operational costs
    - Energy
    - CO_2 cost
  - Price of oil
  - Availability of capital

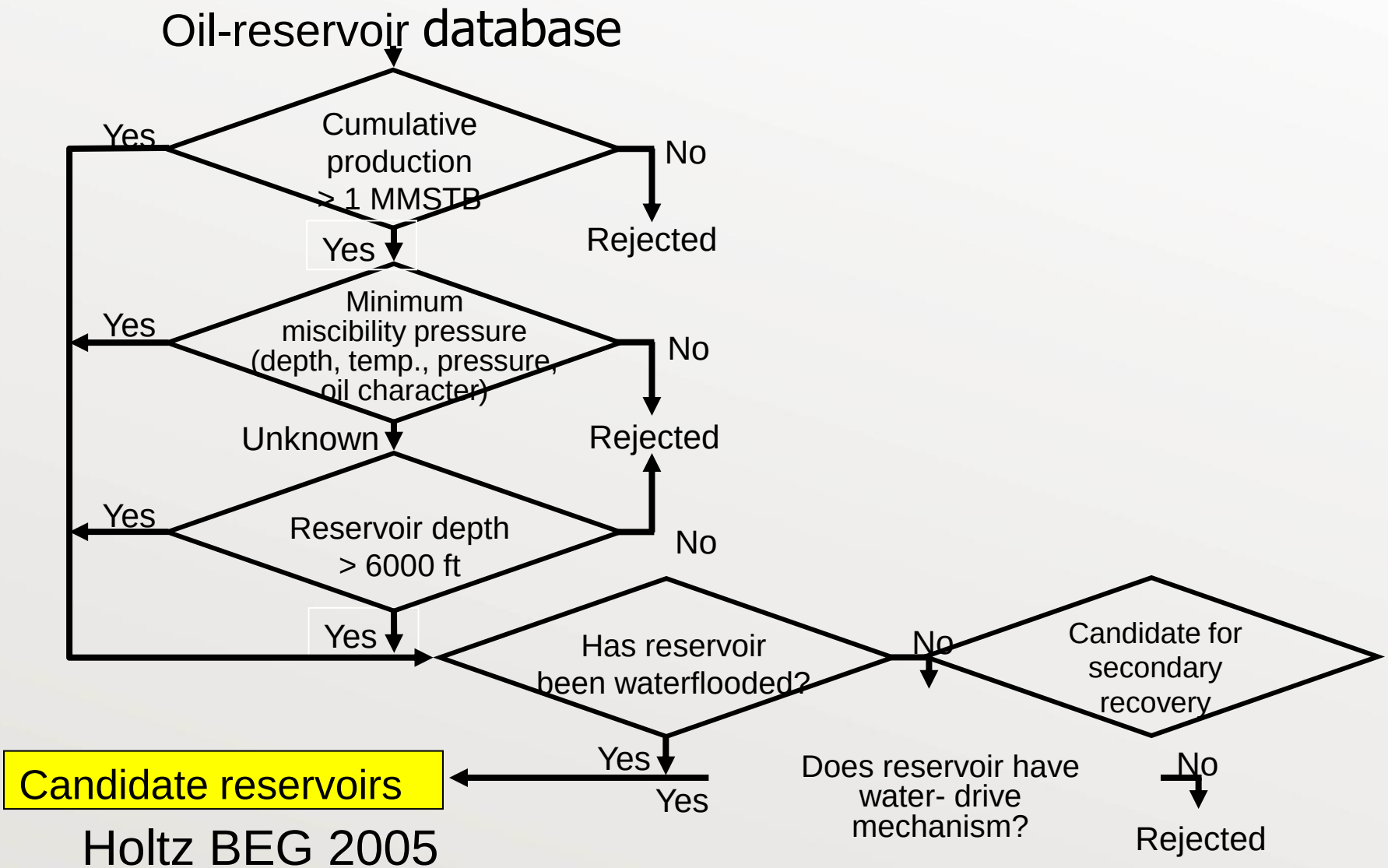
Distribution of oil resources



- Oil field boundaries

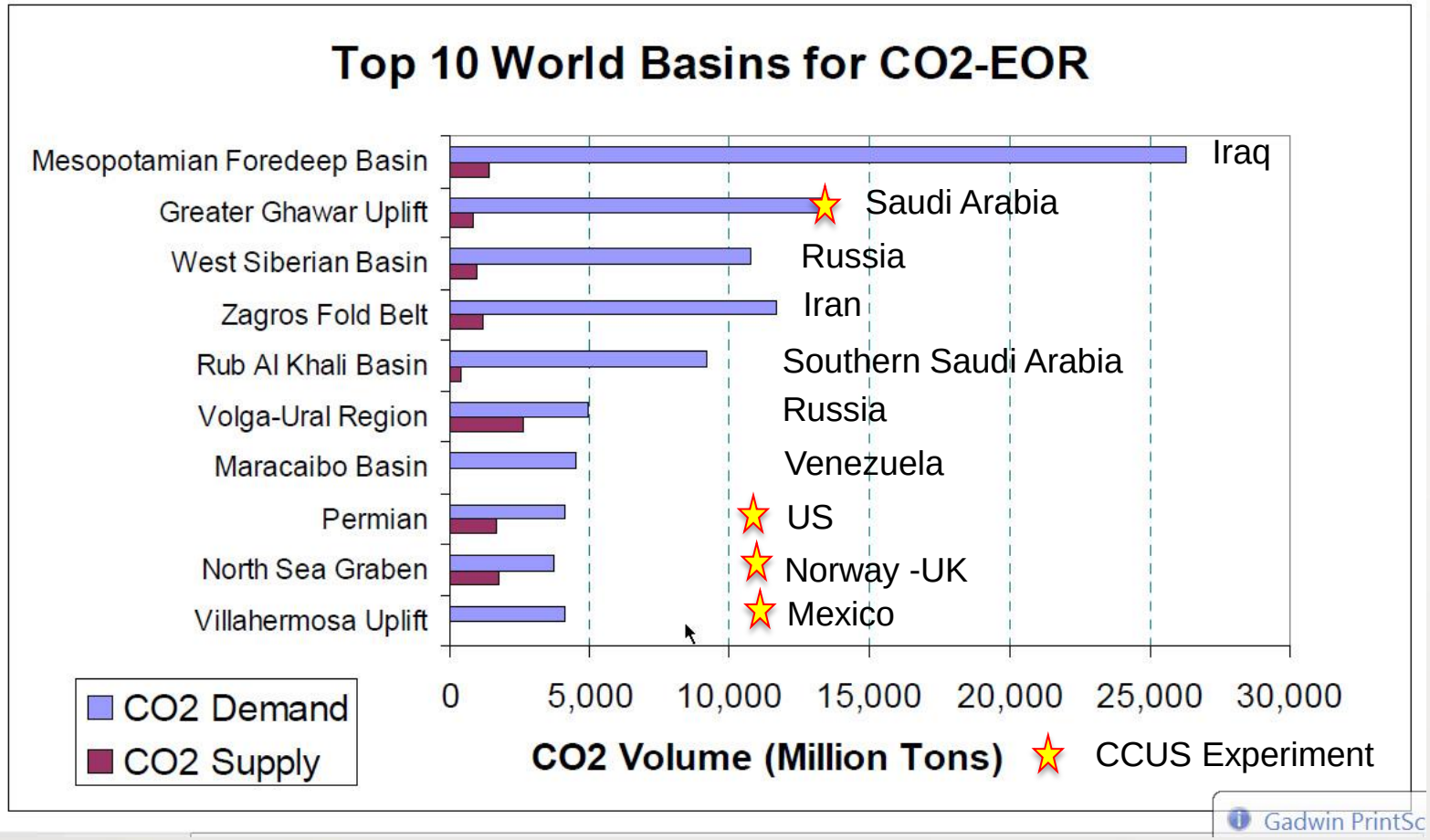
Sedimentary basins

Decision Tree for Screening Candidate Reservoirs



Holtz BEG 2005

Global CO_2 Market Potential for EOR



ARI and Meltzer, 2009 IEAGHG

Comparing CO_2 EOR and CCUS

Issue	**Traditional CO_2 EOR**	**Carbon Capture Use and Storage**
Motivation	Oil recovery, CAPX, OPEX CO_2 price, oil price	In addition, motivation (financial or otherwise) includes storage in isolation from atmosphere and ocean
CO_2 source	Any source; cost, location, volume, availability	Only sources that would otherwise be released to atmosphere
Regulation	Health, safety, environment and resource protection	In addition, assurance that storage is effective via monitoring and accounting

Examples of Integrated CCS Projects

Storage type \ Capture from	Power production	Industry	Gas Separation
For disposal	SECARB- Plant Berry Alabama	ADM Ethanol, IL	Sleipner – North Sea
	AEP Mountaineer, West Virginia	Tomakomai-Hokkaido Japan	Snøvit – Barents Sea
	Aquistore, Sask.	Shell QUEST, Alberta	Otway Australia
For EOR	Boundary Dam, Saskatchewan	Air Products-Port Arthur TX	Many fields in Permian Basin sourced from Val Verde Basin gas, TX
	Kemper - Alabama	Yanchang Ordos, China	Bell Creek, Lost Cabin, WY Multiple midcontinent US projects
	NRG/PetraNova-Houston TX	Coffeeville and Enid OK	Lula Field offshore Brazil
			Uthmaniyah Saudi Arabia

Offshore storage

Completed

Extensive inventory

https://www.globalccsinstitute.com/projects/large-scale-ccs-projects

Examples of Monitoring and Accounting Issues:

- Health and safety
- Protection of underground sources of drinking water
- Induced seismicity
- Long term retention

GCCC Field Tests for Monitoring Verification and Accounting

DOE-NETL and Industry Hosts

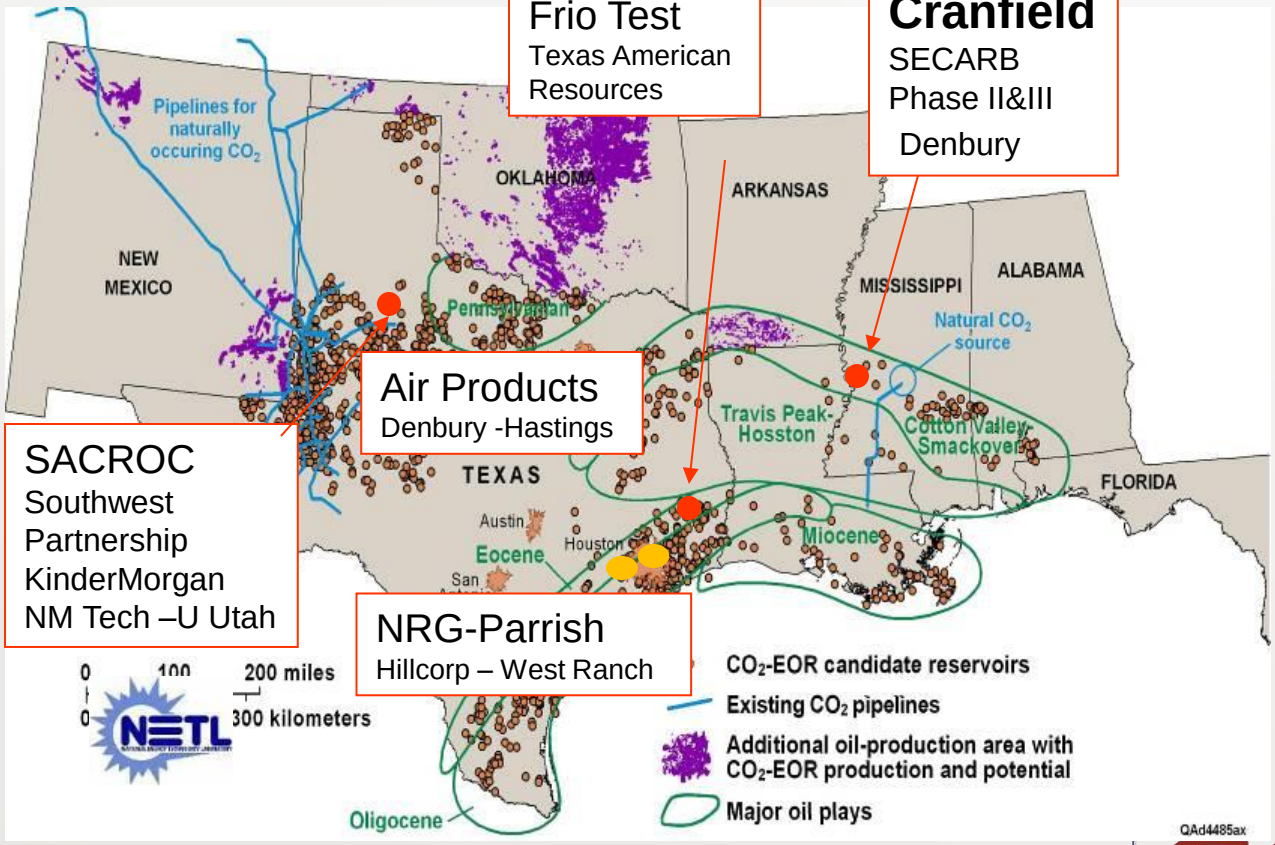
Frio Test
Texas American Resources

Cranfield
SECARB
Phase II&III
Denbury

Air Products
Denbury -Hastings

SACROC
Southwest Partnership
KinderMorgan
NM Tech –U Utah

NRG-Parrish
Hillcorp – West Ranch



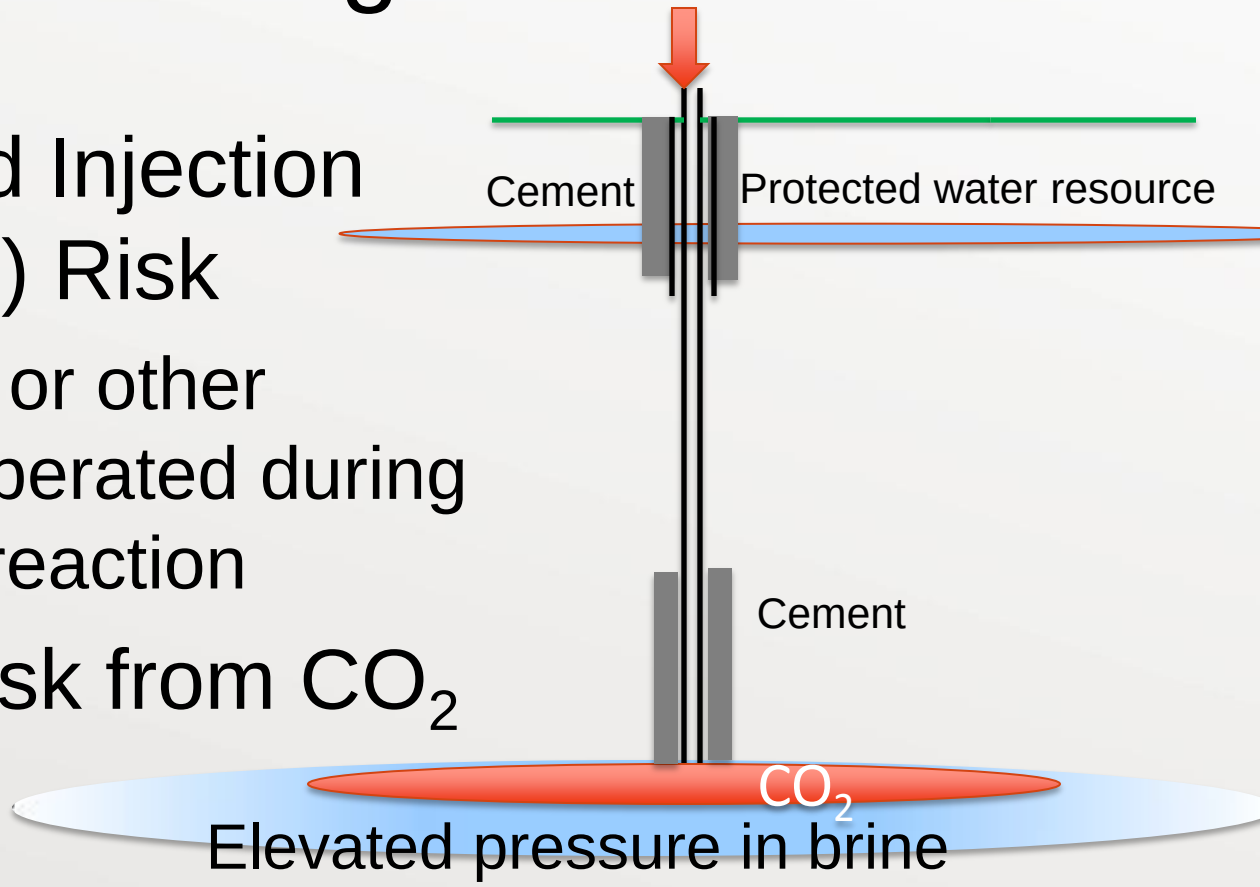
SECARB
Southeast Regional Carbon Sequestration Partnership

QAd4485ax

GCCC
GULF COAST CARBON CENTER

Protection of Underground Sources of Drinking Water

- Well-known Underground Injection Control (UIC) Risk
  - Brine, CO_2, or other impurities liberated during rock-water reaction
- No special risk from CO_2

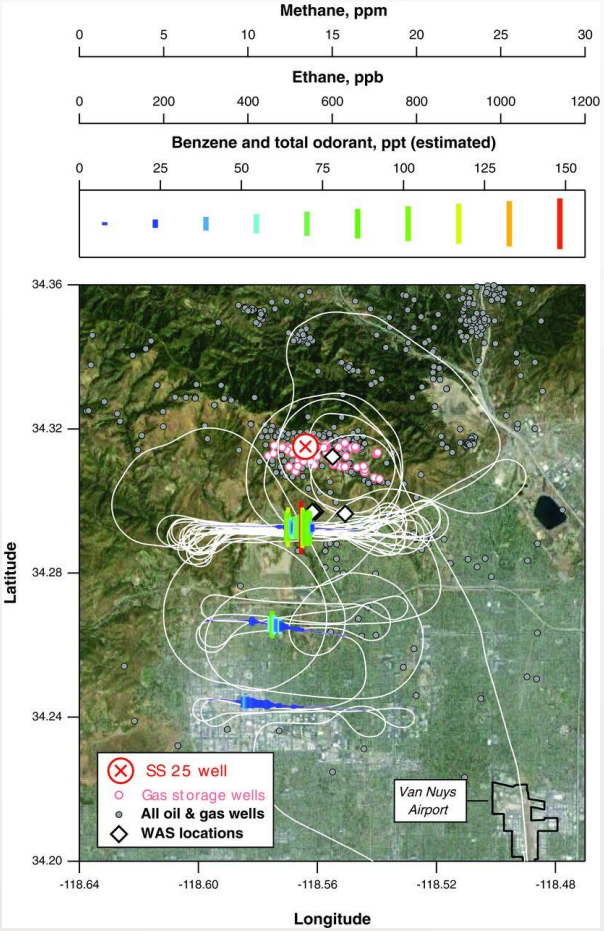


Health and Safety

- Impact from failure of surface infrastructure and wells

Analog study: Aliso Canyon gas storage facility -- well failure

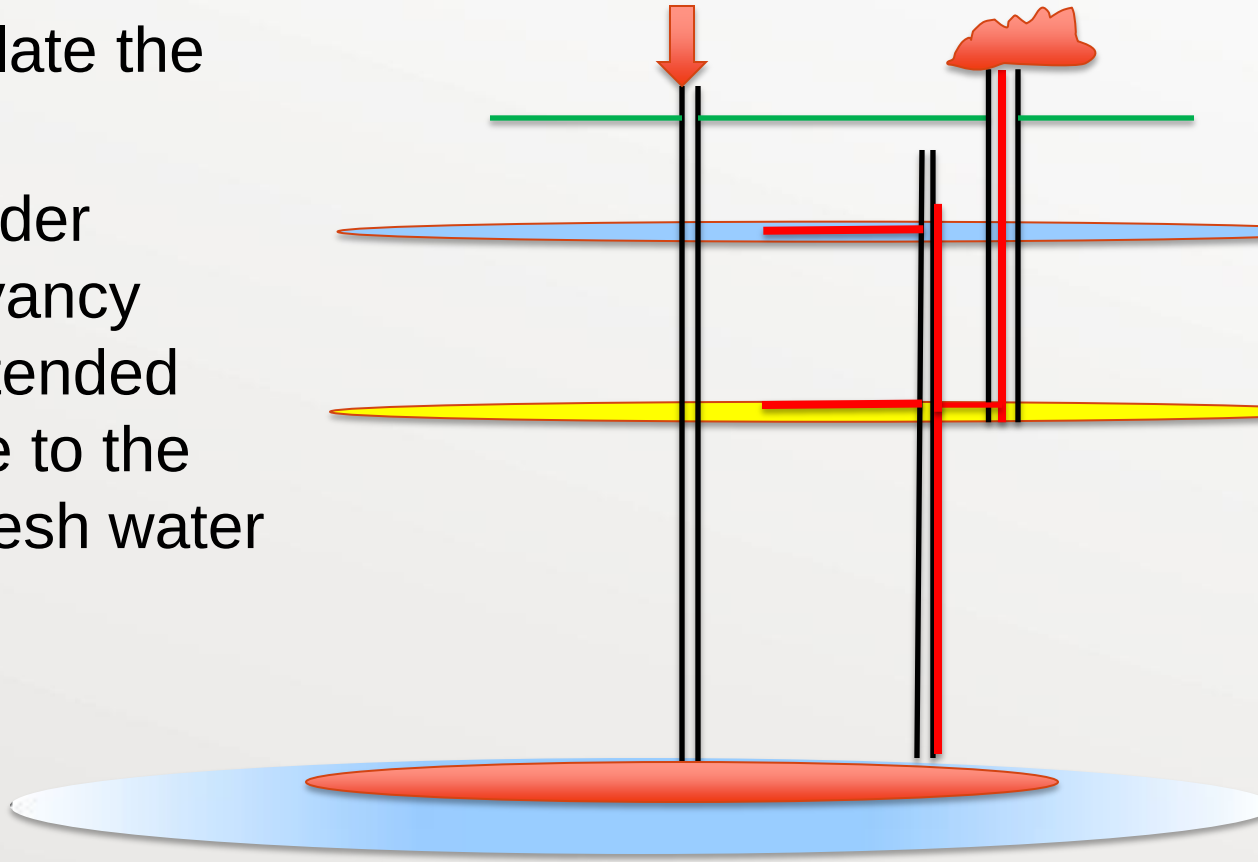
- Geologic failure – any flow will be retarded by tortuous flow paths – more relevant to long term benefit reduction than H&S



S. Conley et al. Science 2016;351:1317-1320

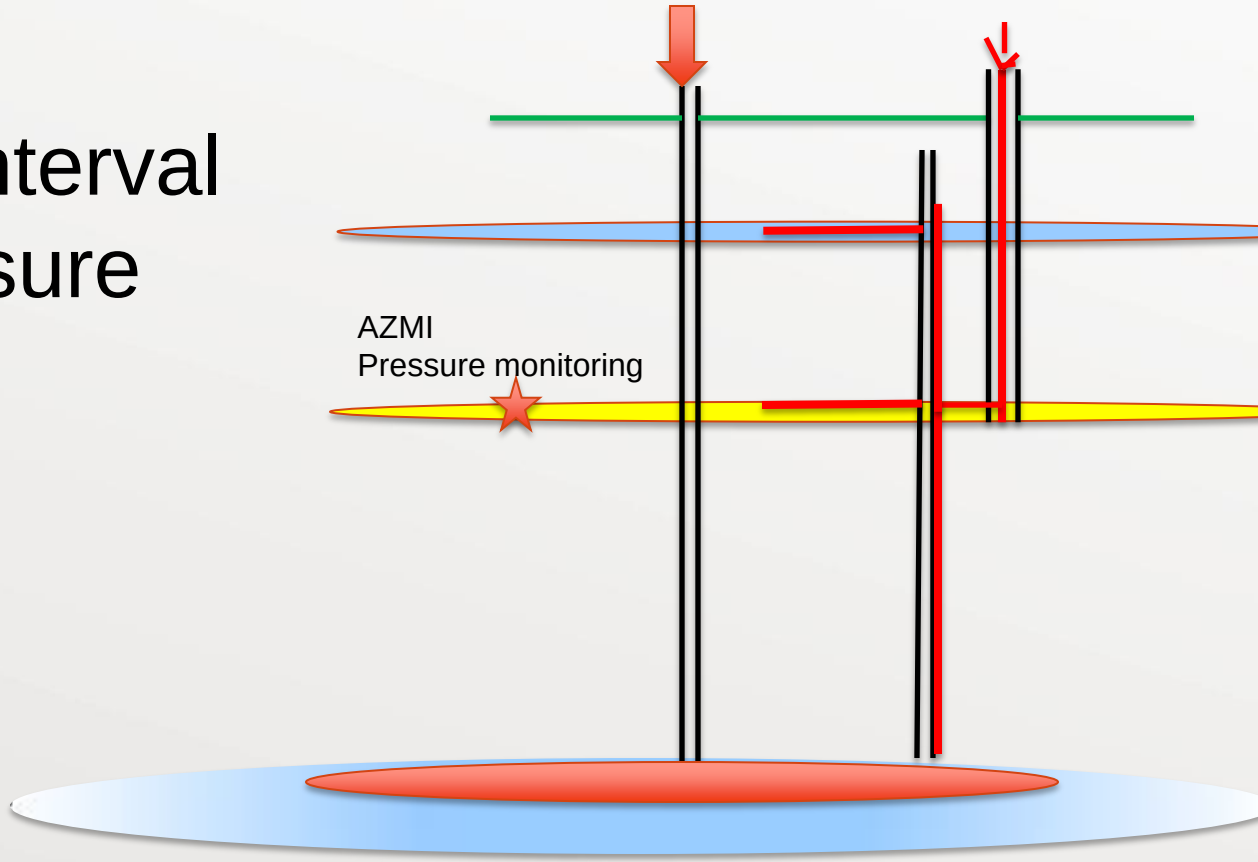
Containment Failure Scenario

- A well fails to isolate the injection zone.
- Fluids , either under pressure or buoyancy Migrate out of intended zone and escape to the surface or into fresh water

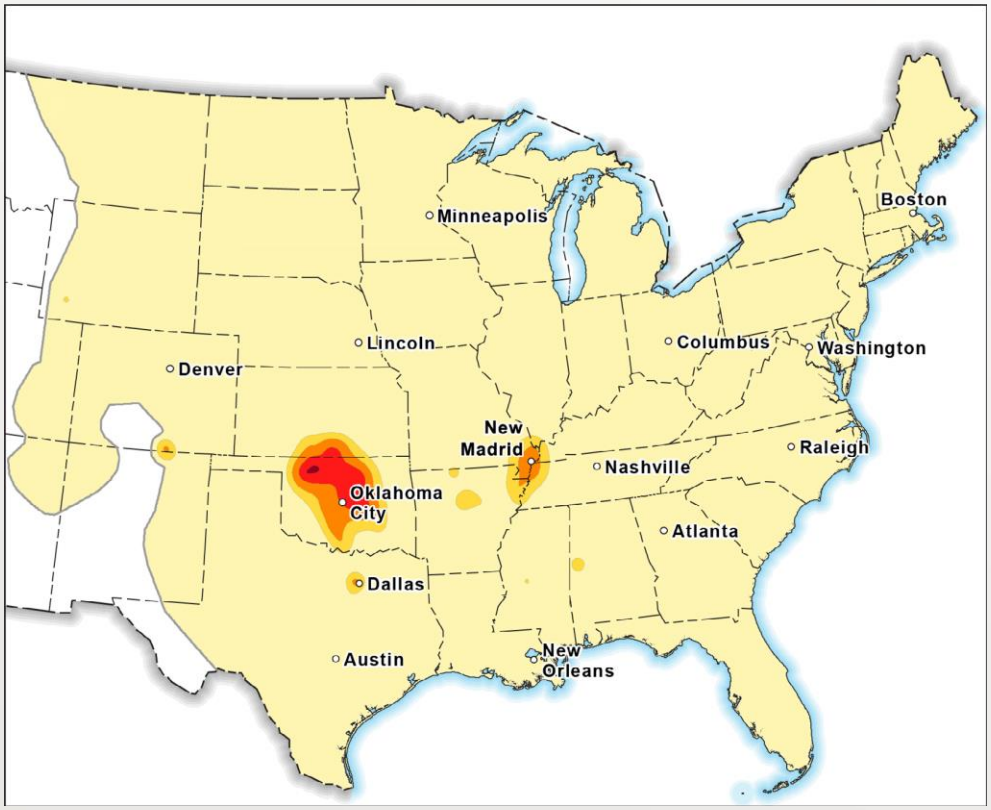


Protection via monitoring

- Above-zone monitoring interval (AZMI) pressure surveillance



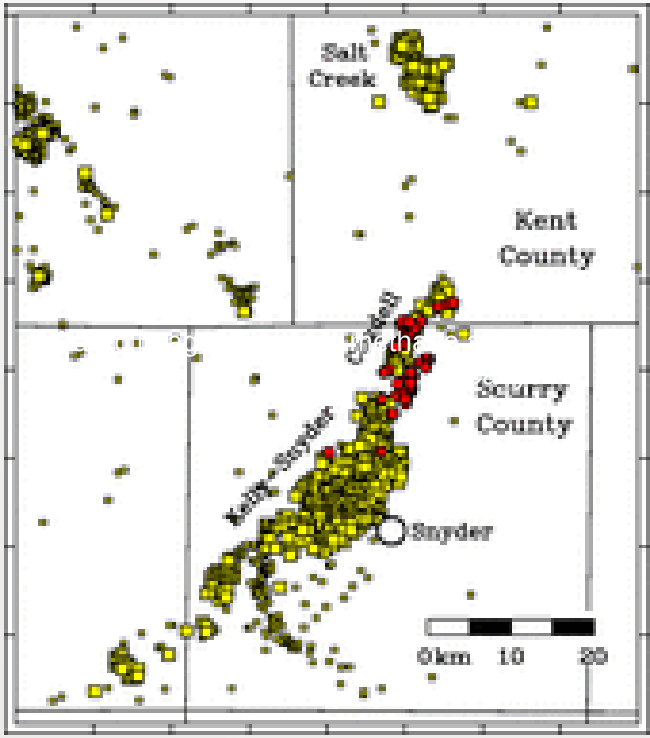
Induced Seismicity



USGS Pedersen, 2016 http://pubs.usgs.gov/of/2016/1035/ofr20161035ver1_1.pdf

Case of induced seismicity during CO_2 EOR

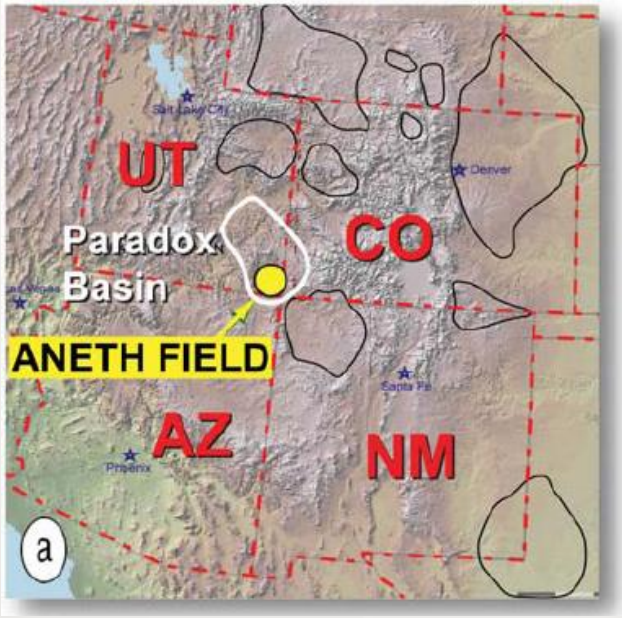
- Only one CO_2 injection at Cogdell field TX has reported seismicity
  - Gan and Frohlich, 2015 Nat Academy of Science



injection volumes exceeded 16,000 m^3/mo during 2004–2011

2009–2011 earthquakes

Case of microseismicity at Aneth field



Zhou and Rutledge, 2010, The leading edge.

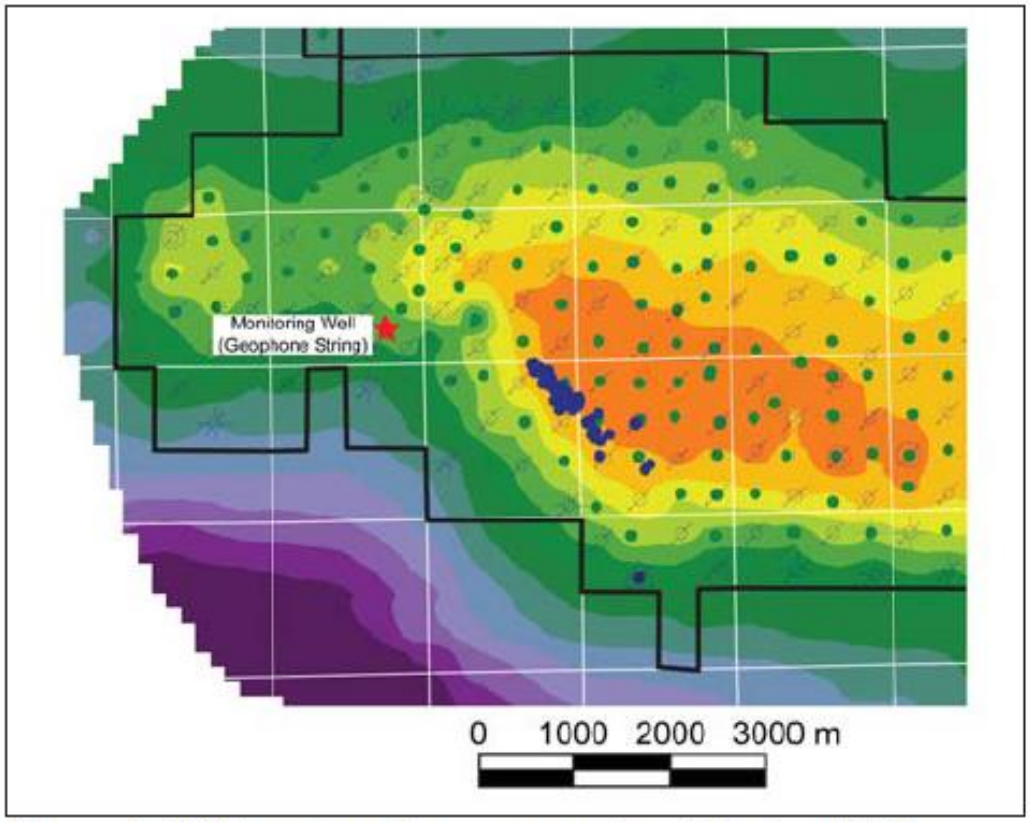
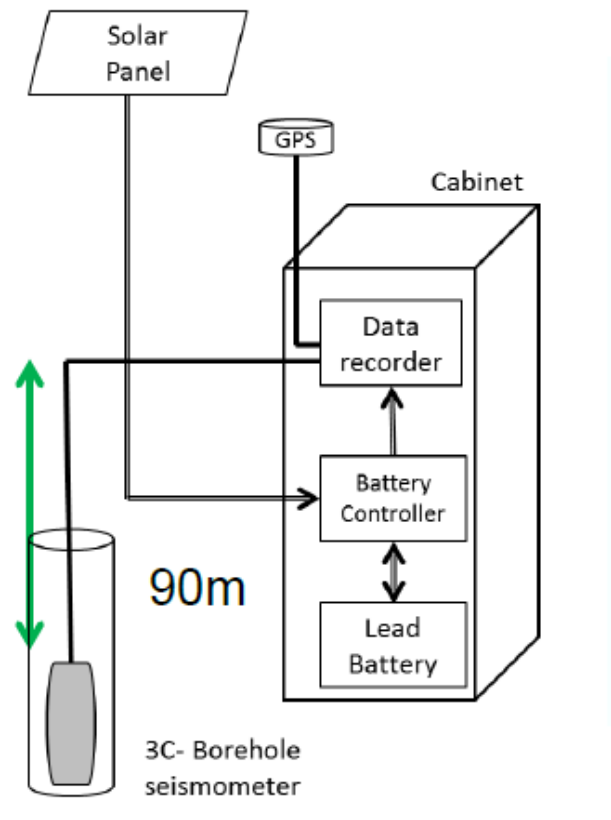


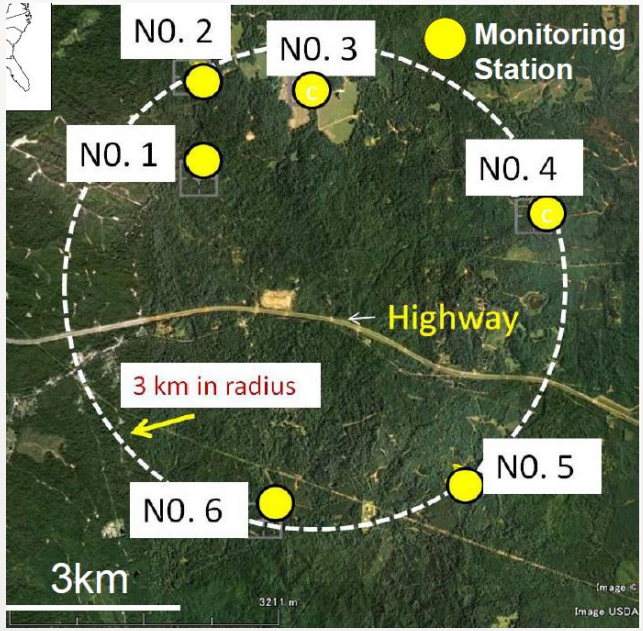
Figure 2. *Well map over the western portion of the Aneth Unit. Green circles are oil producers, and injection wells are the open circles. The monitor well is shown by the red star and the microseismic locations are the blue dots.*

Field Measurements of No Seismicity

3 year seismic detection project by Makiko Takagish, RITE at Cranfield

- Injection of >5 MMT CO_2 over 5 years.
- Pressure increase 1000 psi at times.
- No local microseismicity detection





Minimum detectable amplitudes at reservoir depth are .4 (horizontal) and 0.7 (vertical)

Conclusions

- Use of CO_2 for EOR is mature, but has potential for global expansion if additional anthropogenic CO_2 is available
- Application of CCUS for GHG emissions reductions is occurring slowly but successfully
- CCUS requires modest additional monitoring and accounting techniques available.

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