Identification and Capacity Quantification of CO_2 Storage Sites

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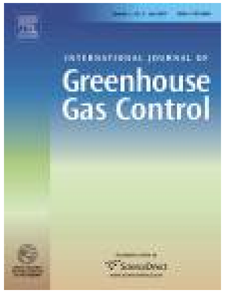


Workshop on Capacity Building in Mexico

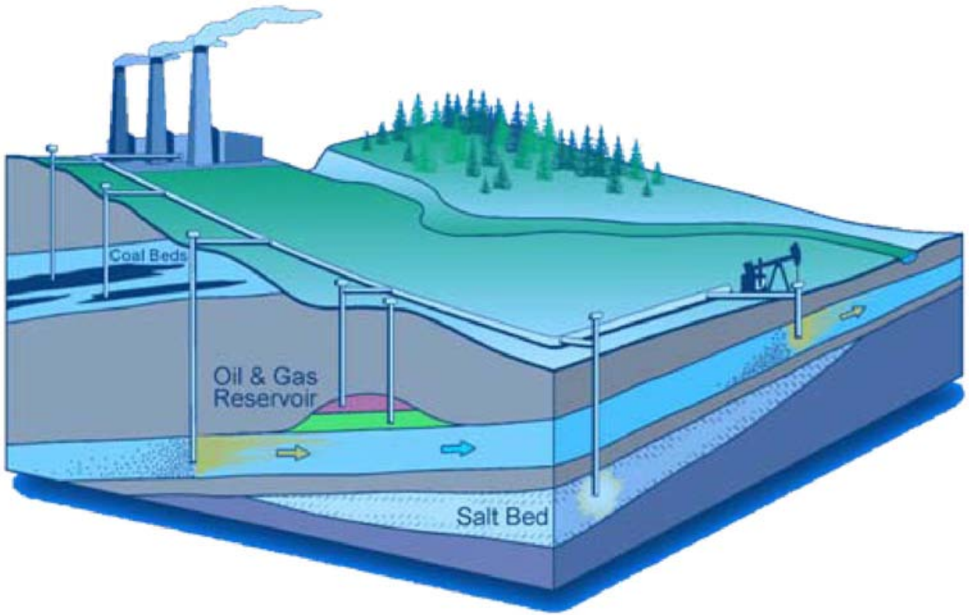
July 9-10, 2008

Mexico City, Mexico

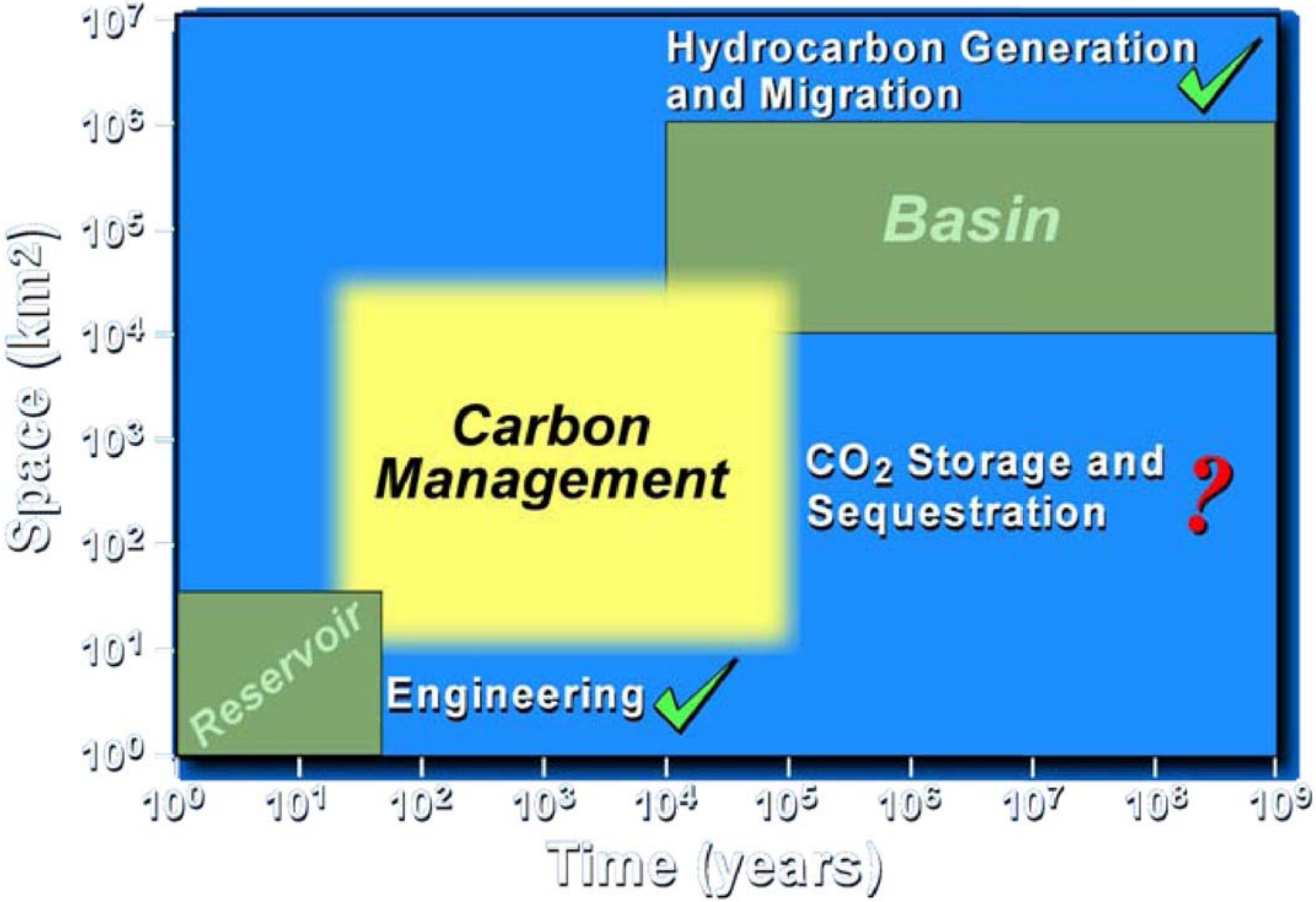
Outline

- Scales of assessment
- Identification of suitable basins and sites
- Storage capacity estimation

Assessment Scales



Process Scales for CO_2 Geological Storage

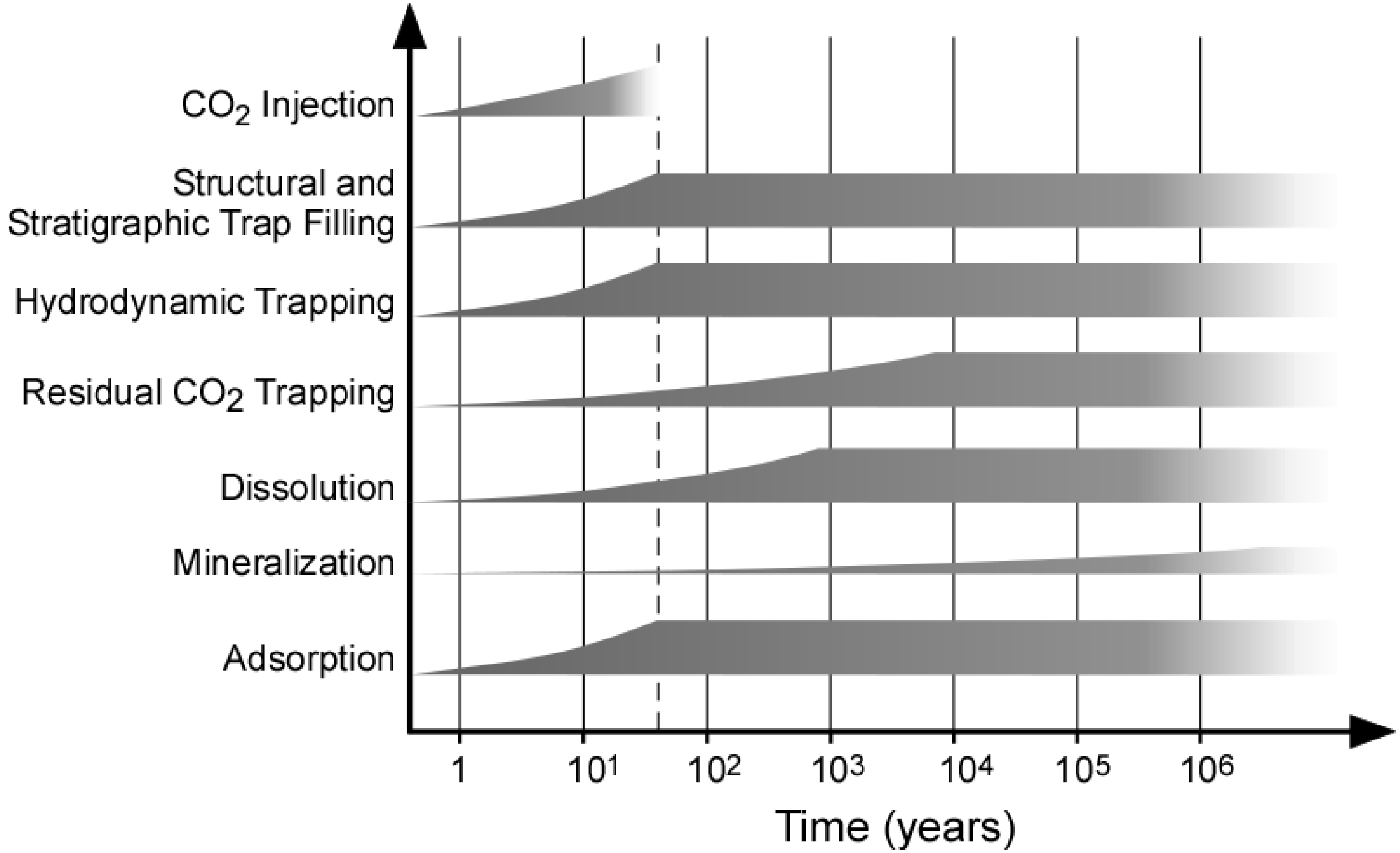


CO_2 Trapping Mechanisms

- Physical Trapping (in free phase)
  - 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)
  - Dynamic Systems (flow in long-range regional-scale systems

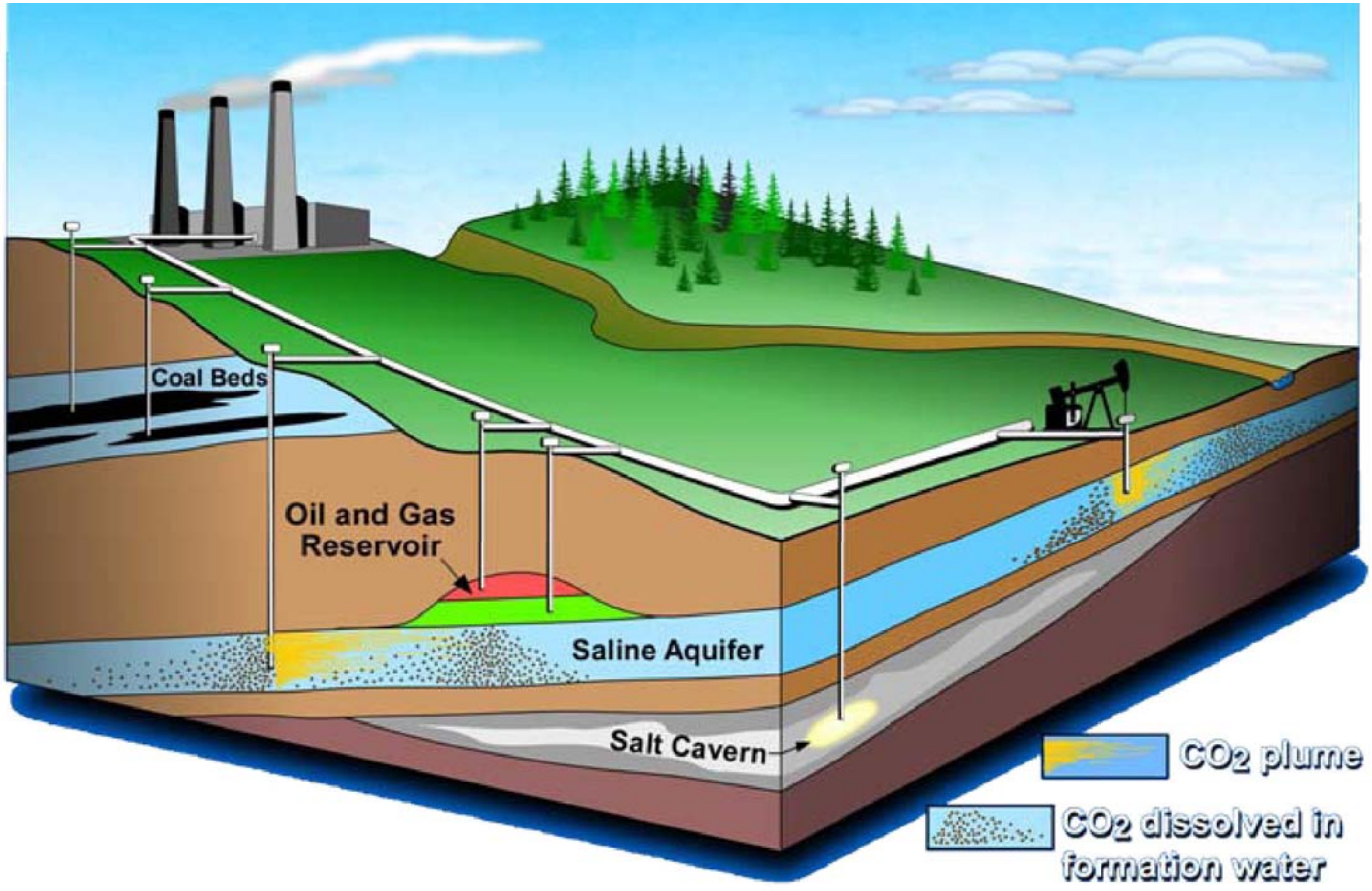
- Chemical Trapping
  - Adsorbed onto organic material in coals and shales
  - Dissolved in formation fluids (oil or water)
  - Precipitated as a carbonate mineral (irreversible process)

Process Time Scales

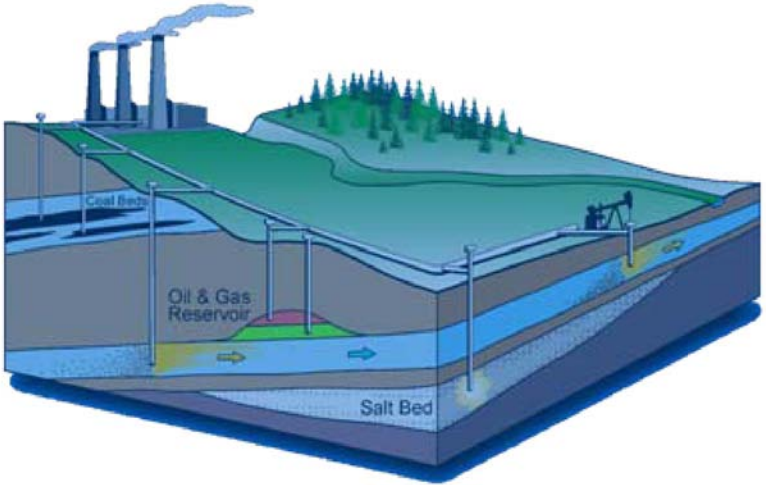


(from IPCC SRCCS, 2005)

Means of CO_2 Geological Storage



Identification of Suitable Basins and Storage Sites



Characteristics of Geological Media Suitable for CO_2 Storage

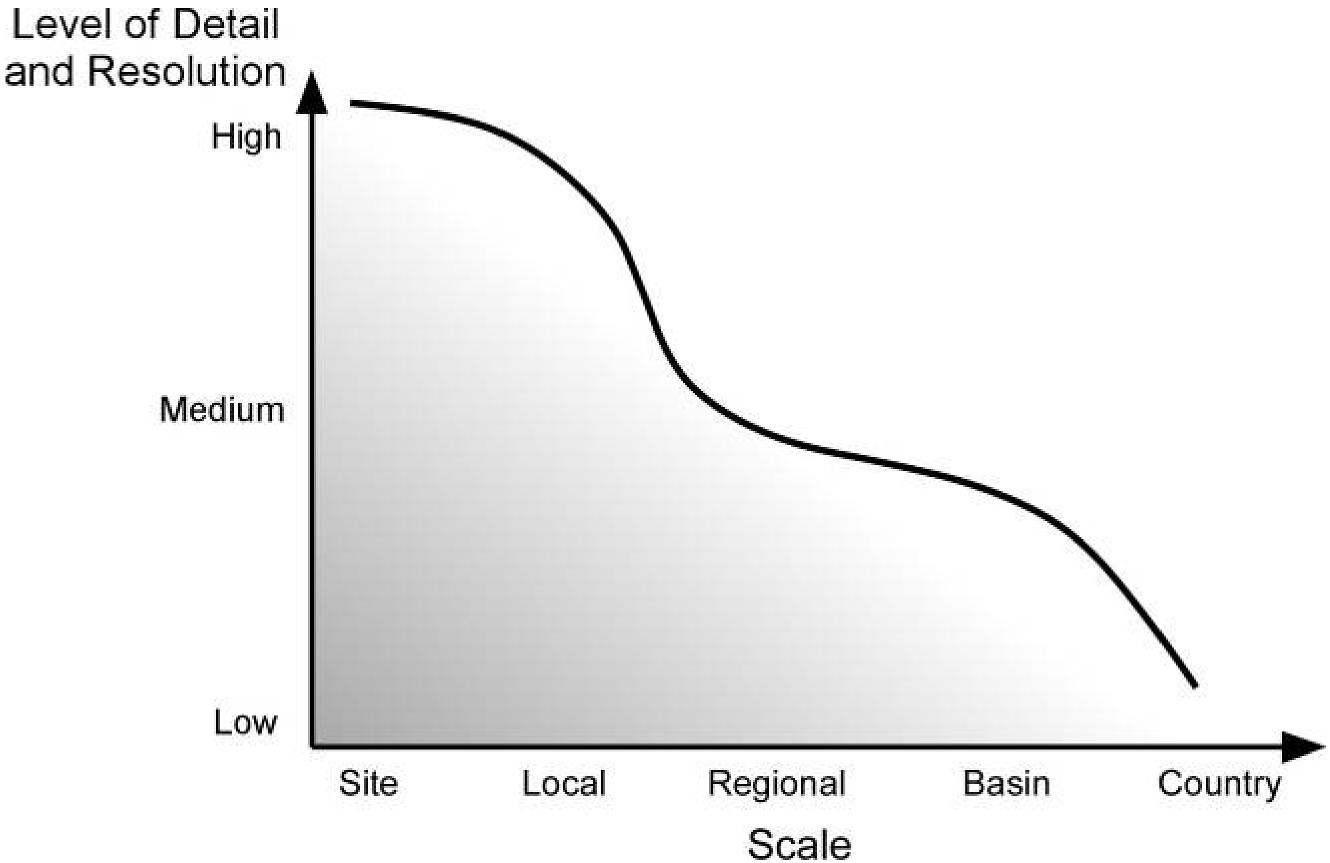
- Capacity, to store the intended CO_2 volume
- Injectivity, to receive the CO_2 at the supply rate
- Containment, to avoid or minimize CO_2 leakage

Assessment Scales and Resolution

- **Country**: high level, minimal data
- **Basin**: identify and quantify storage potential
- **Regional**: increased level of detail, identify prospects
- **Local**: very detailed, pre-engineering site selection
- **Site**: engineering level for permitting, design and implementation

Note: Depending on the size of a country in relation to its sedimentary basin(s), the order of the top two or three may interchange

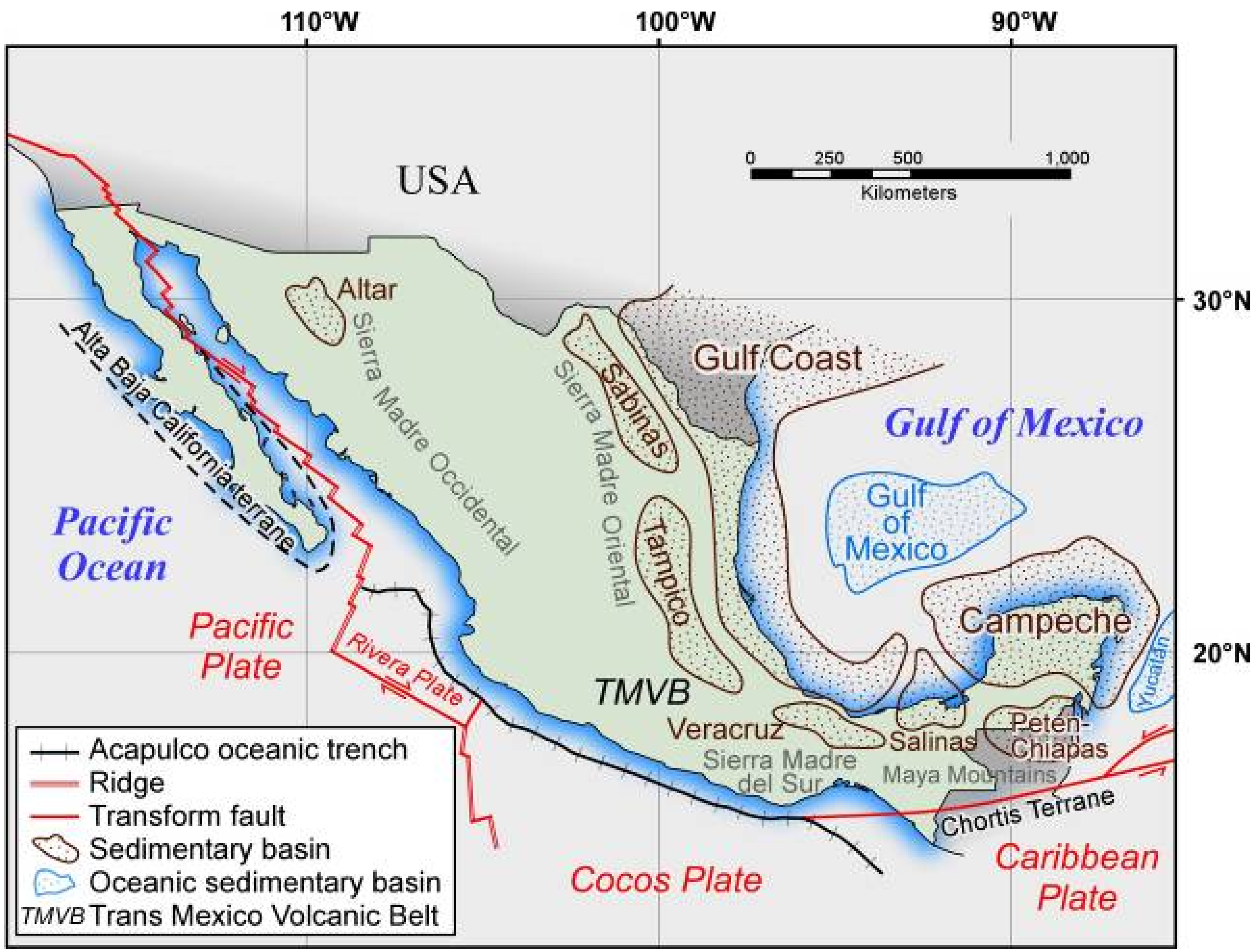
Relationship Between Assessment Scale and Level of Detail and Resolution



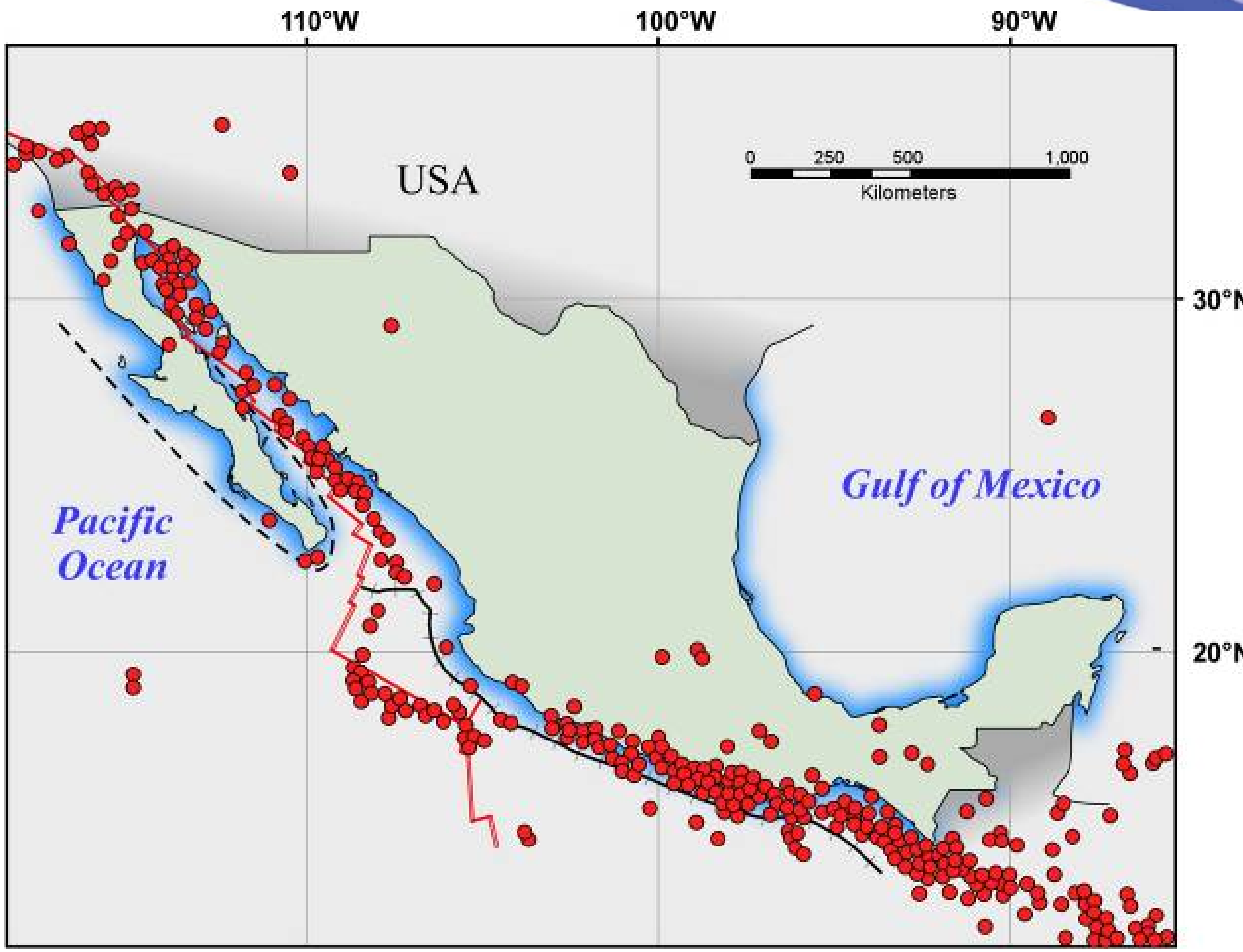
Geological Characteristics of Sedimentary Basins Suitable for CO_2 Storage

- Adequate depth (>800 m)
- Minimal tectonism
- Minimally folded, faulted or fractured
- Strong confining seals (shales or evaporitic beds)
- Harmonious sedimentary successions
- No significant diagenesis that may destroy porosity and permeability

Mexico's Tectonic Setting and Sedimentary Basins



Seismicity in Mexico



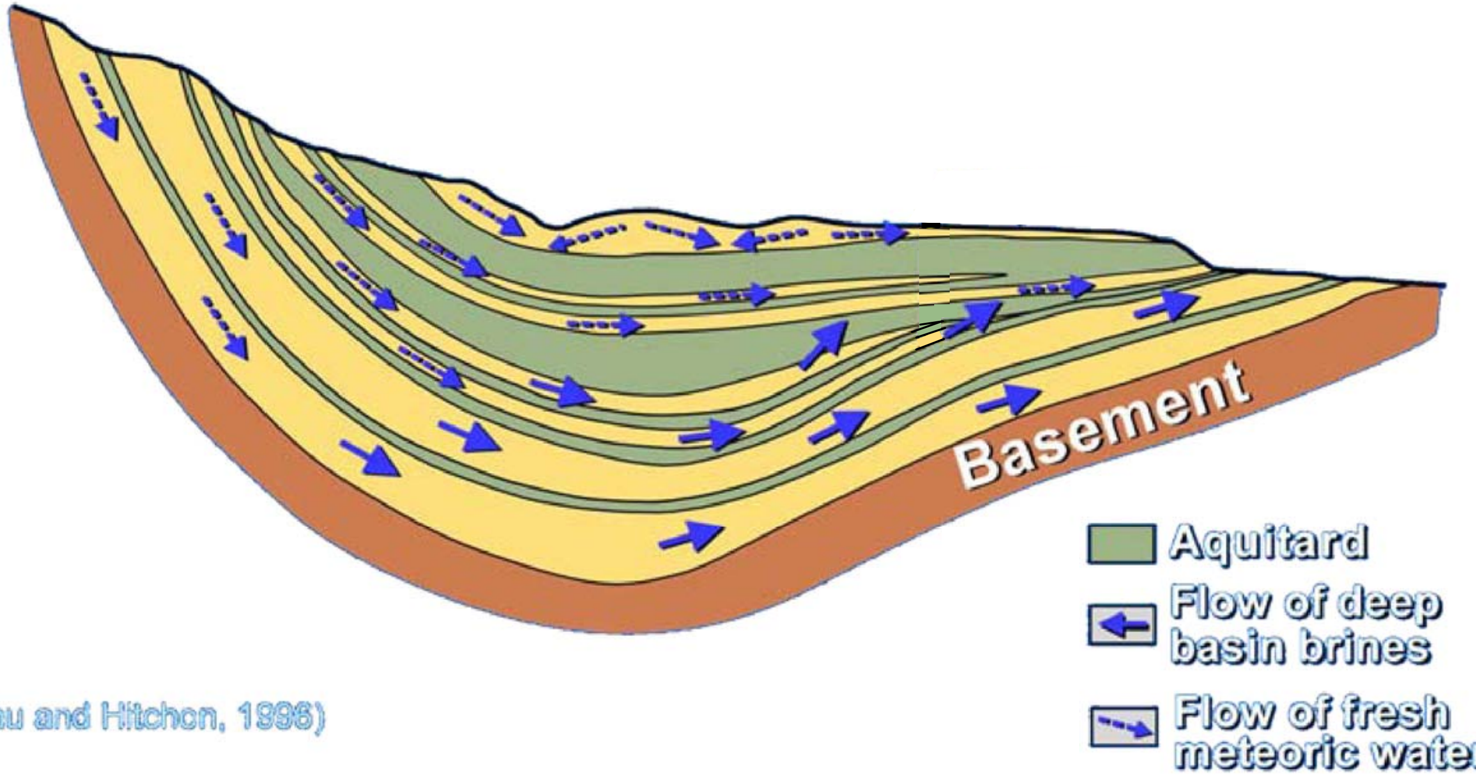
M ≥ 5, 1964-1985

Dewey and Suarez, 1991

Hydrodynamic Characteristics of Geological Media Suitable for CO_2 Storage

- Regional-scale competent sealing units (aquitards or aquicludes, aka caprock)
- Favorable pressure conditions (i.e., not overpressured)
- Favorable flow systems (deep, long travel time)
- Adequate porosity (storage space)
- Adequate permeability (injectivity)

Flow Systems in the Williston Basin



(Bachu and Hitchon, 1996)

Geothermal Characteristics of Geological Media Suitable for CO_2 Storage

Low temperatures ("Cold Basins"), resulting from:

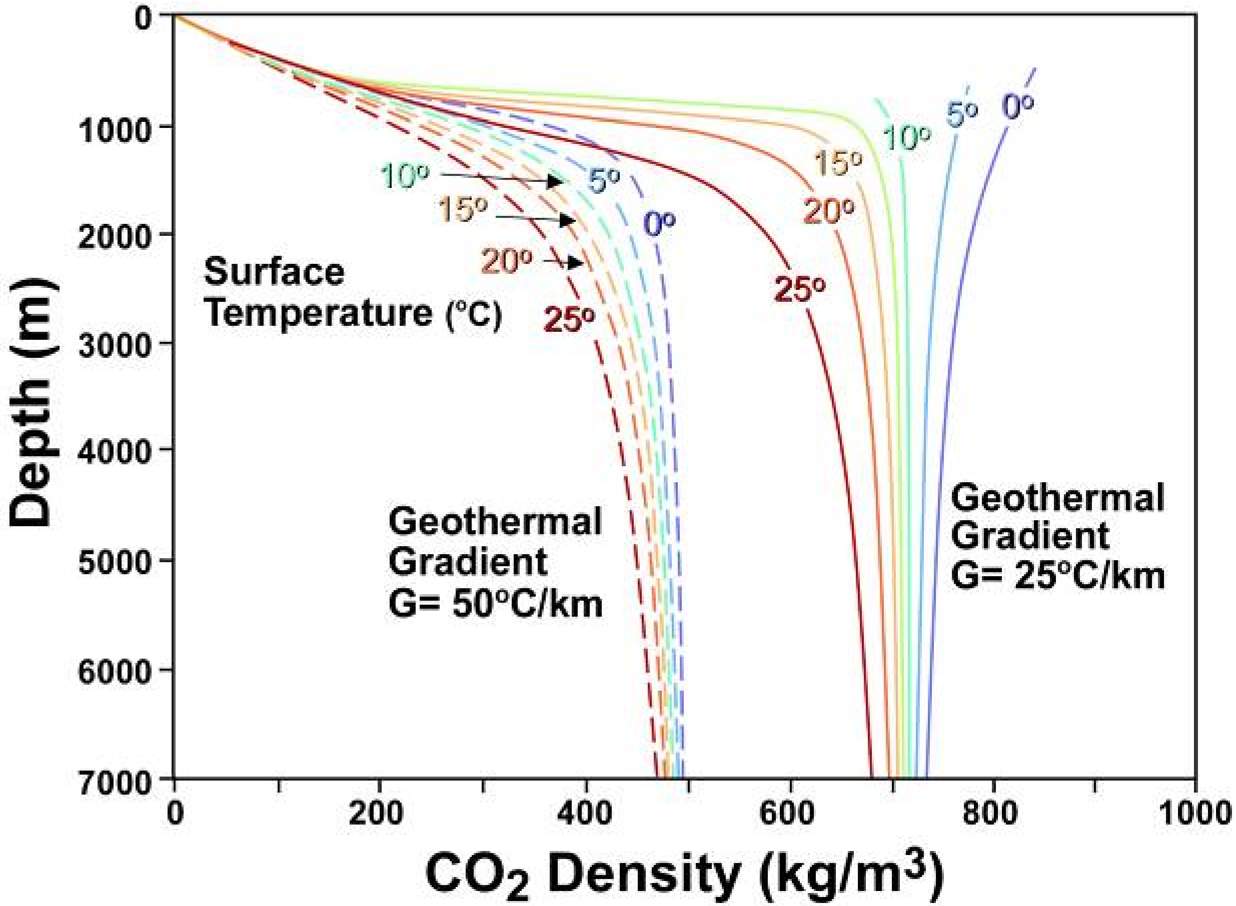
- Low geothermal gradients
- Low surface temperatures

Effects

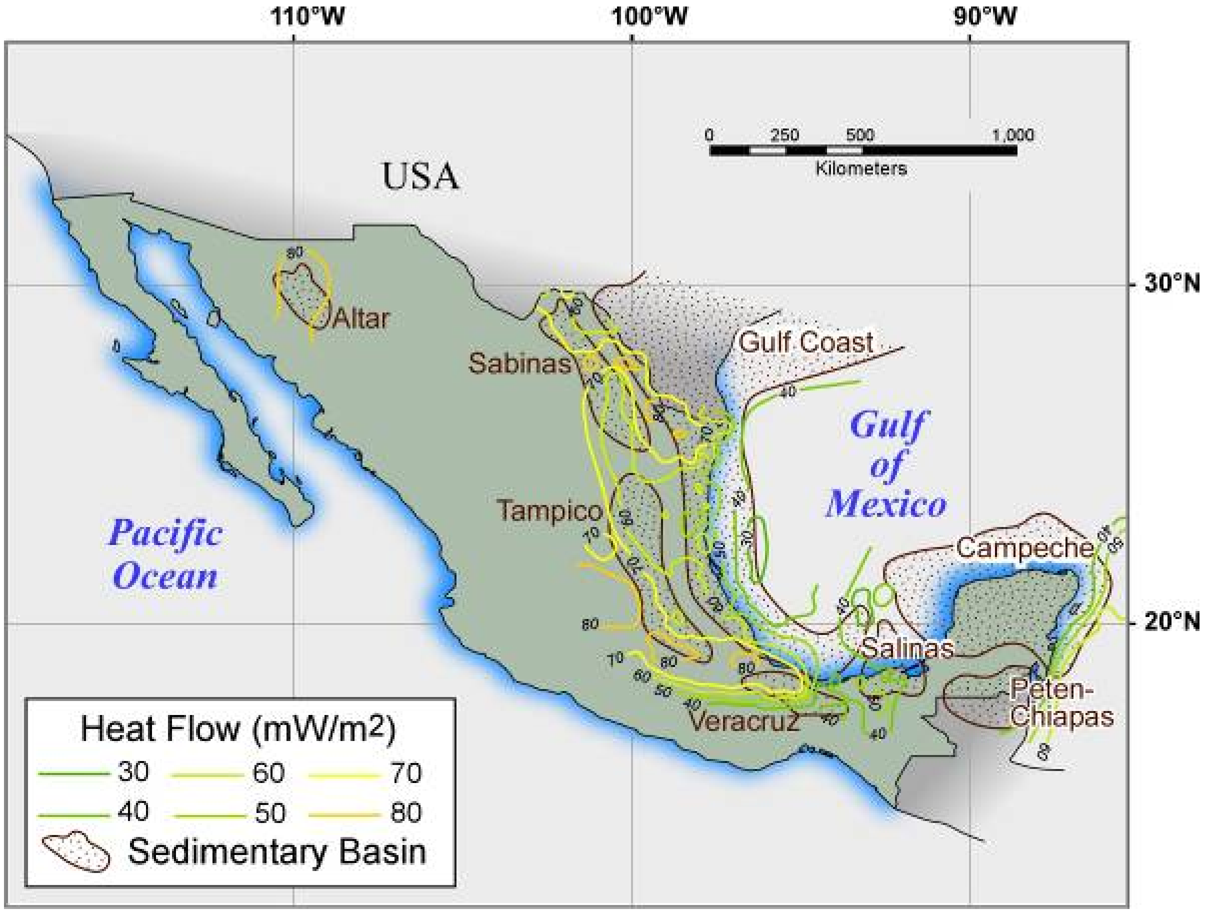
➢ Higher density, hence storage efficiency

➢ Less buoyancy, hence smaller driving force for migration

Variation with Depth and Geothermal Regime of Carbon Dioxide Density



Crustal Heat Flow in Mexico's Sedimentary Basins

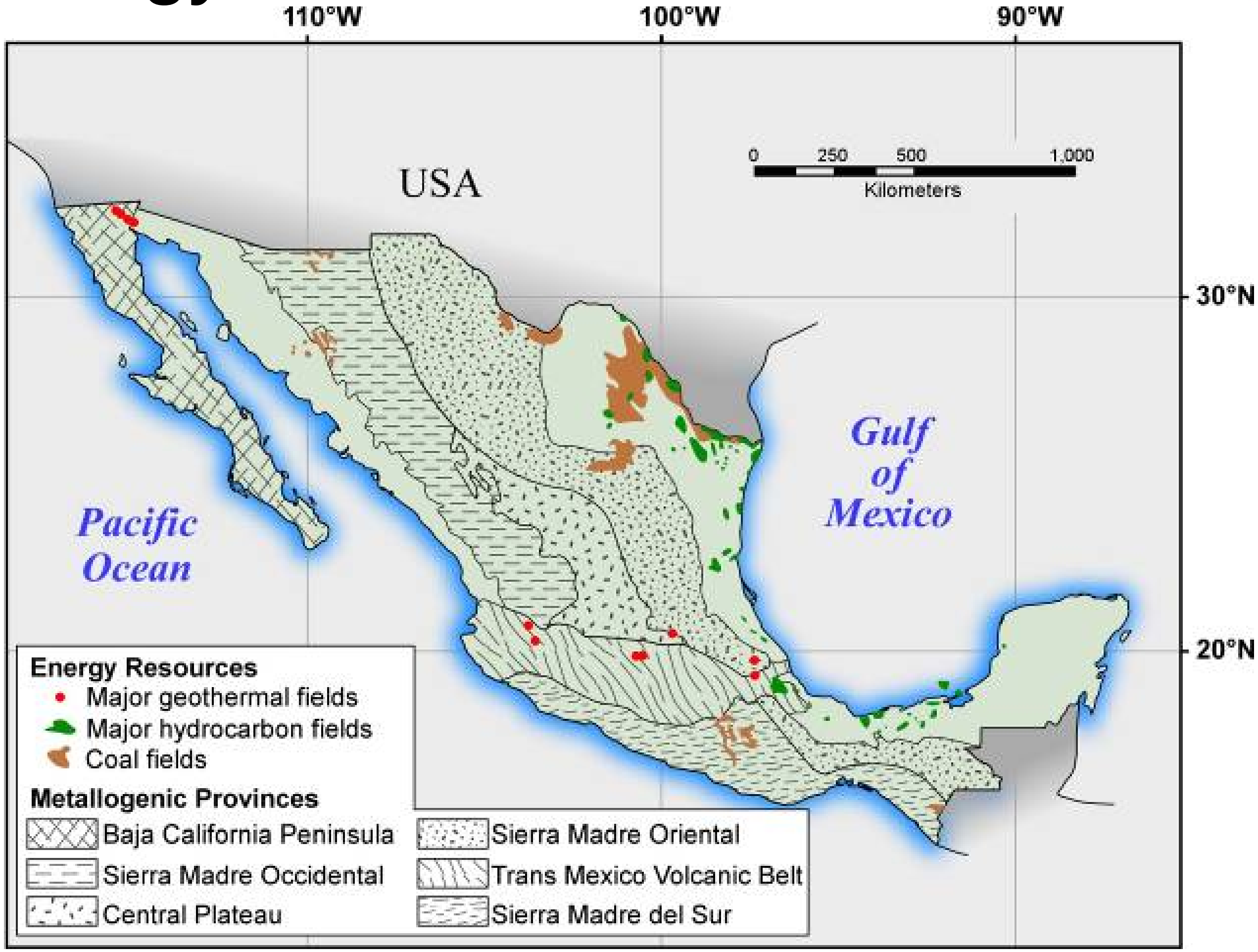


Basin Maturity

Defined by fossil-energy potential (oil, gas, coal) and the degree of exploration and production

- Mature: rich in energy resources, advanced stage of production
- Immature: rich in energy resources, early stage of exploration and production
- Poor: no, or poor energy resources

Location of Mexico's Energy and Mineral Resources



Industry Maturity

- Developed continental basins: access roads, pipelines, wells
- Developed marine basins: drilling and production platforms, pipelines

Local Scale Screening Criteria

Same as for basin and regional scale, plus:

- Safety and effectiveness
- Economic
- Technical specific

Safety and Effectiveness Selection Criteria

- Avoid contamination of energy, mineral and groundwater resources
- Avoid risk to life (vegetation, animal, human)
- Avoid or minimize equity impact
- Avoid, or minimize, leakage for the desired time period

Economic Selection Criteria

- Potential for additional energy production (EOR, EGR, ECBMR)
- Penalty avoidance by meeting regulatory requirements
- Access to surface infrastructure and right of access
- Avoidance of land and subsurface-use conflicts
- Optimization of storage depth to reduce costs of drilling and compression

Selection Criteria
Specific to Oil and Gas Reservoirs

Should have sufficient capacity without raising reservoir pressure above the initial pressure

Selection Criteria
Specific to Enhanced Oil Recovery

- Light oil (25 to 48°API)
- Reservoir pressure greater than Minimum Miscibility Pressure
- Temperature between 31°C and 121°C (85°F to 250°F)
- Homogeneous reservoir
- Preferably thin net pay (<20 m) for horizontal sweep efficiency (vertical sweep suitable for reef reservoirs)

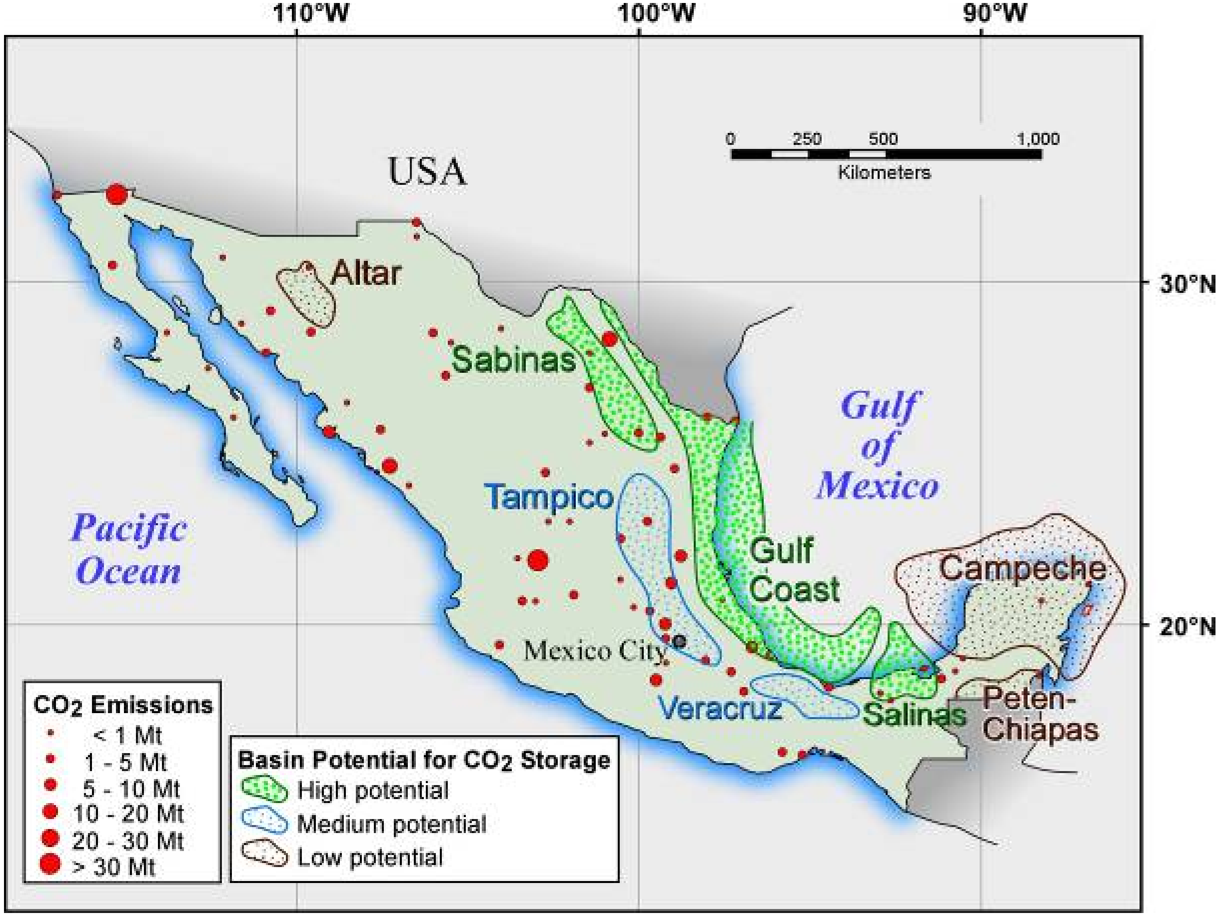
Selection Criteria
Specific to
Enhanced Coalbed Methane Recovery

- Sufficient permeability (at least several millidarcies, considering also coal swelling and loss of permeability)
- CO_2 in gaseous phase
- Minimal faulting and folding of the coal seam
- Low water saturation
- Thin, unmineable and uneconomic coal seams, deeper than potable groundwater

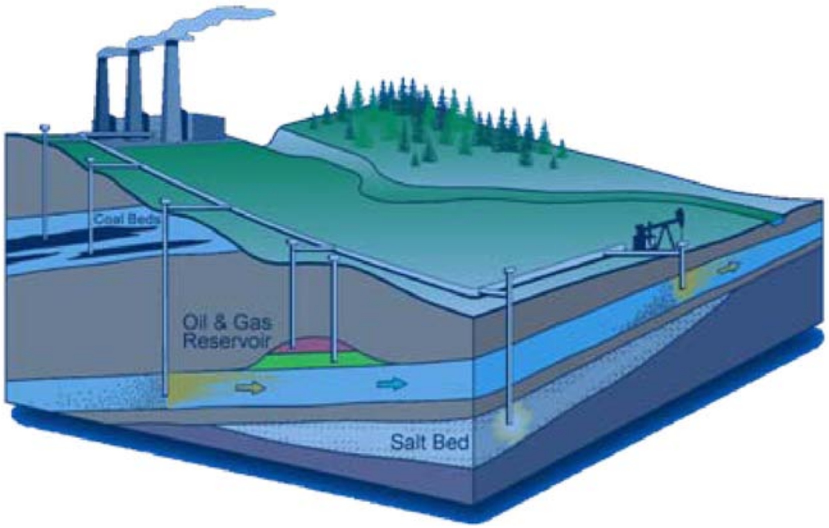
Additional Selection Criteria Based on Source-sink Matching

- Volume, rate and purity of the CO_2 stream
- Proximity and right of access
- Infrastructure for capture, delivery and injection
- Injection, and where appropriate, production strategies
- Terrain and right of way
- Proximity to population centres
- Expertise and know-how
- Legal and regulatory framework

Potential of Mexico's Sedimentary Basins for CO_2 Geological Storage



Storage Capacity Estimation

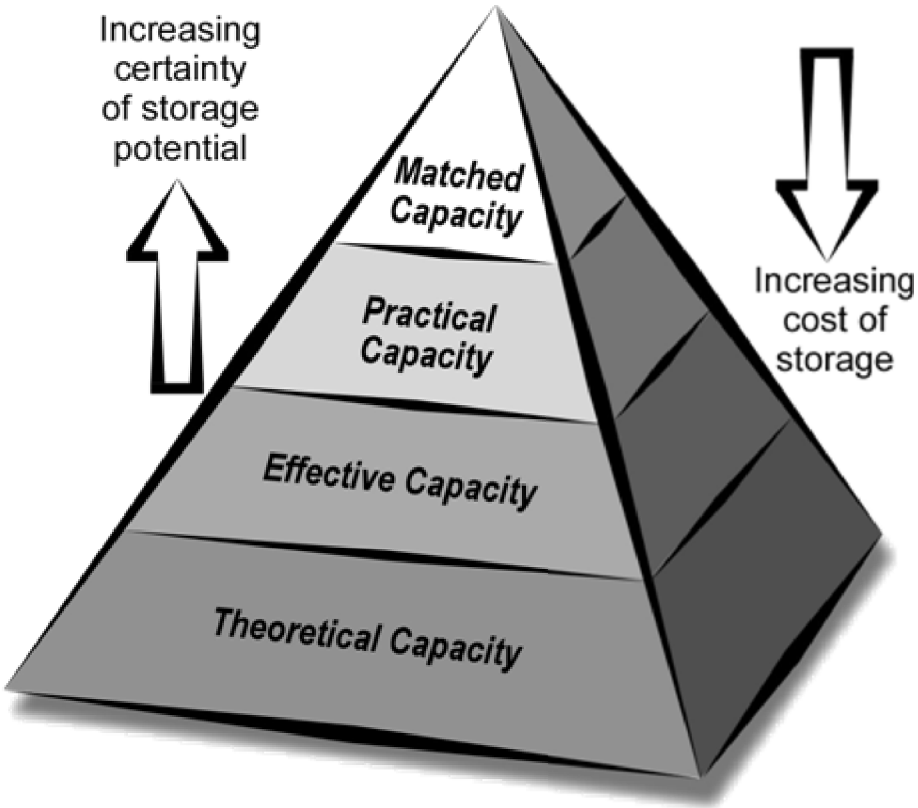


www.cslforum.org/documents/PhaseIReportStorageCapacityMeasurementTaskForce.pdf
or Bradshaw et al., International Journal of Greenhouse Gas Control, vol. 1, no. 1, 62-68, 2007
www.cslforum.org/documents/PhaseIIReportStorageCapacityMeasurementTaskForce.pdf
or Bachu et al., International Journal of Greenhouse Gas Control, vol. 1, no. 4, 430-443, 2007
www.cslforum.org/documents/PhaseIIIReportStorageCapacityMeasurementTaskForce.pdf

Assessment Types

- **Theoretical**: physical limit of the system
- **Effective**: accounts for geological and engineering cut-offs
- **Practical**: accounts for technical, legal and regulatory, infrastructure and economic barriers
- **Matched**: obtained by source-sink matching (SSM)

Techno-Economic Resource-Reserves Pyramid for CO_2 Storage Capacity



Storage Capacity in Depleted Oil Reservoirs

Theoretical Capacity

$$M_{CO2t} = \rho_{CO2r} \times [\, R_f \times OOIP / B_f - V_{iw} + V_{pw}]$$

or

$$M_{CO2t} = \rho_{CO2r} \times [R_f \times A \times h \times \phi \times (1 - S_w) - V_{iw} + V_{pw}]$$

- M_{CO2t}: Theoretical storage capacity
- ρ_{CO2r}: CO_2 density at initial reservoir conditions
- R_f: Recovery factor
- *OOIP*: Original Oil in Place
- B_f: Formation factor
- A: Reservoir area
- h: Reservoir thickness
- ϕ: Porosity
- S_w: Water saturation
- V_{iw}: Volume of injected water
- V_{pw}: Volume of produced water

Storage Capacity in Depleted Gas Reservoirs

Theoretical Capacity

$$M_{CO2t} = \rho_{CO2r} \times R_f \times (1 - F_{IG}) \times OGIP \times \frac{P_S \times Z_r \times T_r}{P_r \times Z_S \times T_S}$$

- M_{CO2t}: Theoretical storage capacity
- ρ_{CO2r}: CO_2 density at initial reservoir
- conditions
- R_f: Recovery factor
- *OGIP*: Original Gas in Place
- F_{IG}: Fraction of (re-)injected gas

- *P*: Pressure
- *T*: Temperature (°K)
- *Z*: Z-factor (gas compressibility)
- *r,s*: reservoir; surface subscripts

Storage Capacity in Depleted Oil and Gas Reservoirs

Effective Capacity

$$M_{CO2e} = C_m \times C_b \times C_h \times C_w \times C_a \times M_{CO2t} \equiv C_e \times M_{CO2t}$$

- M_{CO2t}: Theoretical storage capacity
- M_{CO2e}: Effective storage capacity
- C: Reduction coefficients

Subscripts

- *m*: mobility
- *b*: buoyancy
- *h*: heterogeneity
- *w:* water saturation
- a: aquifer strength
- t: theoretical
- e: effective

Storage Capacity in Structural and Stratigraphic Traps in Deep Saline Aquifers

Theoretical Capacity

$$V_{CO2t} = V_{trap} \times \phi \times (1 - S_{wirr}) \equiv A \times h \times \phi \times (1 - S_{wirr})$$

Or, if the spatial variability is known

$$V_{CO2t} = \iiint \phi (1 - S_{wirr}) dxdydz$$

Effective Capacity

$$V_{CO2e} = C_c \times V_{CO2t}$$

- V_{CO2t}: Theoretical storage volume
- V_{CO2e}: Effective storage volume
- V_{trap}: Trap volume
- ϕ: Porosity
- S_w: Irreducible water saturation
- A: Average trap area
- h: Average trap height
- C_c: Capacity coefficient

Storage Capacity in Residual-Gas Traps in Deep Saline Aquifers

$$V_{CO2t} = \Delta V_{trap} \times \phi \times S_{CO2t}$$

- V_{CO2t}: Theoretical storage volume
- ΔV_{trap}: Volume invaded by water previously occupied by the plume of injected CO_2
- ϕ: Porosity
- S_{CO2t}: *Saturation of trapped CO_2*

- It is a time-dependent process, as the CO_2 plume migrates
- Storage capacity can be determined by numerical simulations only, based on real relative-permeability data

Storage Capacity in Solution in Deep Saline Aquifers

Theoretical Capacity

$$M_{CO2t} = A \times h \times \phi \times (\rho_S X_S^{CO2} - \rho_0 X_0^{CO2})$$

Or, if the spatial variability is known

$$M_{CO2t} = \iiint \phi(\rho_S X_S^{CO2} - \rho_0 X_0^{CO2}) dxdydz$$

Effective Capacity: $M_{CO2e} = C_c \times M_{CO2t}$

- M_{CO2t}: Theoretical storage capacity
- *A:* *Aquifer area*
- *h:* *Aquifer thickness*
- ϕ: Porosity
- *ρ:* *Water density*
- X^{CO2}: *Carbon content in formation water*
- C_c: *Capacity coefficient*
- *s,0:* *saturation and initial, subscripts*

Regional-Scale
CO_2 Storage Capacity in Coal Beds

Theoretical Capacity

$$IGIP = A \times h \times \tilde{n}_C \times G_C \times (1 - f_a - f_m)$$

Effective Capacity

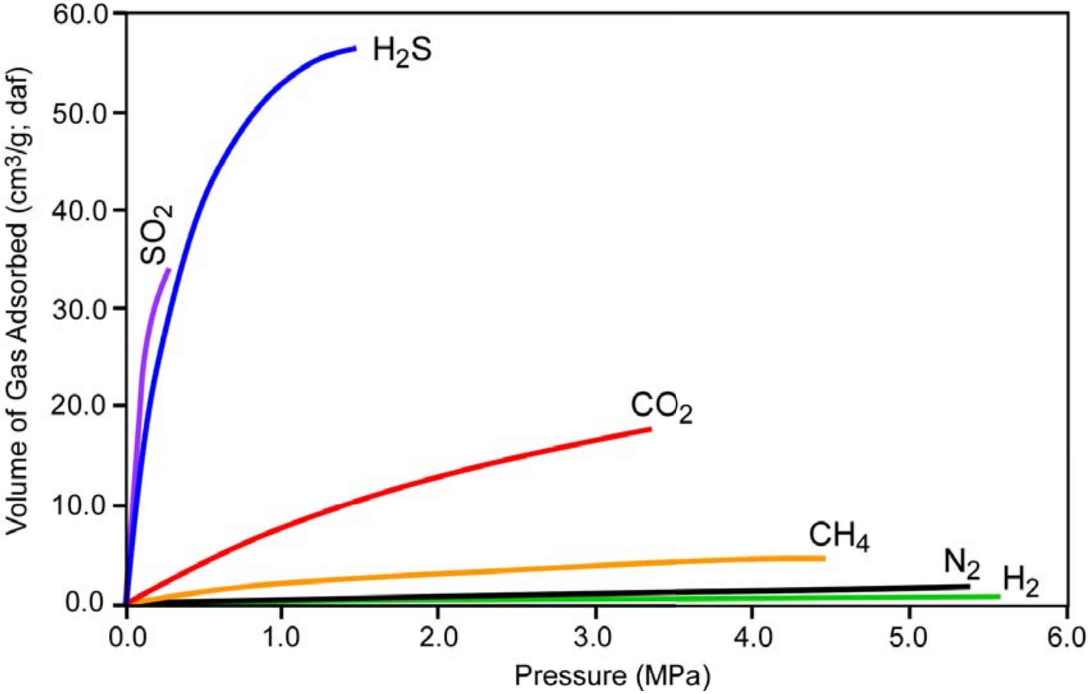
$$PGIP = R_f \times C \times IGIP$$

- IGIP: Initial Gas in Place (or storage capacity)
- A: Area of the coal bed
- h: Net thickness of the coal bed
- n_{C}: Coal density, ~1.4 t/m^3
- G_c: Gas content
- f_a: Ash fraction
- f_m: Moisture (water) fraction
- R_f: Recovery factor
- C: Completion factor

Coal Gas Content

$$G_{CS} = V_L \times \frac{P}{P + P_L}$$

- P: Pressure
- P_L: Langmuir pressure
- V_L: Langmuir volume



Applicability of Methodologies for Estimating CO_2 Storage Capacity to Various Assessment Scales

Storage Mechanism	Trapping Mechanism	Temporal Nature[1]	Coefficients Needed[2]	Assessment Scale				
				Country	Basin	Regional	Local	Site-Specific
Oil & Gas Reservoirs	Stratigraphic and Structural	No	Yes	√	√	√	√	√
	Enhanced Oil Recovery	No	Yes	-	-	-	√	√
Coal Beds	Adsorption	No	Yes	√	√	√	√	√
Deep Saline Aquifers	Stratigraphic and Structural	No	Yes	√	√	√	√	√
	Residual Gas	Yes	?	-	-	-	√	√
	Solubility	Yes	Yes	-	-	-	√	√
	Mineral Precipitation	Yes	Yes	-	-	-	√	√
	Hydrodynamic	Yes	Yes	-	-	-	√	√

[1] – A trapping mechanism has a temporal nature if the physical or chemical storage process continues after cessation of injection

[2] – Various coefficients need to be estimated to cascade the storage capacity estimate down from theoretical to effective and to practical. These coefficients have to be determined based on field experience and/or numerical simulations

Concluding Remarks

- Any assessment of CO_2 storage capacity should carefully consider the processes involved, their spatial and temporal scales, the resolution of the assessment, and the available data and their quality

- Proper communication to decision makers of the assumptions made and methodologies used is essential in establishing sound policy and making the best decision regarding CCS implementation