Geological Sequestration & Sustainability of O&G Industry: Potential, Challenge & Strategy

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Committee – ICCSC (Indonesia Carbon Capture & Storage Center)
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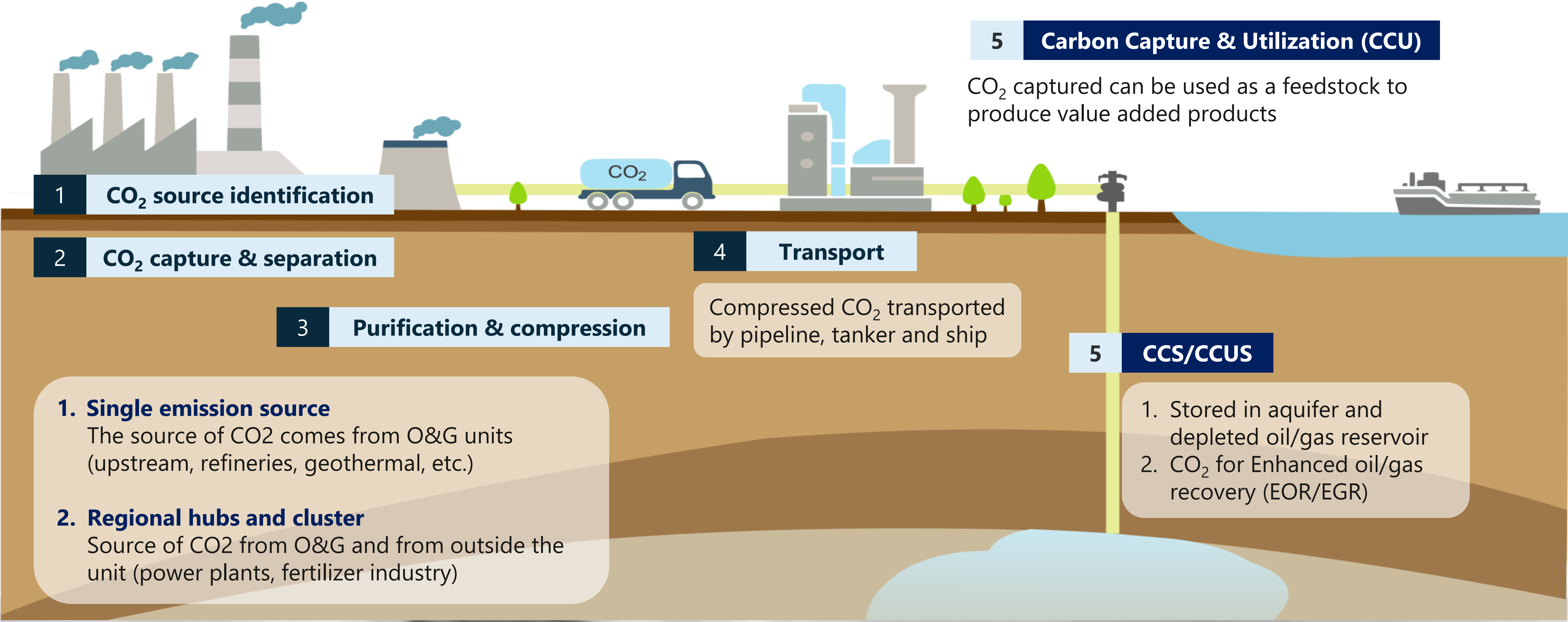
CCS/CCUS Value Chain Developments

CCUS is essential to unlock the full potential of decarbonization



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CCUS from Point Source

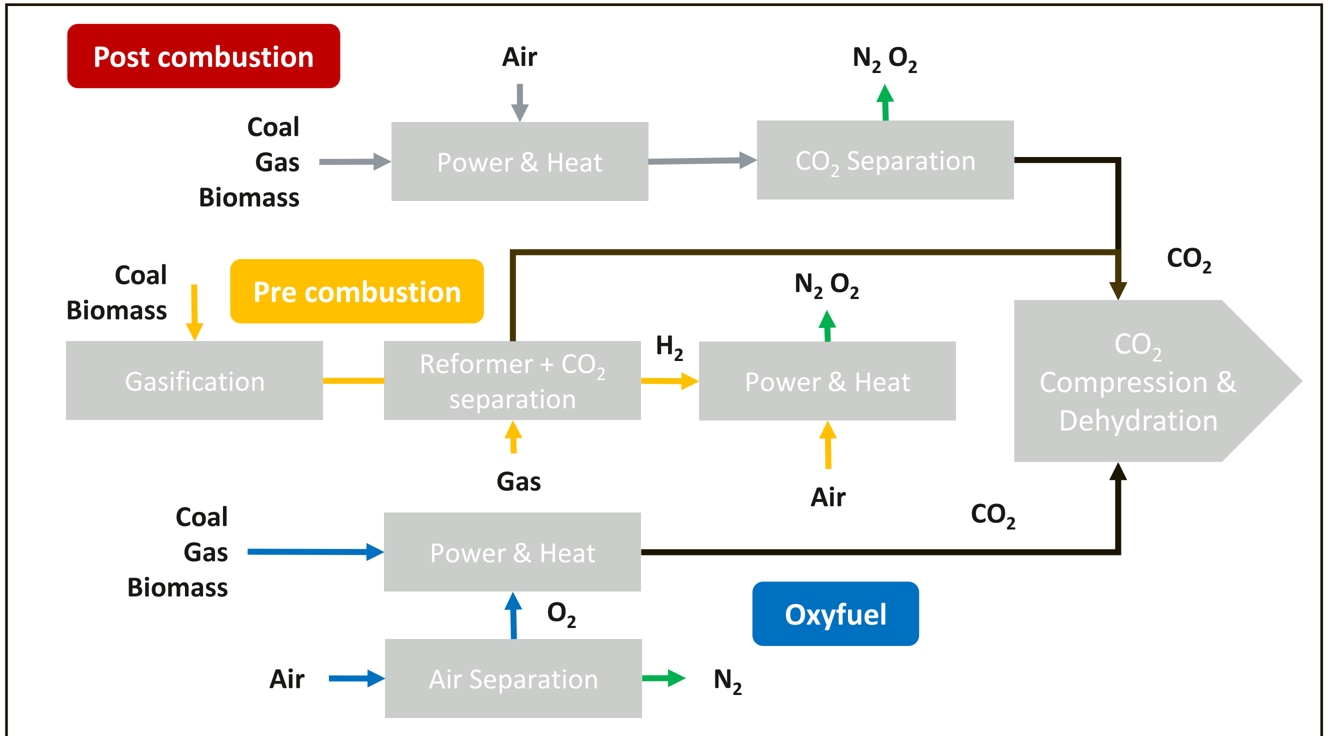
CO_2 source identification → **CO_2 capture & separation**

Mobile sources	Remain as challenges and are effectively treated as atmospheric
Point sources	• Pure CO_2 from steam reforming • Impure CO_2 from cement, steel plants, coal and natural gas power plants
Atmosphere	Lower concentration and capture is being developed

The cost of CO_2 capture depends on the source of CO_2 and separation method

High concentration sources typically have lower costs for CCUS

CO_2 is captured before it reaches the atmosphere in industries

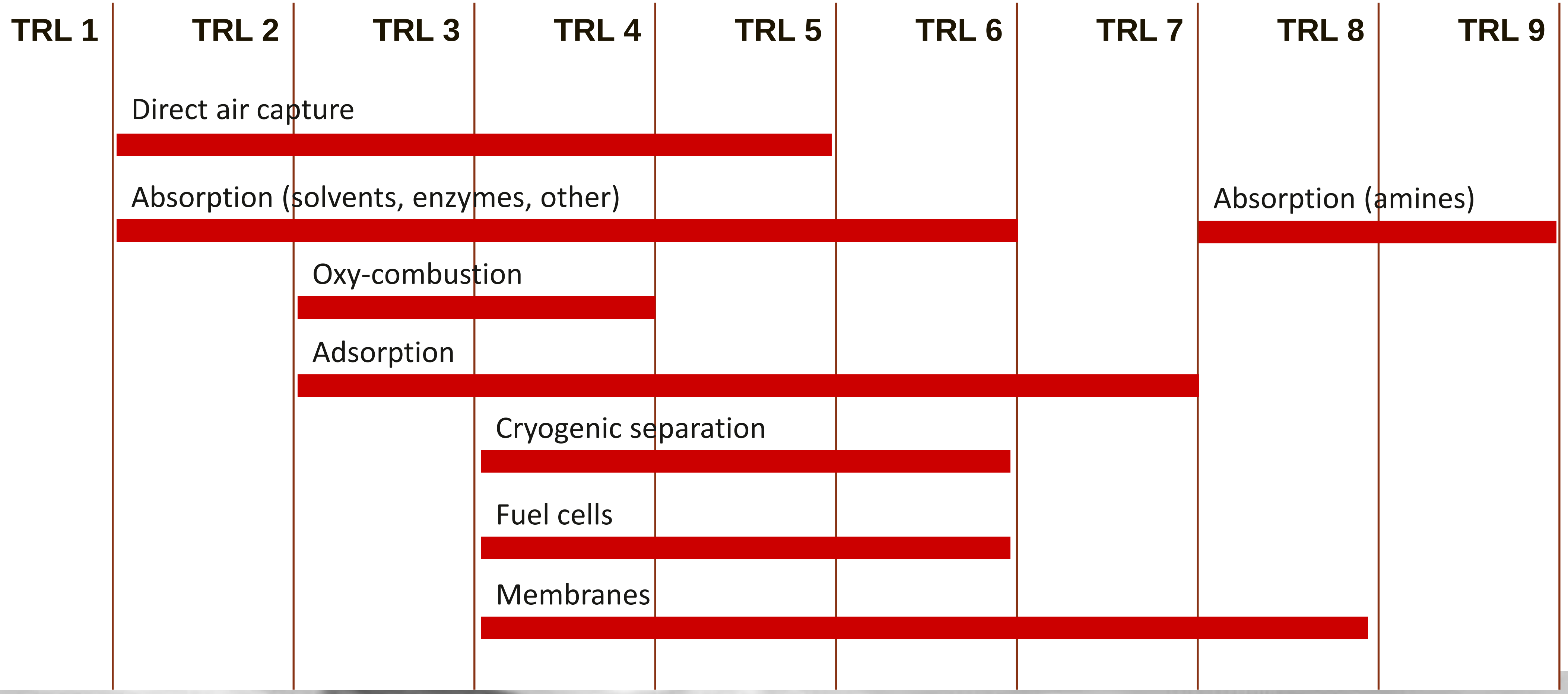


Source: Adapted from IPCC Special Report on CCS, 2005

Carbon capture equipment can be retrofitted in existing fossil infrastructure **to avoid stranded assets while delivering on net zero strategies**

Carbon Capture Technology Readiness Level

Many of the technologies required to move towards carbon neutrality would benefit and progress faster with the appropriate public sector alignment and support



Source:
Natural Petroleum Council: Draft Summary Report, Meeting the Dual Challenge, A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage, December 2019

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Technology and Cost of Carbon Capture

	CO_2 from combustion process (power plant)	CO_2 as by-product from Industrial processes		CO_2 from the atmosphere
Source (vol percentage)	**Coal** (~14 %-vol)	**Fertilizer** (8 - 10 %-vol)	**Cement** (20 - 30 %-vol)	**Ambient Air** (0.04 %-vol)
	Natural gas (3 – 10 %-vol)	**Refineries** (40 – 80 %-vol)	**Steel & Iron** (15 - 20 %-vol)	
	Fuel oil (3 – 8 %-vol)	**Ammonia** (up to 100 %-vol)	**Petrochemicals** (10 - 20 %-vol)	
	Biomass (3 – 8 %-vol)	**Natgas Processing** (90 – 100 %-vol)		
Cost of Capture	**Low CO_2 Concentration** 60 – 150 USD/ton CO_2	**High CO_2 Concentration** 20 – 60 USD/ton CO_2		**Direct Air Capture** 150 – 350 USD/ton CO_2

Global Player

CO_2 Suitable Capture Technology:
Chemicals Solvent

Honeywell | THE LINDE GROUP | BASF | DOW | Lurgi | EASTMAN

High concentration enables **direct separation and cheap capture** whereas low concentrations require an additional expensive concentration step

Source:
- Modified from Kearney - Energy Transition Institute, CCUS (2021)
- IEA (2013

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CO_2 Transport Technology

For long-distance transportation of high volumes, **pipelines are mature**, and shipping is being studied

PIPELINES

Distances: most economical for 1,000 – 1,500 km

Volumes: cost effective for large volumes, high CAPEX, low OPEX

Transport condition:
Compression under the form of supercritical fluid

SHIP

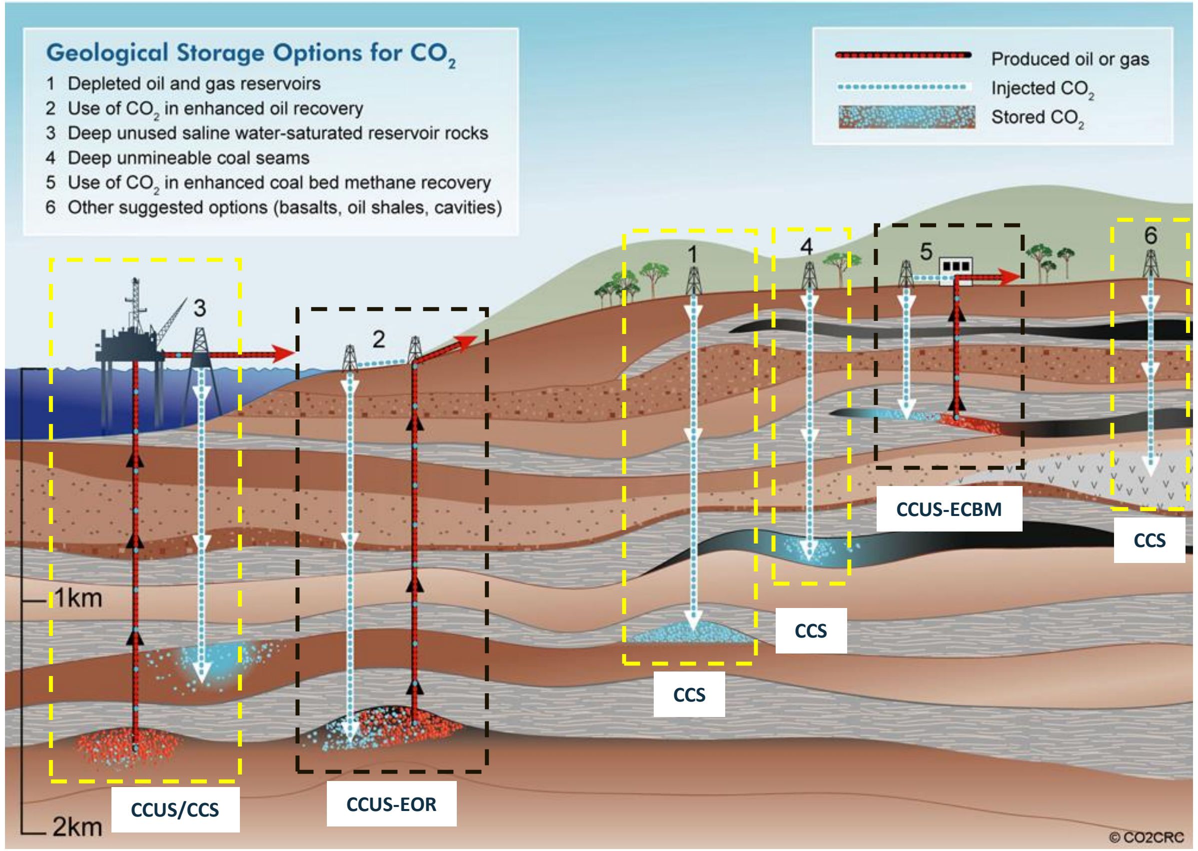
Distances: most economical for > 1,500 km [1]

Volumes: technically feasible to transport large volumes, low CAPEX, high OPEX [2]

Transport condition:
Liquefaction (Requires the construction of a liquefaction facility at the point of origin)

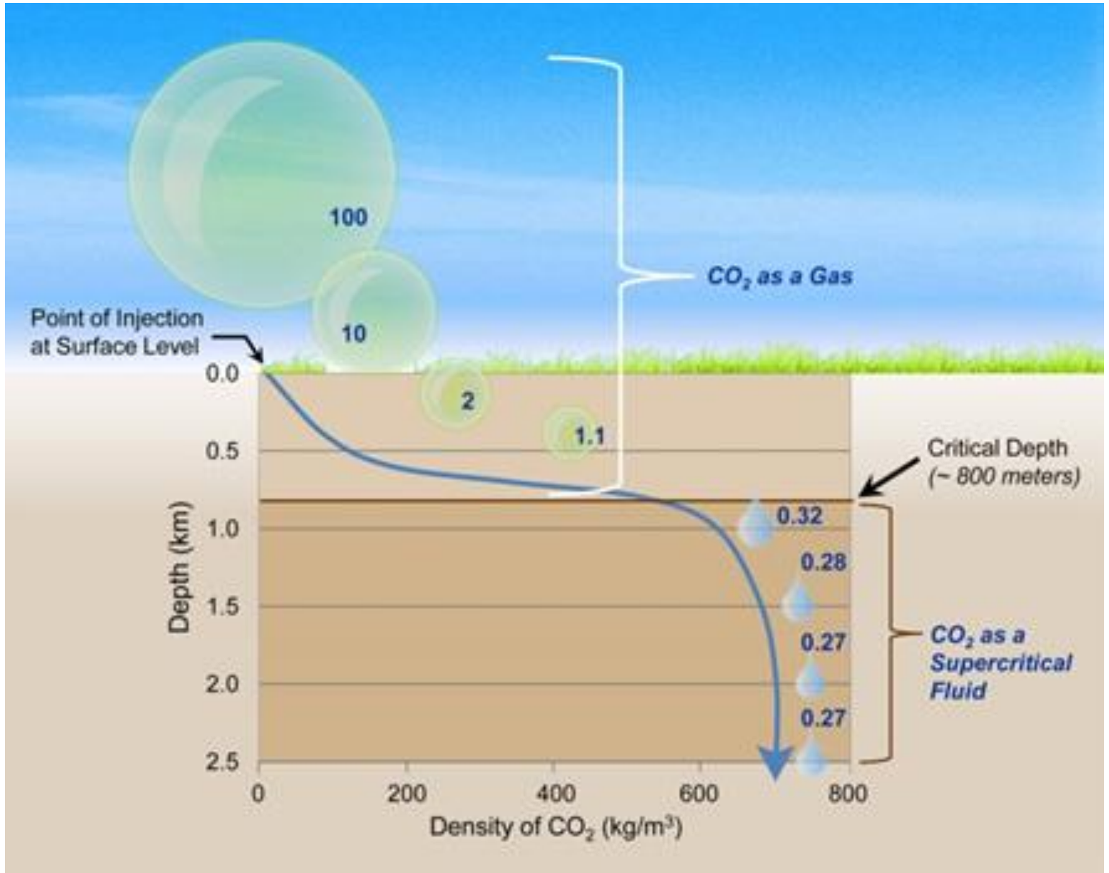
Source:
[1] Zero Carbon Capture Utilization Storage
[2] Kearney, CCUS

The Characteristics of CO_2 Geological Storage



Implementation of CO_2 Geological Storage:

- Deep Saline Reservoir
- Depleted Oil and Gas Reservoir
- CO_2 EOR, EGR and ECBM



CO_2 must be injected >800M in depth with 31^0 C and 1070 psi to achive **"Super Dense Fluid"**

Source:
- IPCC (2005: 208)
- National Energy Technology Laboratory, U.S Department of Energy

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Aspects of CO_2 Storage Sites

1. CO_2 storage capacity

Reaching the supercritical condition is essential for CO_2 to approach a high density and gas-like viscosity, resulting in a complete pore volume utilization and mobility within a reservoir

2. Injectivity

The ease with which fluids can flow through stratigraphic intervals

3. Trapping mechanism

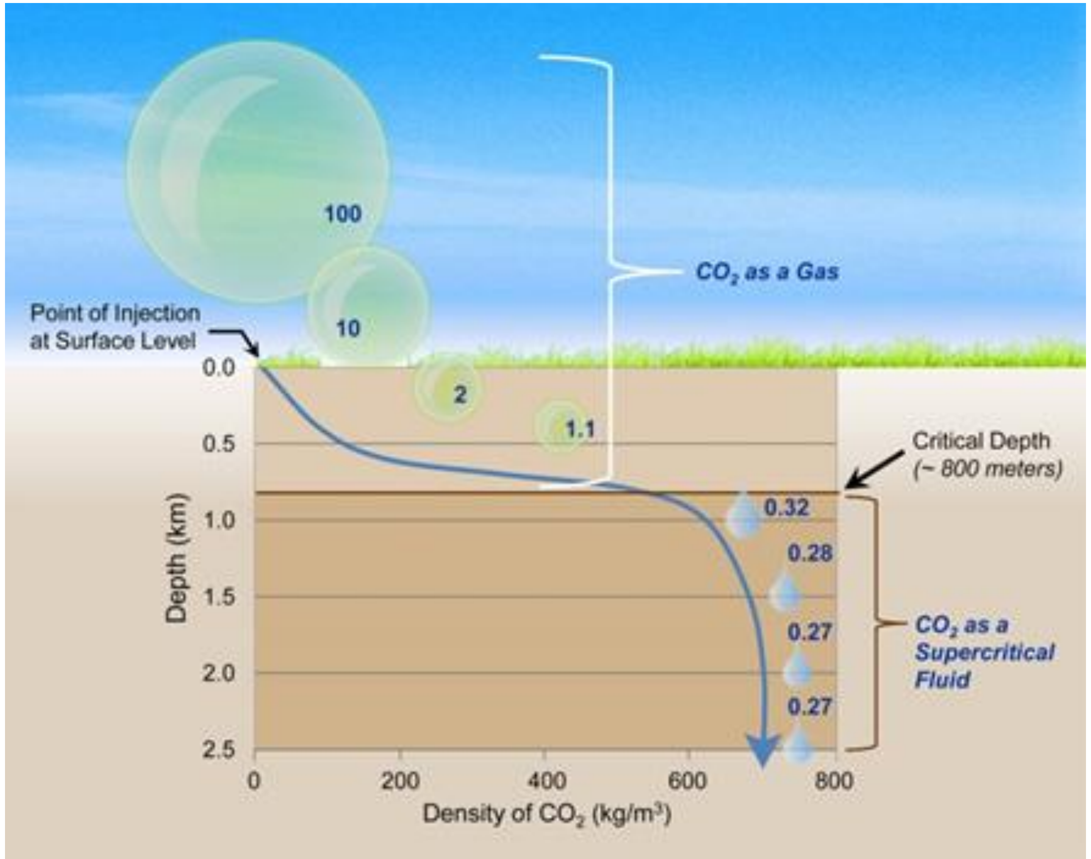
The efficiency of the trapping mechanism, however, depends mainly on reservoir characteristics and in-situ parameters

4. Containment

Containments of a storage site depend mainly on the characteristics of caprocks, faults and fracture surrounding a reservoir

5. Cost

Careful considerations of costs included in a storage project is an essential step at early stages before the injection begins



Source: Raza, et al (2016)

Screening Methodology for CCS/CCUS Field Selection

Field screening methodologies are needed to obtain suitable fields that have potential as CCS/CCUS fields

Preliminary field screening

General criteria

Depth > 1,000 m; Normal Pressure/ Slightly under pressure (P>500)

CO_2 storage capacity calculation

CO_2 storage capacity equation [a]

$M_{CO2} = \rho_{CO2r}$ x RF x $OOIP/OGIP$ x B_o/B_{gCO2} x C_e **(Raza et al, 2017)**

M_{CO2} = $OOIP$x 5,615 x RF x B_o x C **(ITB)**

$M_{CO2t} = \rho_{CO2r}$ x (RF x $OOIP/ B_f - V_{iw} + V_{pw}$) **(Bachu et al, 2007)**

CO_2 source & distance from sink

Suitability/match the emitted CO_2 source with the capacity that can be accommodated by the field sink and considering distance and CO_2 transport infrastructure

Field selected

The selected field will be used as the detailed object feasibility study on the subsurface and surface aspect *(GGRP, geomechanics, surface facility, and monitoring)*

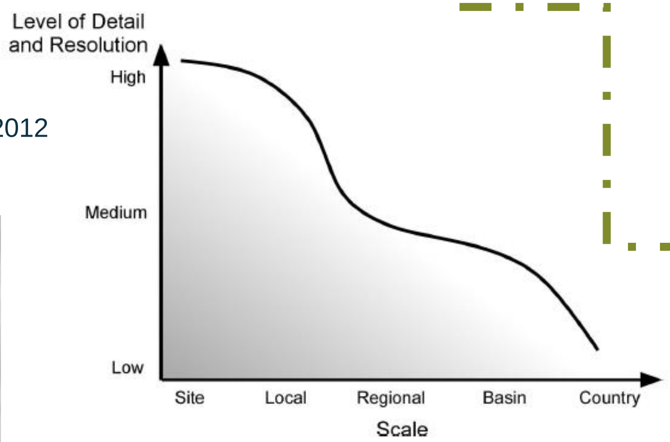
Equation description:

ρ_{CO2r}	= density of CO_2 based on P and T reservoir (kg/m^3)
RF	= recovery factor
OOIP/OGIP	= volume of original oil/gas in place (MMBBO/BSCF)
B_o/B_g	= oil/gas formation volume factor
C_e	= storage capacity factor for the gas fields
$V_{iw} + V_{pw}$	= the volumes of injected and produced water.

**B_o/B_g and C_e can use approximate values from the surrounding field and within one basin*

Benchmark for CCS/CCUS feasibility study

- **Country** (High level, Limited data)
- **Basin** (Identify and quantify storage potential)
- **Regional** (Increased level of detail, identify prospects)
- **Local** (Pre-engineering site selection, very detailed)
- **Site** (Engineering level for permitting, design and implementation)



Ref:

- Bachu, 2013, Bachu et al., 2007 and Bachu, 2012
- National Energy Technology Laboratory, U.S Department of Energy, 2013

Best Practice – NETL

Site Screening Phase (Regional Basin and Sub-basin)

- **Regional Geologic Data:** Injection formation, Adequate depth, Prospective storage resources
- **Regional Site Data:** Protected and sensitive area, Population, Existing resource development, ROW Pipeline
- **Social Data:** Demographic trends, Land Use (Industrial/Enviromental)

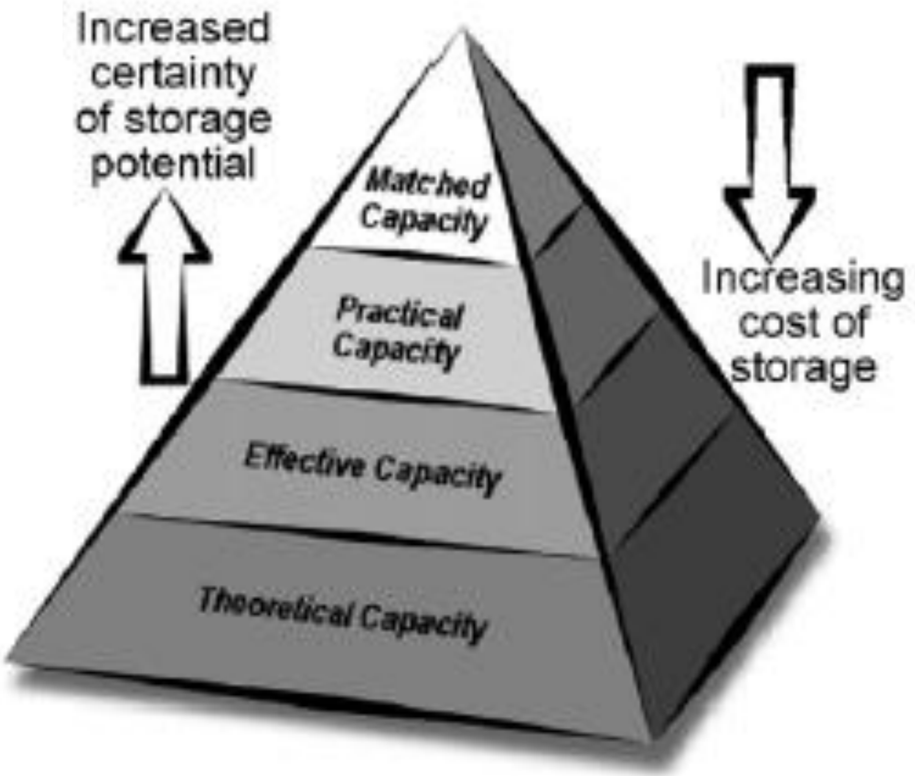
Site Selection Phase

- **Subsurface Geologic Data:** Injection zone, Confining system, Trapping mechanicsm, Potential injectivity, Evaluate existing seismic, Prospective storage resources
- **Regulatory Req:** Well classification, Corrective action, Injection pressure, Containment mechanism, Liability
- **Model Data:** Modelling parameters, Data req and cost, Boundary condition, Intergrate seismic
- **Site Data:** Infrastructure, AOR req, Surface access issues, Pore space ownership
- **Social Data:** Gather and assess social data

Site Characterization Phase

- **Baseline:** Geological, Geochemical, Geomechanical, Hydrological, and Flux
- **Regulatory Req:** Determine applicable regulations, Develop well plan, and Permit planning
- **Model Data:** Test model, Input data/Screnario analysis, and Compare outputs
- **Social Data:** Critical path analysis, Establish outreach team, Identify stakeholders, and Social characterization
- **Site Development Plan:** Update initial plan, Commision feed study, and Develop tender requirements

Detail technical calculation CO2 storage



Theoretical Capacity: Includes large volume of “uneconomic” opportunities. Approaches physical limit of pore rock volume; estimates impractical for project development
Effective Capacity: Applies technical cut off limits, technically viable estimate, more pragmatic, actual site/basin data
Practical Capacity: Applies economic and regulatory barriers to effective capacity
Matched Capacity: Detailed matching of sources and sink including supply and reservoir performance assessment

For a basin's saline aquifer:

$$M_{CO_2} = \rho_{CO_2} \times V_b \times V_p \times P_p \times E$$

ρ_{CO2} : density of CO_2 at average T & P
V_b : volume of sedimentary basin below 1.000 meters
V_p : % of permeable sediments in plays
P_p : % average porosity
E : efficiency of storage is 0.12%

For a basin's coal seams:

$$M_{CO_2} = \rho_{CO_2} \times OGIP \times SF \times E$$

OGIP: original gas in place in coal beds below 600 meters
SF : selectivity factor in the coal, assumed 2

For a depleted oil field:

$$M_{CO_2} = \rho_{CO_2} \times OOIP \times RF \times B_o$$

OOIP: original oil in place
RF : % recovery factor
Bo : oil formation volume factor

For a depleted gas field:

$$M_{CO_2} = \rho_{CO_2} \times OGIP \times RF \times B_g$$

OGIP: original gas in place
Bg : gas formation volume factor

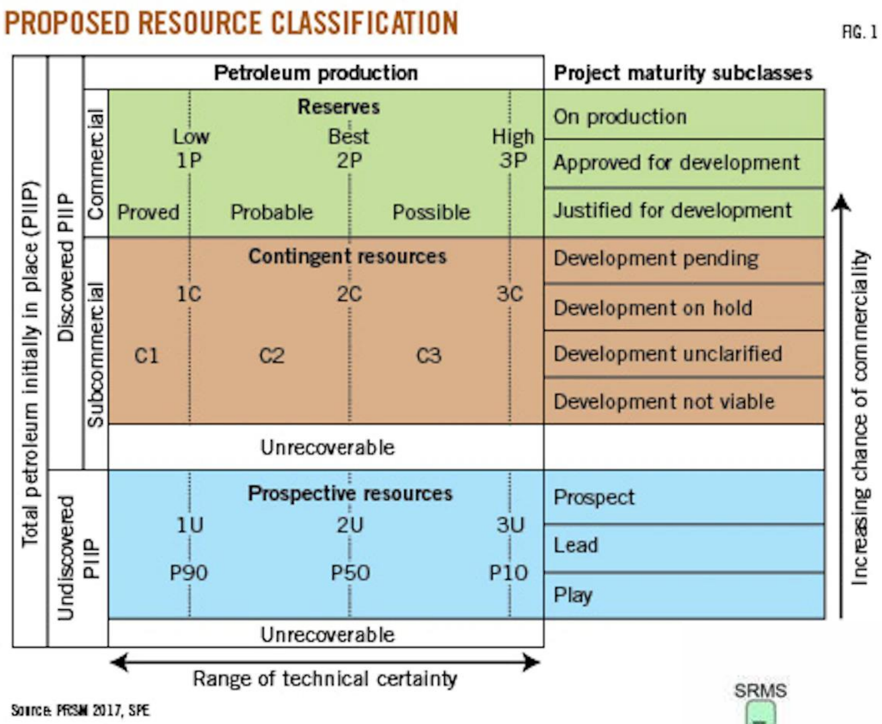
For a oil field due to CO_2-EOR:

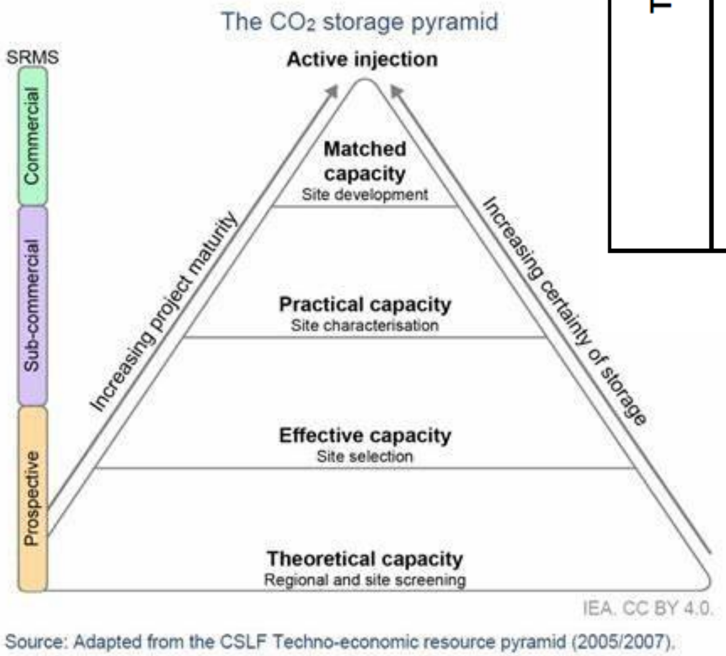
$$M_{CO_2} = \rho_{CO_2} \times IOP \times B_o$$

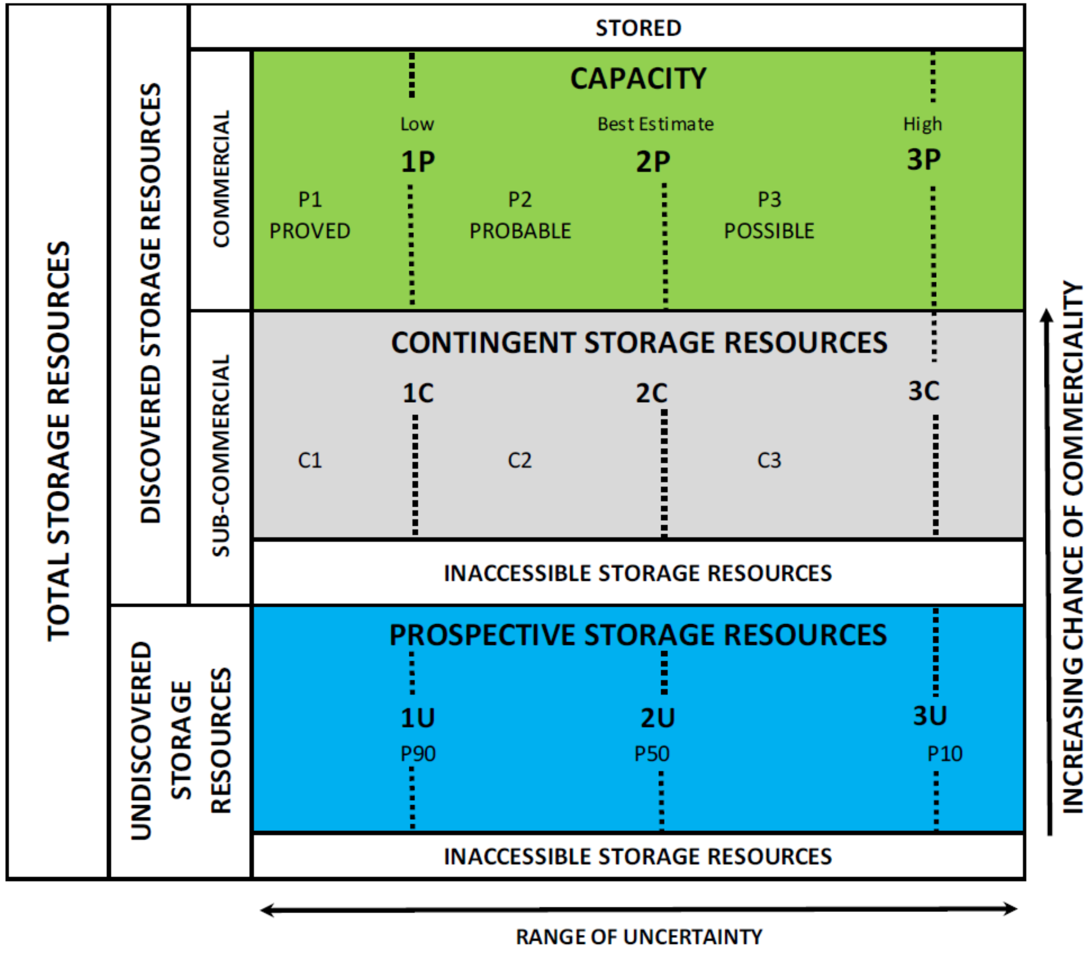
IOP : incremental oil production
M_{CO2}: mega-tonnes CO_2

Source:
- US DOE & National Energy Technology Laboratory, U.S Department of Energy
- Bachu et al., 2007

Storage Resources Management System (SRMS)







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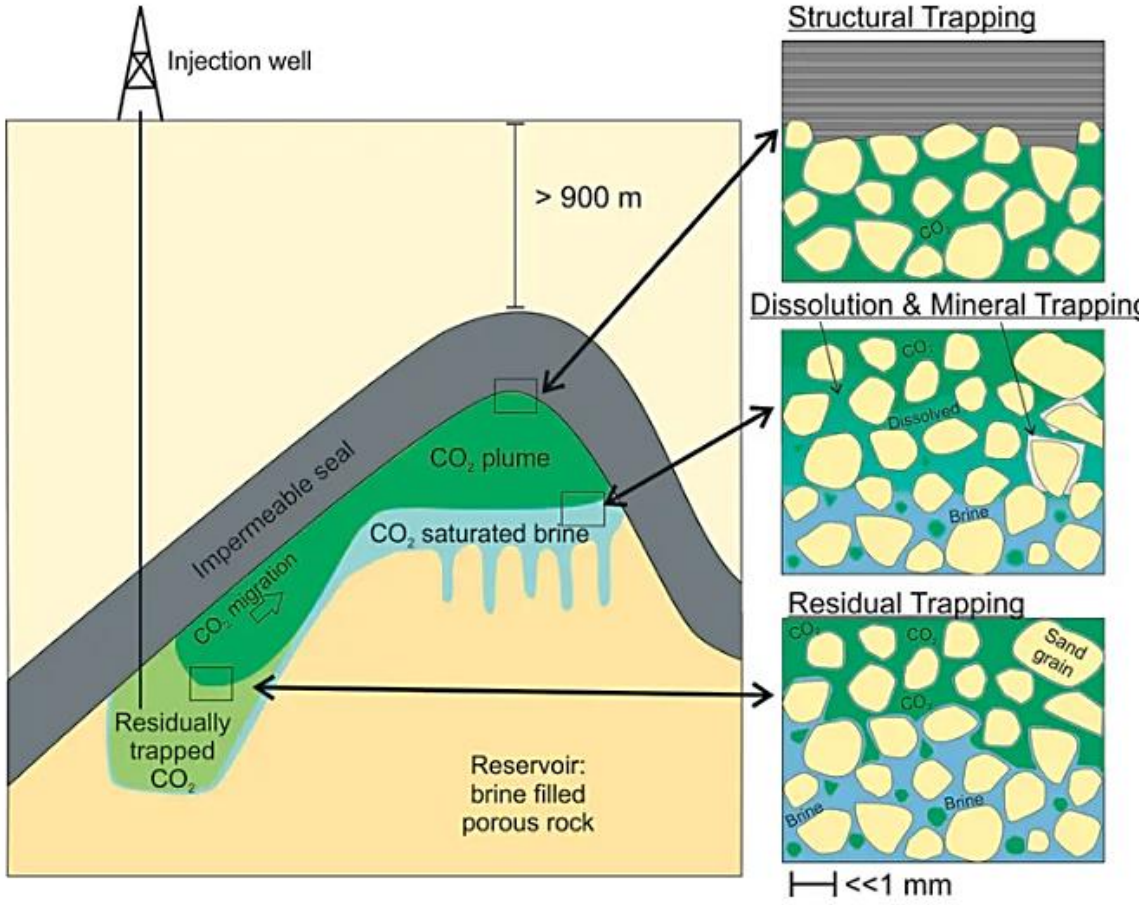
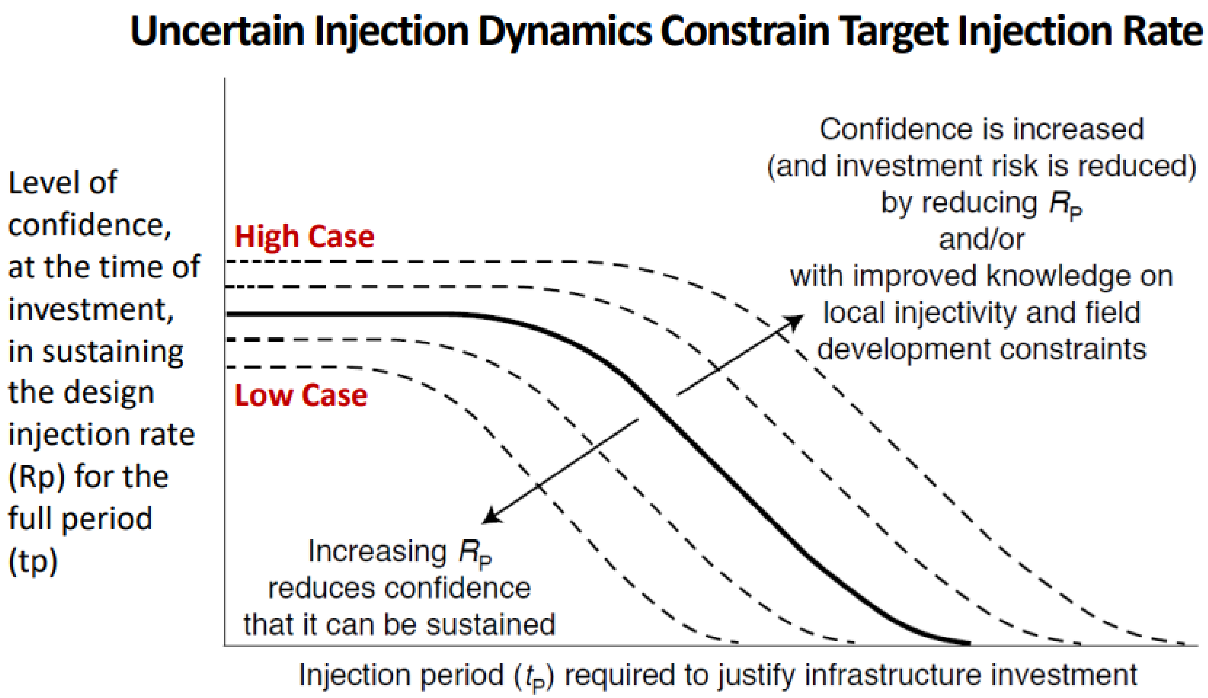
Injectivity Constraints



The different trapping mechanisms that immobilize CO_2 underground [2]

The safety of a storage site depends on a combination of injectivity and trapping mechanism [1]



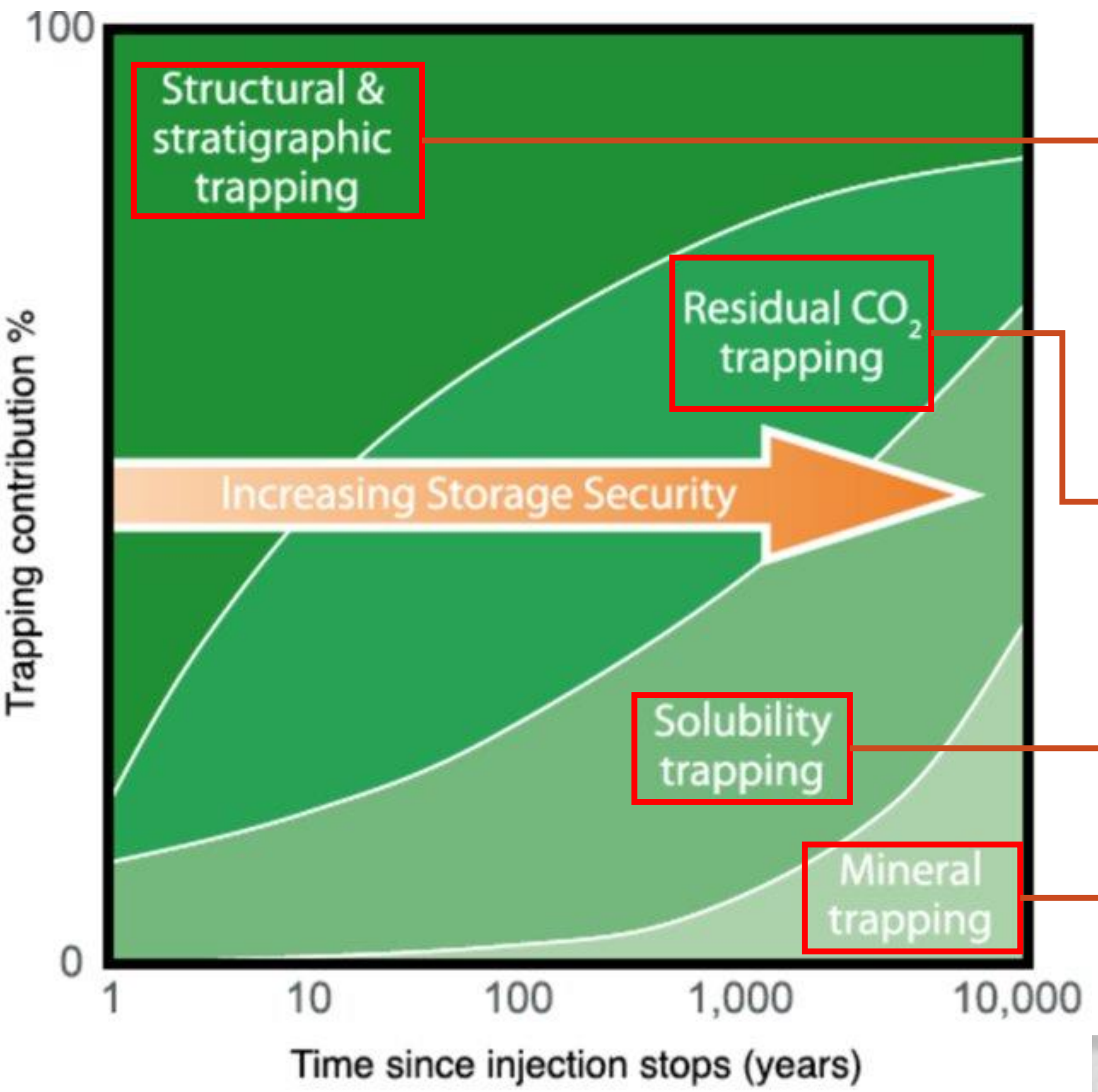
From Lane et al. 2021
https://doi.org/10.1038/s41558-021-01175-7

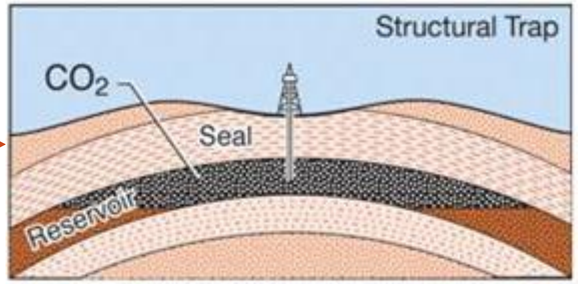
Source:

[1] Modified from IPCC 2005

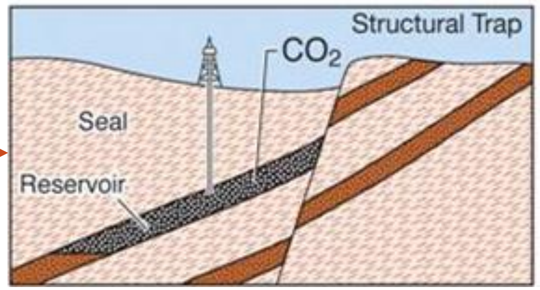
[2] Stephanie Flude, 2020

CO_2 trapping mechanism

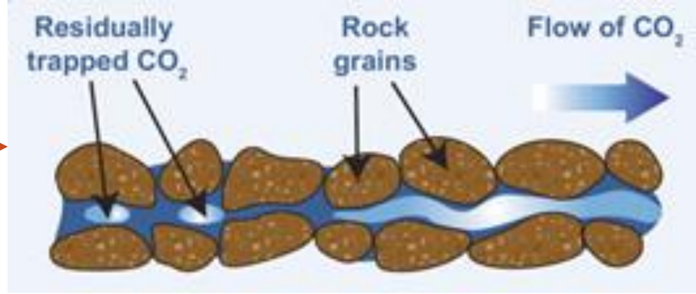




Anticline

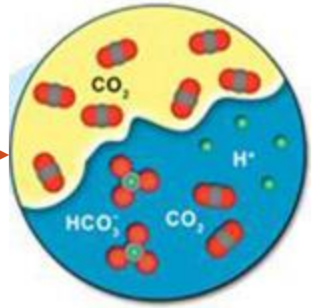


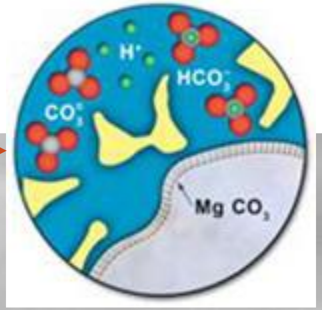
Fault System



- Residual trapping refers to the CO_2 that remains trapped in the pore space between the rock grains as the CO_2 plume migrates through the rock.

- In solubility trapping, a portion of the injected CO_2 will dissolve into the brine water that is present in the pore spaces within the rock





- Mineral trapping refers to a reaction that can occur when the CO_2 dissolved in the rock's brine water reacts with the minerals in the rock.

Source:
- IPCC (2005: 208)
- National Energy Technology Laboratory, U.S Department of Energy

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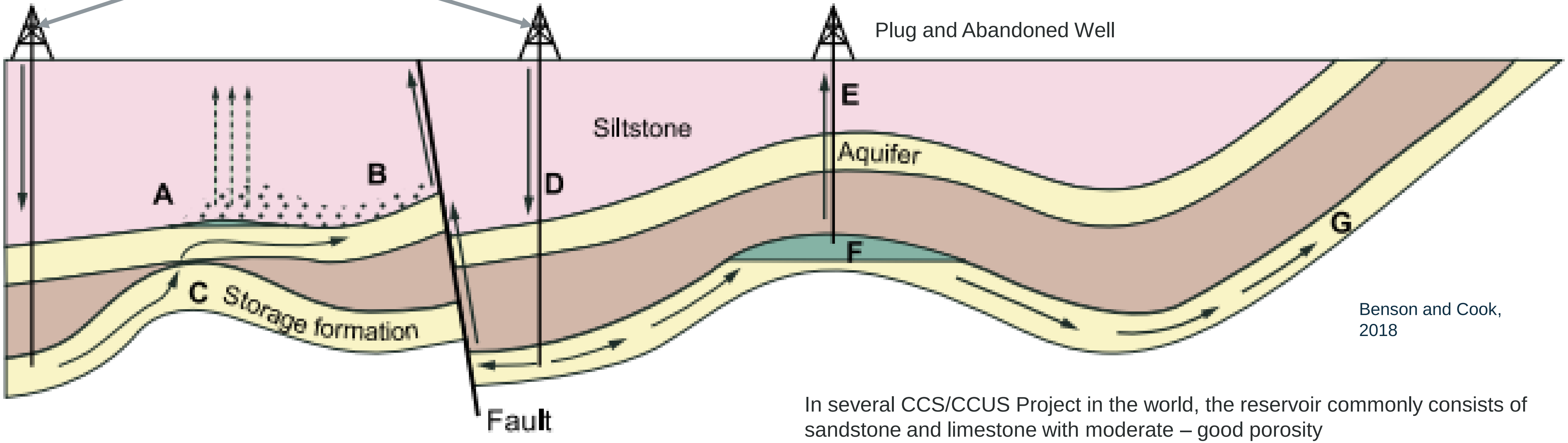
Potential CO_2 Leaking

Injected CO_2 migrates up dip maximizing dissolution & residual CO_2 trapping

E. CO_2 escapes via P & A well

F. Natural flow dissolve CO_2 at CO_2 / Water interface & migrates it out of closure

G. Dissolved CO_2 escapes to atmosphere or ocean



Benson and Cook, 2018

In several CCS/CCUS Project in the world, the reservoir commonly consists of sandstone and limestone with moderate – good porosity

A. CO_2 Gas Pressure > Capillary Pressure

B. CO_2 migrates from zone A into fault system

C. CO_2 escape through "gap" in cap rock into aquifer

D. Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault

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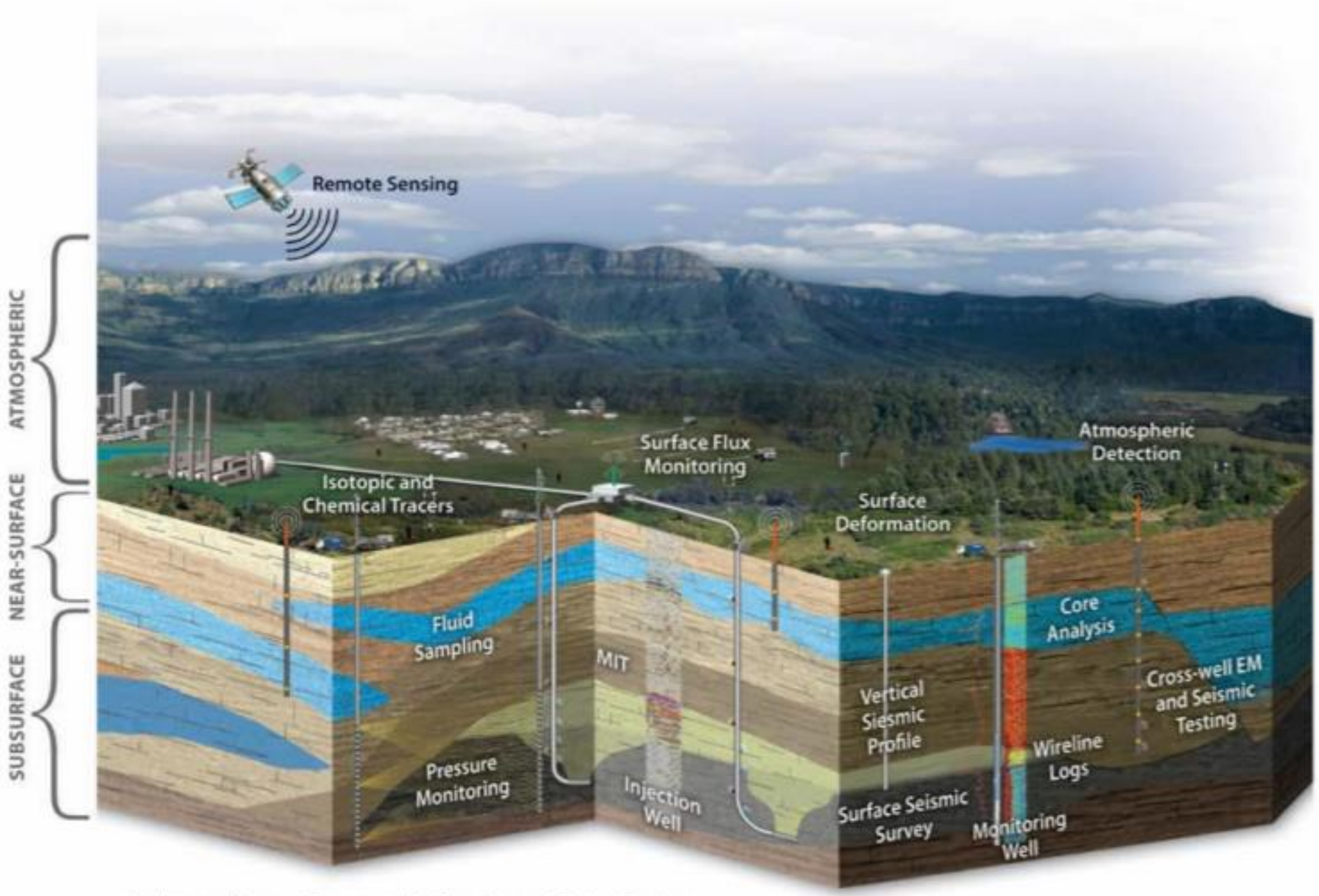
CO_2 Monitoring Mechanism in CCS/CCUS Activities



Background Image Courtesy of Schlumberger Carbon Services

Proposed CCS / CCUS Commercial Scheme

CAPTURE → TRANSPORT → STORAGE & UTILIZATION

Legend:
- project owner (potentially eligible for emission reduction)
- secondary stakeholder

Model	CAPTURE	TRANSPORT	STORAGE & UTILIZATION	Secondary stakeholder
Self-built Model (integration)	*O&G company*			• *Government* • *CO2 offtaker (for utilization)*
Partnership (JV, consortium)	• *Emitter* • *Transport operator* • *O&G Company*			• *Government* • *CO2 offtaker (for utilization)*
External emitter (pay at the gate)	*Emitter*	*Transport operator*	*O&G Company* *Potential Partners*	• *Government* • *CO2 offtaker (for utilization)*
Hub / cluster	*Emitter 1* *Emitter 2* *Emitter 3*	*O&G Company & Potential Partners*		• *Government* • *CO2 offtaker (for utilization)*

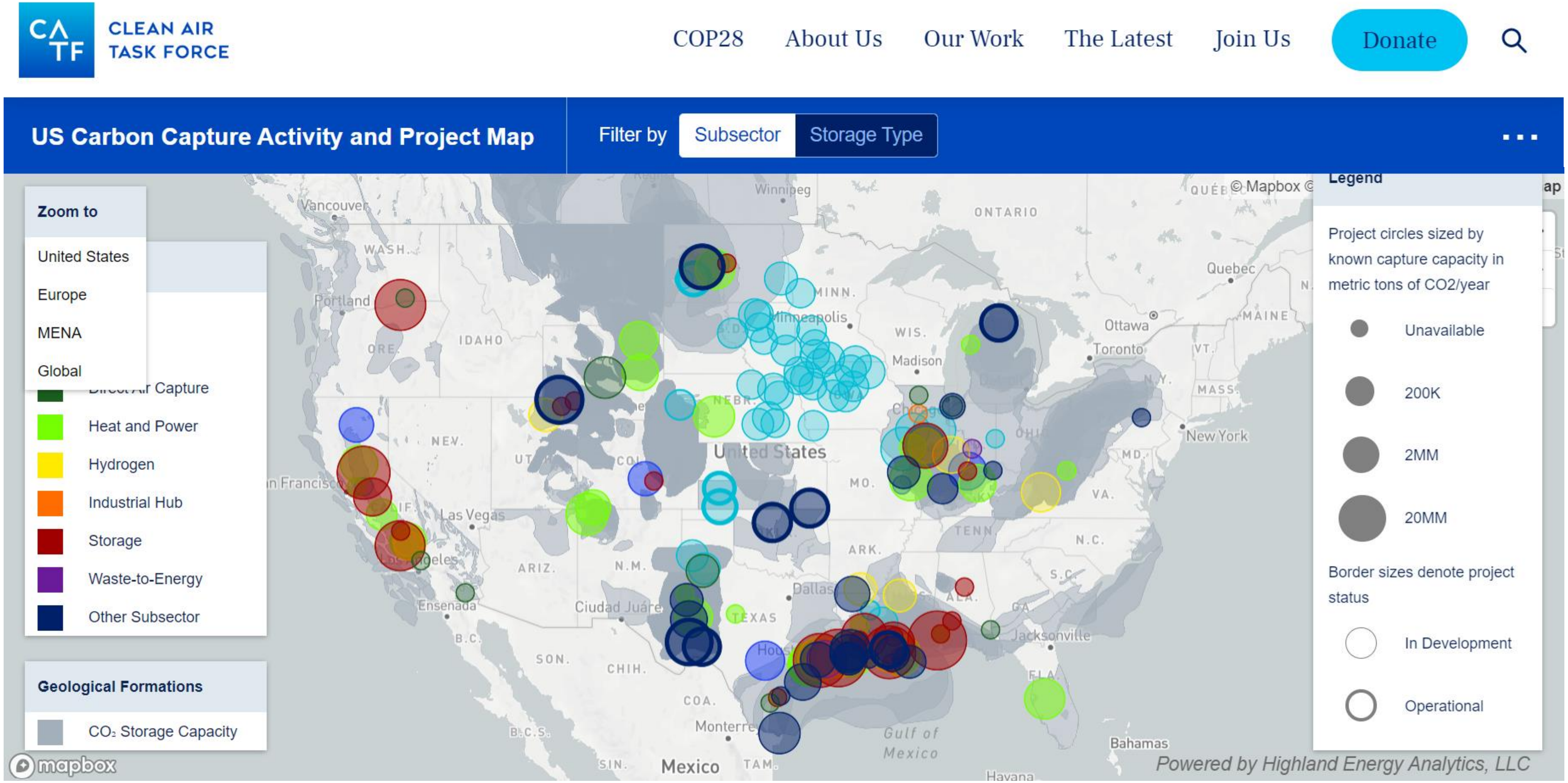
Self-built Model (integration):
- *Single integrated project owner, high level of control, no major coordination issues*
- *Limited to O&G or very large CO2 emitter only*

Partnership (JV, consortium):
- *Several project owners share costs and risks*
- *Risk of cancellation if partners pulls out*
- *Difficulties in managing different industrial cultures*

External emitter (pay at the gate):
- *Emission reduction potentially be shared based on agreement among parties*
- *O&G company may receive CO2 injection fee as compensation*

Hub / cluster:
- *Shared infrastructures for transport and storage reduce up-front CAPEX*
- *Involvement of public authorities facilitates public acceptance*
- *Not for early demonstration phase*

Global Comparison (US Cases)



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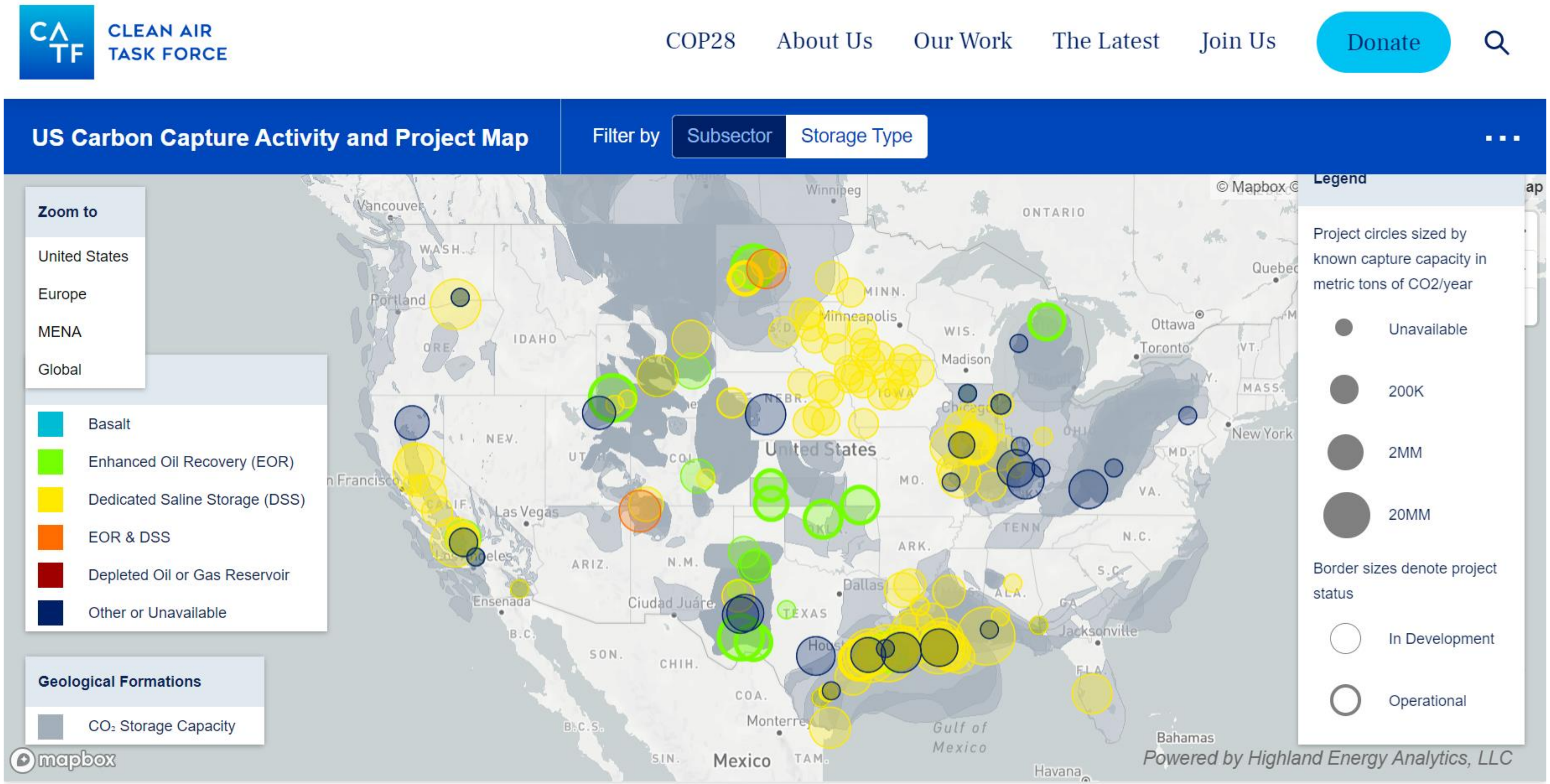

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Q & A

DISCUSSIONS

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