Deep Saline Formations: The Largest Potential Volumes for Geological Storage of CO_2

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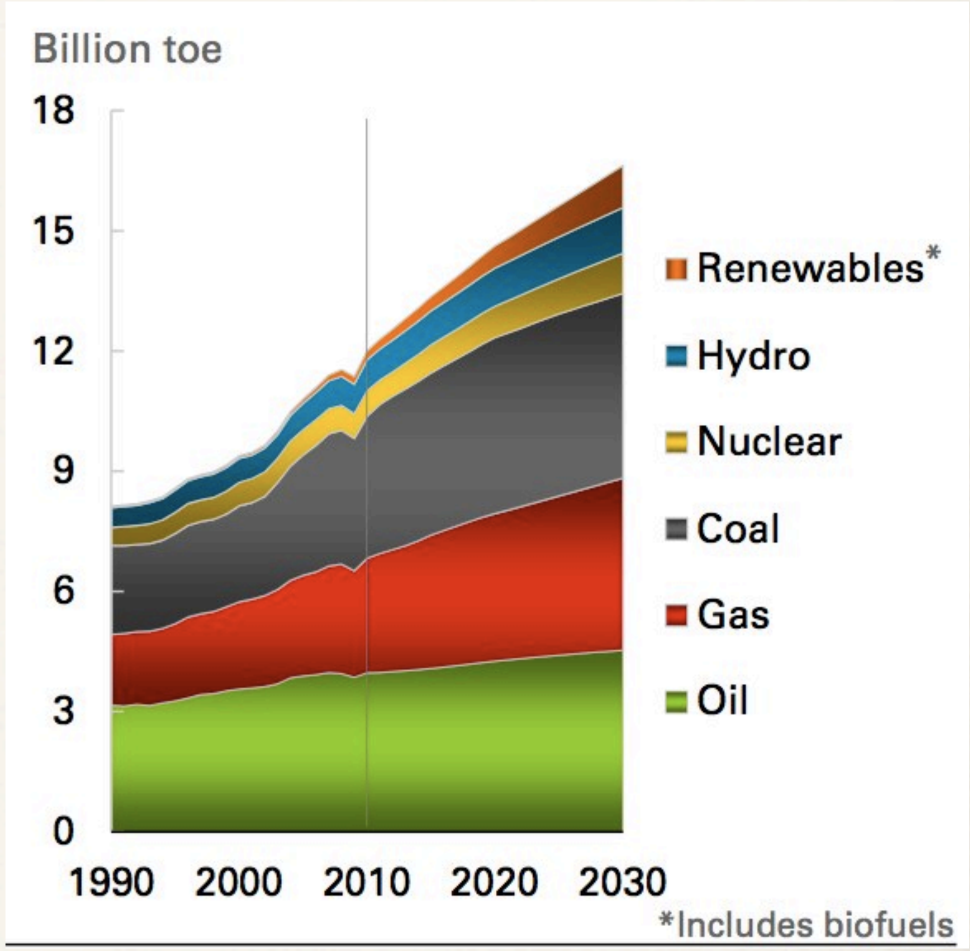
Energy Source for 21st Century: Fossil Fuels

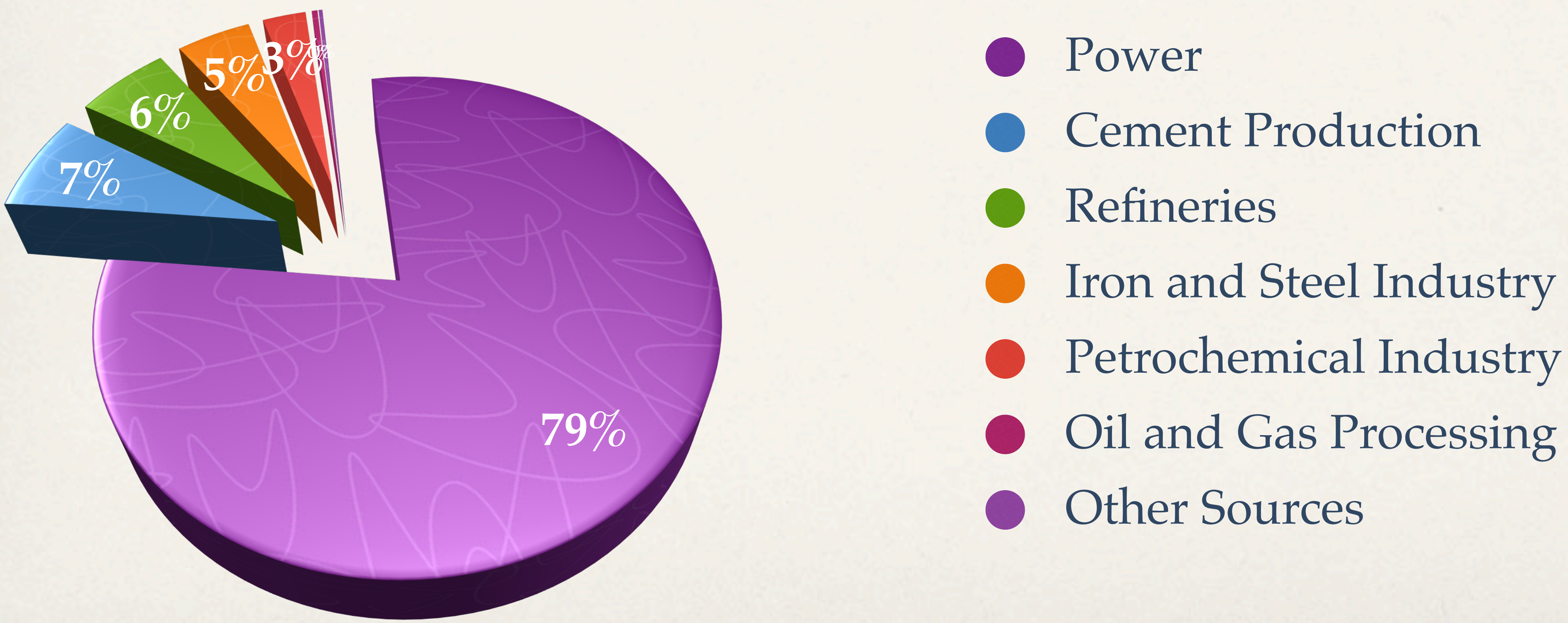
- Fossil fuels currently satisfy 85% of global energy demand.
- According to European Commission forecast, the renewable energy share of total EU consumption was to increase from 4.6% in 1990 to 8-9% in 2010-2015.
- This means that fossil fuel would still have to provide about 70-80% of the rising total energy consumption.



- The remainder to be provided by nuclear energy.

Fossil Fuels: Main Source of Energy and Main Source of Emissions

- Emissions of CO_2 from fossil fuel use in the year 2000 totalled about 23.5 $GtCO_2$ per year.
- Nearly 60% of this emissions (13,466 $GtCO_2$ per year) was attributed to large stationary emission sources.



Worldwide Large Stationary CO_2 Sources with Emissions of More Than 0.1 $MtCO_2$ per year (IPCC, 2005)

CCS as a Mitigation Option

- In the absence of mitigation, the resulting emissions will further increase in atmospheric CO_2, causing further warming and inducing many changes in global climate.

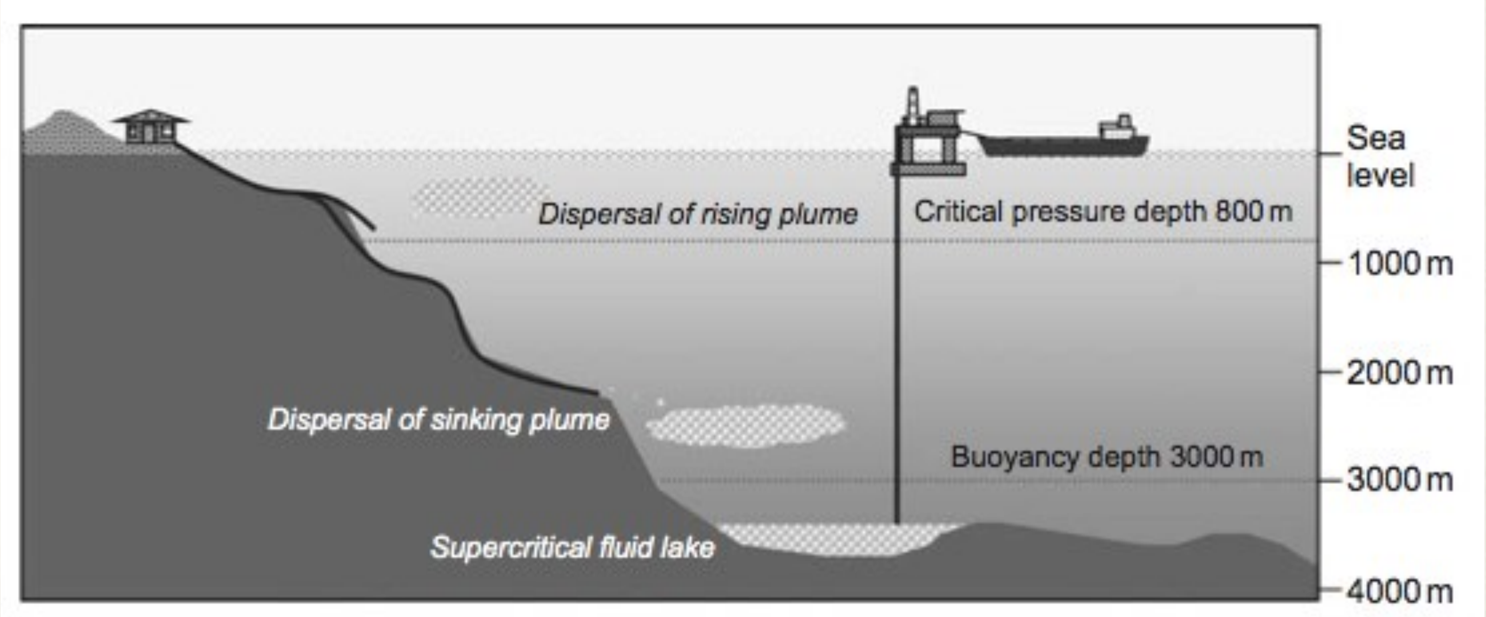
- Mitigation options include
  - energy efficiency improvements,
  - the switch to less carbon-intensive fuels,
  - nuclear power,
  - renewable energy sources,
  - enhancement of biological sinks,
  - reduction of non-CO2 greenhouse gas emissions,
  - and Carbon Capture and Storage (CCS)

CCS Technology

- CCS is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere.

- There are four main storage methods:

1. **Ocean storage:** Direct release into the ocean water column or onto the deep seafloor.



Rackley, 2010

CCS Technology

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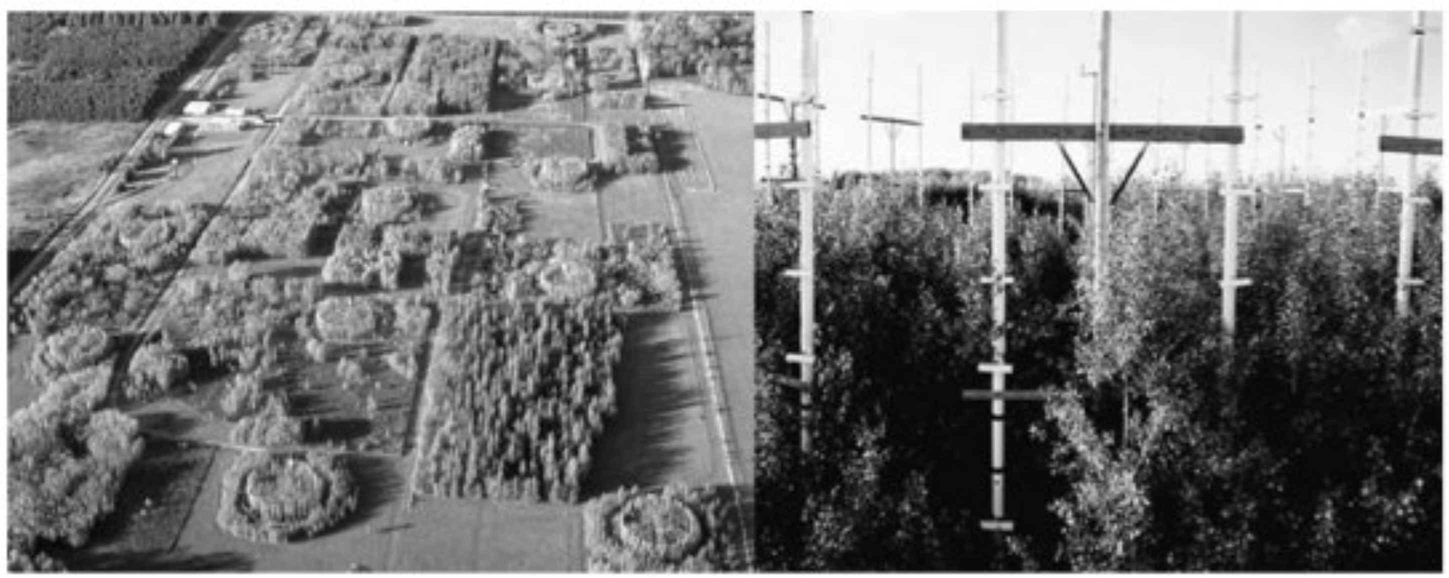
2. **Storage in terrestrial ecosystems**



Aspen FACE experimental configuration (Courtesy; Michigan Technological University. Photo Credit David F. Karnosky.)

CCS Technology

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3. **Storage by mineral carbonation:** industrial fixation of CO_2 into inorganic carbonates.

$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O$$

CCS Technology

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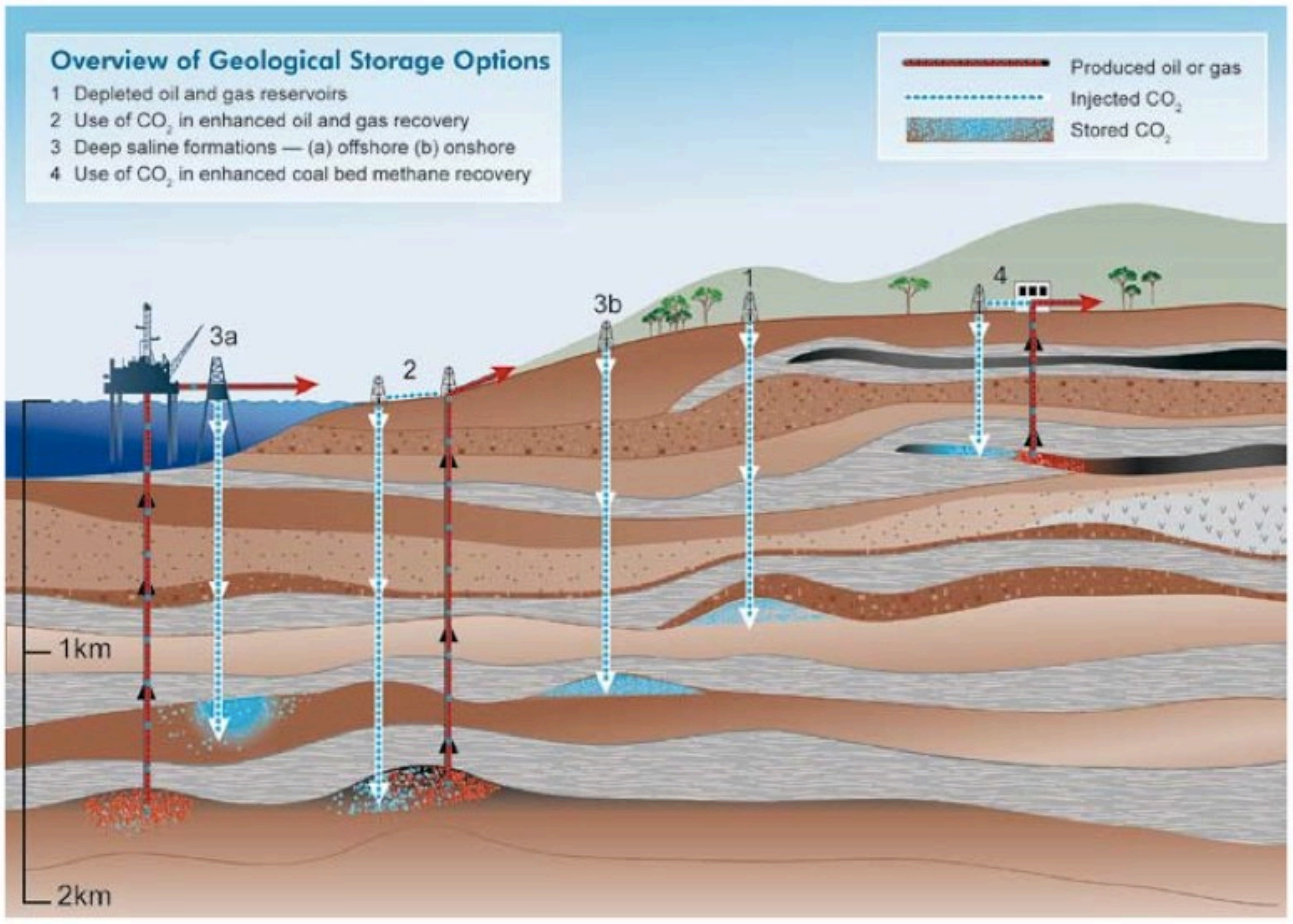
- There are four main storage methods:

4. Geological Storage

CO_2 Production & Capture → CO_2 Compression → Transport → Injection → Underground Storage

Geological Storage



Overview of geological storage options (Courtesy; CO2CRC)

Global CO_2 Geologic Storage Capacity

- According to IPCC 2005
- Depleted oil and gas reservoirs: 675 - 900 $GtCO_2$
- Unminable coal formations: 3 - 200 $GtCO_2$
- <u>Deep saline formations</u>: at least 1000 $GtCO_2$

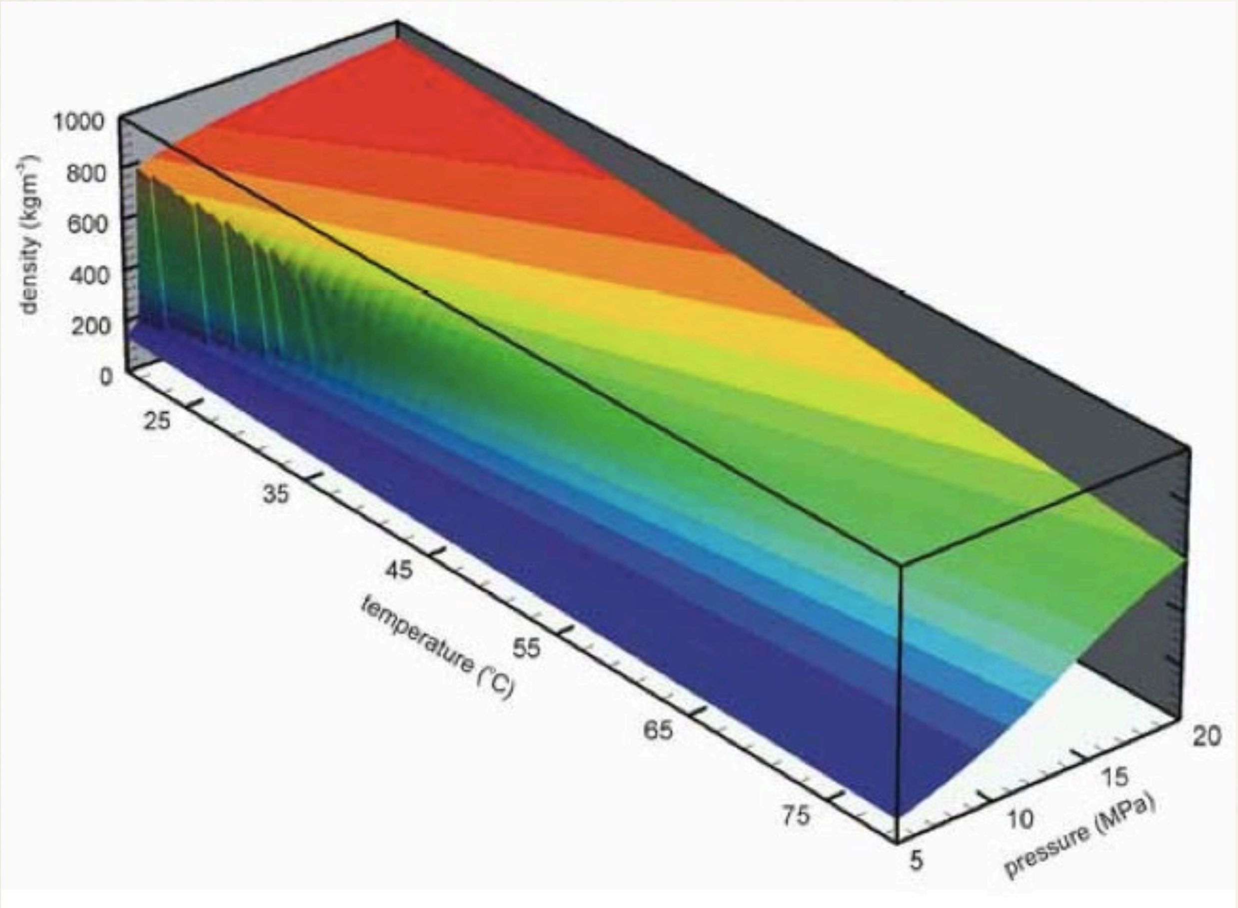
Pros and Cons of Saline Aquifers

- **Disadvantages**
- Increased site selection and proving requirements due to a relative lack of data for geological characterization.
- Lack of established methods to establish site suitability, long-term integrity, and storage capacity
- Lack of economic boost from enhanced oil or gas recovery
- Storage capacity limited by water compressibility and aquifer volume.

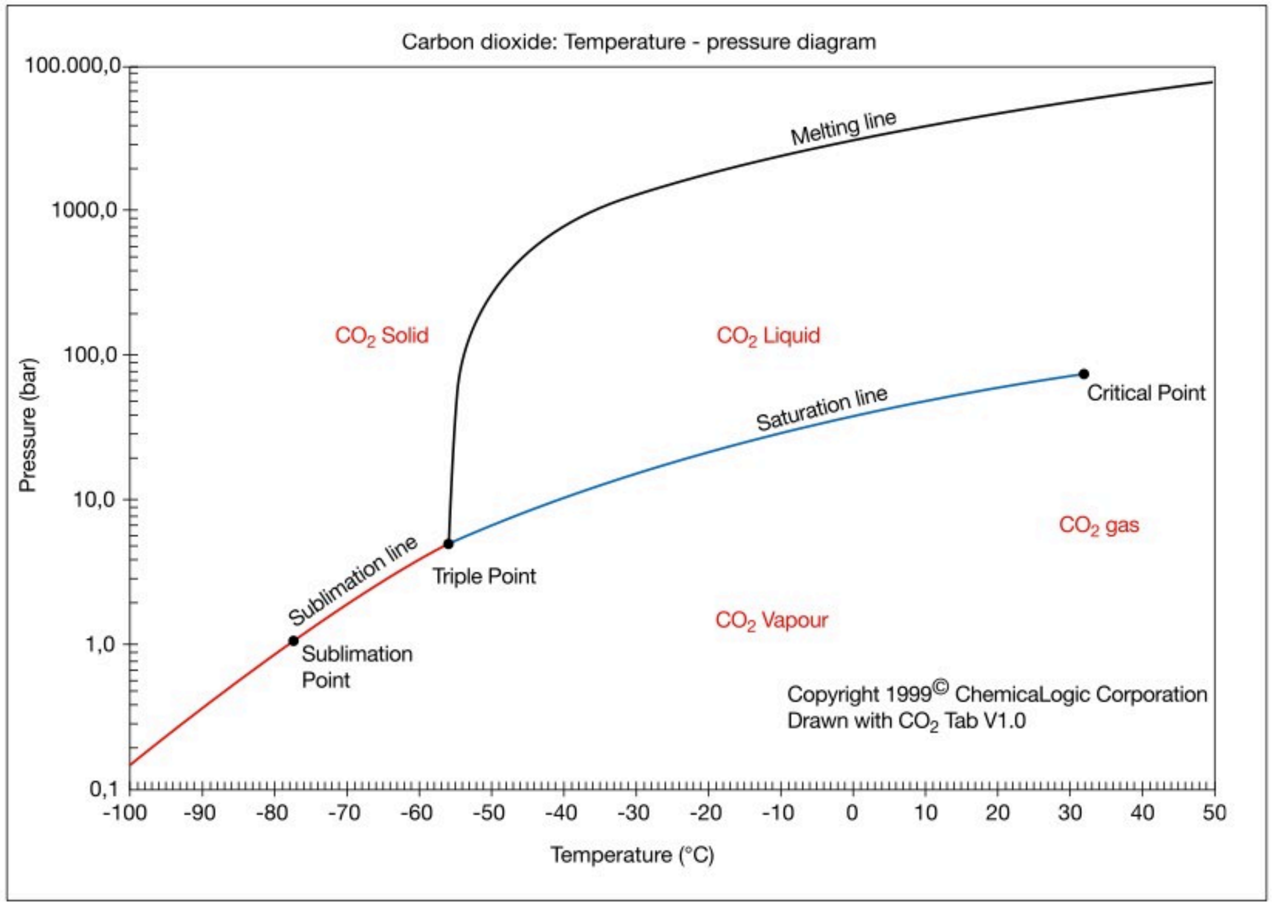
Pros and Cons of Saline Aquifers

- **Advantages**
- More widespread and therefore more accessible to capture sites, reducing or eliminating transportation costs.
- Typically fewer well penetrations, reducing the risk of leak paths.

CO_2 Properties

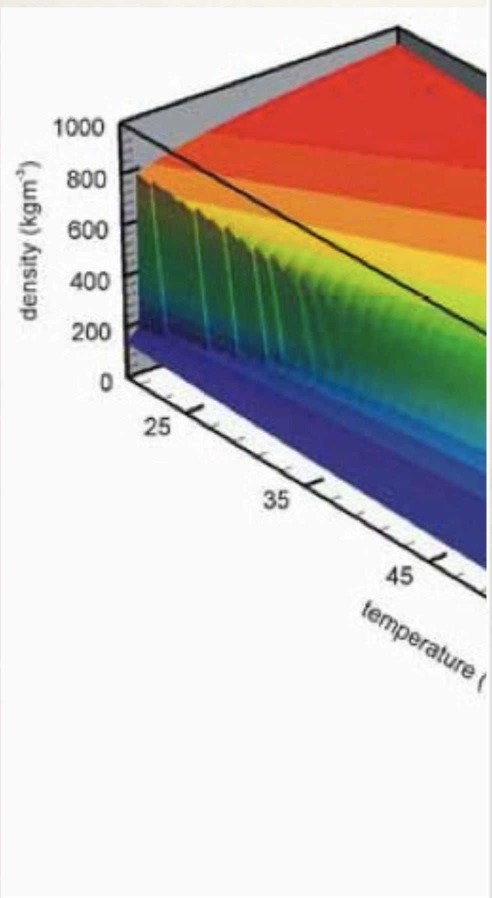


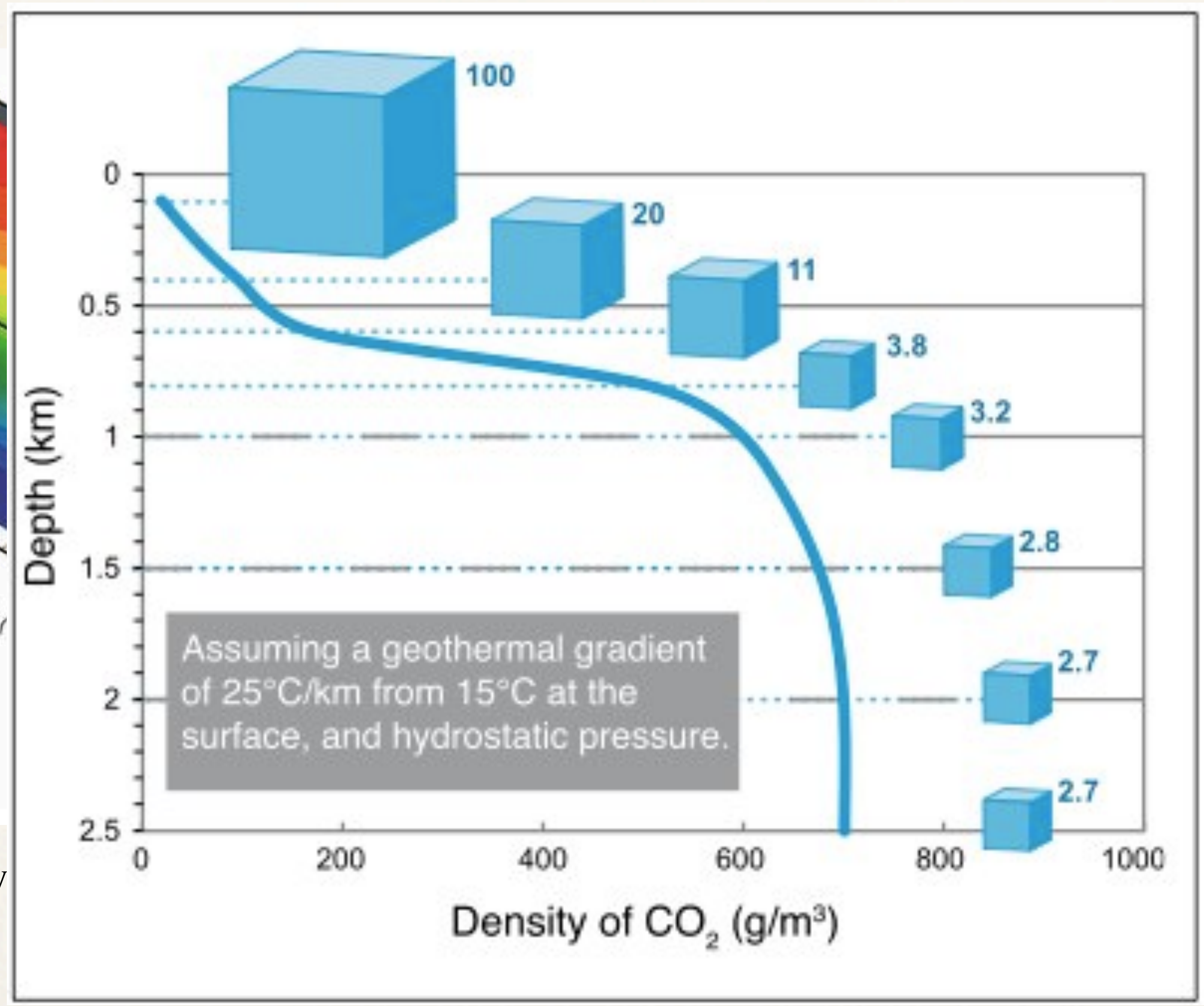
Variation of CO_2 density (Chadwick et al., 2008)

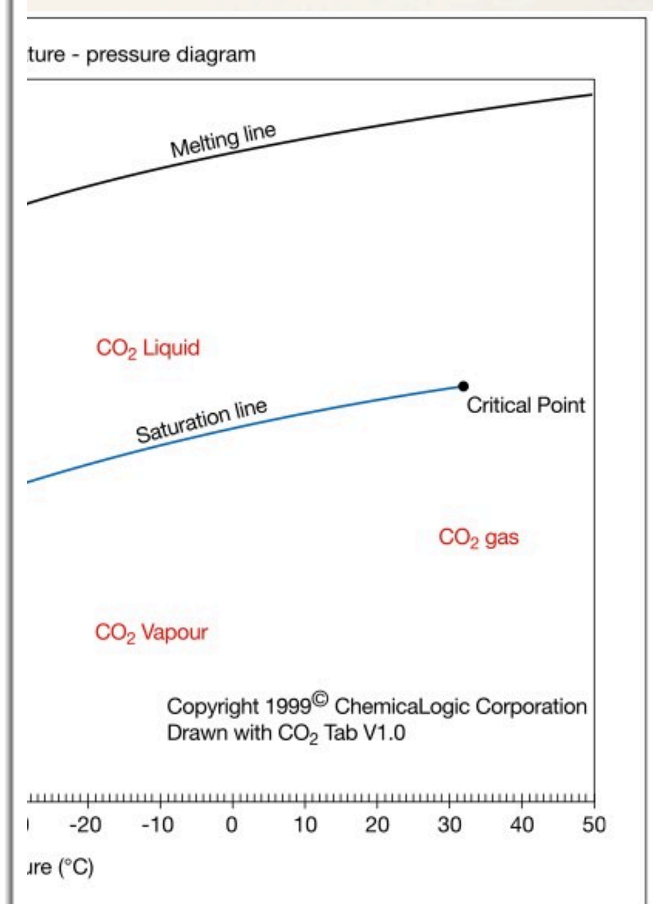


Phase Diagram for CO_2 (IPCC 2005)

CO_2 Properties



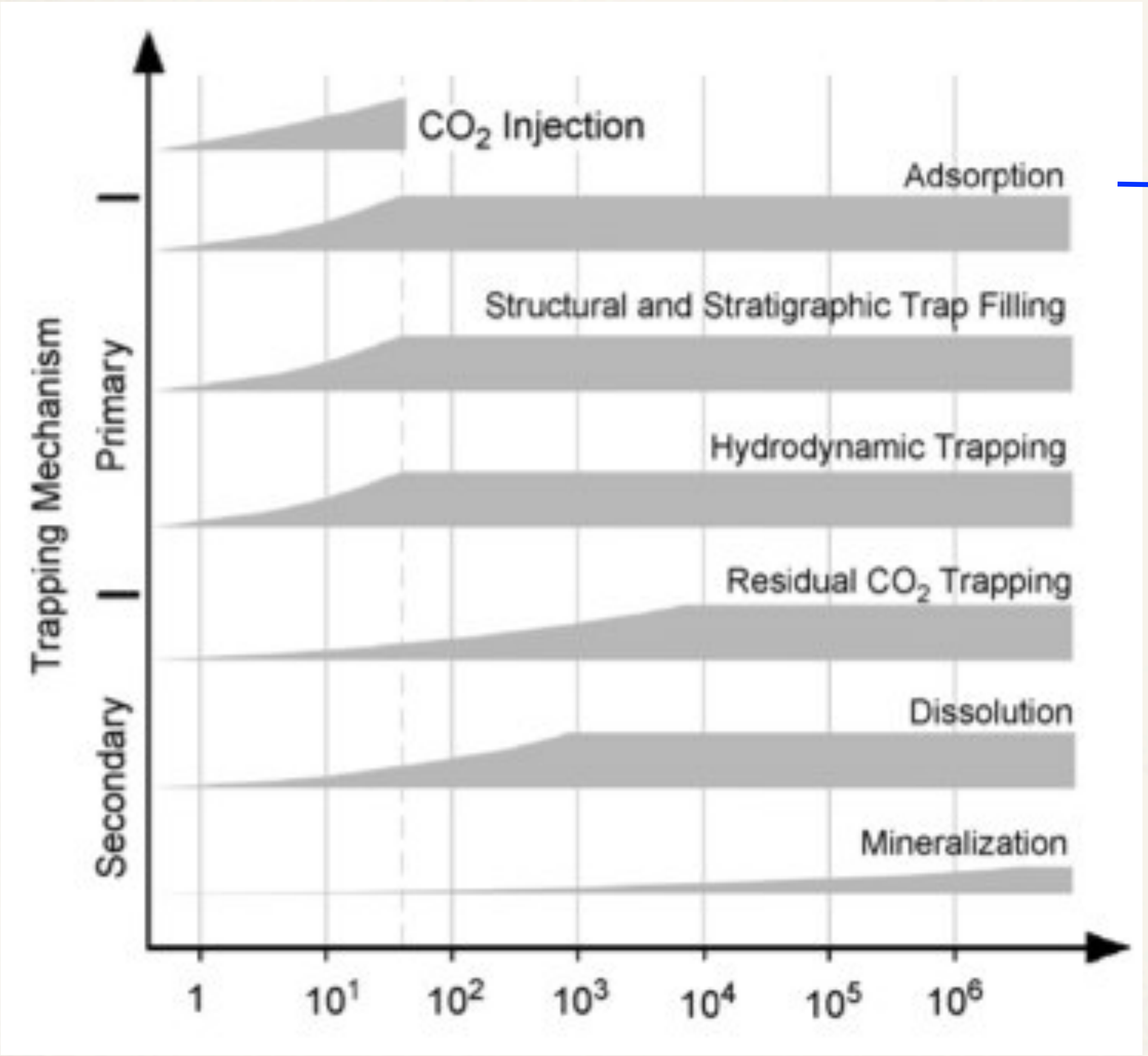




Variation of CO_2 density ... 2005)

Variation of CO_2 density with depth (IPCC 2005)

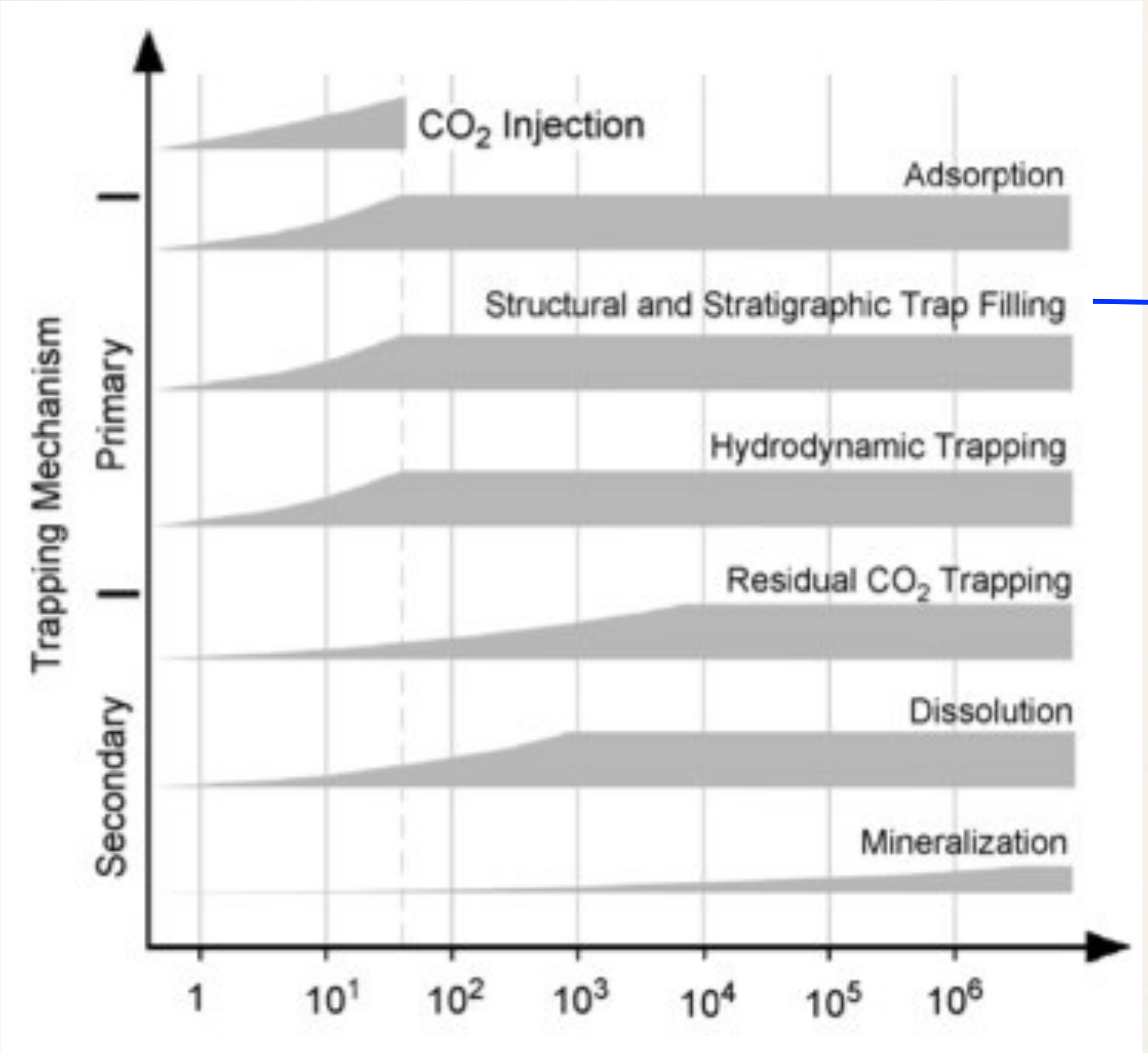
Trapping Mechanisms

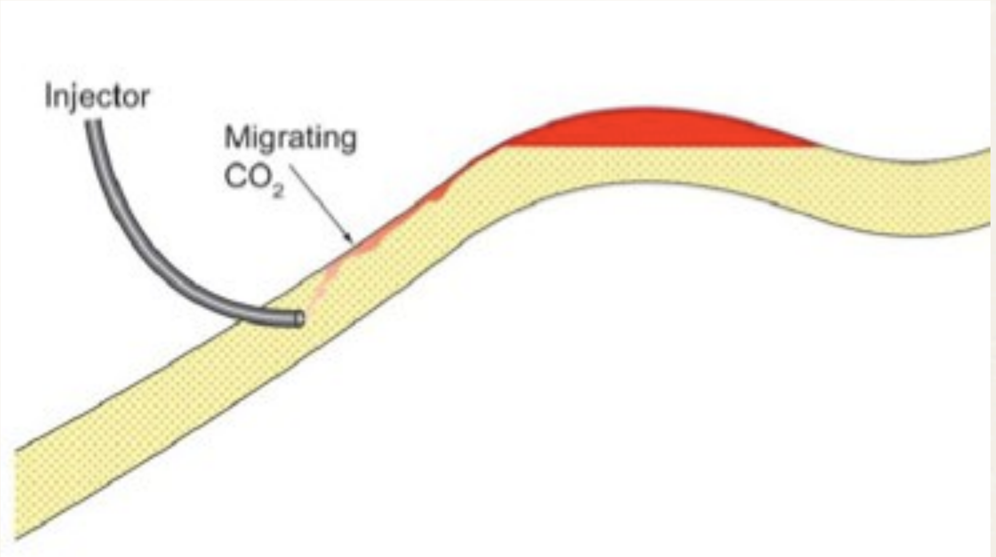


Bachu 2008

→ Relevant to unminable coal seams

Trapping Mechanisms





Structural and stratigraphic trapping refers to trapping beneath a seal, and requires the presence of a structural or stratigraphic trap of the same type as those that result in the presence of mobile hydrocarbon accumulations.

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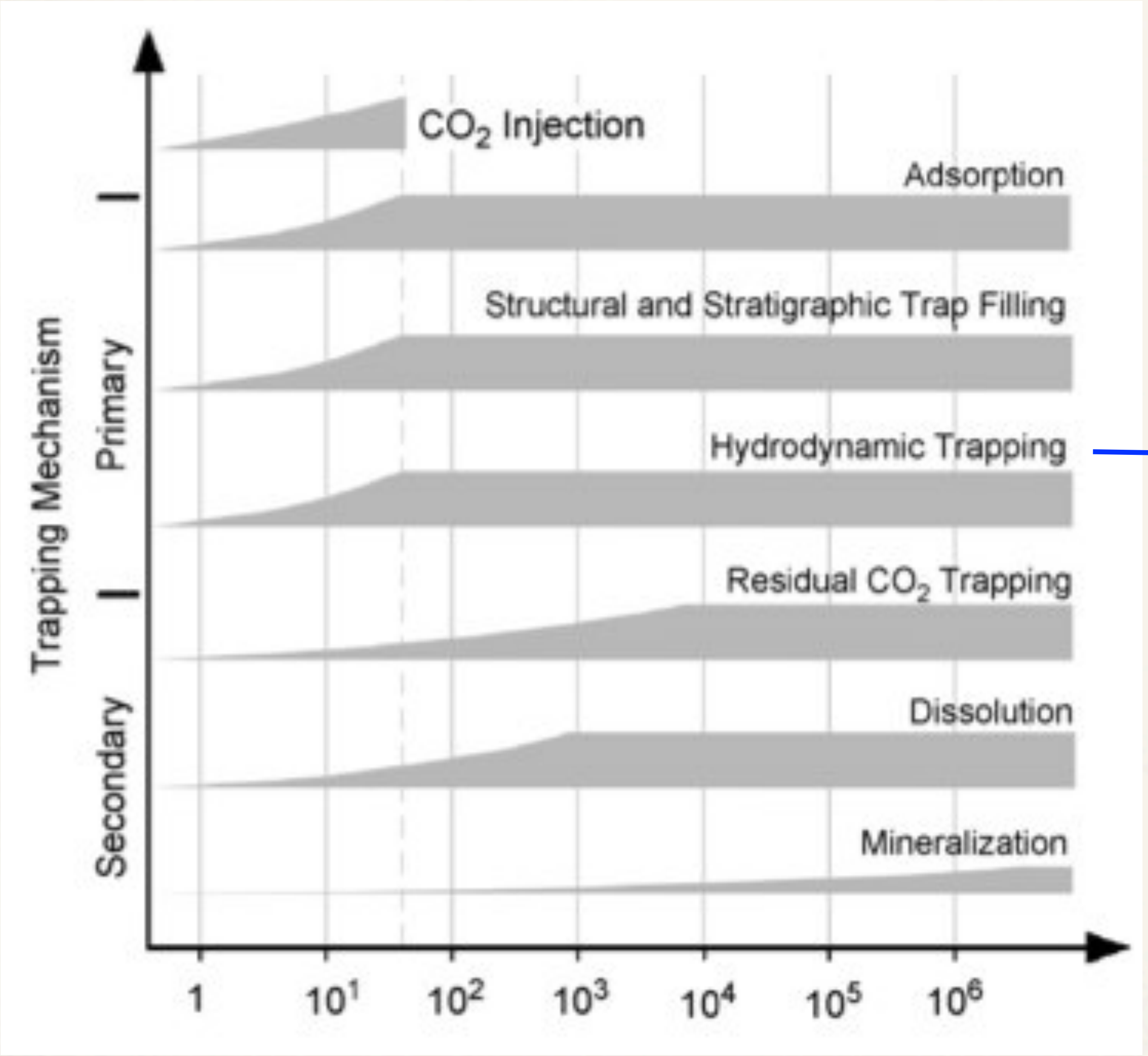
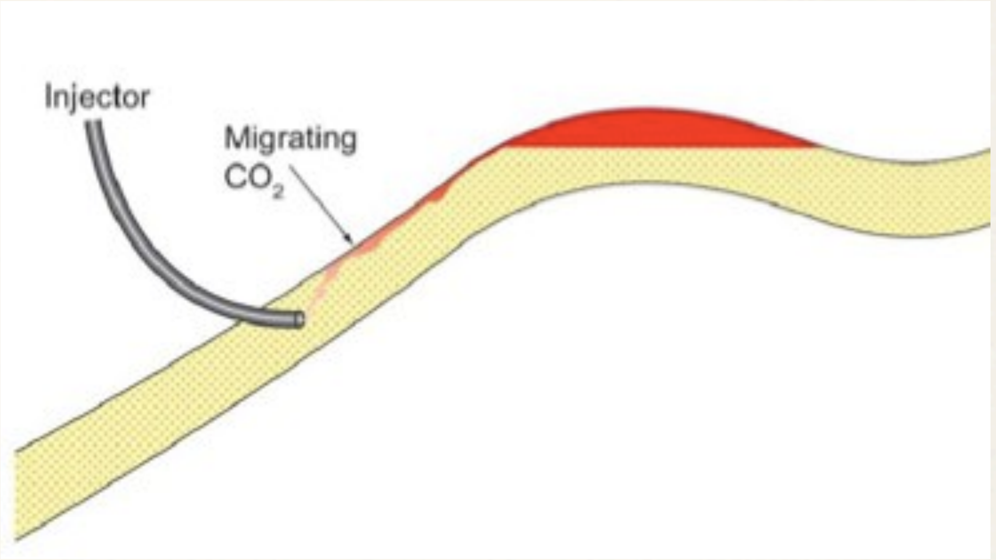
Trapping Mechanisms





The term hydrodynamic trapping is used to describe CO_2 that moves in the subsurface, typically as CO_2 finds its way from an injector to a trap.

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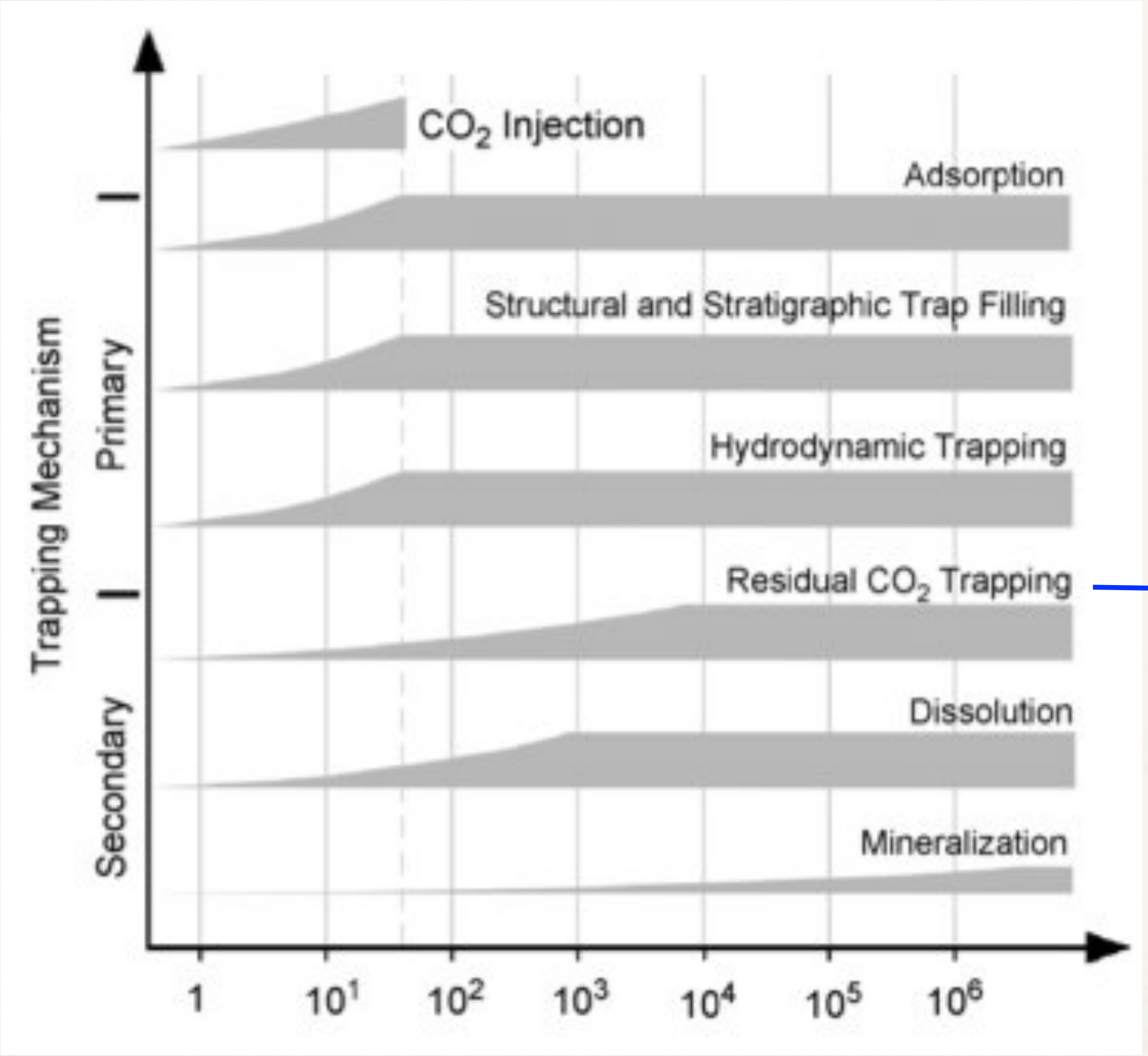
Trapping Mechanisms



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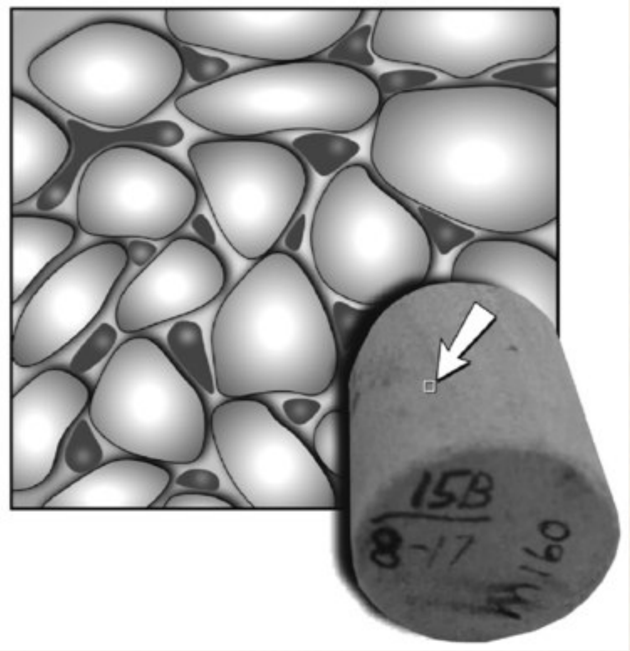
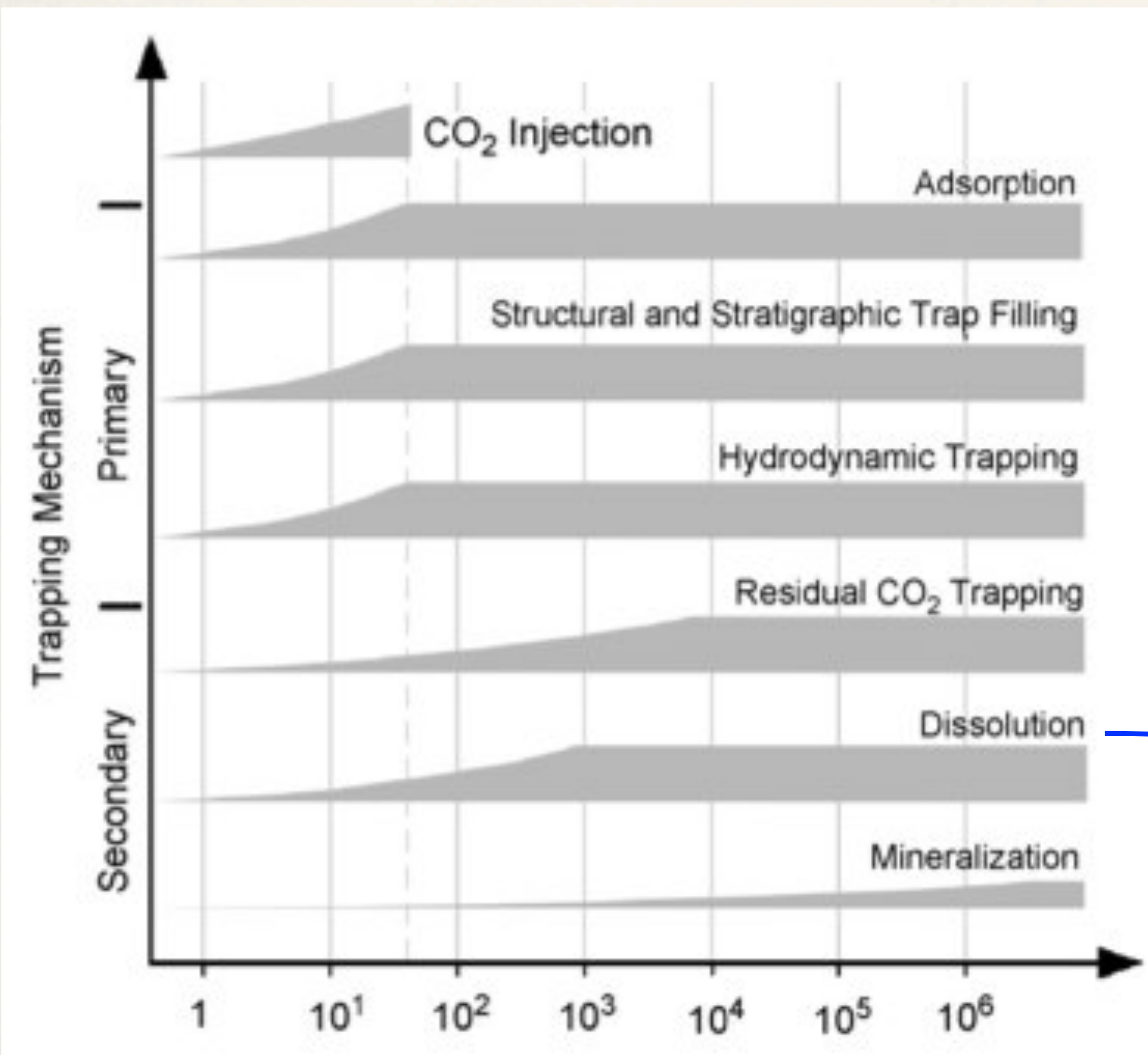
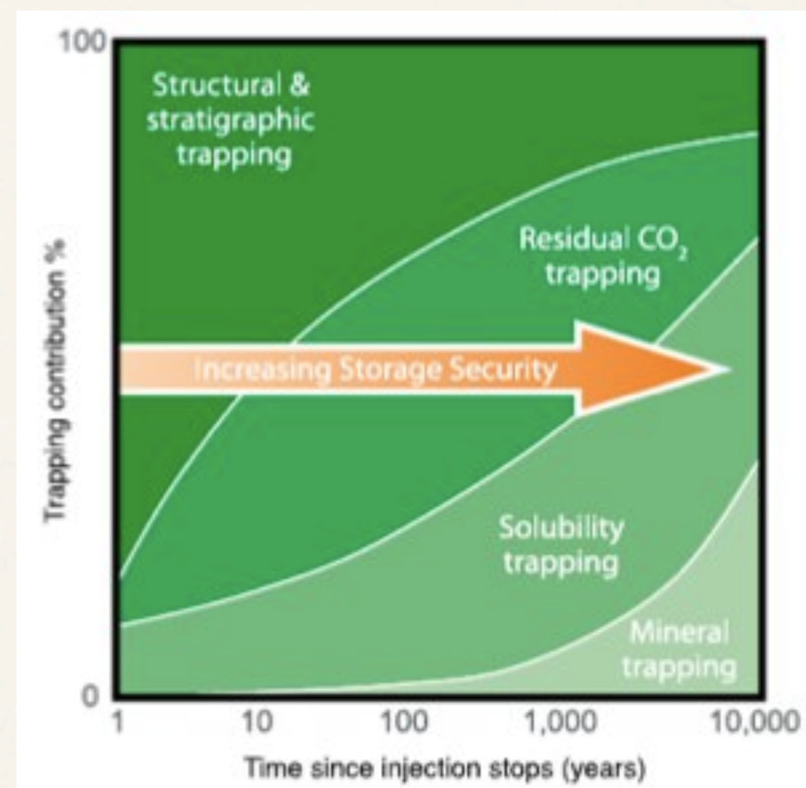


Residual trapping, on the other hand, refers to the CO_2 that remains in a porous rock after it has been flushed with water.

Trapping Mechanisms





Dissolution of CO_2 in formation water is likely to be the major trapping mechanism in saline aquifer storage.

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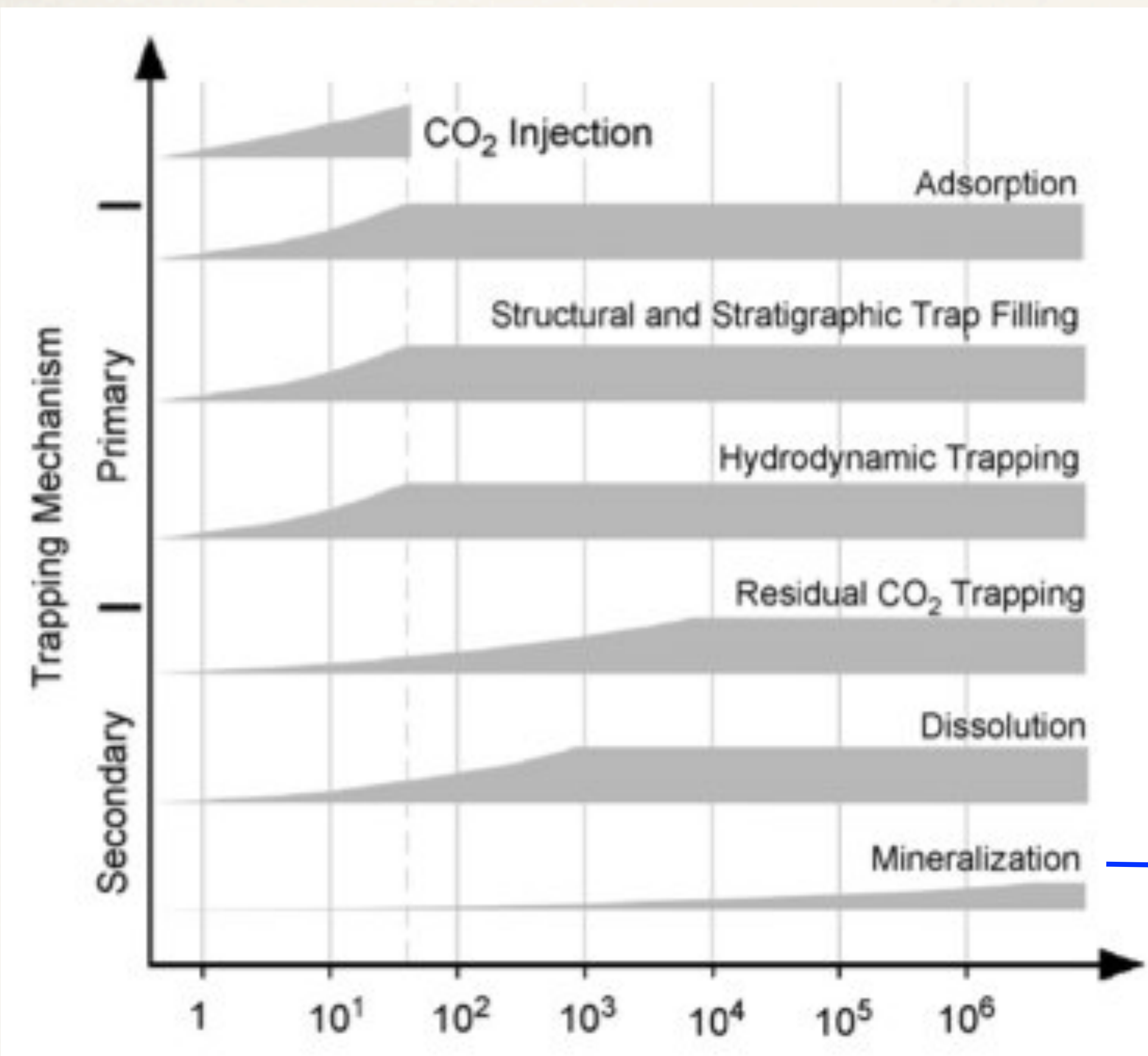
Trapping Mechanisms



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$$3\ \text{K-feldspar} + 2H_2O + 2CO_2 \leftrightarrow \text{Muscovite} + 6\ \text{Quartz} + 2K^+ + 2HCO_3^-$$

The reaction of dissolved CO2 with Ca-, Fe-, or Mg-containing minerals in the rock matrix can result in the precipitation of carbonates in the pore space.

Site Selection Criteria

- A prospective site should initially satisfy four high-level conditions

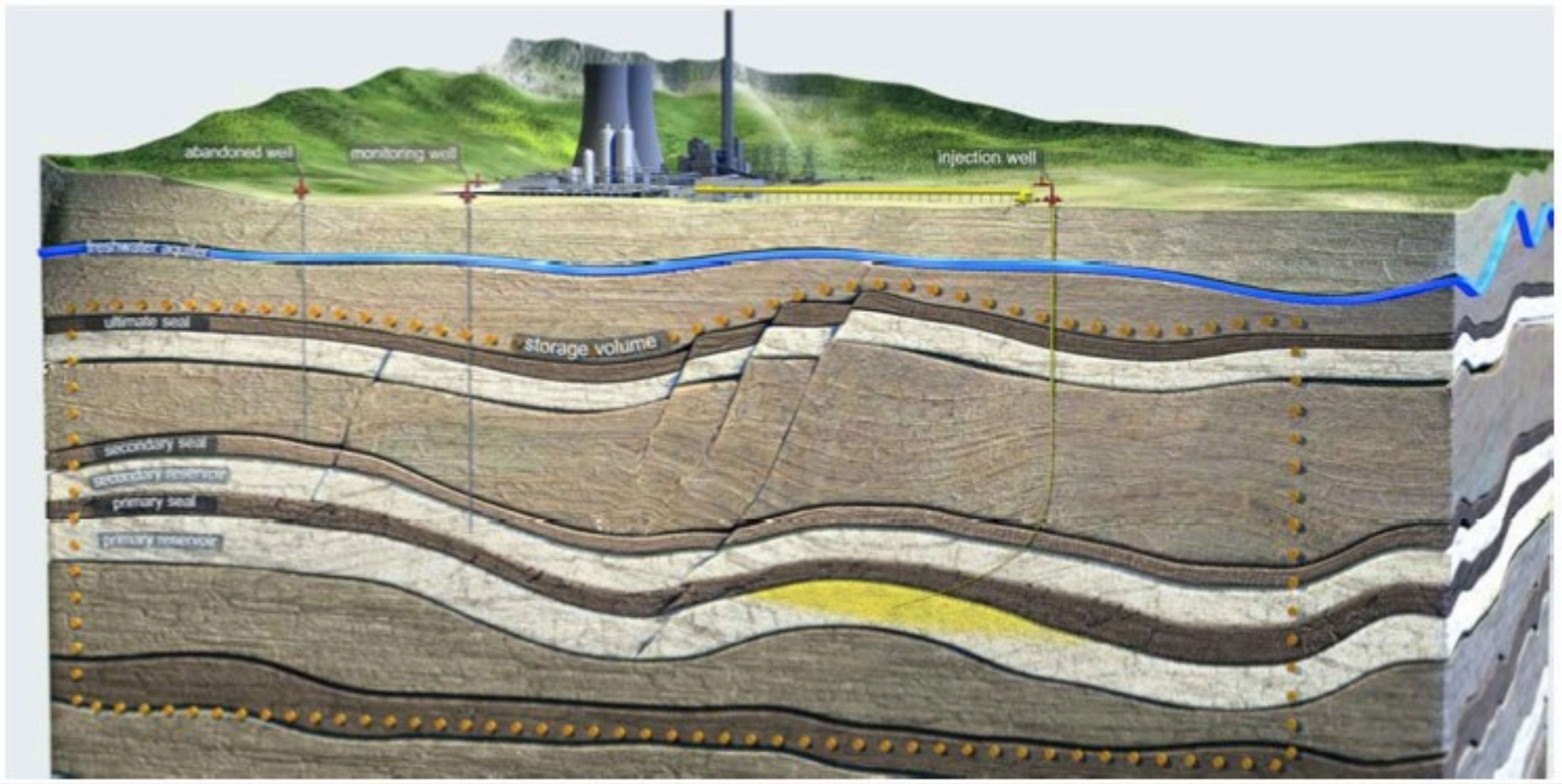
1. Adequate porosity and thickness (for storage capacity) and permeability (for injectivity) at sufficient depth of injection

2. An impermeable caprock (such as shale, mudstone, salt or anhydrate beds)

3. The geological environment should be sufficiently stable to avoid compromising the storage integrity.

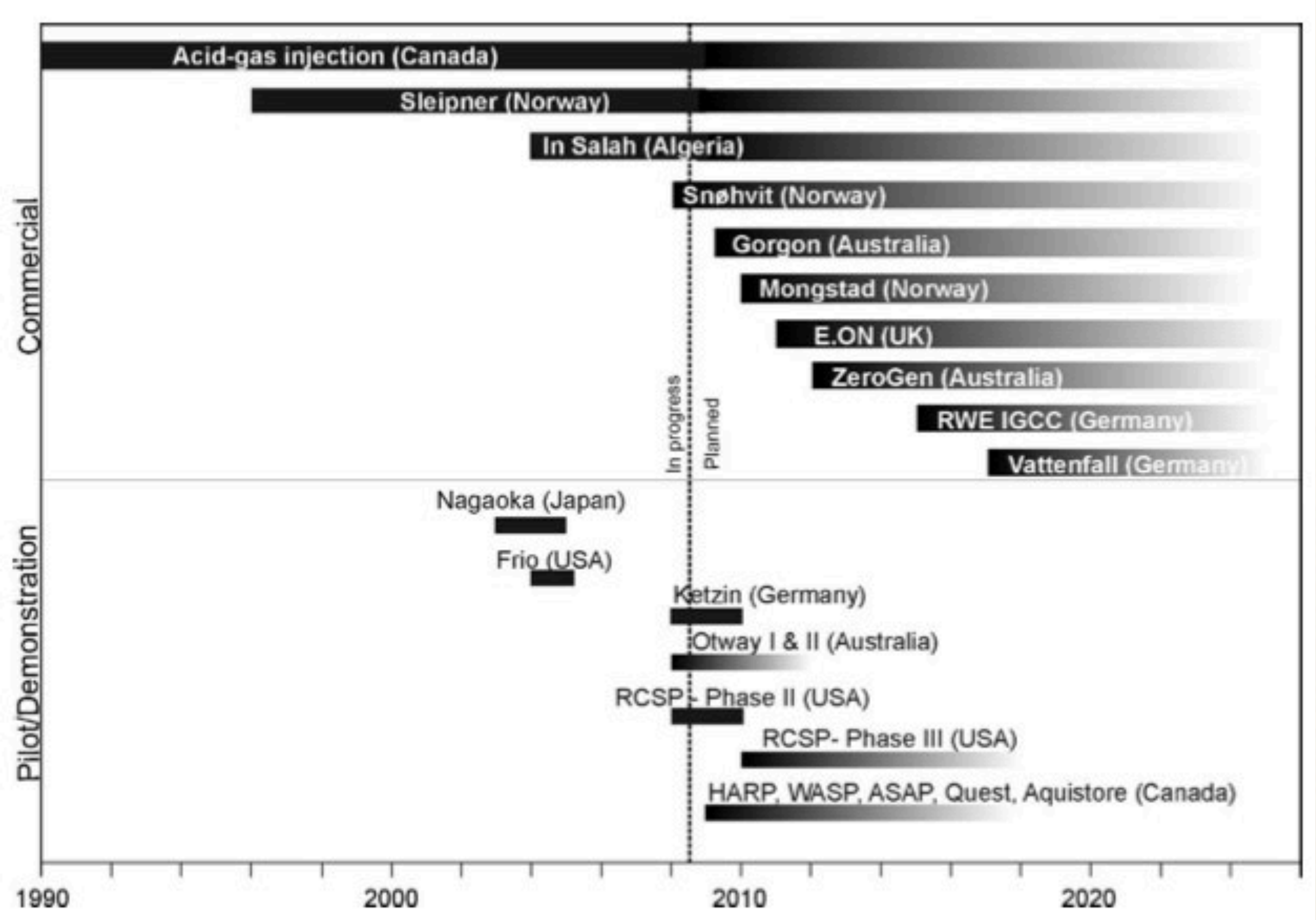
4. Sites where other natural resources are present with current or potential future value that may be compromised by the CO_2 storage operation should be carefully coordinated.

Multi Barrier Systems



Arnes et al., 2010

Active Projects



Past and planned future implementation of CO_2 geological storage in saline aquifers. (Michael et al., 2010)

Properties of Commercial Sites

Project Name	Porosity %	Permeability, md	Depth, m	Formation Thickness, m	Seal Lithology	Seal Thickness, m
Snohvit	13	450	2550	60	Shale	30
Sleipner	37	5000	1000	250	Shale	75
In Salah	17	5	1850	29	Mudstone	950

(Michael et al., 2010)

Thank you