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Fundamentals of CO_2 Storage in Geological Media

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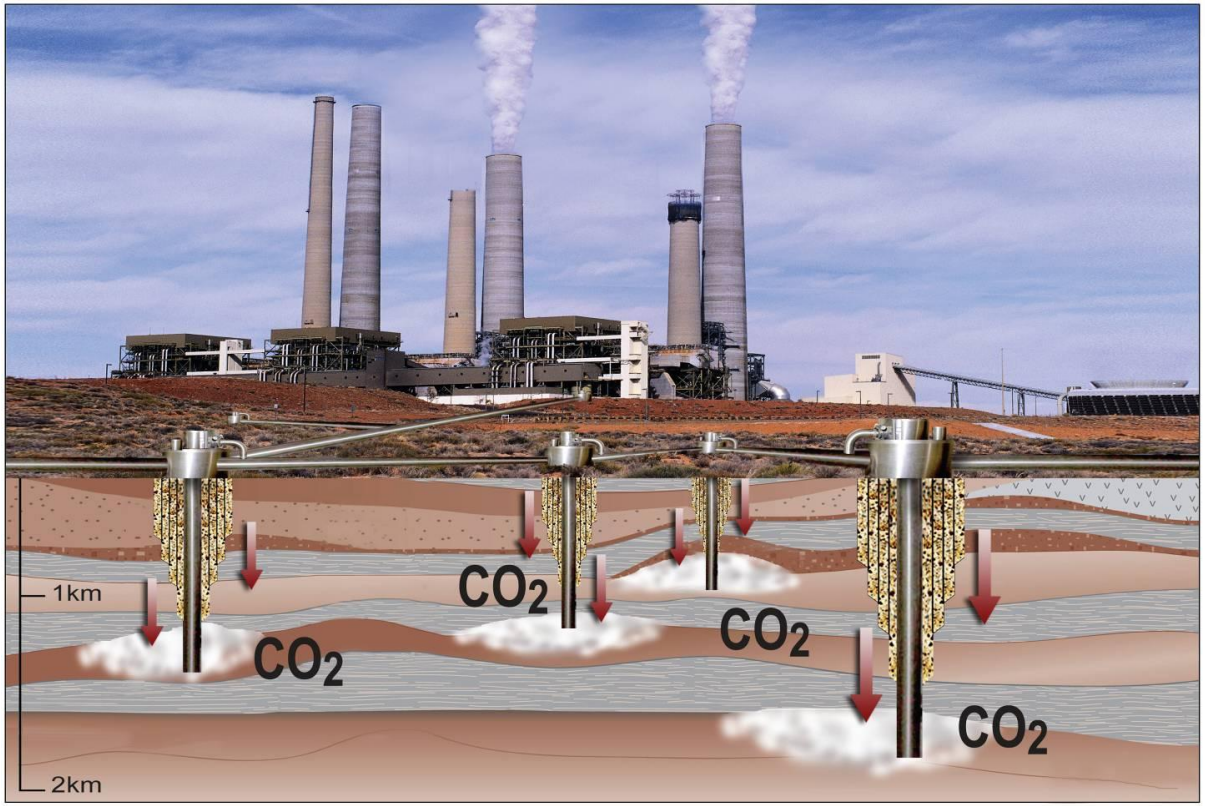
CO_2 Capture and Storage Chain



Capture → Compression → Pipeline Transport → Underground Injection & Storage

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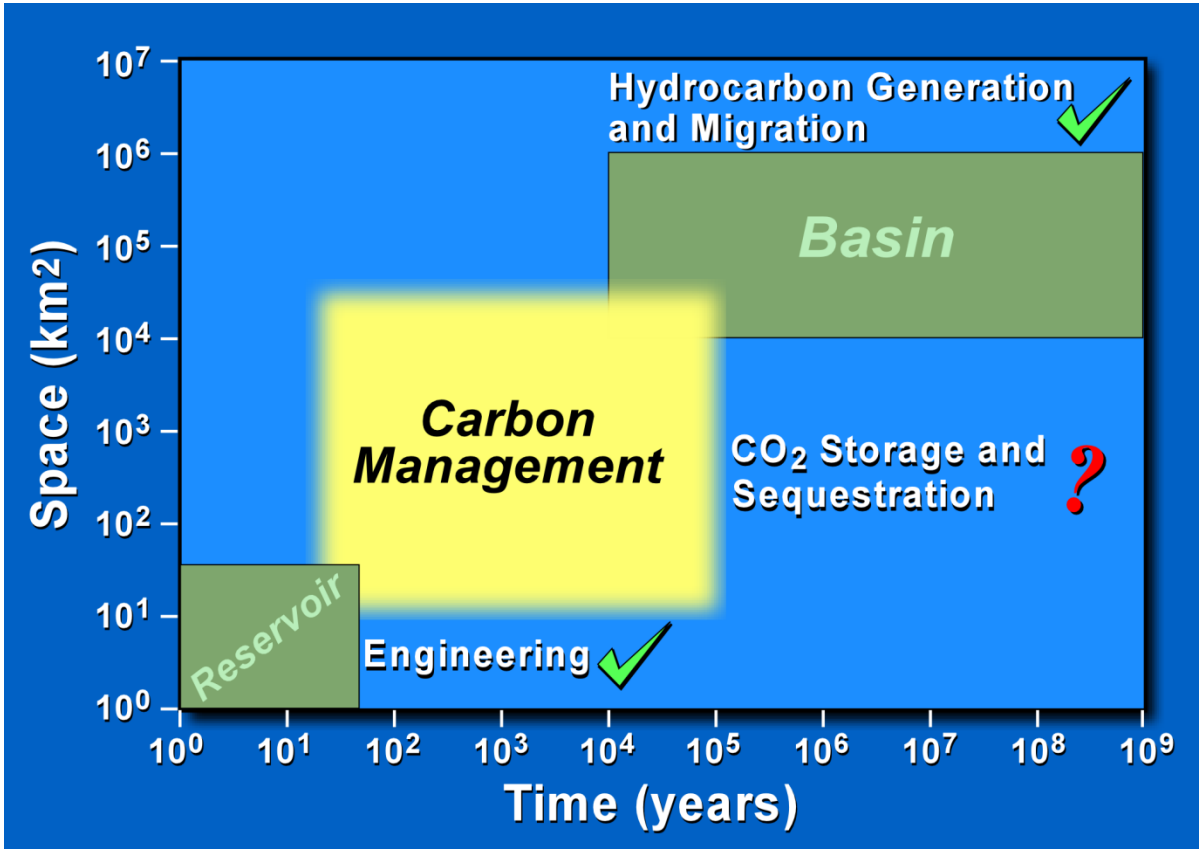
Process Scales for CO_2 Geological Storage



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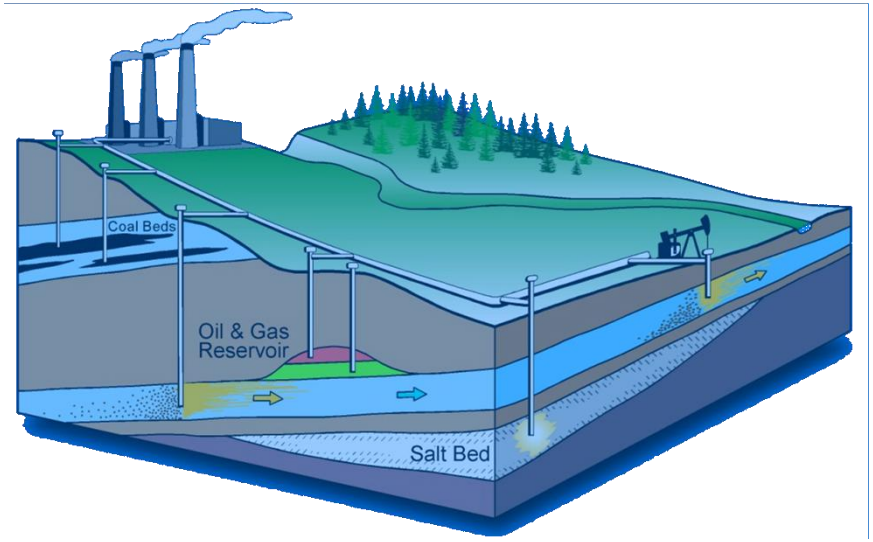
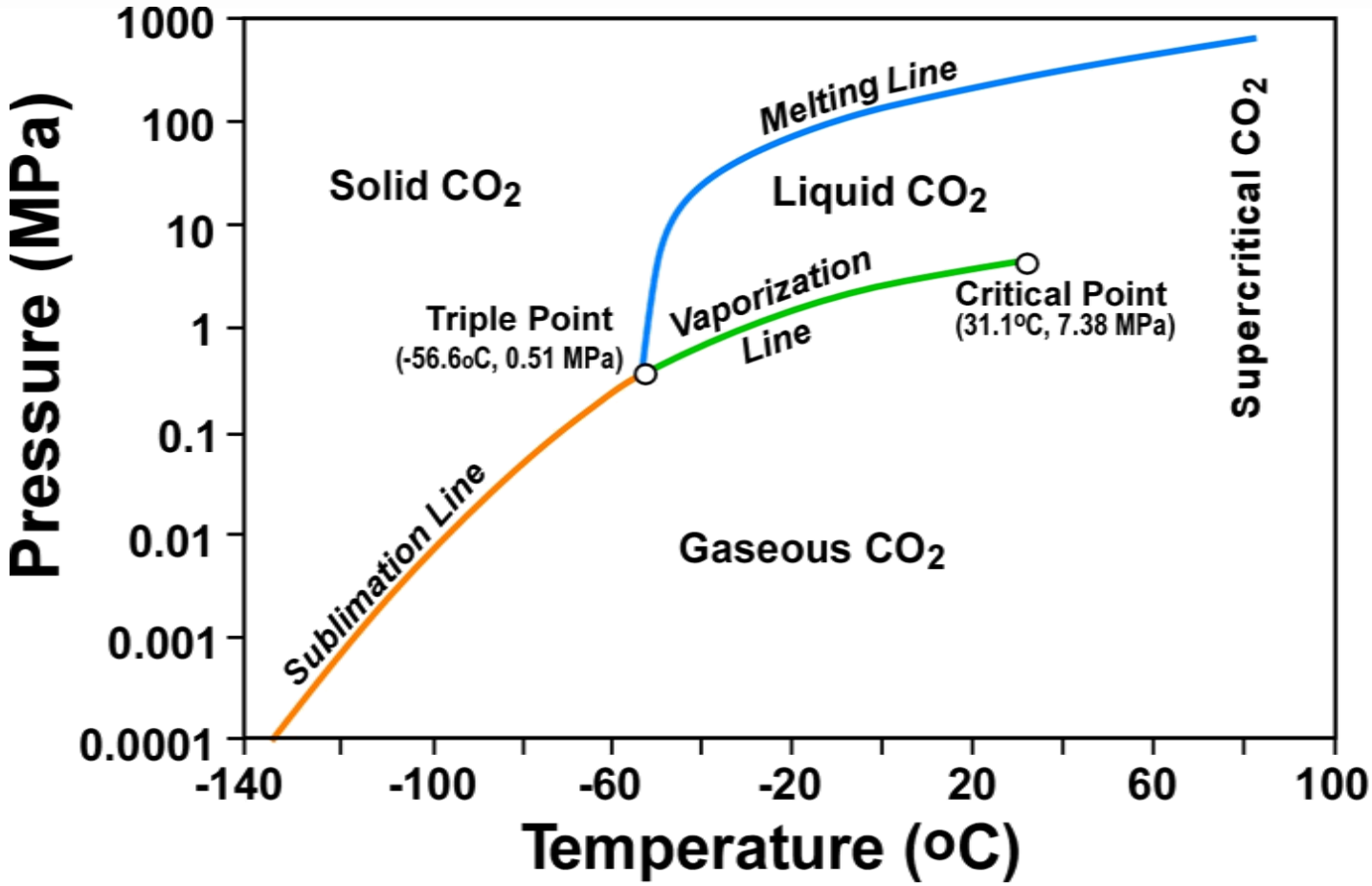
Relevant CO_2 Properties, CO_2 Trapping Mechanisms, Means and Media for CO_2 Geological Storage



Phase Diagram for Carbon Dioxide



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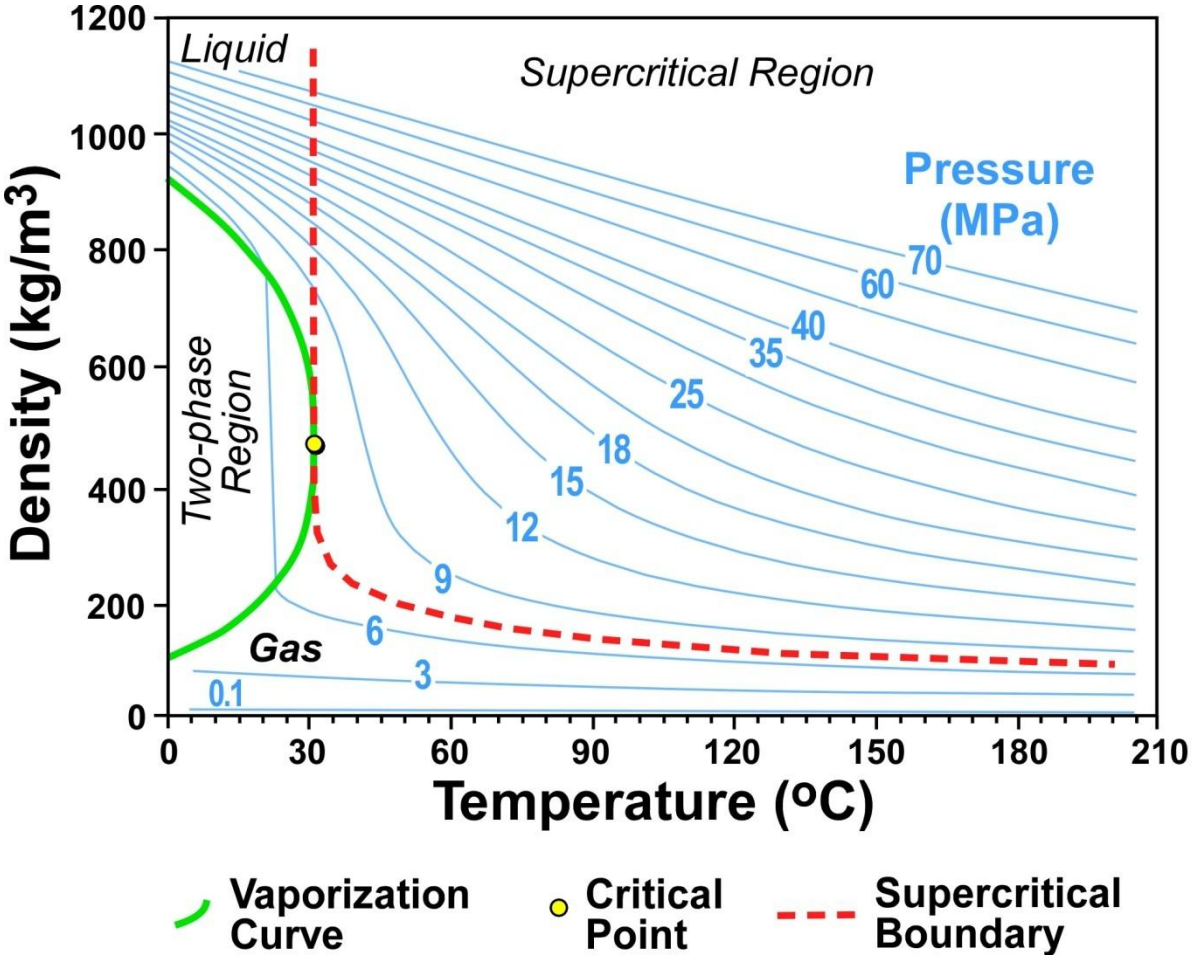
CO_2 Density for Pressure and Temperature Conditions in the Earth Crust



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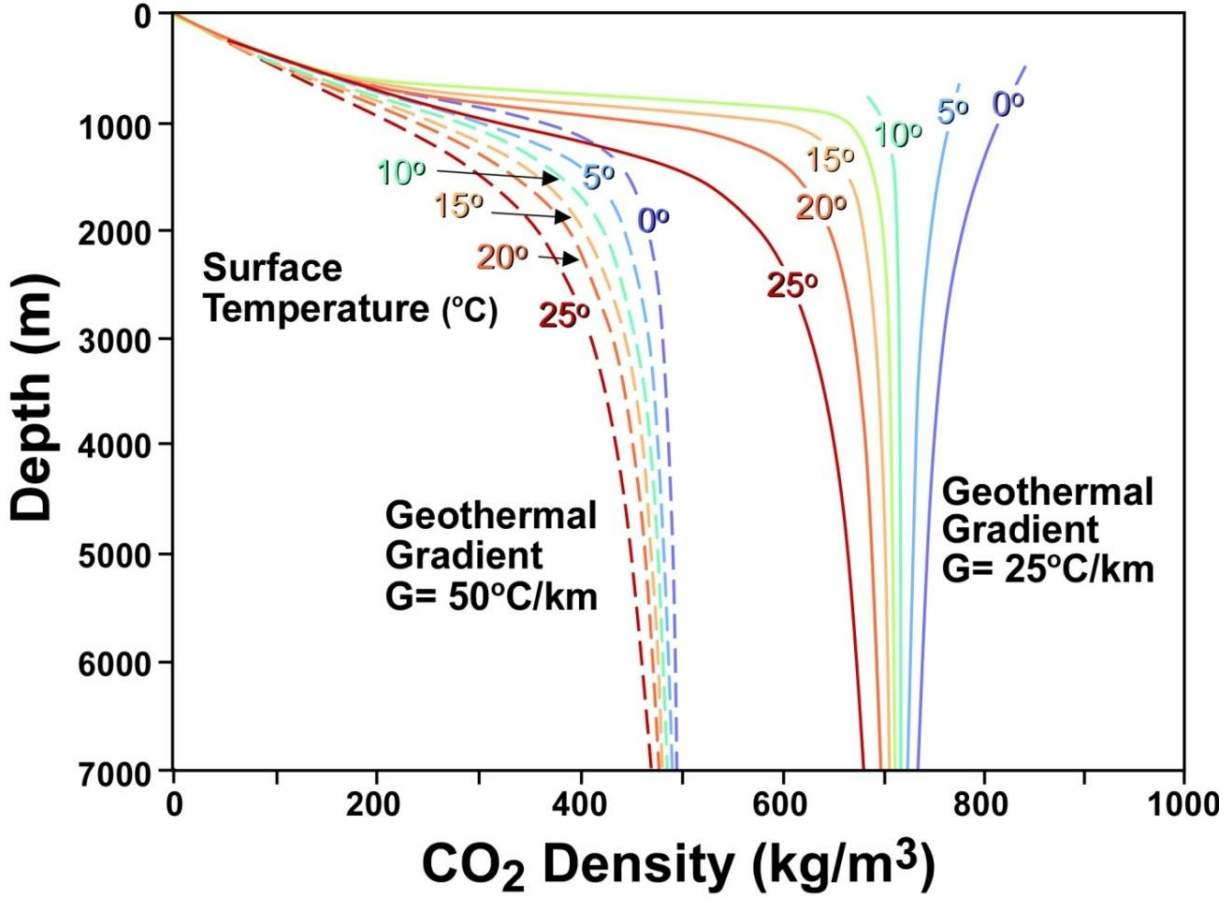
Variation of CO_2 Density with Depth and Geothermal Regime



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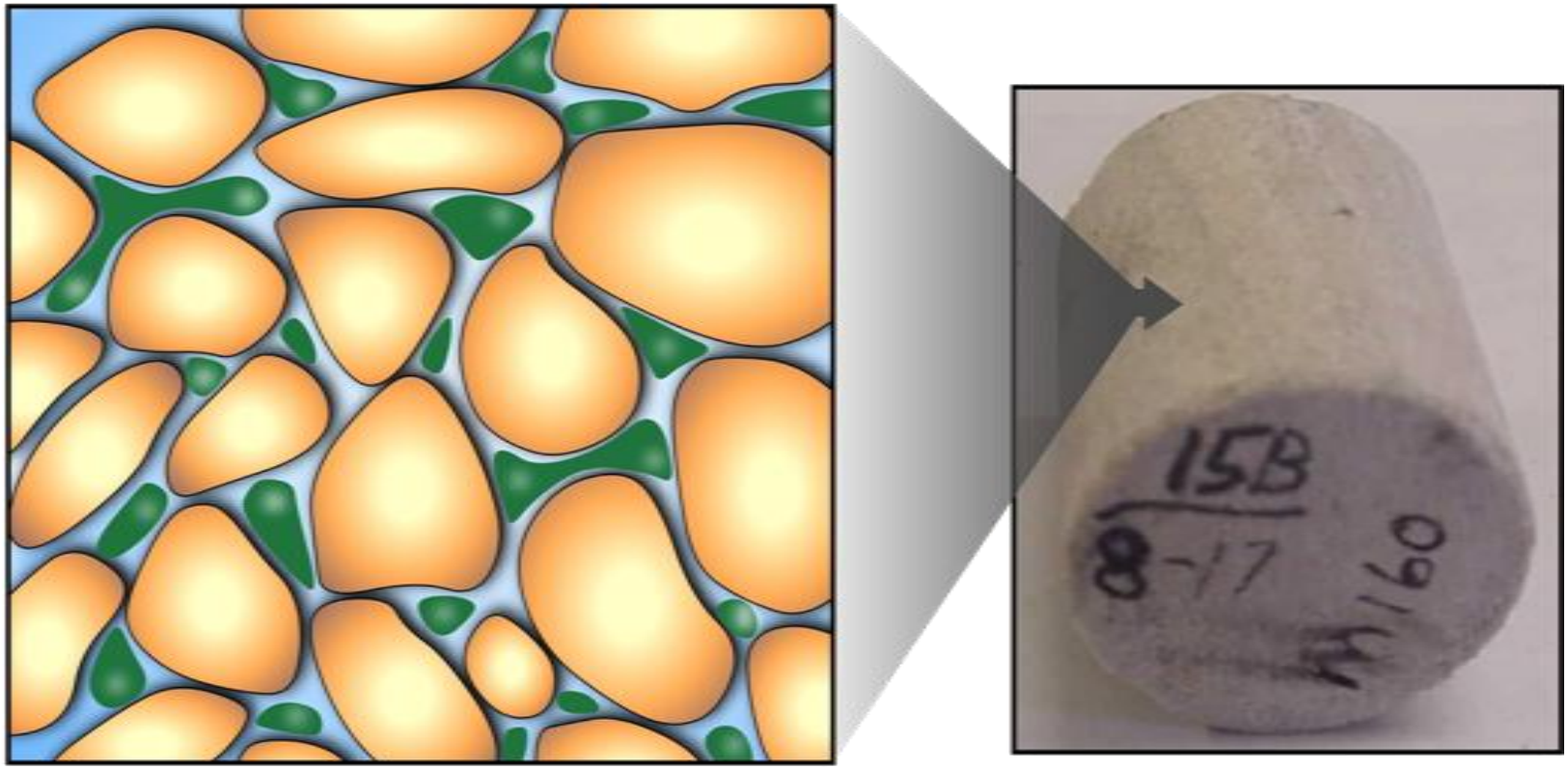
Trapping of CO_2 in the Pore Space at Irreducible Saturation



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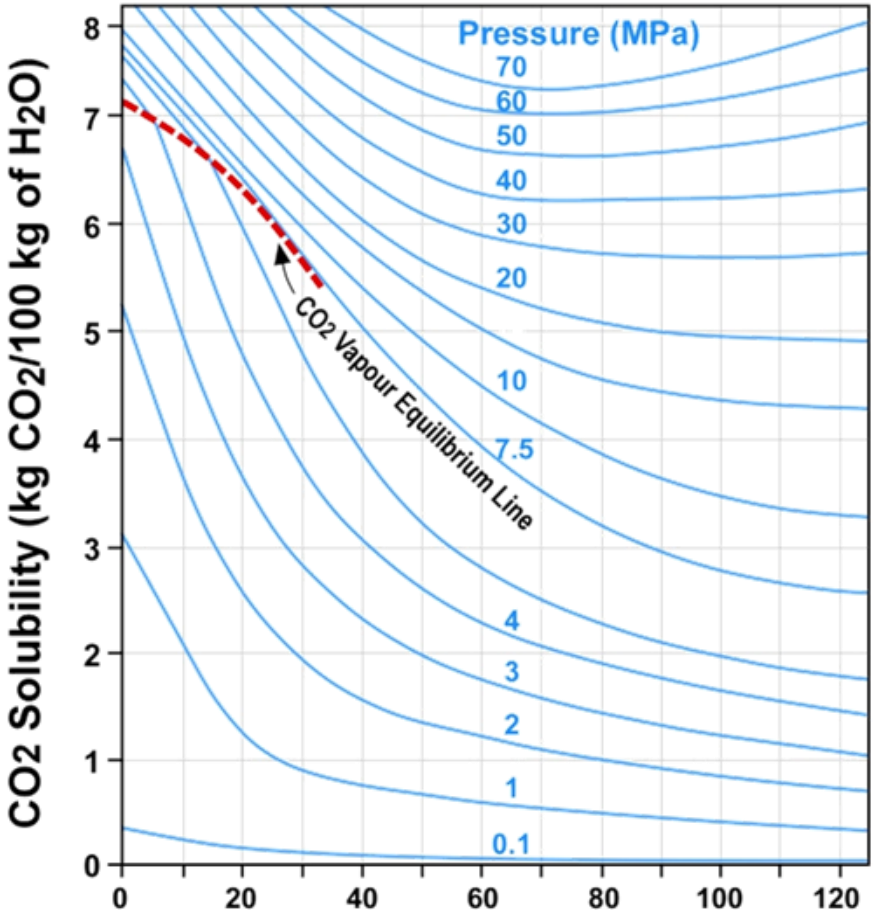
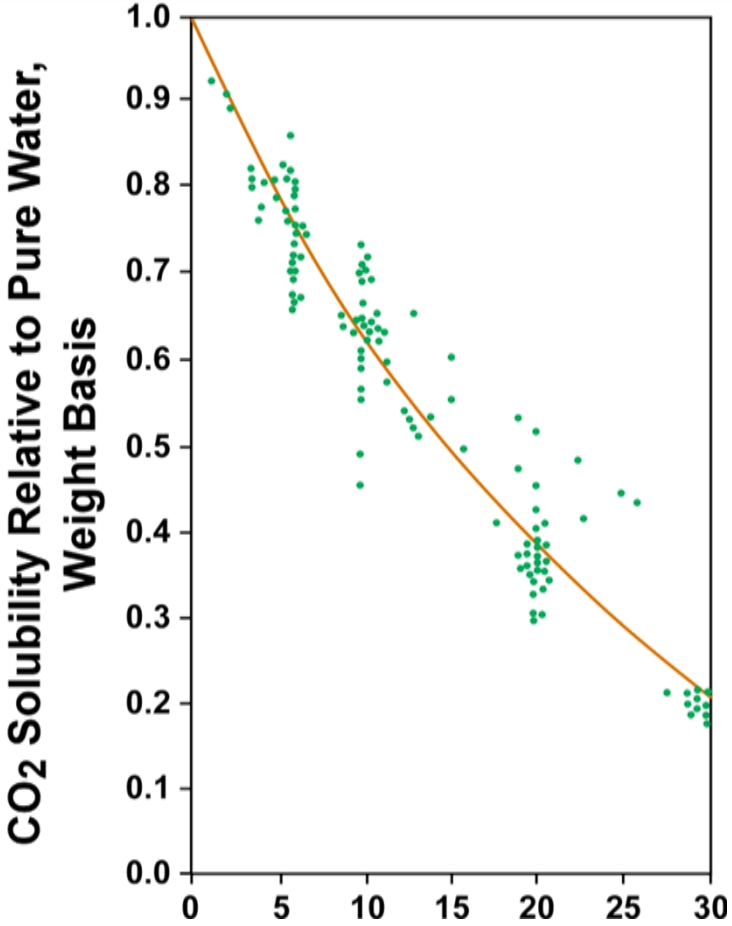
Carbon Dioxide Solubility in Water

In pure water



In brine



Sequence of Geochemical Reactions between CO_2 and Formation Water and Rocks

1. Solubility Trapping

$CO_{2(g)} \leftrightarrow CO_{2(aq)}$

$CO_{2(aq)} + H_2O \leftrightarrow H_2CO_{3(aq)}$

2. Ionic Trapping

$H_2CO_{3(aq)} \leftrightarrow HCO^-_{3(aq)} + H^+$

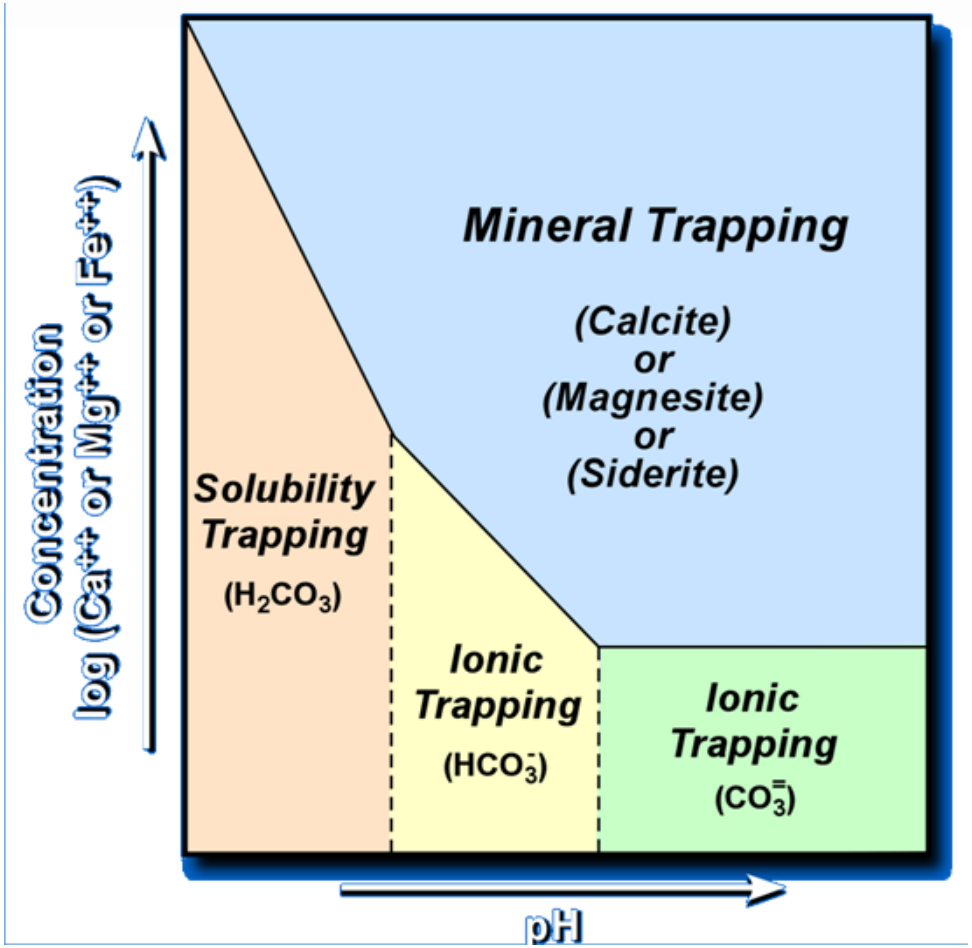
$HCO^-_{3(aq)} \leftrightarrow CO^{2-}_{3(aq)} + H^+$

3. Mineral Trapping

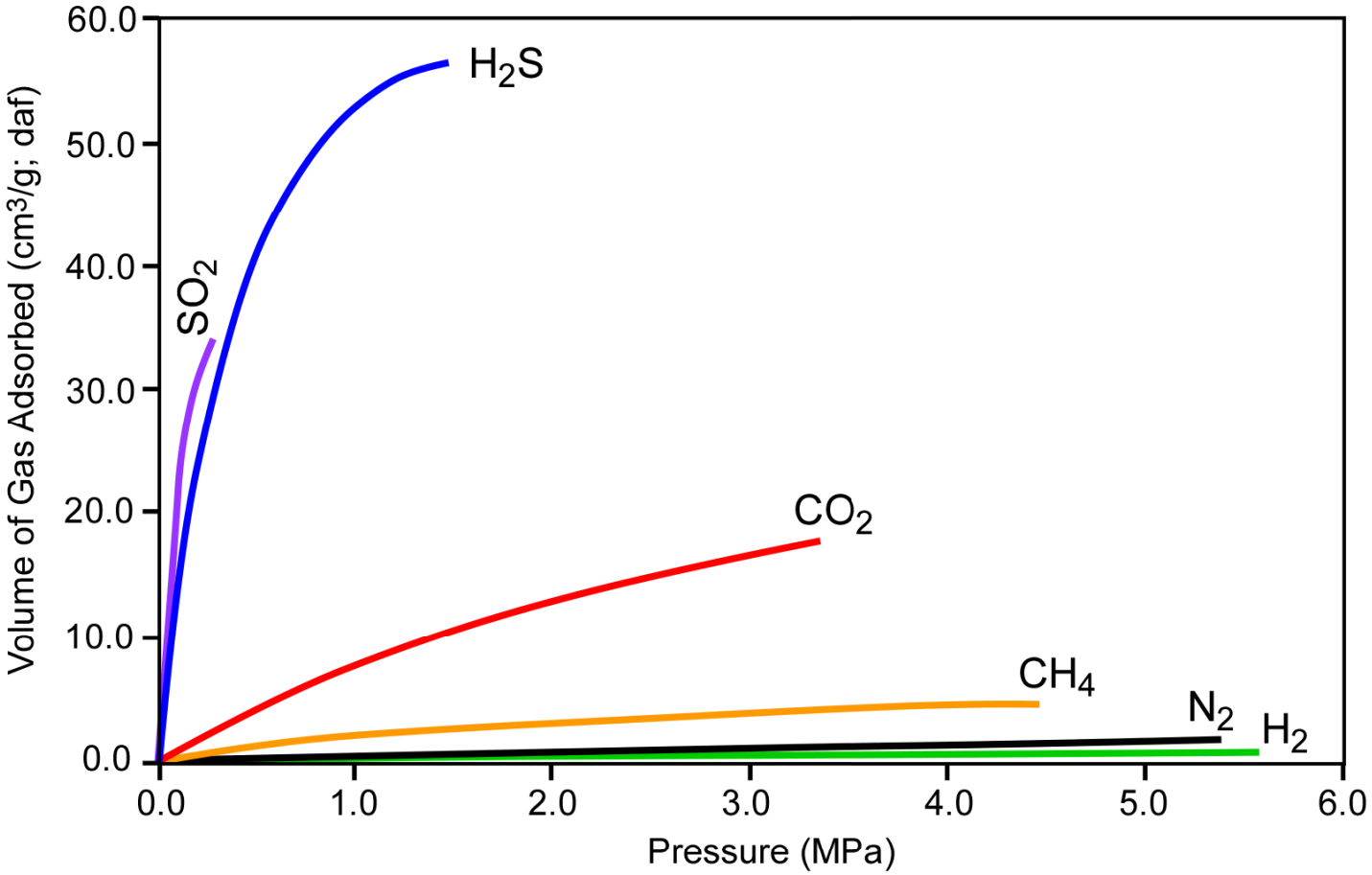
$CO^{2-}_{3(aq)} + Ca^{2+} \rightarrow CaCO_{3(s)}$

$HCO^-_{3(aq)} + Ca^{2+} \rightarrow CaCO_{3(s)} + H^+$

Aqueous Species Dominance Diagram



Adsorption of Various Gases on Coal



CO_2 Trapping Mechanisms

- **Physical Trapping** (in free phase)
  - In Static Systems (no flow)
    - In large man-made cavities
    - In the pore space in stratigraphic and structural traps
      - Mobile (continuous phase able to flow)
      - At irreducible saturation (immobile residual gas)
  - In Dynamic Systems (flow in long-range regional-scale systems

- **Chemical Trapping**
  - Adsorbed onto organic material in coals and shales
  - Dissolved in formation fluids (oil or water)
  - Precipitated as a carbonate mineral (irreversible process)

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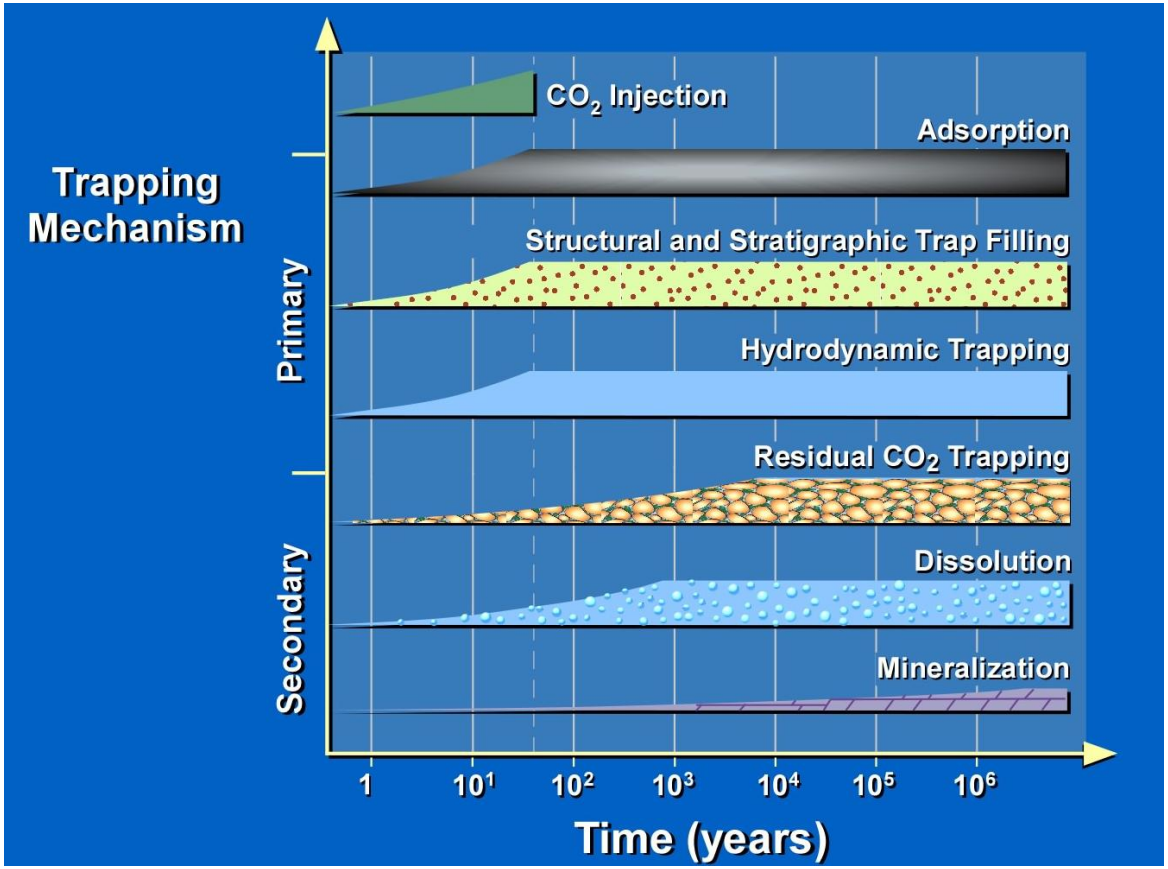
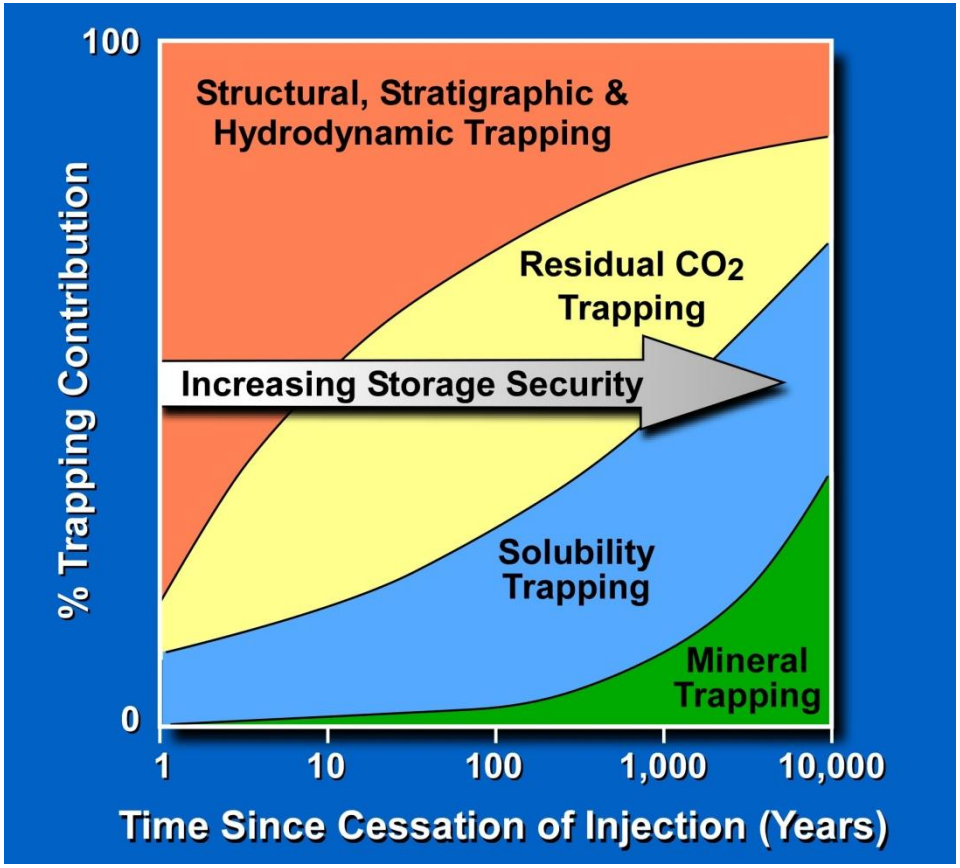
Temporal Scales of CO_2 Injection and Geological Storage Processes



From IPCC SRCCS, 2005

Relation between Time, Trapping Mechanisms and CO_2 Storage Security



From IPCC SRCCS, 2005

Required Characteristics of Geological Media Suitable for Storage of Fluids

- Capacity, to store the intended CO_2 volume
- Injectivity, to receive the CO_2 at the supply rate
- Containment, to avoid or minimize CO_2 leakage

Rocks Suitable for CO_2 Storage

- Igneous rocks
  - Rocks formed from cooling magma
    - Granite
    - Basalt
- Metamorphic Rocks
  - Rocks that have been subjected to high pressures and temperatures after they are formed
    - Schist
    - Gneiss
- ✓ Sedimentary rocks
  - Rocks formed from compaction and consolidation of rock fragments
    - Sandstone
    - Shale
  - Rocks formed from precipitation from solution
    - Limestone

Crystalline
Low porosity
Low permeability
Fractures

Granite

Crystalline
Low porosity
Low permeability
Fractures

Schist

High porosity
High permeability
Few fractures

Sandstone

Geological Media Suitable for CO_2 Storage

- Porous and permeable rocks (sandstone and carbonate) overlain by tight rocks (shales and evaporitic beds):
  - Oil and gas reservoirs
  - Deep saline aquifers
- Coal beds
- Salt caverns

⇨ All are geological media found ONLY in sedimentary basins

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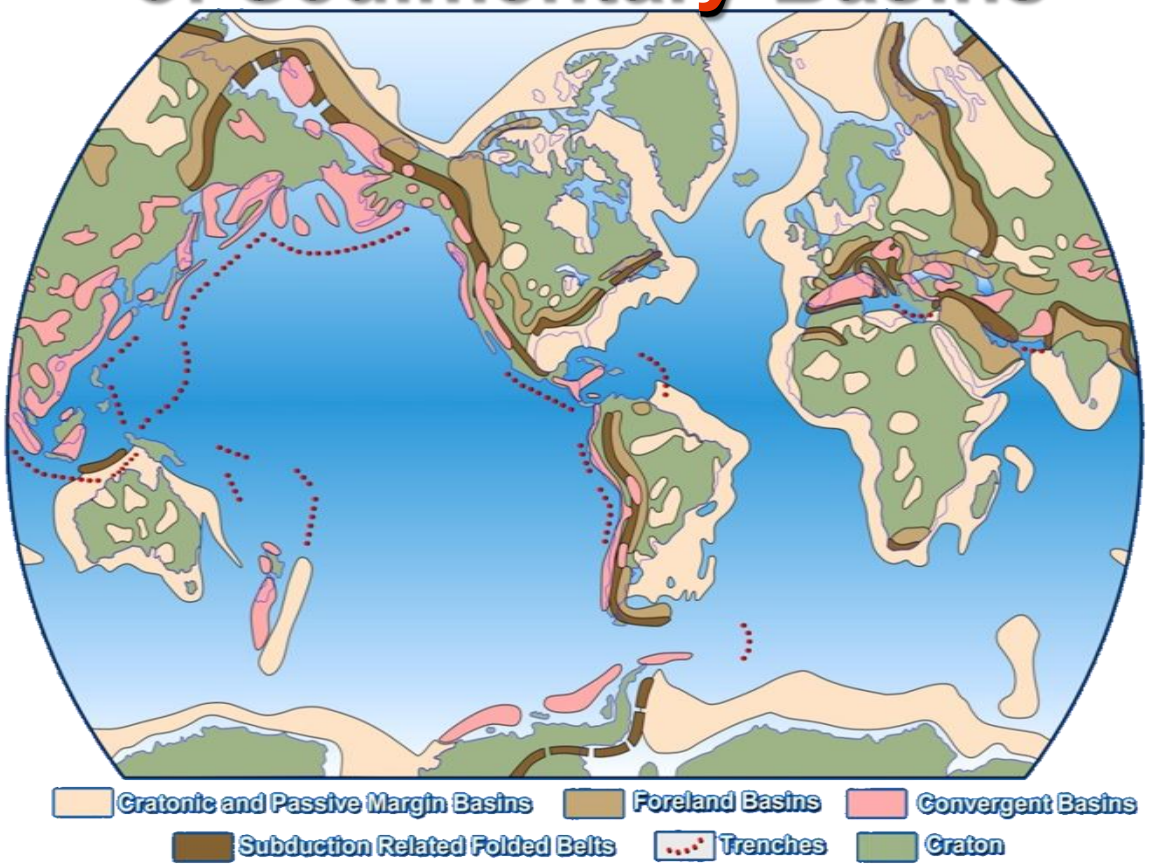
Types and World Distribution of Sedimentary Basins



(based on St. John et al., 1984)

Means for CO_2 Geological Storage

As a byproduct in energy production operations

- In oil reservoirs in enhanced hydrocarbon recovery
- In coal beds in enhanced coalbed methane recovery

In disposal operations

- In depleted oil and gas reservoirs
- In deep saline aquifers
- In salt caverns (mainly as a buffer in CO_2 collection and distribution systems)

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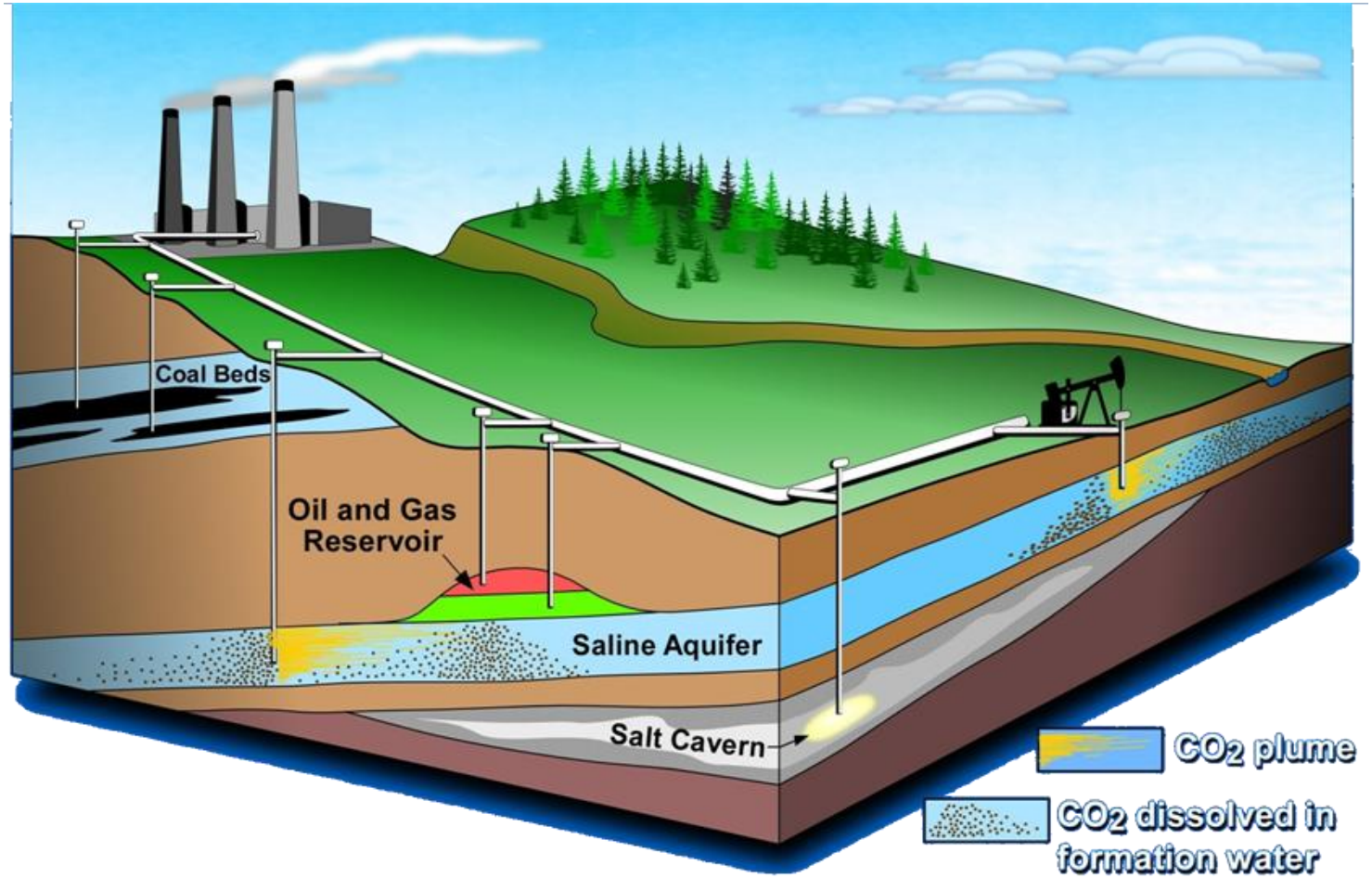
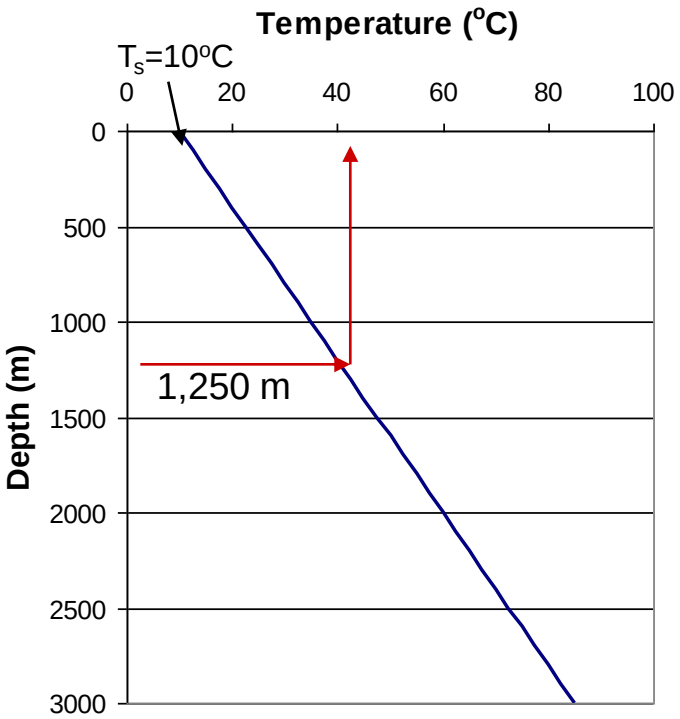
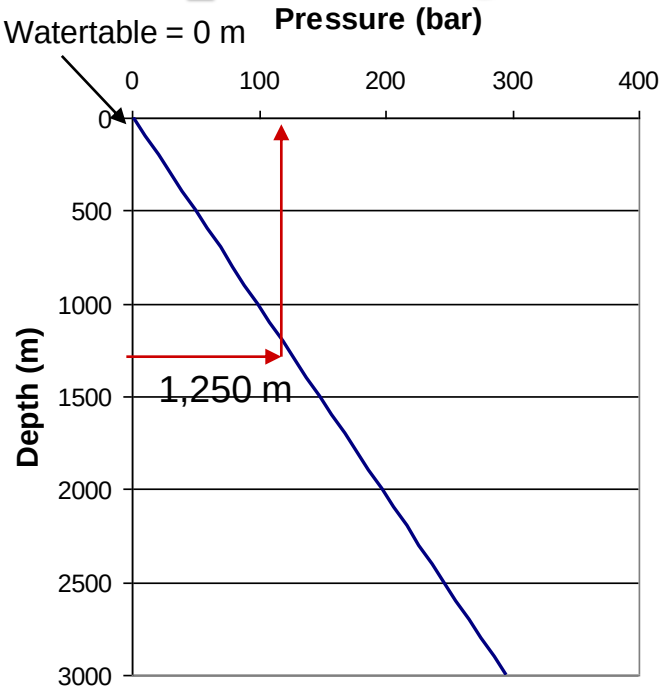
Means of CO_2 Geological Storage



Example of Subsurface Temperature and Pressure for CO_2 Storage



T = 10°C + 25°C/1,000 m x 1,250 m
= 41.25°C



p= 10^5 Pa + 1,000 kg/m^3 x 9.81 m/s^2*1,250 m
= 12.36 MPa (123.6 bar)

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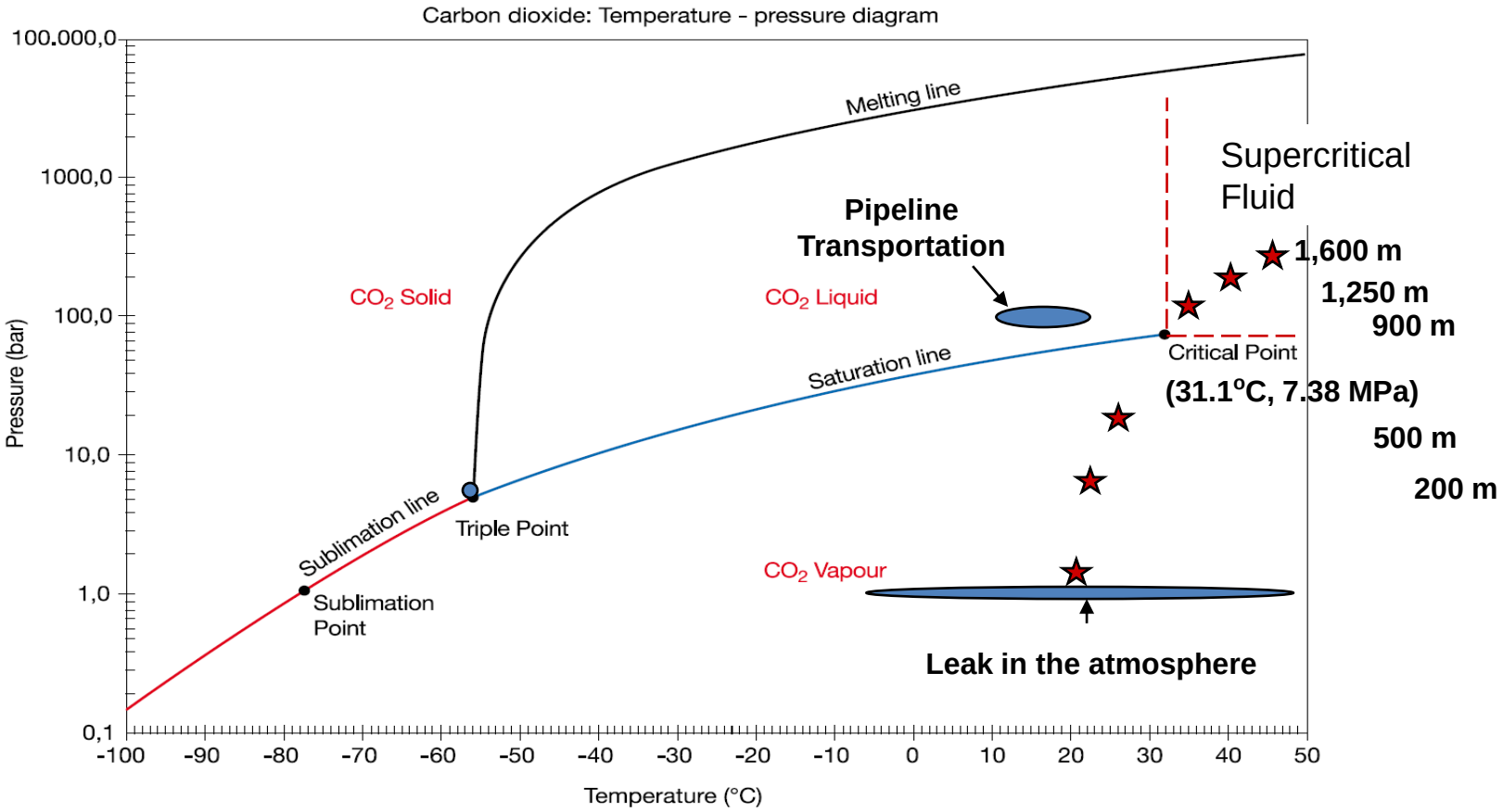
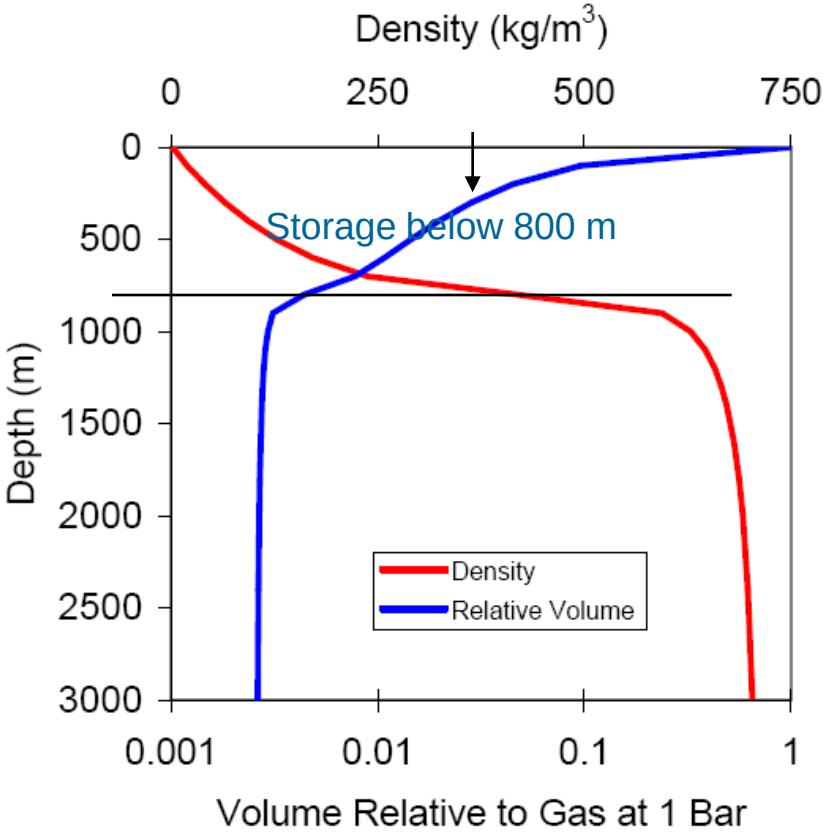
CO_2 Phases in a Transportation and Storage System



Storage Depth is Defined by CO_2 Density

- Storage below 800 m
  - Supercritical CO_2
  - Dense phase CO_2 (500 to 800 kg/m^3); Water is1.3 to 2 times denser (heavier)
  - Low viscosity (0.04 to 0.06 MPa·s); Water is 10-20 times more viscous
- Rule-of-thumb
  - Depends on P and T profile
  - Will vary from site to site
    - Watertable depth
    - Mean annual surface temperature and geothermal gradient



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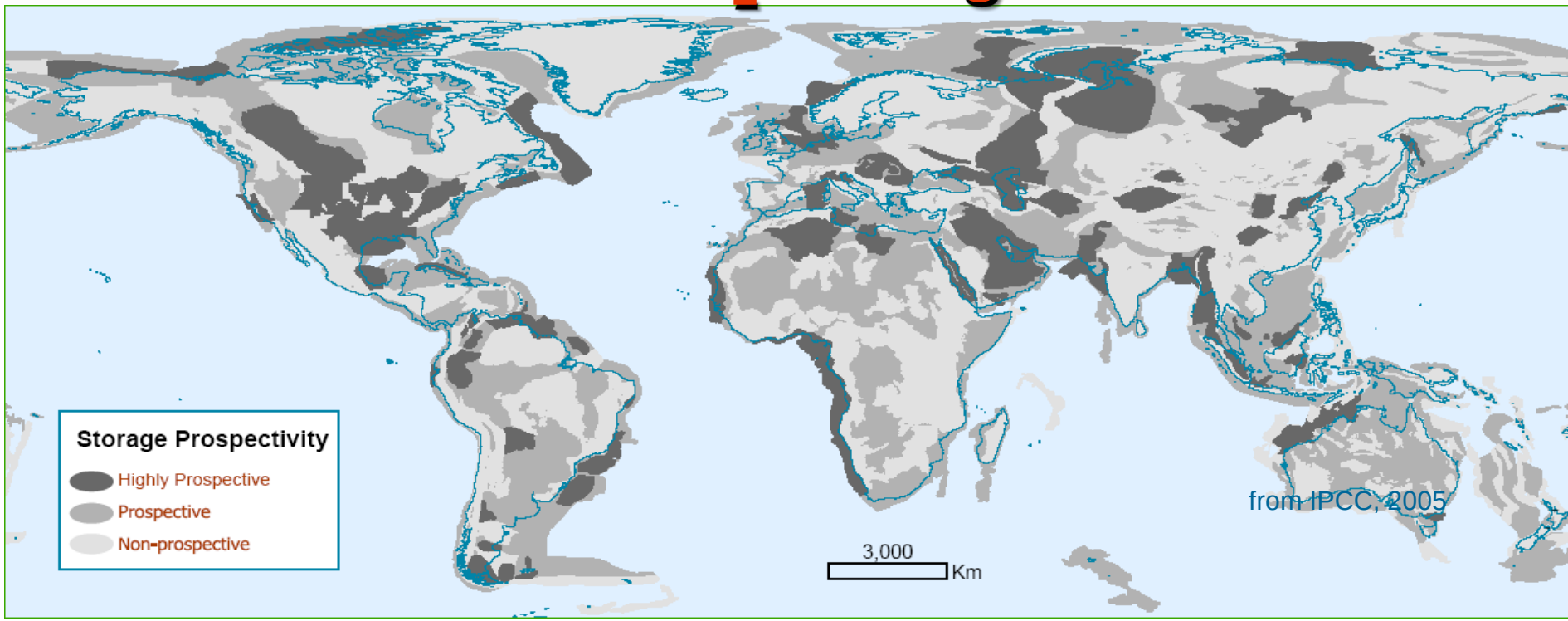
Prospectivity of Sedimentary Basins for CO_2 Storage



- Three primary conditions
  - Sedimentary rocks with storage reservoirs and seals
  - Pressure and temperature greater than critical values (31°C, 78.3 bars)
  - Not a source of drinking water

Controversial Storage Media

Among the media proposed for CO_2 storage:

1. Storage in coal beds:
   - Has never been successfully demonstrated
   - Uneconomic coals have not been defined

2. Storage in shales rich in organic material:
   - Based on the same principles as storage in coal beds
   - Has not been attempted and demonstrated
   - Will require fracturing the shale, which constitute the caprock for hydrocarbon reservoirs and deep saline aquifers

3. Storage in basalts (based on rapid geochemical reactions)
   - Very controversial because of basalts' high porosity and permeability
   - A test is attempted in western Washington state

Concluding Remarks

- CO_2 can be trapped in free phase, mobile and/or immobile, in solution in formation water or oil, adsorbed onto coal or organic-rich shales, and as a mineral precipitate in the pore space or in basalts
- CO_2 can be stored in oil and gas reservoirs, deep saline aquifers, uneconomic/unmineable coal beds, salt caverns, and possibly in organic-rich shale beds and basalt flows
- Various trapping mechanisms operate on different temporal time scales that need to be taken into account

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