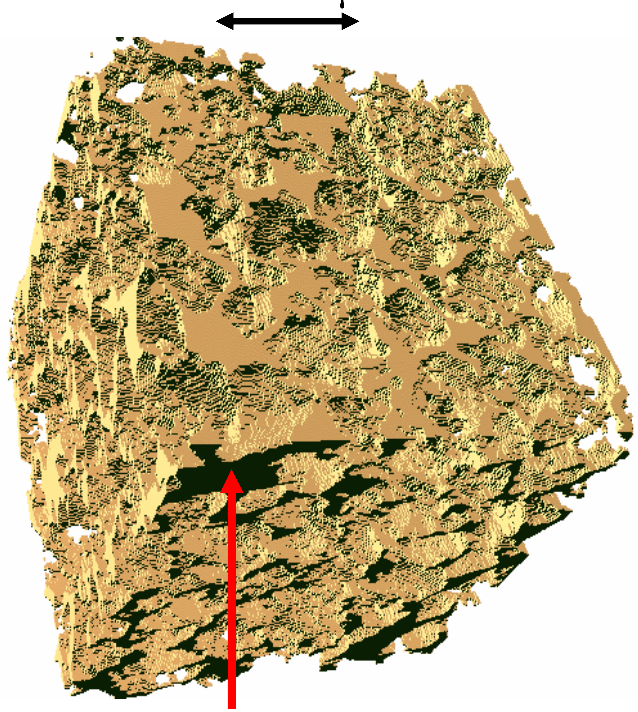
Geological sequestration or storage of CO_2



Berea sandstone
Dmitriy Silin - UC Berkley, 2005

Fluids (oil, natural gas, CO_2 and/or water) are contained in tiny pore spaces in porous (5-30%) geological matrices.

CO_2 can be stored in:

- Oil reservoirs – enhanced oil recovery (EOR).
- Saline aquifers.
- Coal beds.

Similar to a sponge

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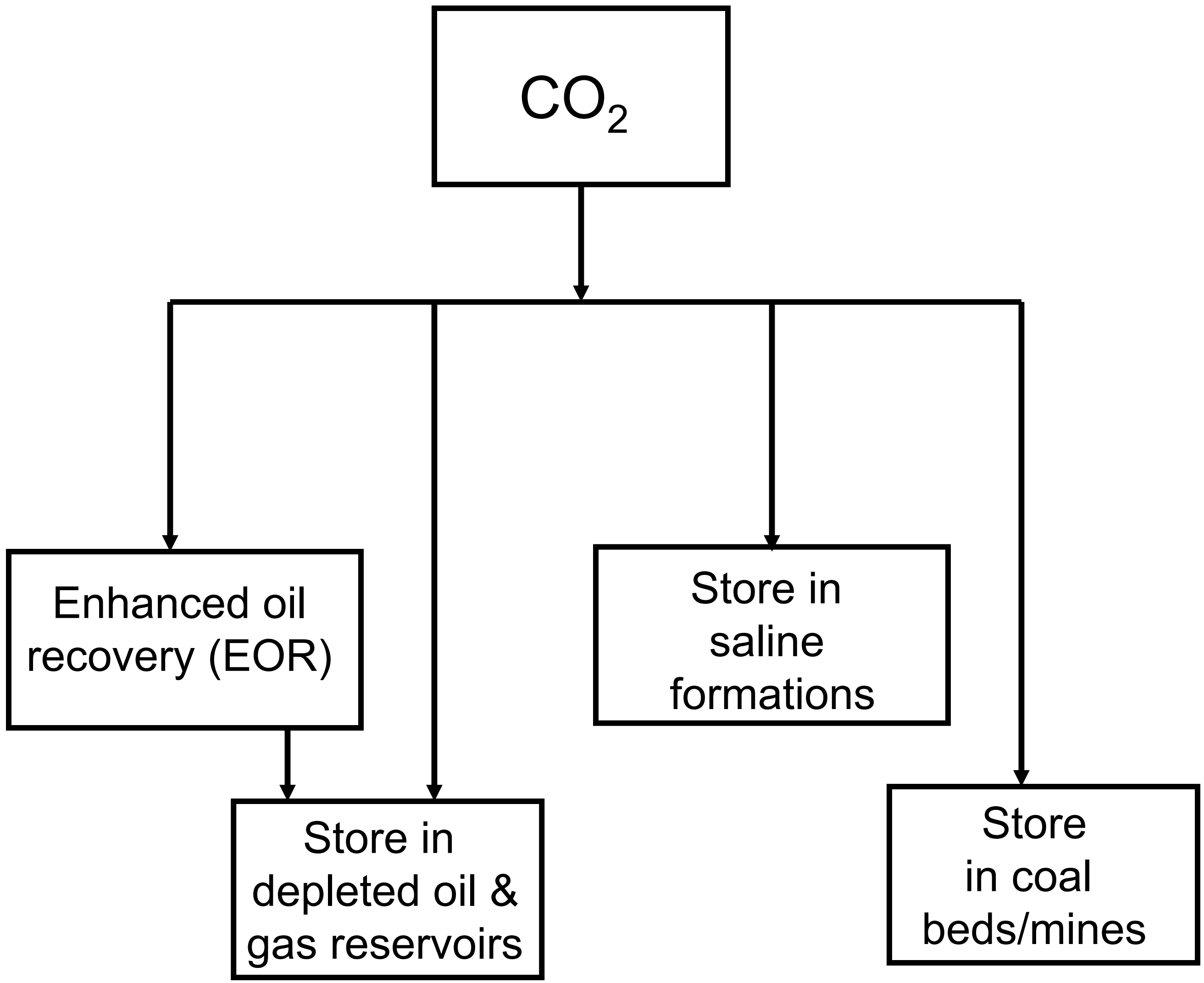
Jim Rawson
GE Global Research
October 2007

Use and/or storage of CO_2 from coal-fired plants



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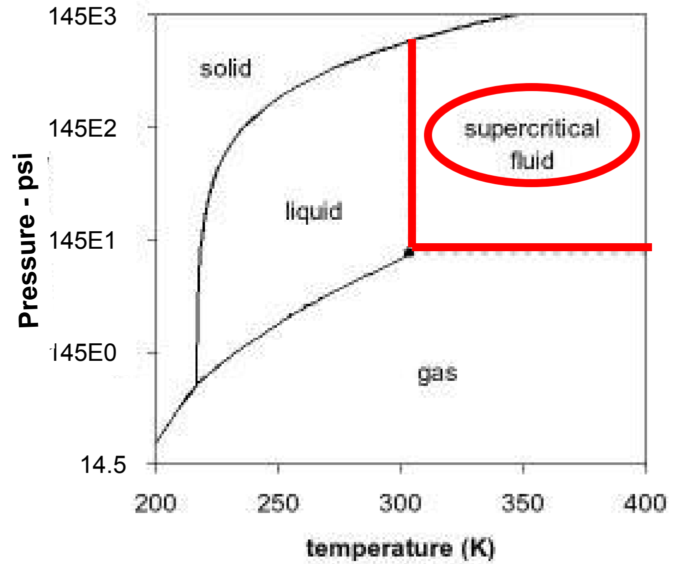
CO_2 specs for injection into a geological storage formation

- Supercritical CO_2:
  - P & T dependent.
- High pressure required to maintain a supercritical liquid:
  - 1087 psi (88°F/31°C).
  - Minimum subsurface depth of 2400 ft.



CO_2 P-T phase diagram

If you understand CO_2 – EOR, it's easy to understand other types of geological storage of CO_2

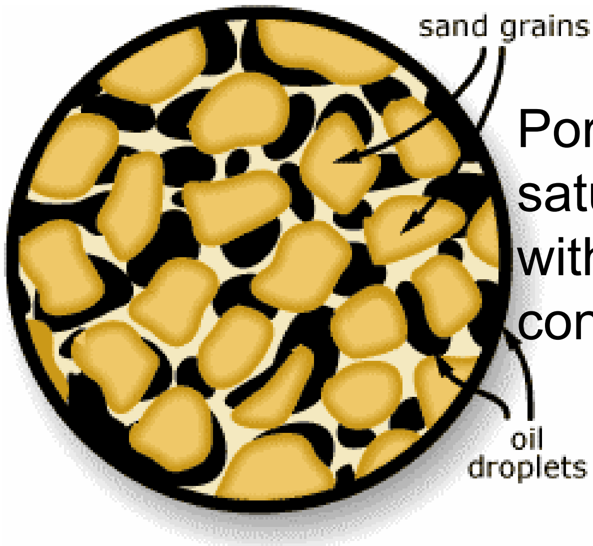
Important physical properties of a geological storage formation:

- Porosity: % Void space.
  - Controls volume (tons) of CO_2 that can be stored.
- Permeability: Flow of fluids through void space of rock.
  - Controls ease of fluid flow.
- Long term containment.

Important physical chemical properties of oil for EOR:

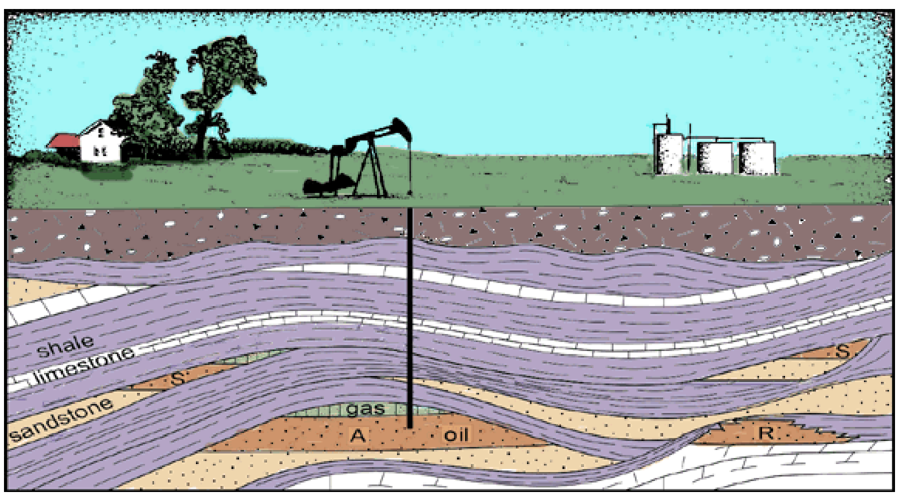
- Viscosity.
- Interfacial tension – affinity of oil for geological surface.
- Chemical composition – low asphaltenes.

Primary oil production



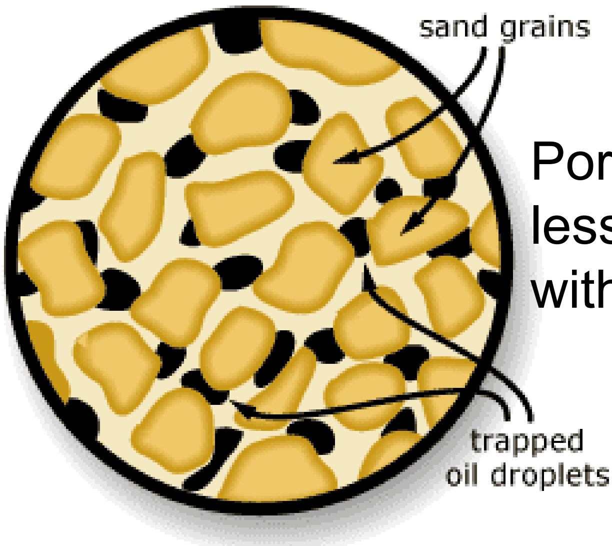
Pore space saturated with oil, gas & connate water.

Hydrostatic pressure production of oil & gas.

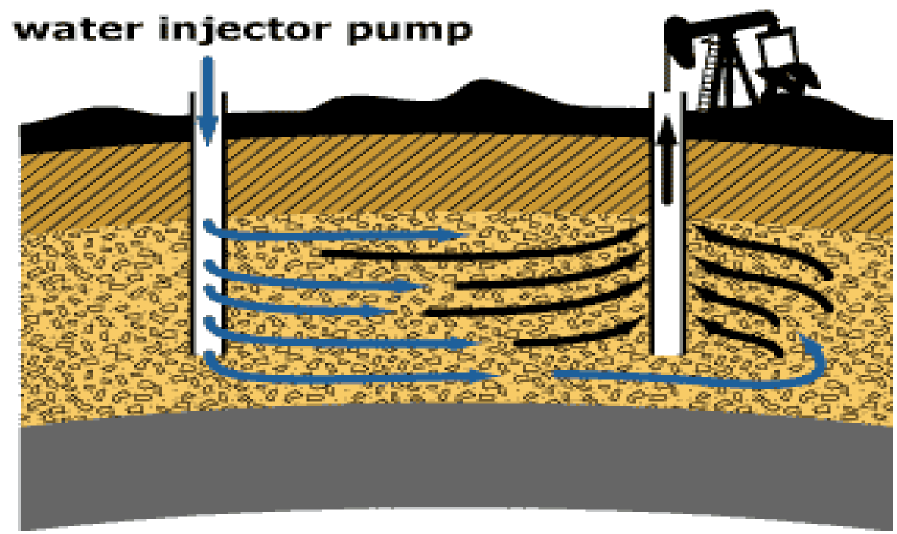


- After oil ceases to flow on its own, it can be pumped out of a reservoir until the well runs “dry”.
- Up to 20% of the oil can be recovered by pumping.

Enhanced oil recovery - EOR



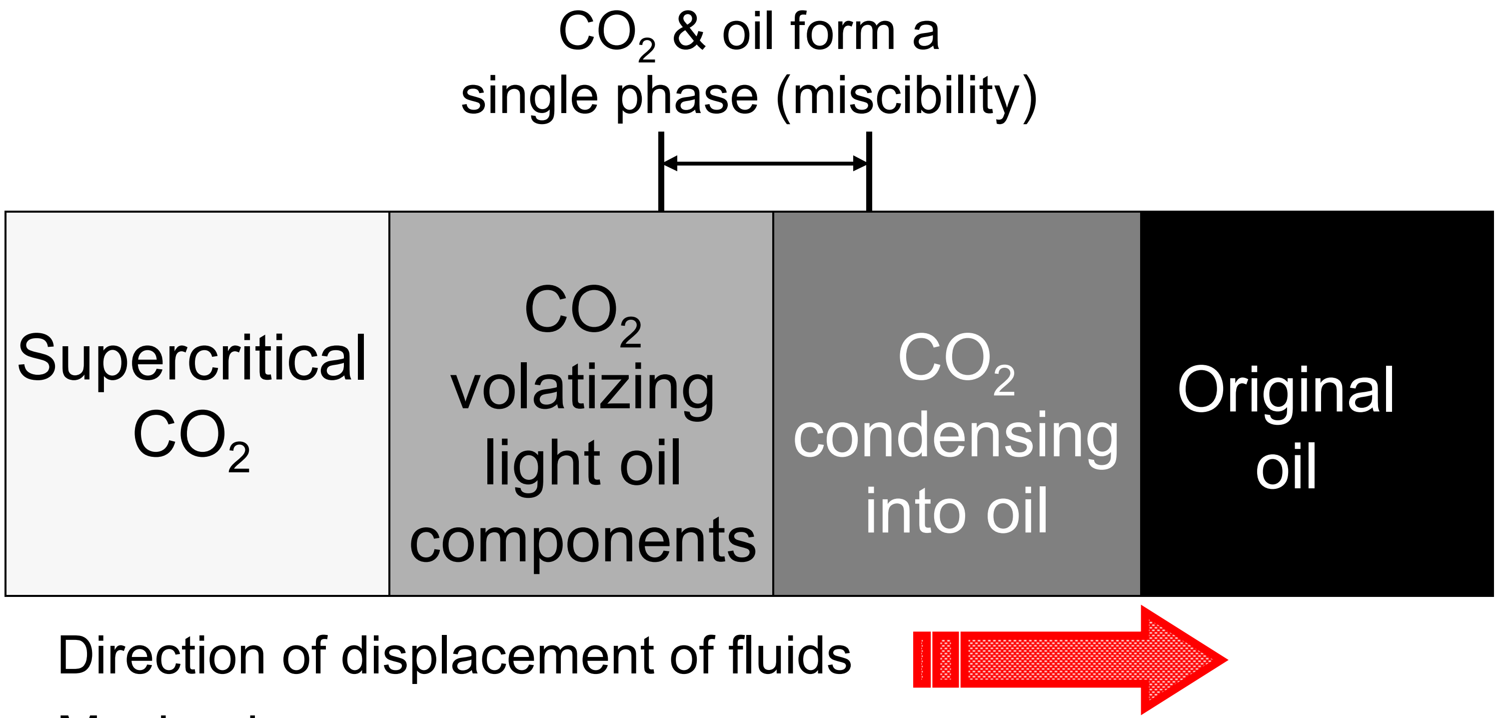
Pore space less saturated with oil



When a well runs “dry”, reservoir conditions must be altered to recover additional (residual) oil:

- Waterflood – water mobilizes residual oil & pushes it to a recovery well.
- Miscible gas flood – gas dissolves into oil & changes properties of the oil. CO_2 can be used for this purpose.

CO_2 miscible flood for EOR

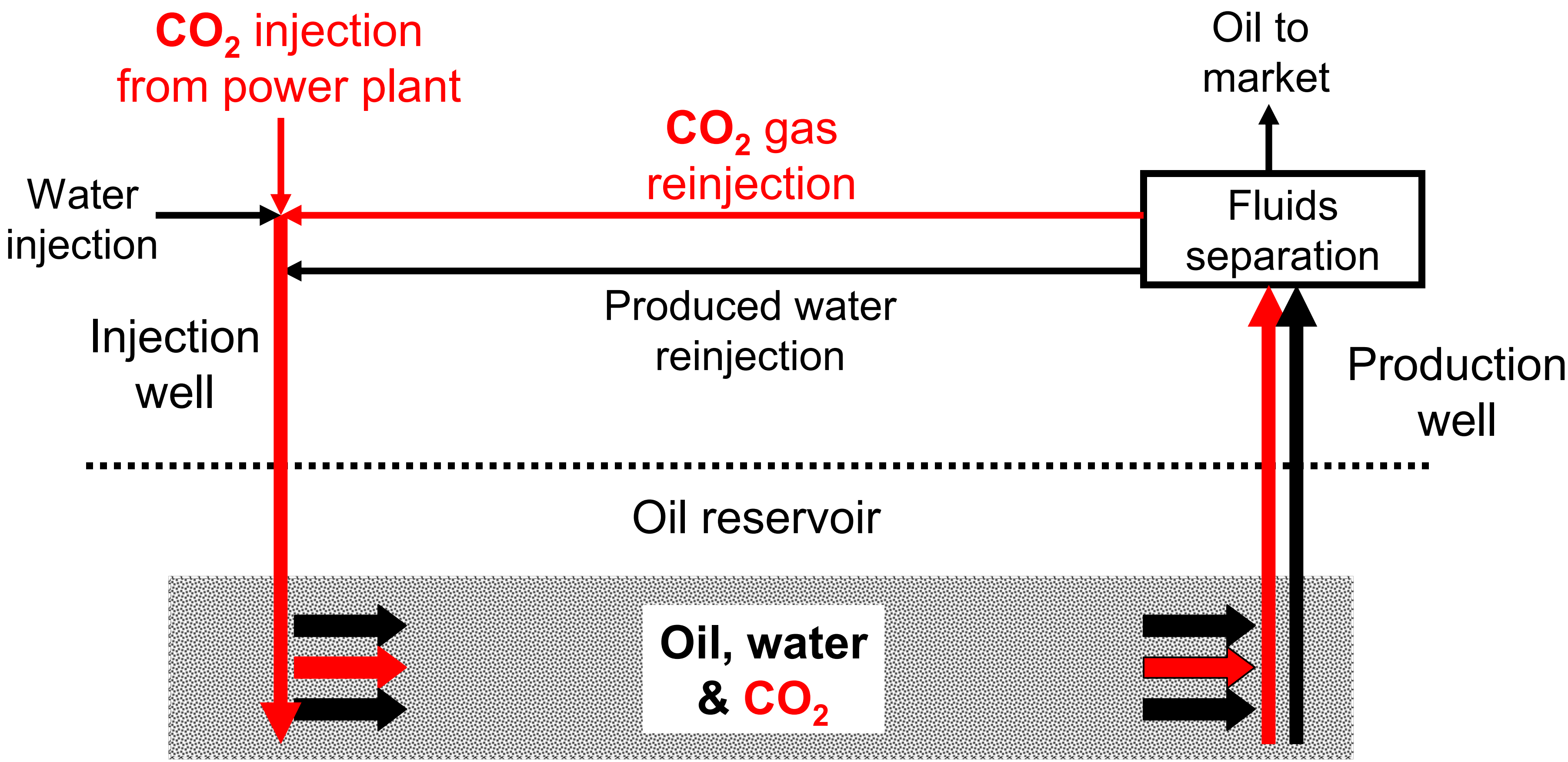


Mechanism:

- CO_2 & oil become miscible:
  - Minimal miscible pressure (MMP) is minimum pressure required to dissolve CO_2 into oil.
  - Lowers the viscosity of the oil.
  - Lowers the interfacial tension between the oil & the rock.

CO_2 EOR can only be used for light oils

CO_2 EOR – fluids handling



Multiple fluids (oil, water & CO_2)
are simultaneously produced.
30-80% of injected CO_2 is produced with the oil – must be reinjected

1 barrel oil requires ~ 0.5 ton of CO_2 (8000 cf)

CO_2 purity – Why worry?

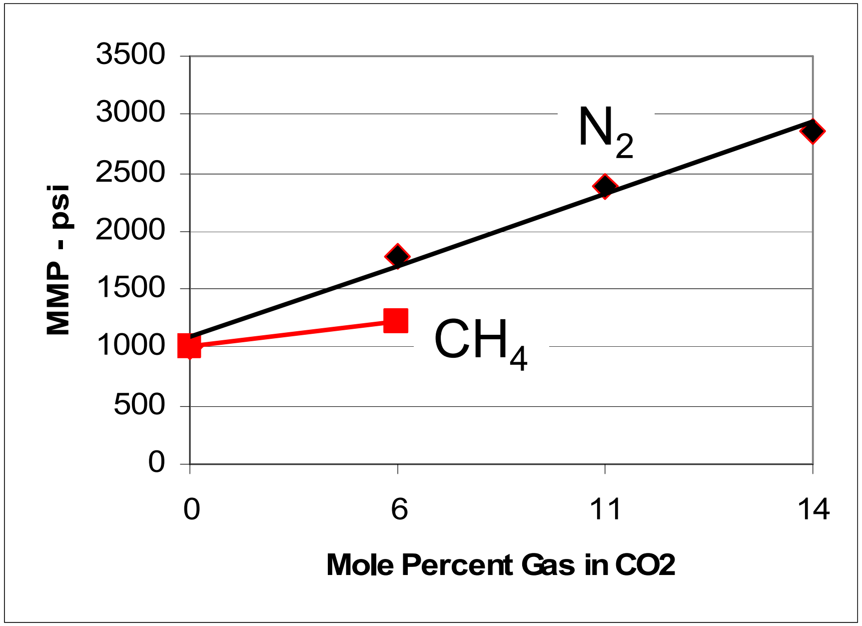
- Cost of compression to form supercritical CO_2.
- Controls MMP requirements for EOR:
  - Cost of injection pressure to generate required MMP.
- MMP must be less than fracture pressure of bedrock.
  - No leakage & safety.
- Cost of handling sour (H_2S) produced fluids during EOR.
- Pipeline transportation safety – H_2S:
  - Cost of pipeline materials.
  - Regulations associated with transporting hazardous materials.

Physical chemistry of gases controls the formation of supercritical CO_2.

- N_2 & CH_4 decrease the supercritical P.
- H_2S increases the supercritical P.

Physical chemistry of gases & oil control the MMP.

- N_2 & CH_4 increase MMP.
- H_2S decreases MMP.
- Composition of oil also controls MMP.



Ref.: Johnson & Pollin (1981) SPE/DOE 9790

Status of use of CO_2 for EOR in the U.S.

U.S. Dept. Of Energy (Feb. 2006)

- Approximately 80 CO_2 EOR projects:
  - Natural CO_2
  - 3000 miles of CO_2 distribution pipelines in Permian Basin (U.S.).
  - Efficiency of CO_2 EOR ranges from 11 to 15% OOIP.
- Multiple oil reservoirs are available for CO_2 EOR.
- Many CO_2 EOR projects have been limited by CO_2 availability.

A lot has been safely done in the past.

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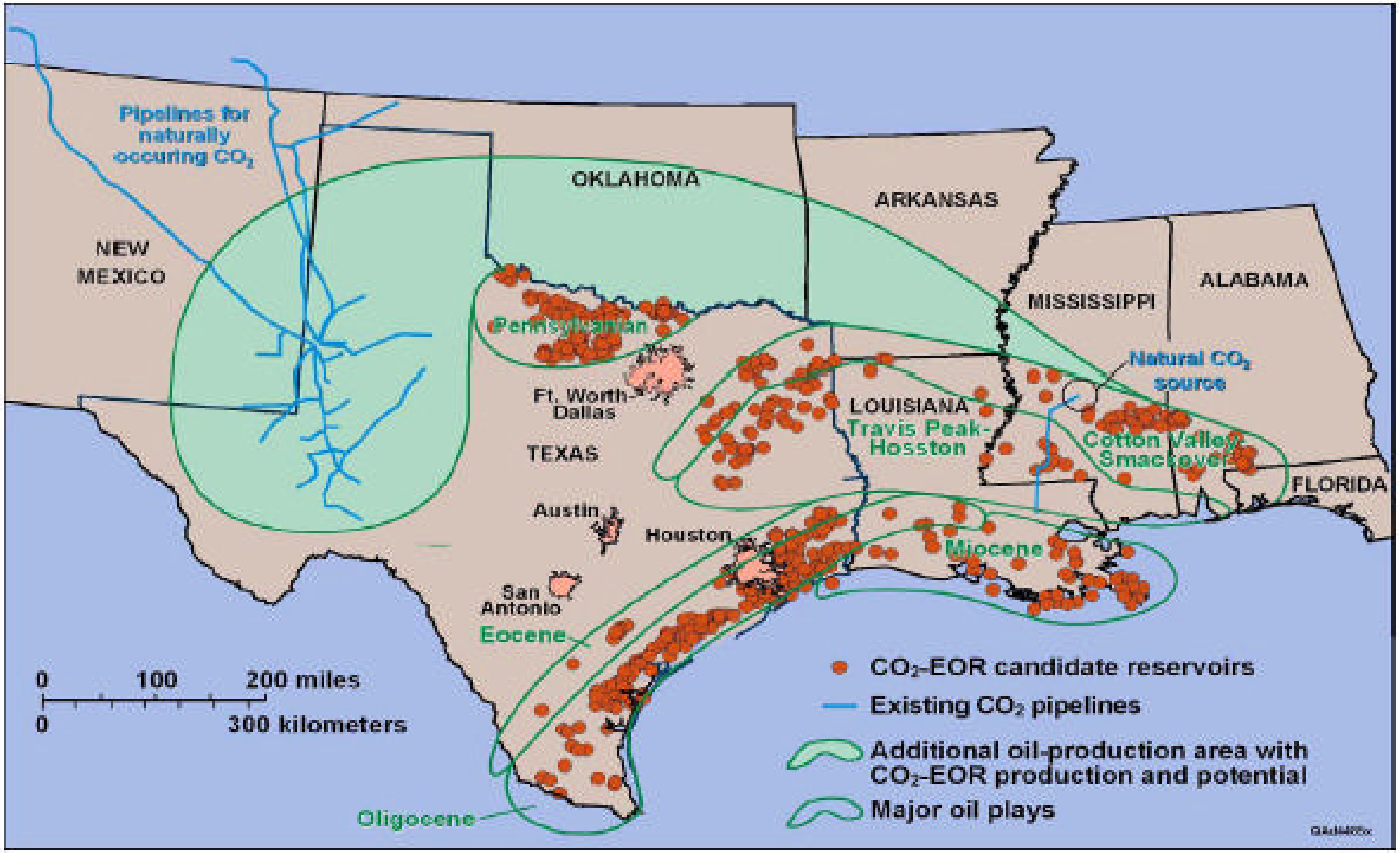
Permian Basin areas with CO_2 EOR potential

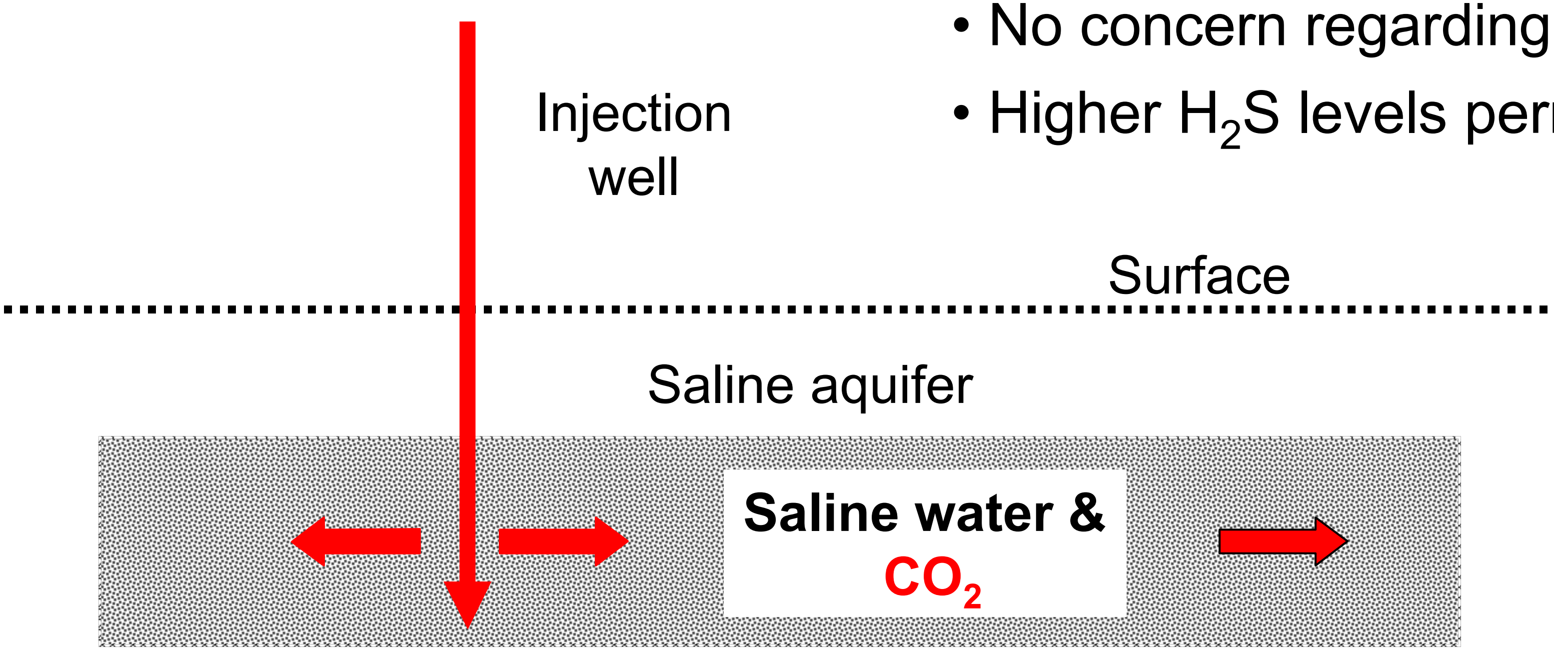


- ***Multiple natural sources of CO_2 available.***
- ***Multiple reservoirs available for CO_2 EOR.***

Saline aquifer – fluids handling

CO_2 injection
from power plant

CO_2 specs for saline aquifers:
- Less stringent.
- No concern regarding MMP.
- Higher H_2S levels permitted.



No production of fluids

Status of geological storage of CO_2 in saline aquifers

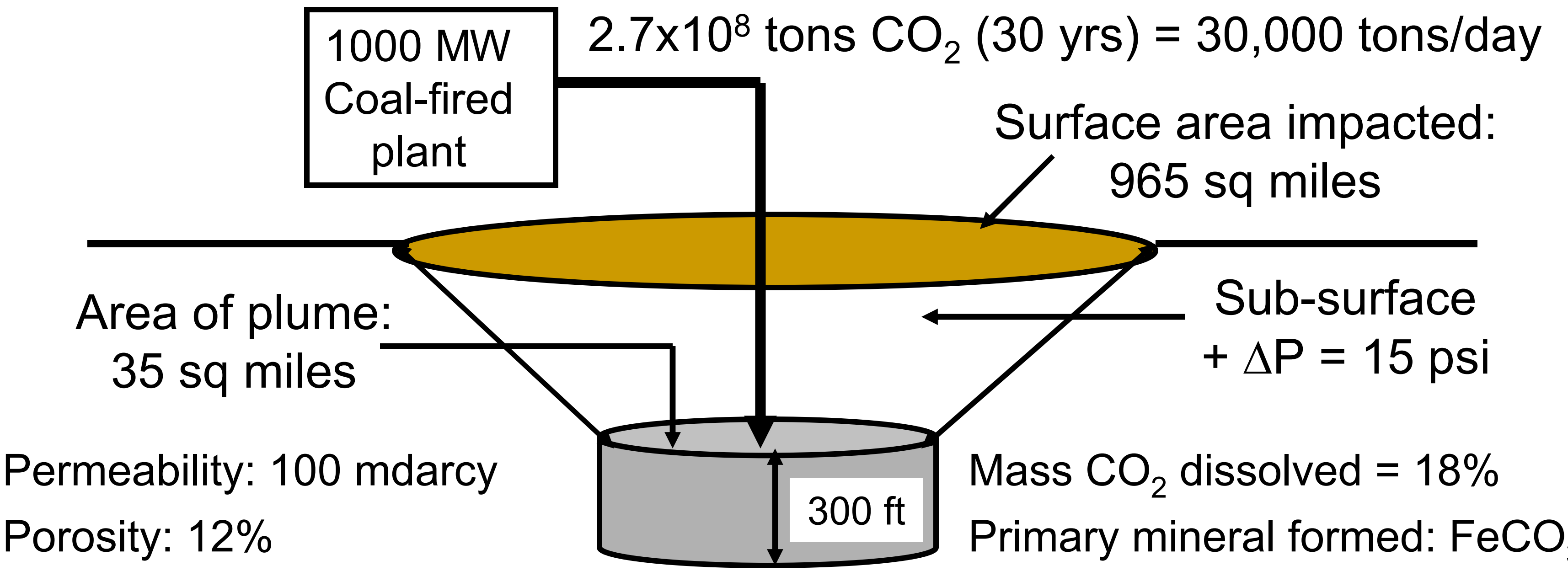
<u>Field</u>

Sleipner – North Sea: $1x10^6$ tons CO_2 per yr.

In Salah – Algeria: $1x10^6$ tons CO_2 per yr.

Frio – Texas: 1600 tons total.

<u>Modeling:</u> Pruess et al. (2003) SPE Journal. pp 49.

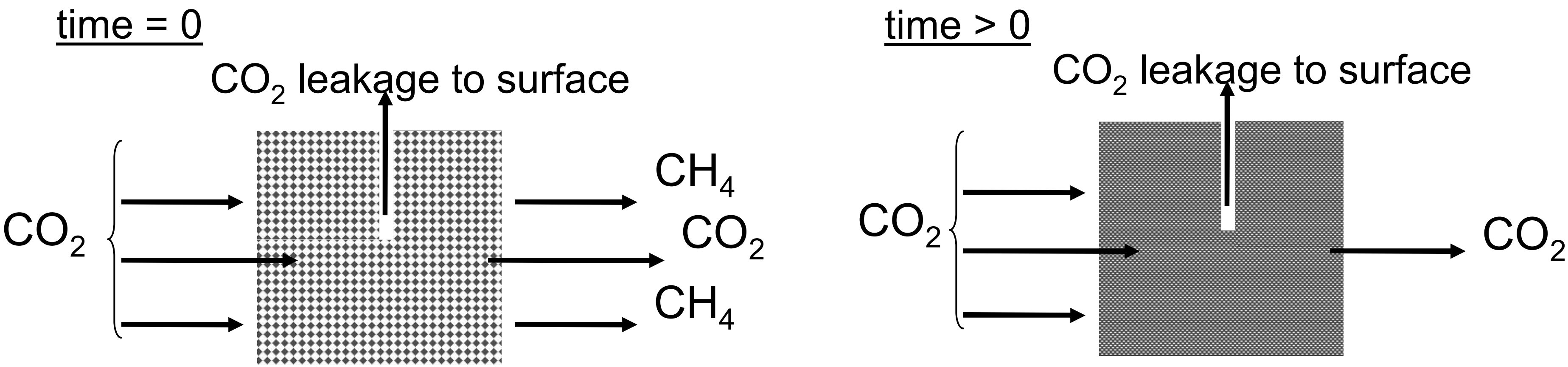


Mass CO_2 / formation volume = 0.037 tons/m^3

CO_2 storage in coal beds & natural gas recovery

Significant unique technical hurdles

- Fractures – channeling & leakage.
- Swelling of coal – lowers permeability & injectivity.



Example: Allison Unit, NM – Burlington Resources

- Increased methane recovery ~ 20%.
- Only ~ 80% of CO_2 remained in coal bed.
- 20% of CO_2 produced with methane.
- Significant decrease in permeability.

Use of CO_2 for enhanced natural gas recovery from coal beds is in its infancy

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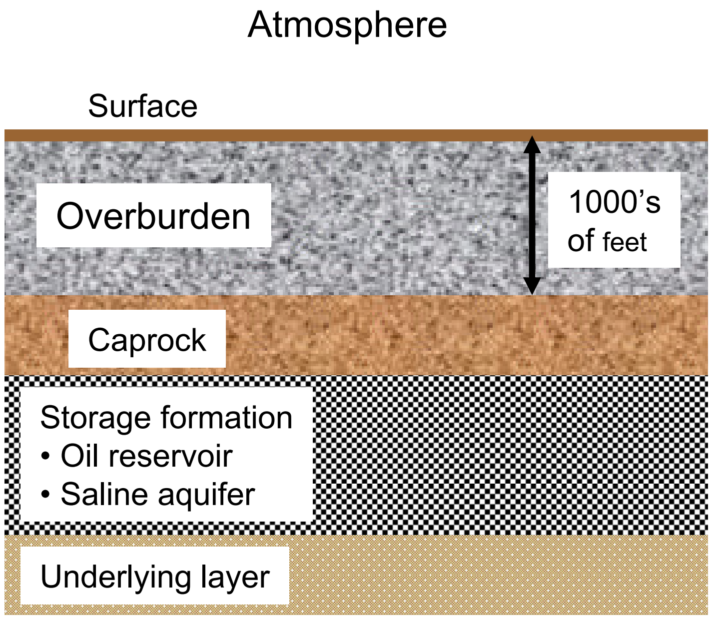
Characteristics of a good CO_2 geological storage site

Complete characterization of the geological formation:

- Geologically stable.
- Geological containment structures.
- Minimal leakage potential.
- Injectivity.
- Geochemistry.
- Oil chemistry.
- No adjacent sensitive aquifers.
- CO_2 capacity.



Greatest uncertainty is calculating the CO_2 storage capacity

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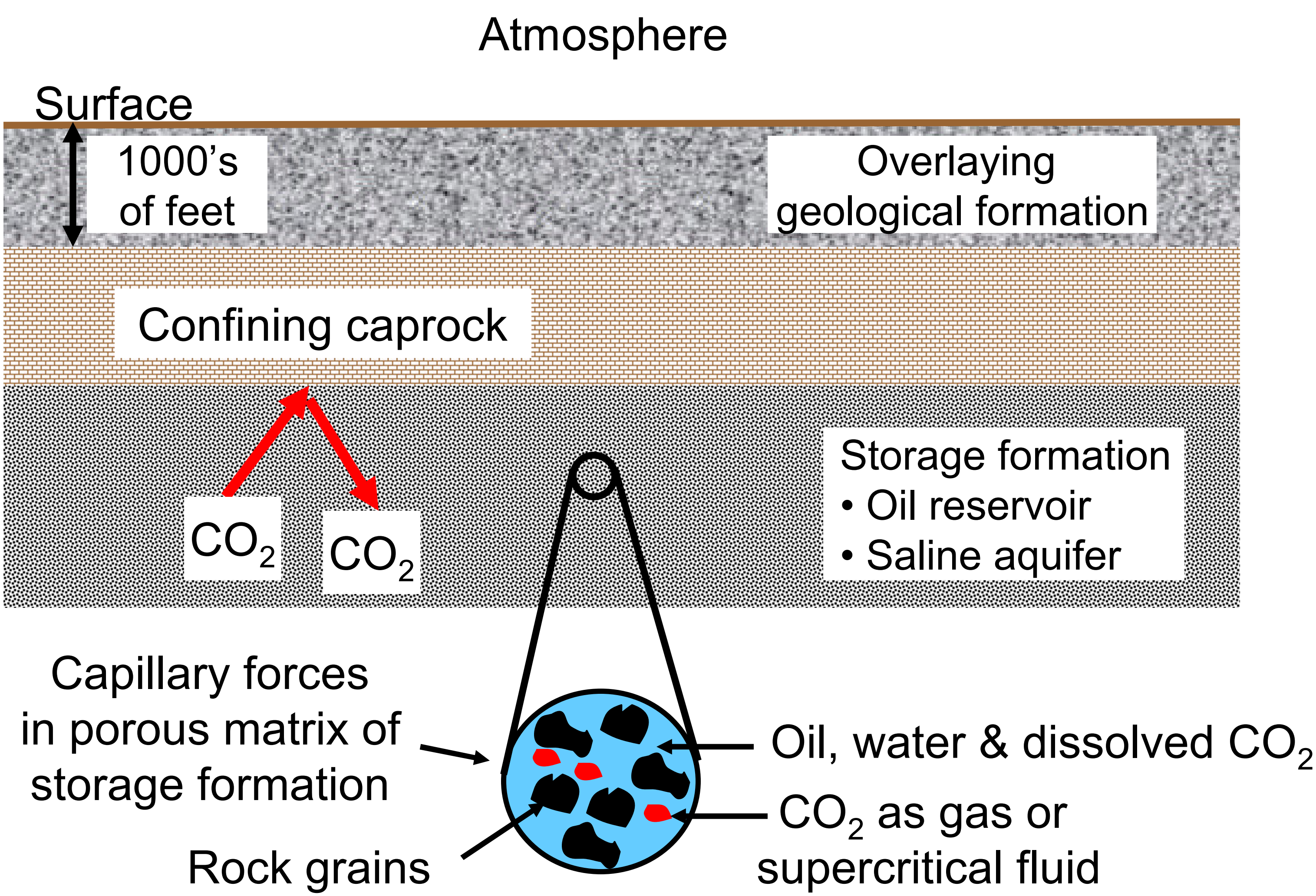
Initial CO_2 containment mechanisms in a geological storage formation are geophysical processes



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Long-term CO_2 containment mechanisms in a geological storage formation are <u>geochemical</u> processes

- Aqueous solubility trapping (oil reservoirs & saline aquifers):
  - CO_2 is dissolved into water
  - Ions are formed

$$CO_2 + H_2O \rightarrow H^+ + HCO_3^{2-} \rightarrow H^+ + CO_3^{2-}$$

- Mineral formation (oil reservoirs & saline aquifers):
  - Carbonate ions react with dissolved metals: Ca^{2+} & Fe^{2+}
  - $CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$ (insoluble)
  - $CO_3^{2-} + Fe^{2+} \rightarrow FeCO_3$ (insoluble)

  } Geology dependent

- Miscibility of CO_2 with oil (oil reservoirs):
  - CO_2 is dissolved into oil

High pressures in geological storage formations favor these geochemical processes.

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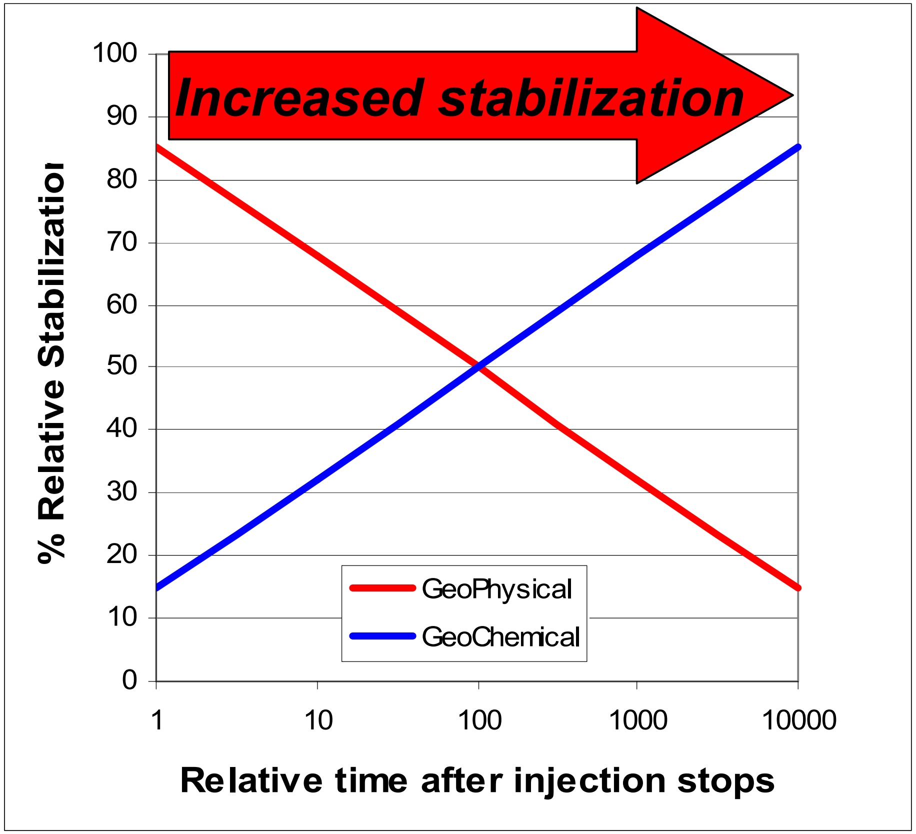
Relative time frame of CO_2 storage processes



Storage mechanisms:

- Geophysical:
  - Confining caprock.
  - Capillary forces in porous matrix.
- Geochemical:
  - Aqueous solubility trapping.
  - Mineral formation.
  - Miscibility of CO_2 with oil.

Storage security increases over time.

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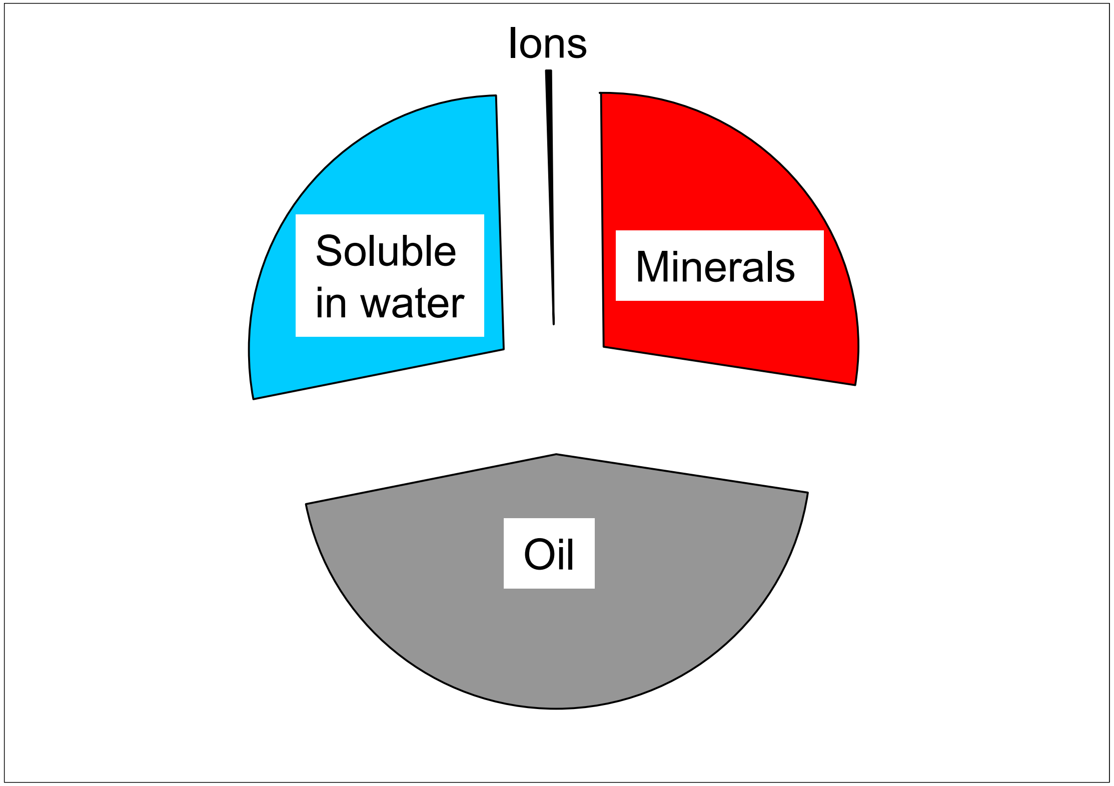
CO_2 distribution in Weyburn reservoir – 5000 years



Phase distribution of CO_2

- Mineral trapping – 27.5%
- Oil miscible – 44.2%
- Solubility trapping – 28.0%
  - CO_2 dissolved in water
- Ionic trapping – 0.3%
  - HCO_3^- & CO_3^{2-}

Based on geochemical modeling – IEA GHG Weyburn (PTRC)

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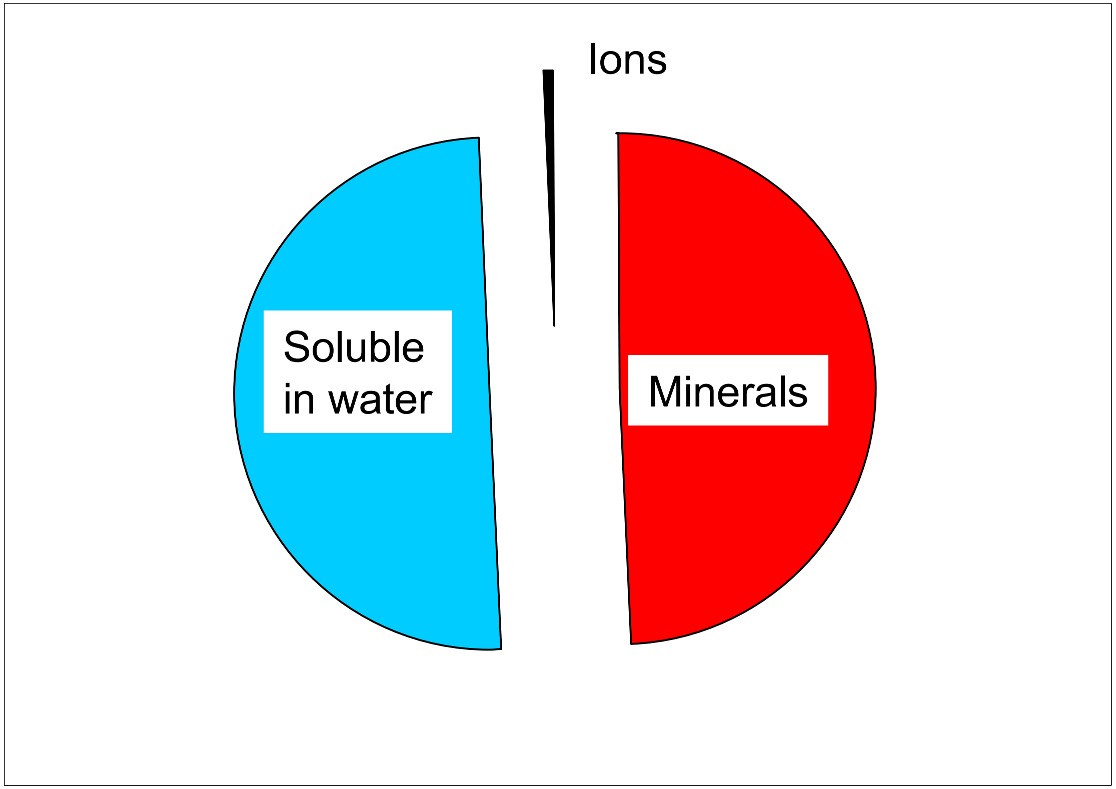
CO_2 distribution in saline aquifer – 5000 years

Ions



Phase distribution of CO_2

- Mineral trapping – 49.3%
- Solubility trapping – 50.2%
  - CO_2 dissolved in water
- Ionic trapping – 0.5%
  - HCO_3^- & CO_3^{2-}

Based on geochemical modeling – IEA GHG Weyburn (PTRC)

- Assumed no oil & proportionally adjusted percent distribution.

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Major "No, No's" in geological storage of CO_2

Do not:

- Plug the geological storage formation!
  - Carbonate scale formation.
  - Iron sulfide formation.
  - Gas hydrates.
- Over pressure the geological storage formation!
  - Fracture the bedrock:
    - Seeps to surface.
    - Fluid channeling & subsequent bypassing of oil (EOR).

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Commercial implementation of CO_2 storage

Initial sequestration sites will be CO_2 EOR projects:

- 50% of CO_2 must be recycled.
- At end of EOR (10-20 yrs), project must be switched to a storage site.

A lot remains to be learned about CO_2 storage in saline aquifers:

- Multiple saline aquifers must be evaluated to find a viable storage site.
  - In Germany, 126 saline aquifers identified. Only 26 suitable for CO_2 storage.
- Greatest technical uncertainty:
  - ***CO_2 storage capacity.***

Comparison of cost of CO_2 EOR to CO_2 storage in saline aquifers

Activities	Relative Cost	EOR	Saline Aquifer
Site location/Exploration	High	Previously completed	Required
Geological characterization	High	Previously completed	Required
Drilling wells	High	Previously completed	Required
Identifcation of leaky wells	Medium	Required	Not required
Plug leaky wells	Medium	Required	Not required
Oil chemistry	Low	Required	Not required
Saline aquifer chemisty	Medium	Not required	Required
Model/Optimize CO_2 injection	Medium	Required	Required
Modify oil production facilities	High	Required	Not required
Recapture & compress CO_2	High	Required	Not required
Monitoring program	Medium	Required	Required

Relative Cost Legend

High: > $5MM

Medium: $1MM to $5MM

Low: < $1MM

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Comparison of options for geological storage of CO_2

Characteristics	EOR	Saline Aquifers	Depleted Oil & Gas Reservoirs	Coal Beds
Technical Maturity	High	Learning	Learning	To date, one failure
Storage Capacity	Moderate	Very high (10-100 x EOR)	Unknown	Low
Leakage Risk	Very low	Low	Very low	High
Accessibility to CO_2 Source	Limited	Extensive	Limited	Very limited
Likelihood of Success	100%	High	100%	Very low
Economics	Oil production could offset some of cost	Gov't incentive required	Gov't incentive required	Gov't incentive required
Overall Risk	Very low	Low	Very low	High
Other Comments	Most EOR projects do not have sufficient demand for CO_2 for 1 coal fired plant (30 yrs)	Best bet for success	CO_2 capacity needs to be quantified	Significant technical uncertainty

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