Gulf Coast Land Institute

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Powering The Profession

CCUS Geology for the Landman

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Outline

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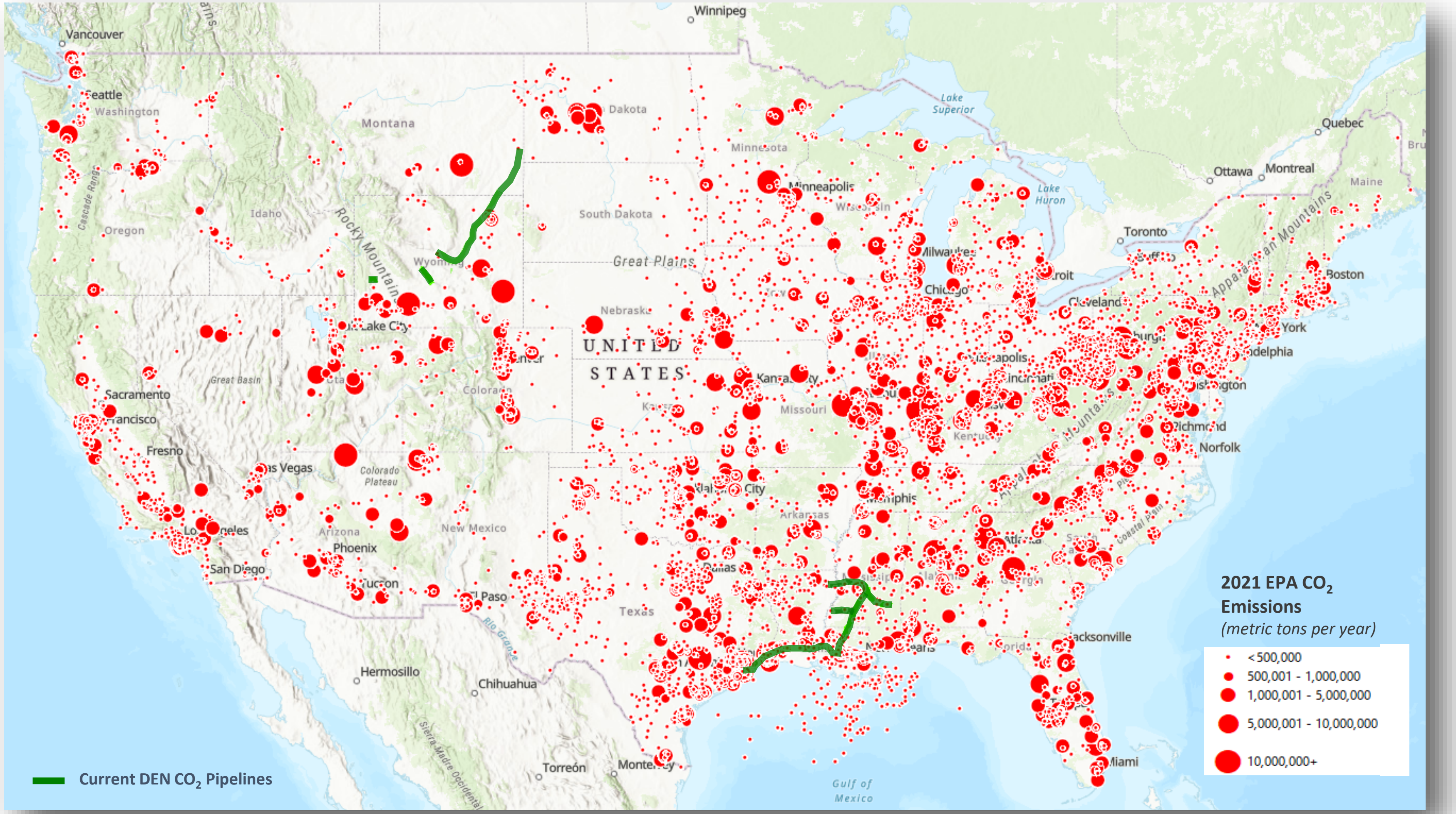

CCUS Overview

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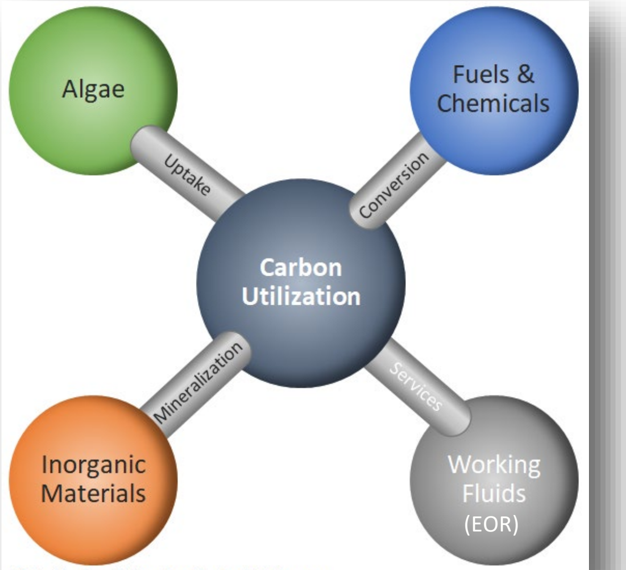
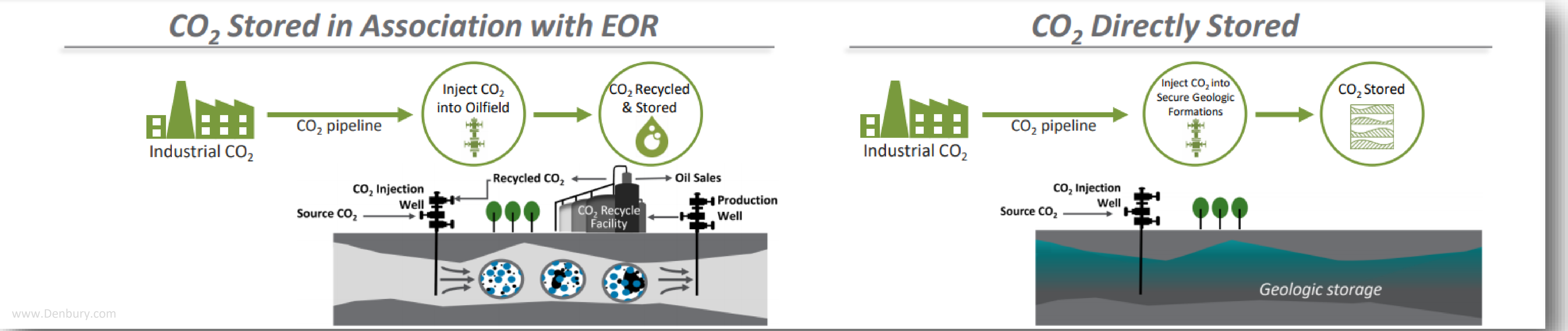
What is CCUS

- CCUS- Carbon Capture Utilization and Storage
  - A process that involves capturing industrial carbon dioxide (CO_2) at its source or from the atmosphere, *transforming it to valuable products in an efficient, economical, and environmentally-friendly way*, or storing it permanently underground
- CCS- Carbon Capture and Storage
  - A process that involves capturing industrial carbon dioxide (CO_2) at its source or from the atmosphere and storing it permanently underground



Major Carbon Utilization Product Pathways

www.netl.doe.gov



www.Denbury.com

Greenhouse Gas Comparison

Greenhouse Gas (GHG)	Atmospheric Lifetime (yrs)	Global Warming Potential (GWP)	Primary Current Sources
Carbon Dioxide (CO_2)	300-1,000	1	Fossil fuel use, cement
Methane (CH_4)	12 ± 3	21	Fossil fuel use, agriculture
Nitrous Oxide (N_2O)	120	310	Mostly agriculture, ~1/3 are anthropogenic
Hydrofluorocarbons (HFCs)	1.5-209	150-11,700	Alternative to ozone depleting substances
Perfluorocarbons (PFCs)	2,600-50,000	6,500-9,200	Primary aluminum production; semiconductor manufacturing
Sulfur Hexafluoride (SF_6)	3,200	23,900	Use in electric power transmission, magnesium and semiconductor industries

High GWP Gases

-GWP- total energy that a gas absorbs over 100 years relative to CO_2

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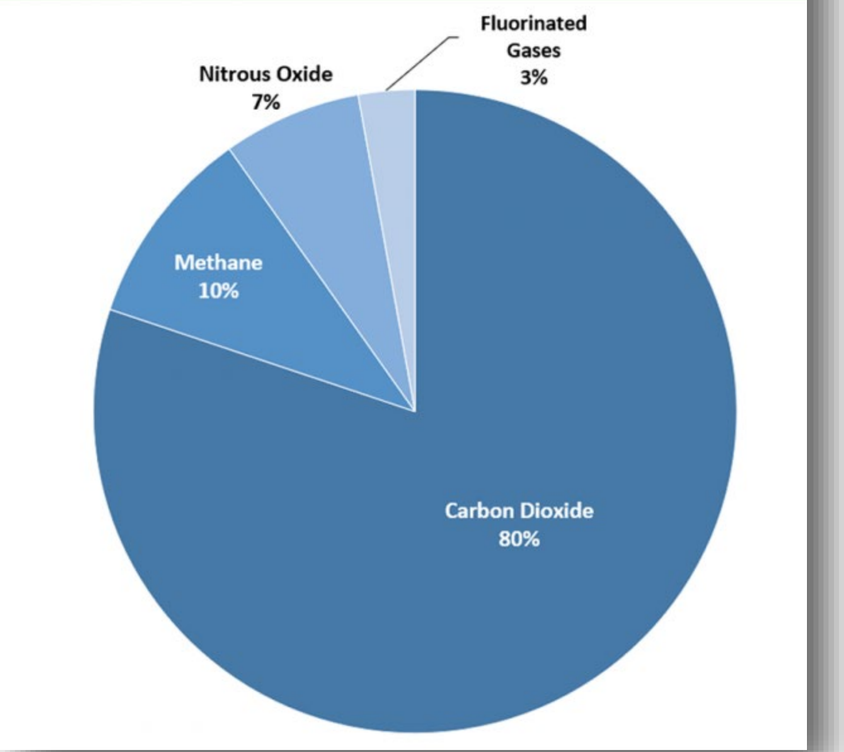
Overview of U.S. Greenhouse Gas Emissions in 2019[1]



[1] www.epa.gov

Why CCUS

- Paris Agreement was enacted to “limit global warming to well below 2°C, preferable 1.5°C, compared to pre-industrial levels”[1].
  - 2°C above pre-industrial temperature levels is considered the critical warming limit by IPCC
  - 2°C is based on **integration of climate-based impact, economic damage, and achievability**
- To limit global warming to 2°C at the end of the century, 140 billion tonnes of CO_2 must be captured and sequestered by 2060[2]
- Lowest cost pathway to deep reductions in global emissions requires the deployment of a portfolio of low emission technologies, including CCUS[1]

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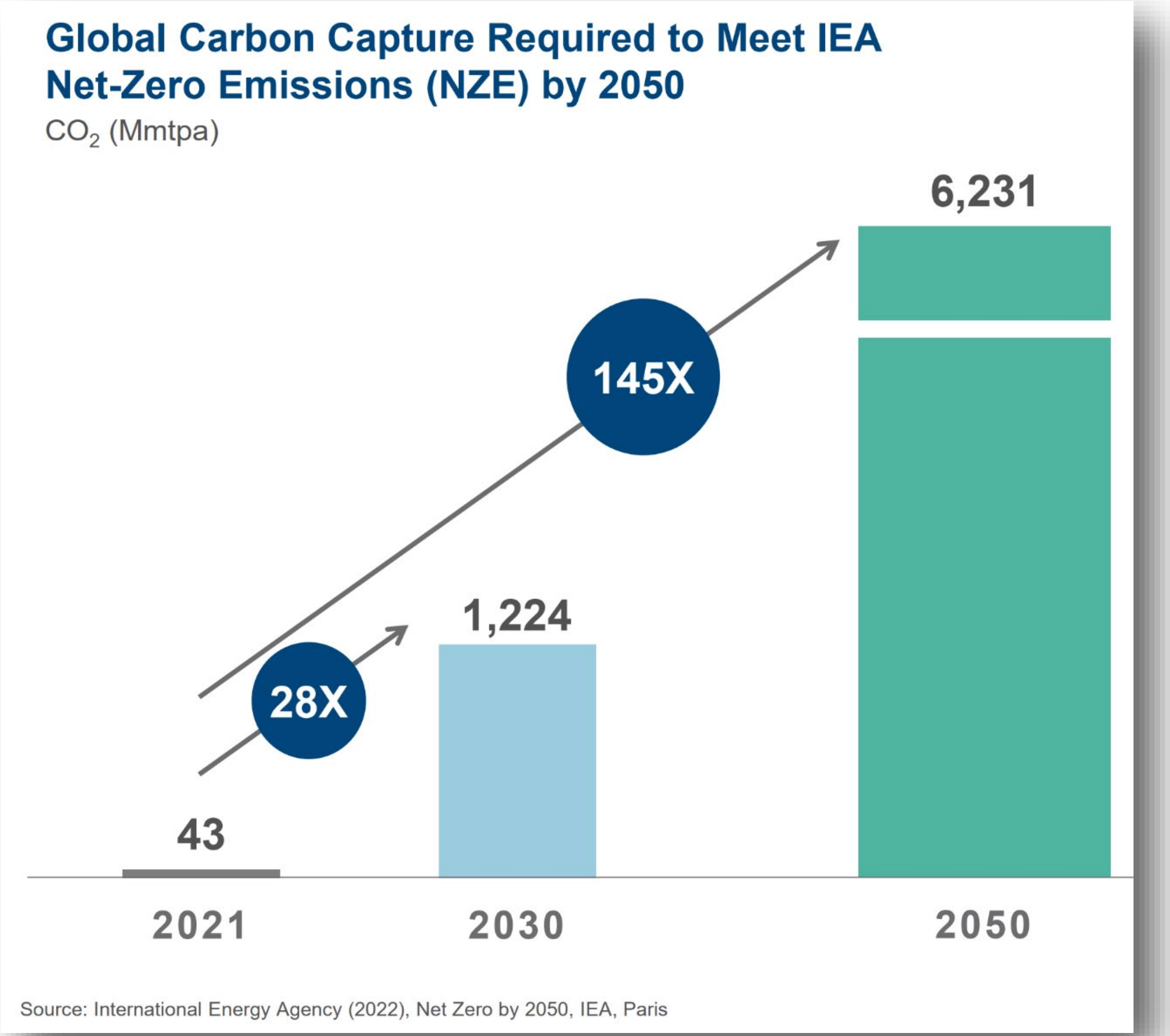

Source: International Energy Agency (2022), Net Zero by 2050, IEA, Paris

IPCC- Intergovernmental Panel on Climate Change
IEA- International Energy Agency

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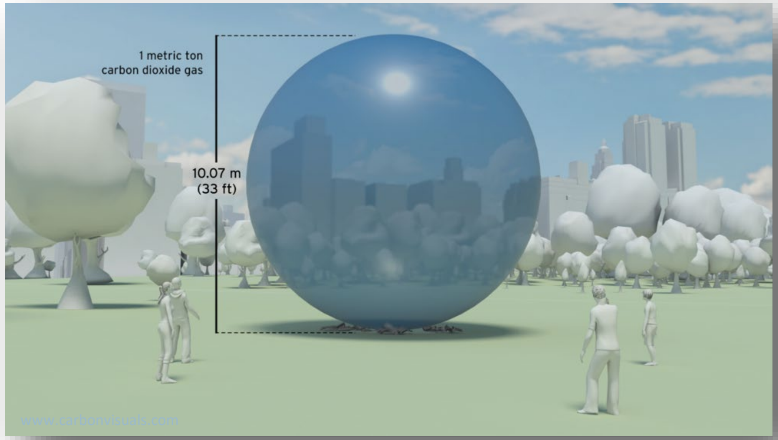
[1] www.IPCC.ch
[2] www.co2crc.com.au

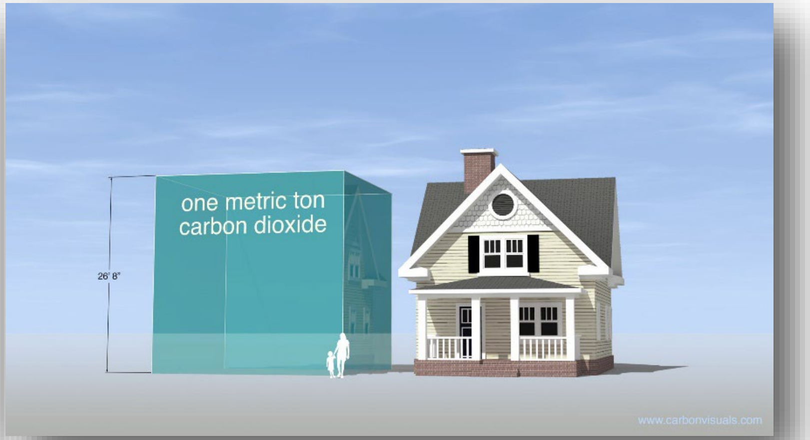
Units of Measurement

Ton, Tonne, Metric Ton, Short Ton, Long Ton, US Ton, British Ton (this is a ton of work!)

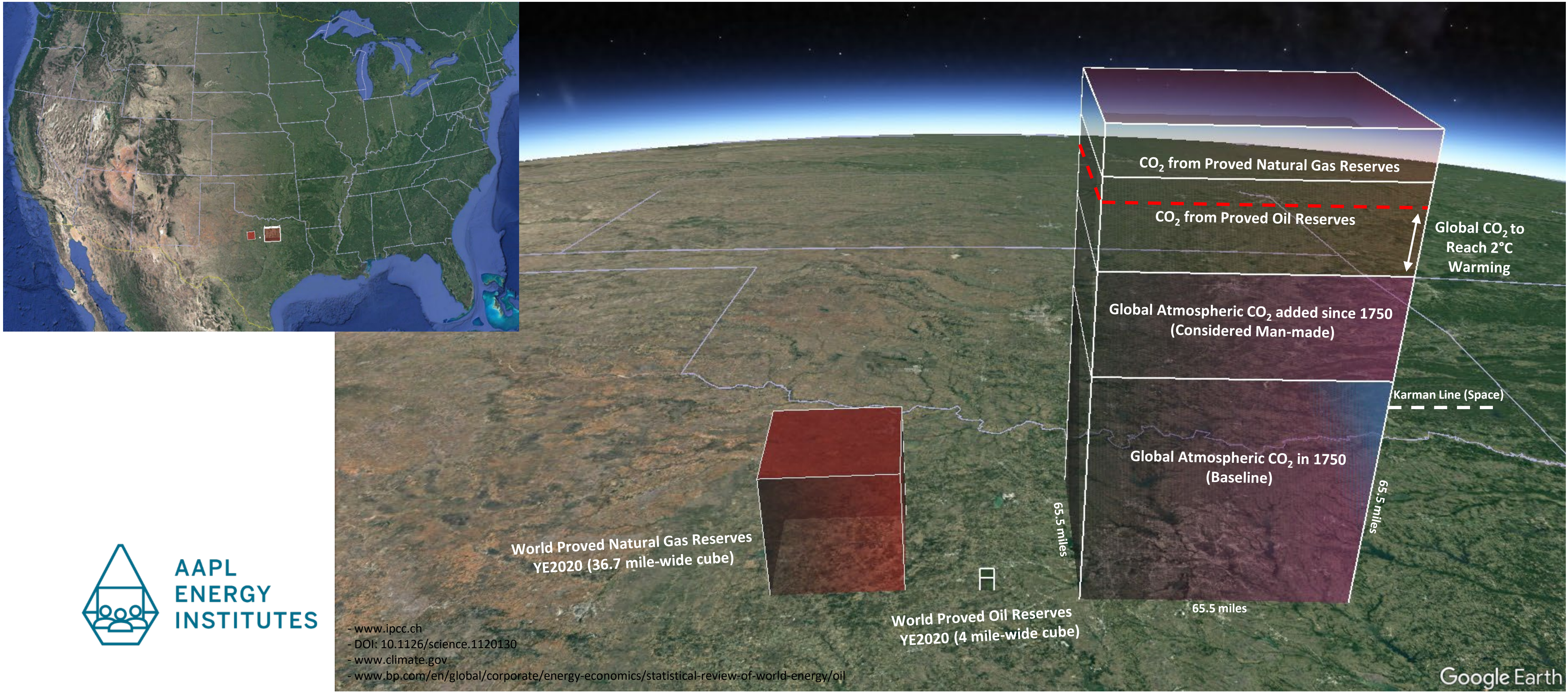
- Imperial Measurement:
  - British ton (long ton) = 2,240 lbs
  - American ton (short ton) = 2,000 lbs
- Metric Measurement:
  - Metric ton (or tonne) = 1,000 kg (2,204.6 lbs)
- But wait, there's more! A ton can be a unit of volume (displacement ton (DT)) or a unit of energy (ton of TNT)
  - The later is important because explosive power is often referred to in Megatons (but 1 million tonnes is also referred to as a Megatonne)
  - Ton is also slang for 100 (Britain) 1,000 (Finland) 100,000 (Netherlands) and "a lot" (USA)

- The CCUS industry uses "tonne or metric ton" to quantify a volume of CO_2
  - Megatonne (Mt)- million tonnes
  - Gigatonne (Gt)- billion tonnes
- Common conversions:
  - 1 metric ton CO_2 =
    - 19.274 mcf at SATP
  - 1 MMCF = 51.8821 tonnes
  - 1 BCF = 51,882.1 tonnes
  - 20 Mt = 385 BCF
  - 50 Mt = 964 BCF (minimum CarbonSAFE site)





CO_2 Volume Visualization



- www.ipcc.ch
- DOI: 10.1126/science.1120130
- www.climate.gov
- www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/oil

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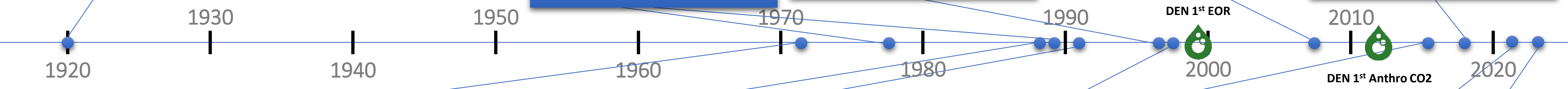
History of CCUS



1920

CO_2 capture technology invented

1972

First CO_2 EOR
- SACROC

1977

First suggestions of capturing CO_2 to prevent release to atmosphere

1988

First major media attention to "global warming"
- Hottest summer on record (at that time) and widespread drought/wildfires

1989

United Nations creates Intergovernmental Panel on Climate Change (IPCC)
- To provide a scientific view of climate change

1991

Norway enacts CO_2 tax on all offshore oil and gas operations
- Currently ~$88/tonne

1996

First large-scale CCS project, the Sleipner CCS Project in North Sea
- Captures separated CO_2 stream from natural gas production and injects into saline aquifer

1997

The Kyoto Protocol
- First global agreement to reduce greenhouse gases adopted
- Start of extreme politicization of climate change

2008

Energy Improvement and Extension Act
- Added a credit for CO_2 sequestration to the tax code in IRC section 45Q

2015

Paris Climate Agreement
- Signed by 197 counties who pledged to set targets to cut greenhouse gases

2018

Bipartisan Budget Act expanded and extended the 45Q tax credit
- Initiation of CCS industry as expanded 45Q starts to make CCS economically viable

2021

IRS issues final regulations for claiming 45Q

2022

Inflation Reduction Act
- Increases 45Q Credit along with other program changes

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CCUS Incentives

Carrot or the Stick (Carbon Credit or Tax)?

Tax

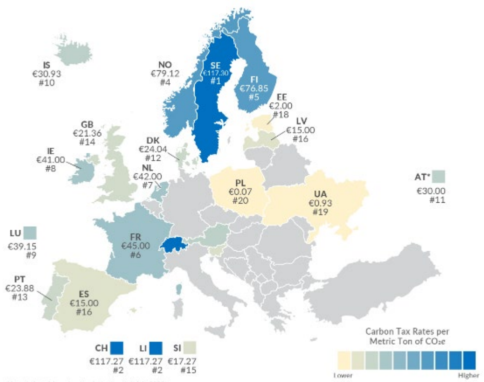
- Europe
    - $0.08-$130 per metric ton CO2

Credit

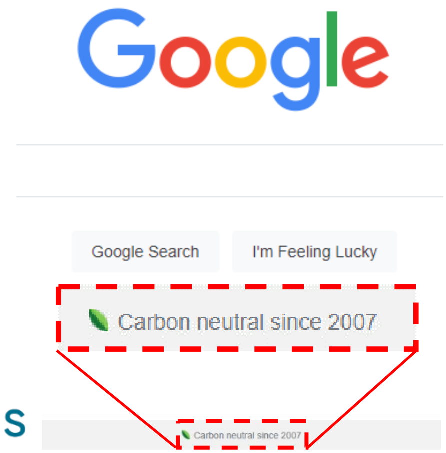
- IRC Section 45Q
    - $60-$180 per metric ton CO_2
- CA Low Carbon Fuel Standard
    - Credit value based on market (currently $69 per metric ton)
- Value of Public Perception
    - Company initiatives to be “carbon neutral” or “carbon net-zero”
    - Buy “credits” to offset own emissions

Carbon Taxes in Europe

Carbon Tax Rates per Metric Ton of CO_2e, as of April 1, 2022



Note: * Austria's carbon tax is due to start July 2022.
The carbon tax rates were converted using the EUR-USD currency conversion rate as of April 1, 2022.
Source: World Bank, "Carbon Pricing Dashboard."



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IRC Section 45Q History

- 2008
    - $10 per tonne for EOR / $20 per tonne for sequestration tax credit adjusted annually for inflation
    - Only good on initial 75 Mt from all projects
    - Must capture at least 500,000 tonnes/yr to qualify
    - Tax credit only available to capturer
    - UIC Class VI designation created
- 2018
    - Increase tax credit from its worth in 2017 ($12.83/$22.66) linearly to ($35/$50) in 2026 and then adjusted annually for inflation
    - Removed 75 Mt cap
    - Good for first 12 years of project
    - Construction must start before Jan 1, 2024
    - Tax credit transferable to CO_2 disposing or utilizing entity
    - Direct Air Capture (DAC) allowed to qualify
- 2021
    - Construction first start delayed to Jan 1, 2026
    - Better described how to demonstrate “secure geologic storage”
- 2022
    - Tax credit increased to $60/$85
    - DAC credit increased to $180
    - 5 years of direct pay / 7 years credit
    - Construction first start delayed to 2033

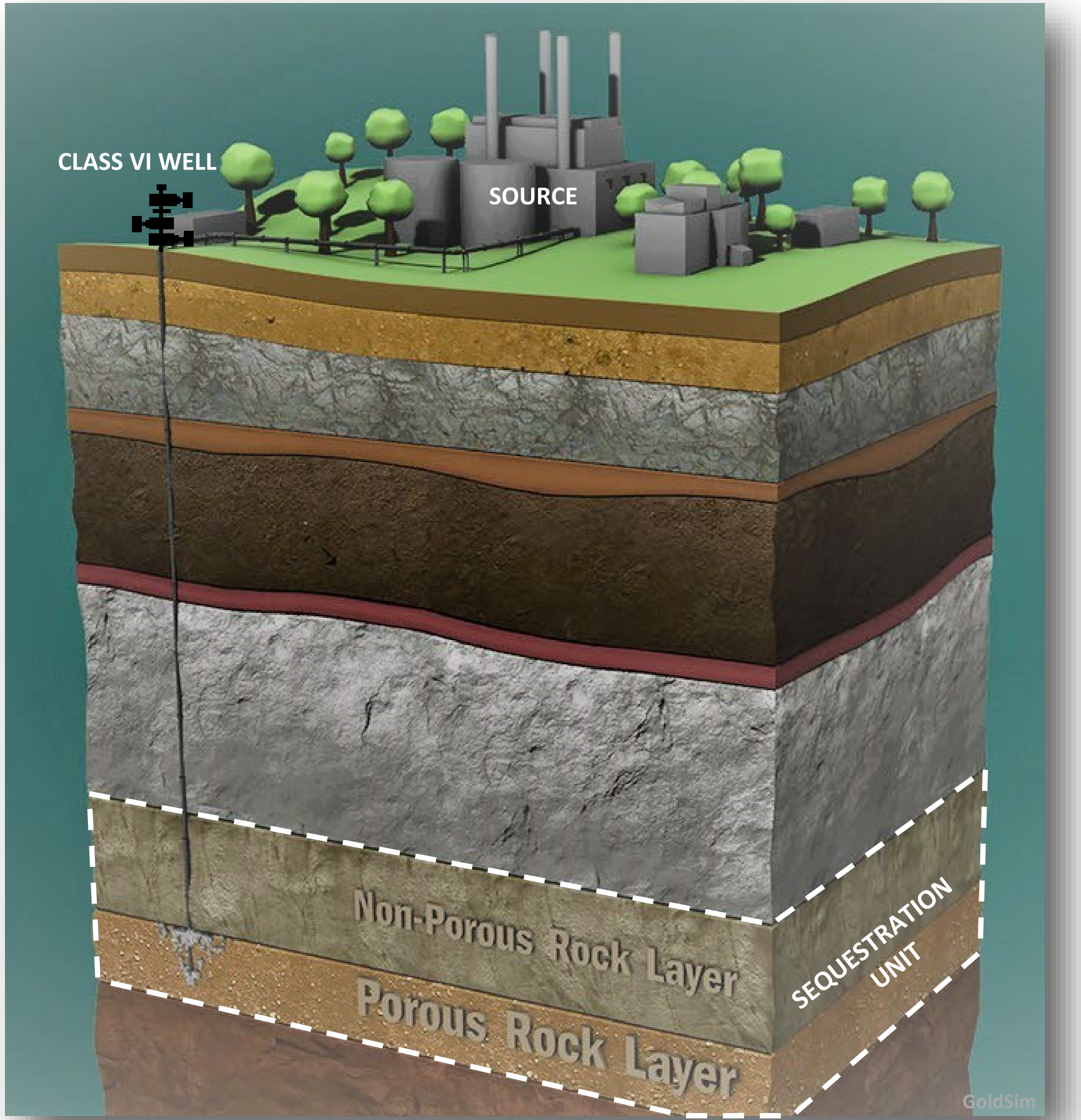
THE CLIMATE PLEDGE
Paris…
10 years
Early

CCS Site Requirements

- Anthropogenic Source of CO_2 or DAC (Direct Air Capture
  - Captured
  - Compressed
  - Transported

- Geologic Sequestration Unit
  - Acquire surface rights
  - Acquire pore space rights
  - Acquire mineral rights (if applicable)

- Class VI Well:
  - Area of Review containing existing wells, geology, and culture
  - Geomechanical modeling
  - Geochemical modeling
  - Lifetime simulation of project including CO_2 plume and pressure extent
  - Well construction requirements
  - Demonstrated financial responsibility
  - Monitoring plan
  - Post-injection site plan
  - Emergency and remedial response plan



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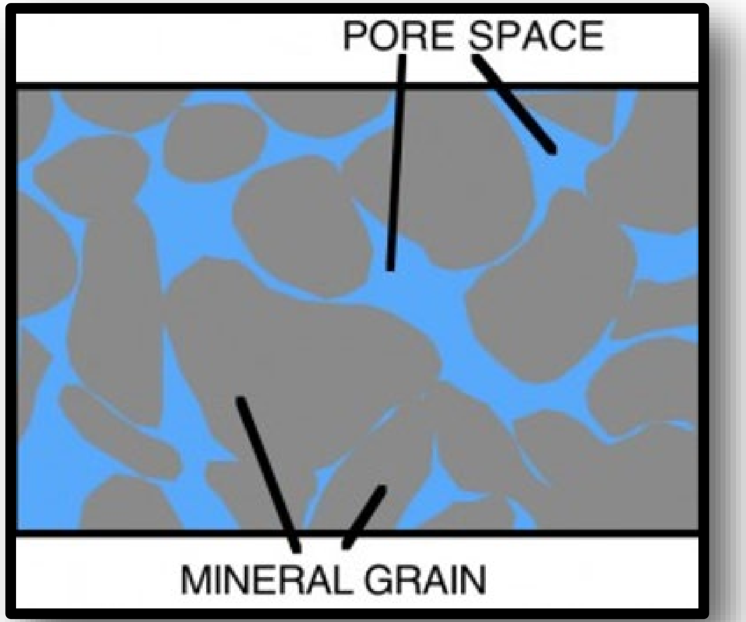
*limited application of Class II wells for permanent storage

CCUS Key Uncertainties (Non-geologic)

- Timing: Federal vs State Regulation
    - Class VI wells permitted through EPA (UIC) until states gain primacy
        - 2 states currently have primacy (ND & WY) with a third (LA) expected to gain primacy in 2023
            - CO, WV, AZ, TX recently applied or expected to in near term
        - State guidelines must meet the EPA requirements at a minimum
        - 2 Class VI wells permitted and drilled to date (both through EPA)
            - Each took ~6.5 years to complete
            - 43 current Class VI applications/permits (EPA-30 / ND-9 / WY-4)
- Pore Space Ownership
    - Individual states determine who owns pore space
        - 7 states have legislation addressing the issue (WV, IN, ND, WY, MT, LA, MS)
        - Each state has different requirements
    - Case law is split on who owns pore space (based on natural gas storage, salt dome, and substrate lawsuits)
        - In general, surface owner owns the pore space
        - Gray area is what constitutes a “mineral” and burden of proof
        - “Public interest” designation (airspace above property)
    - No full Federal framework currently exists to set up a CCUS facility*



*Some guidance documents & modifications to OCSLA released. CCUS on federal lands will be by ROW

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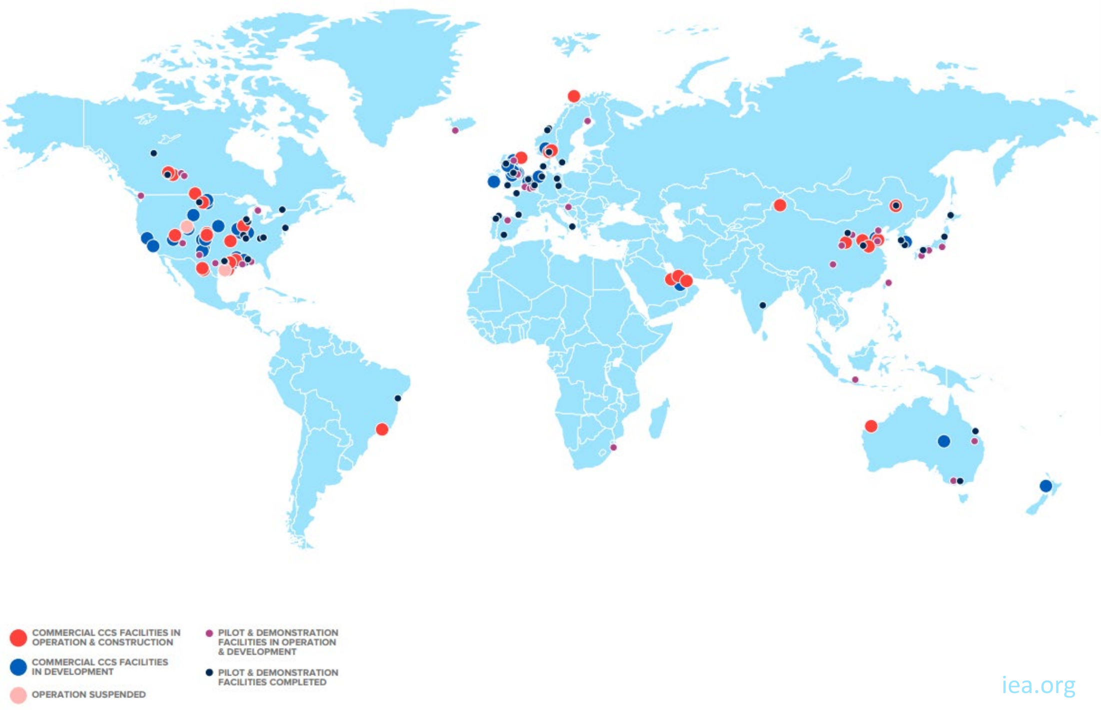
CCUS Current Status

Currently 26 major CCUS projects operating worldwide capturing ~40 Mtpa (5 saline storage)

- Sleipner (Norway)
- Gorgon (Australia)
- Decatur (USA)
- Quest (Canada)
- Snohvit (Norway)



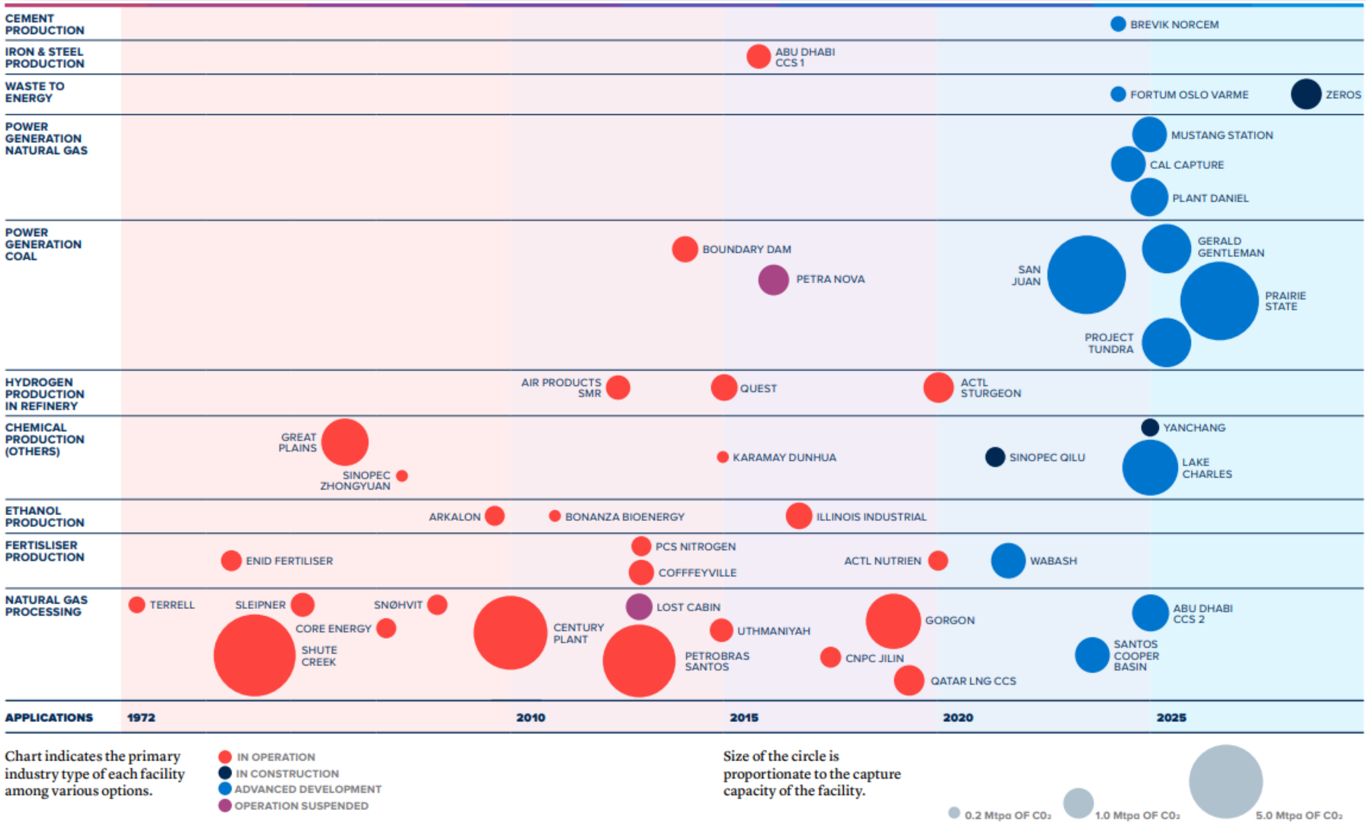


Chart indicates the primary industry type of each facility among various options.

Size of the circle is proportionate to the capture capacity of the facility.

- Shute Creek Gas Processing Plant (EOR) is largest at 7 Mtpa
- Gorgon Project is largest saline storage project at 4 Mtpa
- Sleipner Project has largest cumulative saline storage to date at 20 Mt

CCUS Lifecycle

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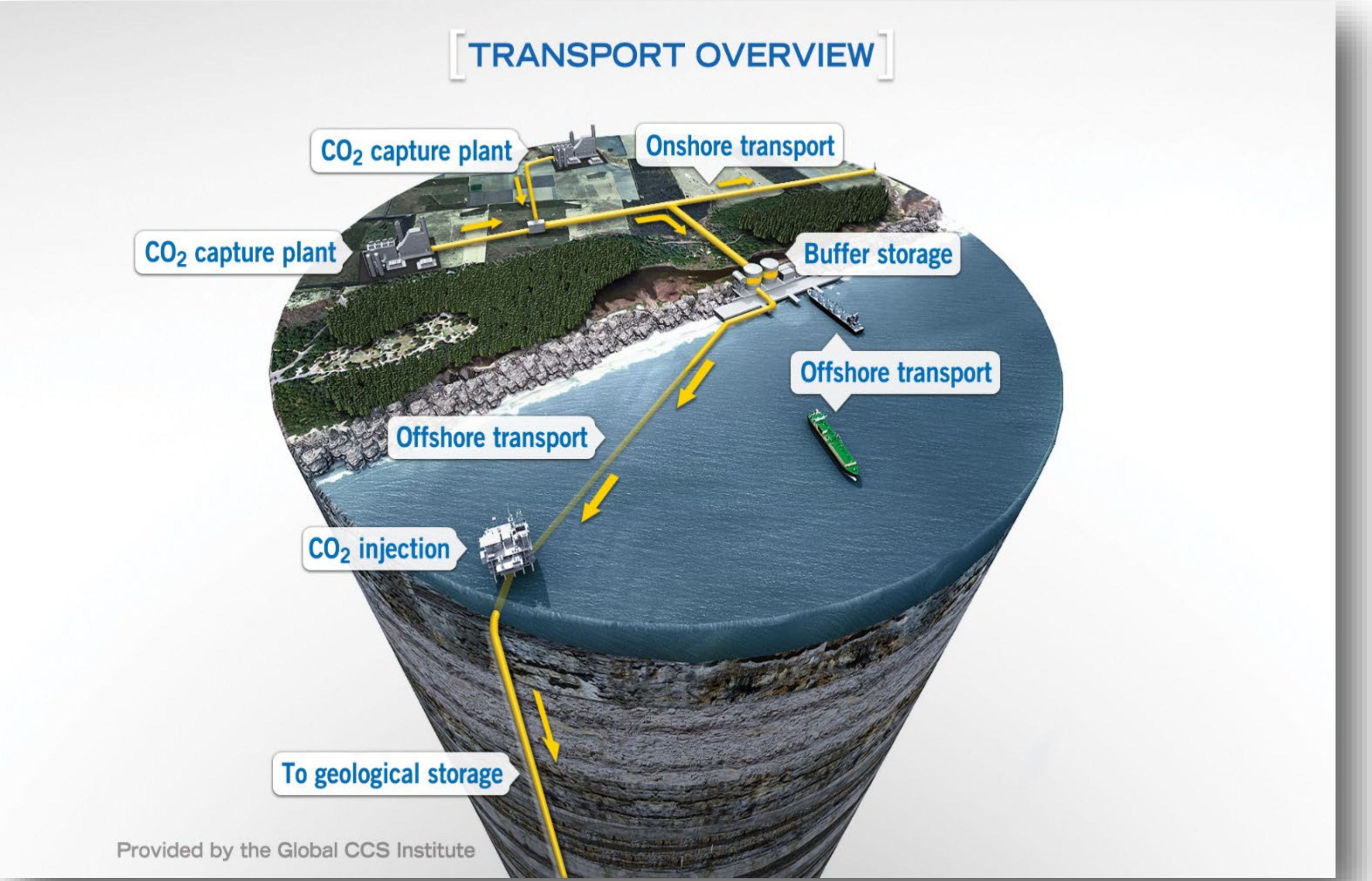
CCS Lifecycle

- 3 Main Components:
  - Capture
    - Source of anthropogenic CO_2
    - Compress for transport
  - Transportation
    - Move CO_2 from source to storage
  - Storage
    - Permanently sequester CO_2 underground



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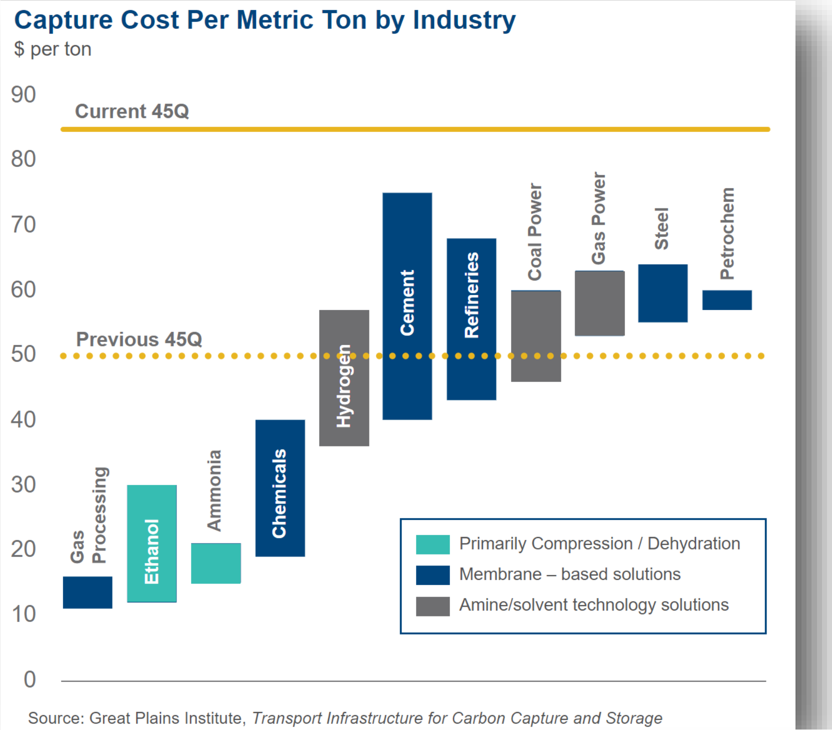
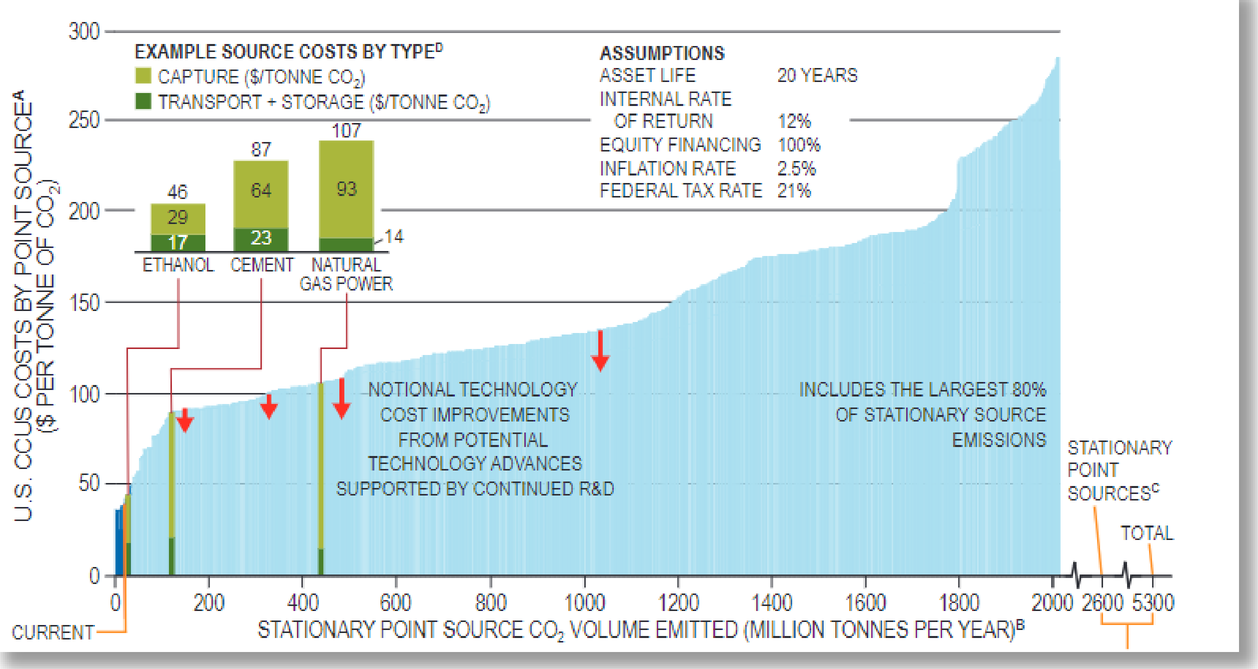
Capture

- Industrial Source
  - Low Cost Sources:
    - Ammonia
    - Natural gas processing
    - Ethanol
  - High Cost Sources:
    - Power plants
    - Steel
    - Cement
- DAC (Direct Air Capture)
  - Pulling CO_2 directly from atmosphere
  - Pros
    - Can build where there's storage (no transportation needed)
    - Modular design allows scalability
  - Cons
    - Take up a lot of space
    - Uses a lot of energy due to low concentration of CO_2
    - Can use a lot of water



Source: Great Plains Institute, *Transport Infrastructure for Carbon Capture and Storage*

2019 National Petroleum Council Report, Meeting the Dual Challenge



Capture is typically the highest cost of a CCUS project

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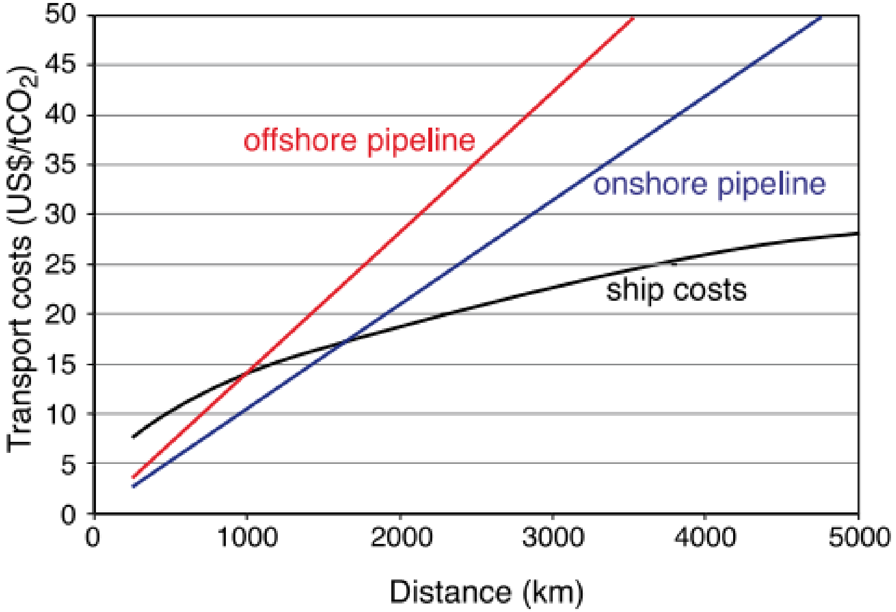
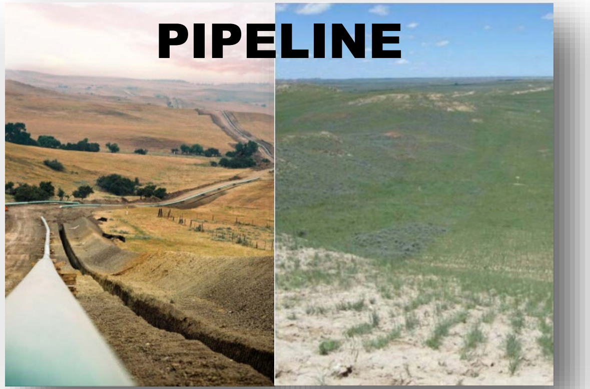
Transportation

- CO_2 can be transported by pipeline, truck, rail, or ship
  - Large scale: pipeline & ship
  - Small scale: truck & rail
- CO_2 is most economically transported in dense phase
  - Need pipelines rated to higher pressure than most natural gas lines
  - Approx 5,000 miles of CO2 pipeline out of 2.3 million miles of pipeline in US[1]
    - 0.2%
    - Denbury has >1,300 miles (~25%) of the CO2 pipeline[2]





10-100's Mtpa

20 tonnes/load

82 tonnes/car

25-225k tonnes/load[3]

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[1] PHMSA (2018)

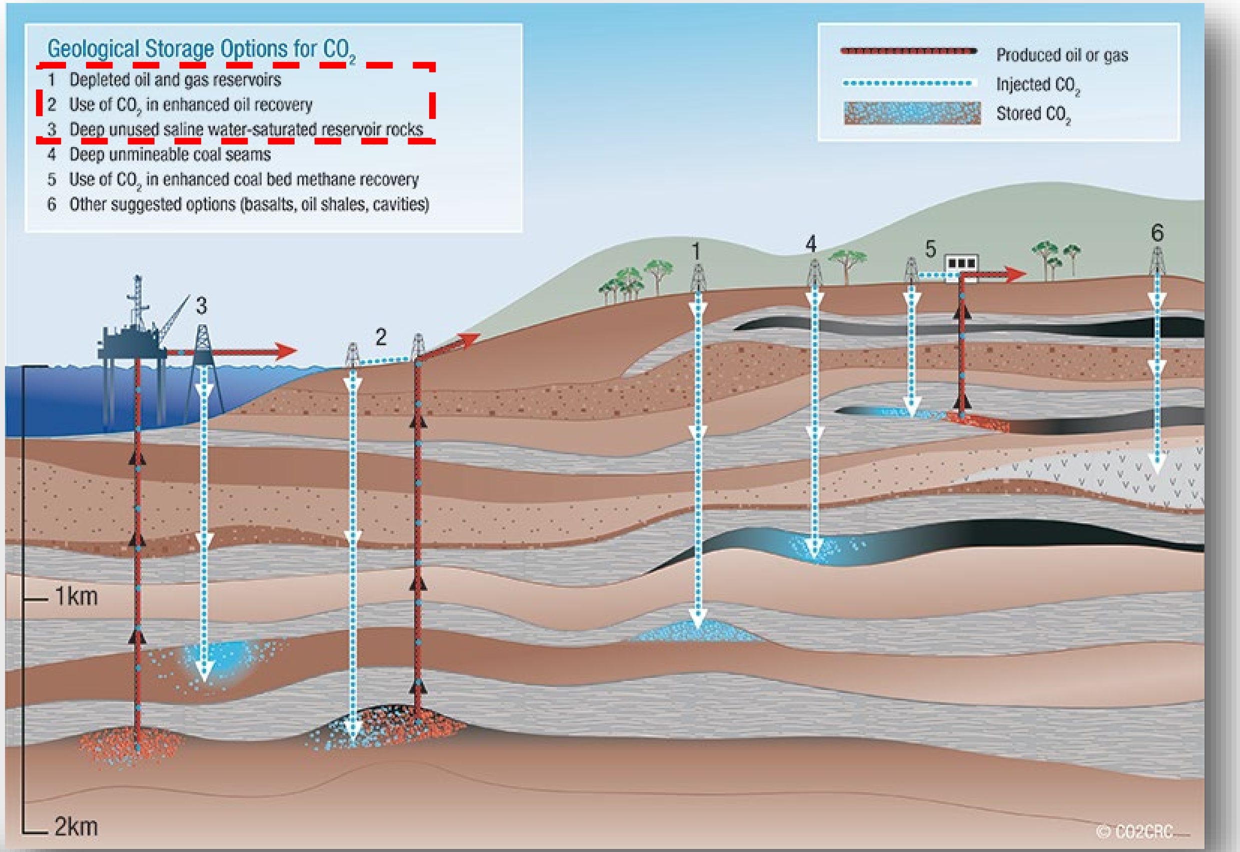
[2] Per 2021 National Petroleum Council Report, *Meeting the Dual Challenge*

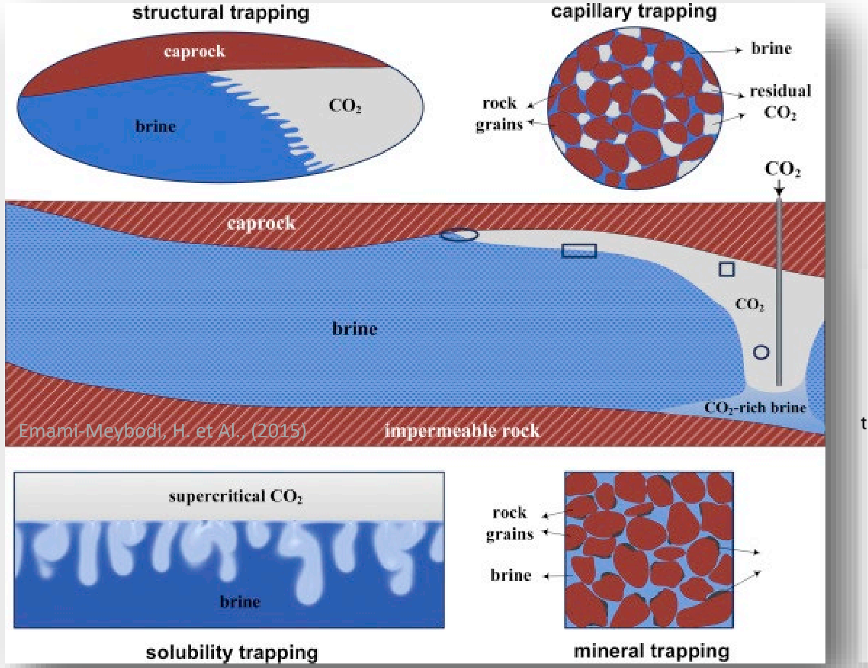
[3] A review of large-scale CO2 shipping and marine emissions management for carbon capture, utilization and storage

[4] IPCC Chapter 4

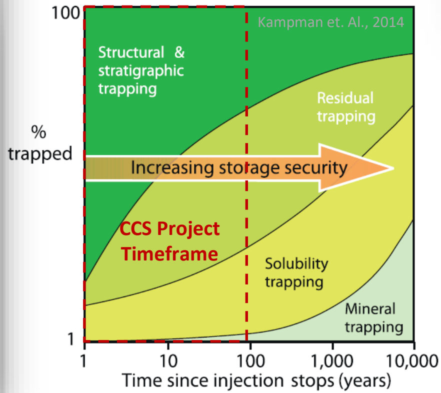
CO_2 Storage

- 6 main types of storage:
  - **Saline aquifers**
  - **Depleted oil & gas fields**
  - **EOR**
  - Coal (Un-mineable coal/coalbed methane)
  - Organic-rich shale
  - Basalt





Emami-Meybodi, H. et Al., (2015)



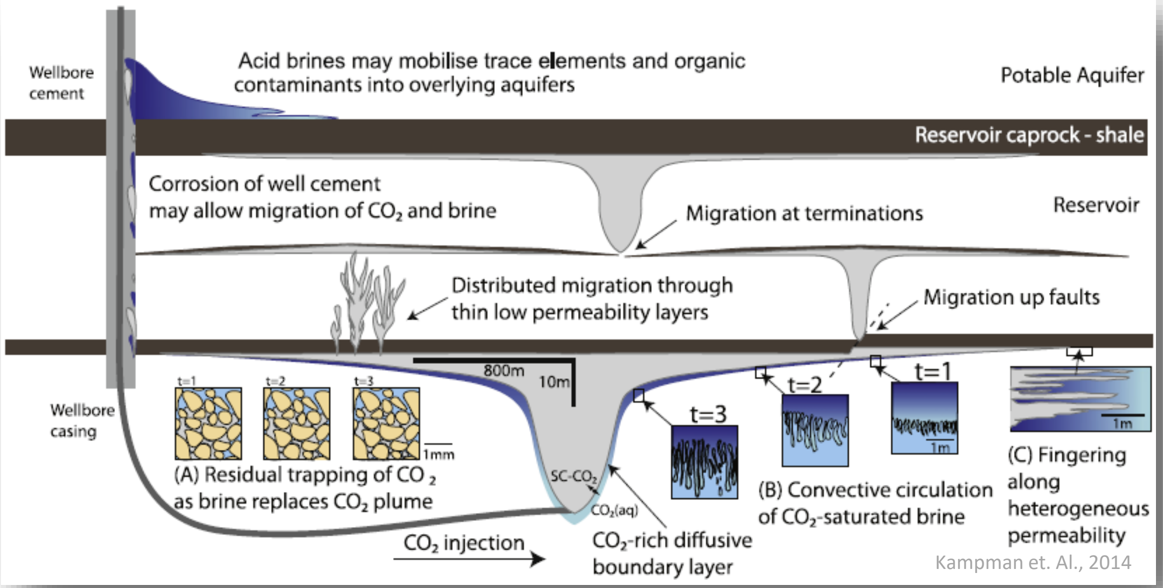
Kampman et. Al., 2014

- 4 trapping mechanisms:
  - Buoyant (structural)
  - Residual (capillary)
  - Solubility
  - Mineral

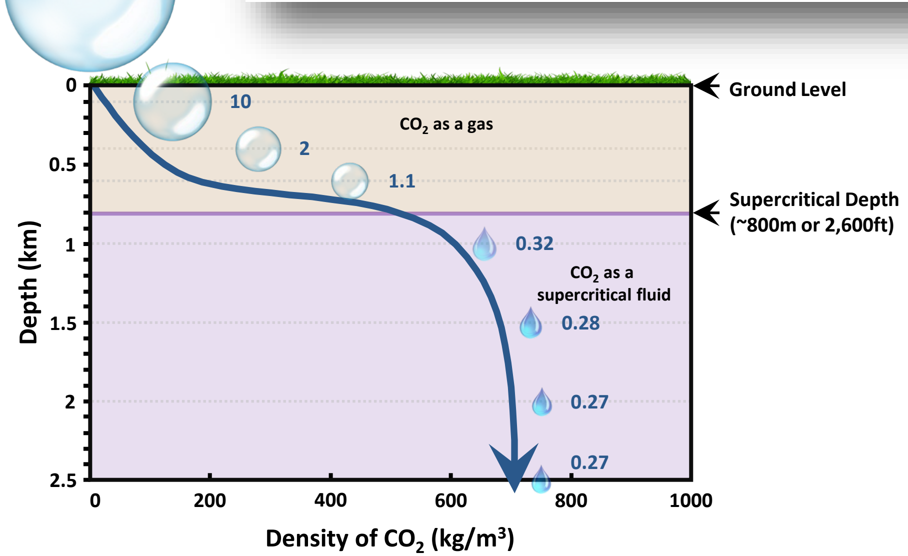
Targeting CO_2 Storage

What makes a viable CO_2 storage target

- Proximity of site or nearby pipeline infrastructure to financially feasible, large CO_2 sources
- Depth ranges
    - Shallow limit determination
        - ~3,000ft due to supercritical state of CO_2
        - Depth of fresh water (<10,000 mg/L TDS) water
    - Deep limit determination
        - Based on well cost, reduction of favorable geologic properties, overpressure
        - Typically around 15,000ft
- Trap/Reservoir Presence
    - Structural/stratigraphic/low dip
    - Favorable reservoir architecture
    - Favorable petrophysics
- Seal Presence
    - A thick, laterally continuous, unfractured, high displacement pressure lithological unit
- Mitigated Risk
    - No deep freshwater zones, redundant traps, few wellbores, no critically stressed faults



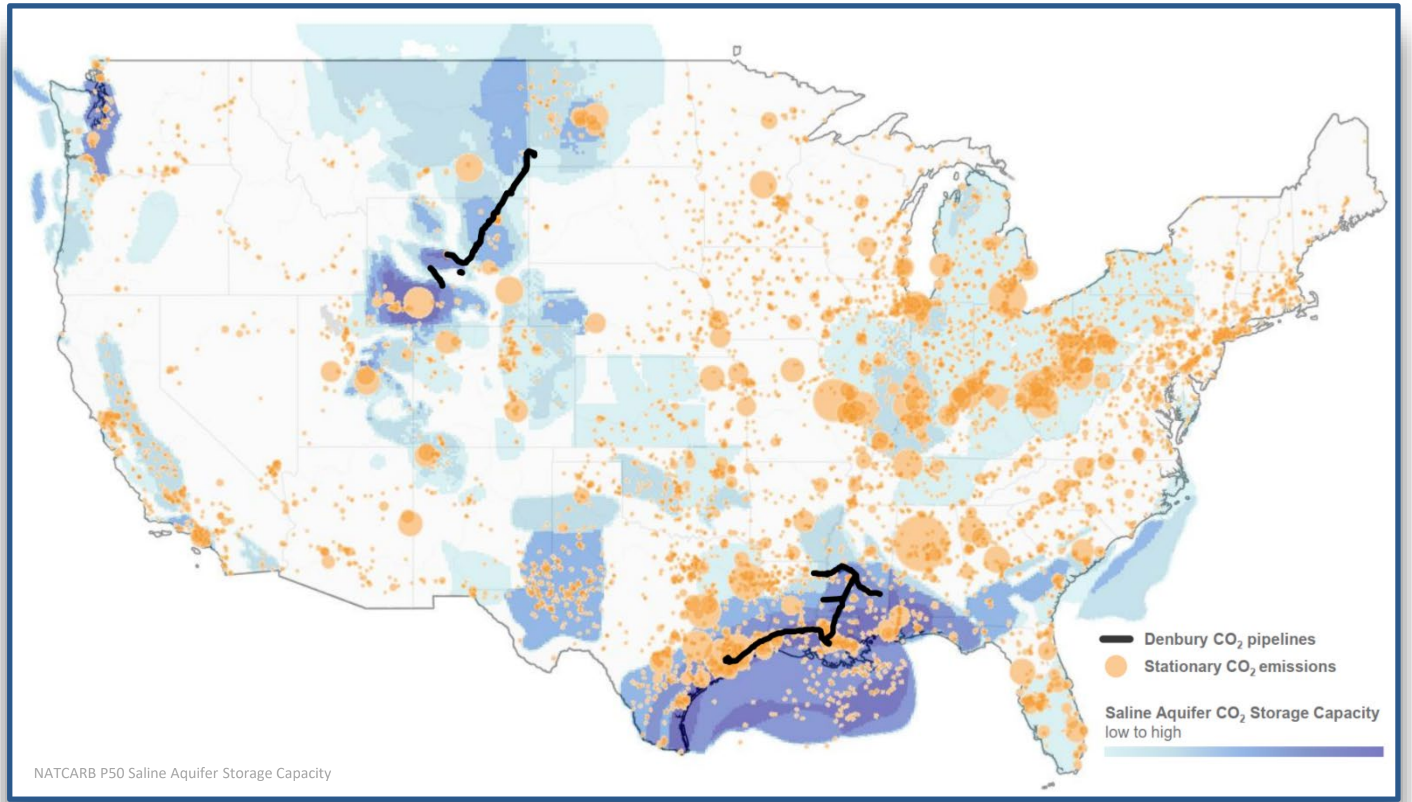
Kampman et. Al., 2014



the volume of CO_2 is 277 times less at critical point than at surface

U.S. Gulf Coast-A World-class CCUS Opportunity

- **The Gulf Coast has one the highest concentrations of stationary CO_2 emissions**
- **Advantaged for greenfield projects**
  - Access to low-cost natural gas feedstock, waterways and deep-water ports, supportive regulatory policy
- **Expandable CO_2 pipeline infrastructure already in place**
  - DEN has the only dedicated CO_2 pipeline network in the Gulf Coast at >900 miles
- **High-quality geology for secure long-term storage of CO_2**
  - Large reservoirs, high injectivity & laterally extensive confining intervals
  - Approximately 5 trillion tonnes potential storage capacity in the U.S. Gulf Coast



NATCARB P50 Saline Aquifer Storage Capacity

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Project Evolution

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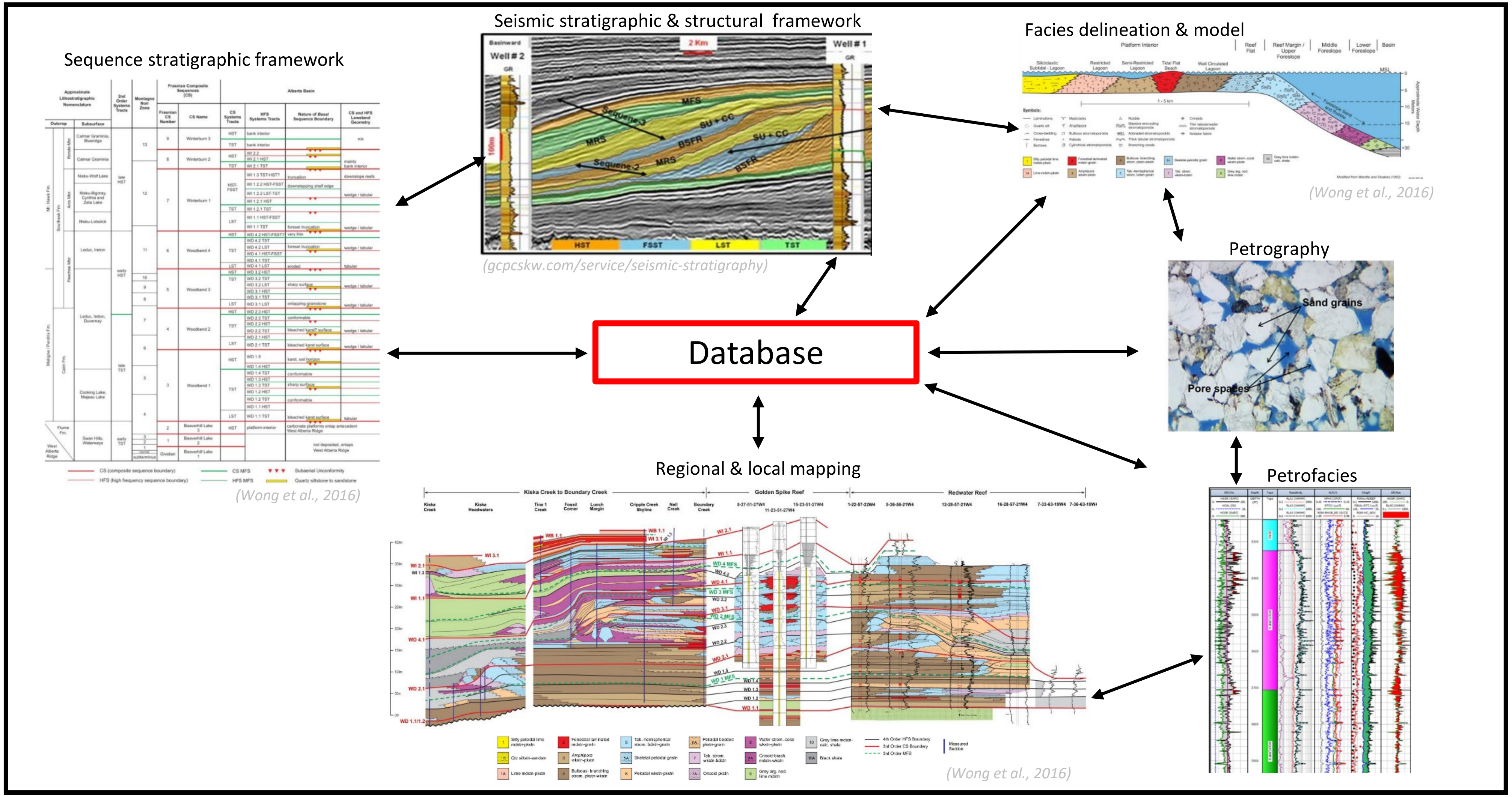
Site Selection Foundational Geoscience Technical Work

CCS projects require detailed geologic analyses to ensure technical & economic feasibility



(Wong et al., 2016)

(gcpcskw.com/service/seismic-stratigraphy)

(Wong et al., 2016)

(Wong et al., 2016)

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Site Selection Critical Criteria


Site Selection and Characterization Period → Initial Application and Permitting Period → Pre-injection Period → Injection Period → Closure Period → Post-closure Period

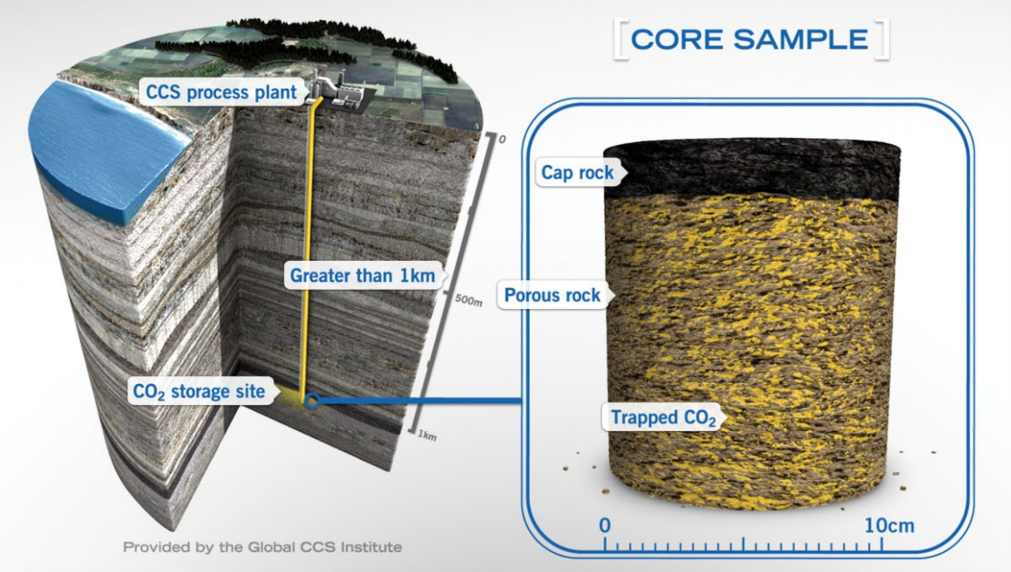
Three critical components of carbon sequestration:

1) Injectivity
2) Capacity
3) Containment

Geologic controlling factors related to injectivity, capacity & containment

National Energy Technology Laboratory

Characteristic	Favorable Geologic Controlling Factors	Inhibitors
Injectivity	• Thick reservoirs • High reservoir permeability • Homogeneity in reservoir permeability distribution	• Effective permeability constraints arising from geochemical effects (e.g., mineral dissolution/precipitation phenomena, salt precipitation) • Reservoir over-pressurization from injection and/or proximity to other injection wells • Near-well formation damage and effective permeability loss • Transport constraints associated with CO_2 and rock interactions
Storage Capacity	• Large reservoir areal extent • Large reservoir thickness • High reservoir porosity • Stacked reservoirs • Open boundary system	• Thin reservoirs with low net storage thickness • Limited effective pore volume due to high heterogeneity • Formations with limited areal extent and closed or semi-closed boundary conditions
Containment	• Multiple and/or thick confining zones that are laterally extensive • Low confining zone permeability absent of faulting or fractures • High confining zone capillary entry pressure • Absence of leakage conduits • Closed boundary system	• High permeability zones causing extensive vertical or lateral CO_2 and/or brine migration • Poor integrity of wellbores penetrating confining layers • Thinning or intermittent presence of caprock • Dissolution of confining zone material due to reactions with CO_2/brine mixture • Natural or induced seismic activity, which may activate flow pathways in confining units



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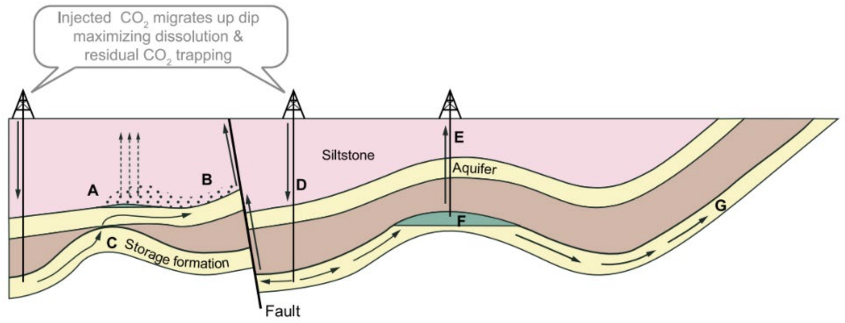

Potential Escape Mechanisms

- **A.** CO_2 gas pressure exceeds capillary pressure & passes through siltstone
- **B.** Free CO_2 leaks from A into upper aquifer up fault
- **C.** CO_2 escapes through 'gap' in cap rock into higher aquifer
- **D.** Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault
- **E.** CO_2 escapes via poorly plugged old abandoned well
- **F.** Natural flow dissolves CO_2 at CO_2 / water interface & transports it out of closure
- **G.** Dissolved CO_2 escapes to atmosphere or ocean

IPCC, 2005

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Design Process

- Gather all pertinent subsurface information
- Build three-dimensional geologic models
- Run a series of dynamic models to determine the impacts of CO_2 injection
- Iterate through thousands of design decisions to obtain the design with the best risk weighted value opportunity
  - Negotiate/Lease
  - Final Investment Decision
- Implement
- Incorporate new data to quickly determine if the plan should be altered or continued

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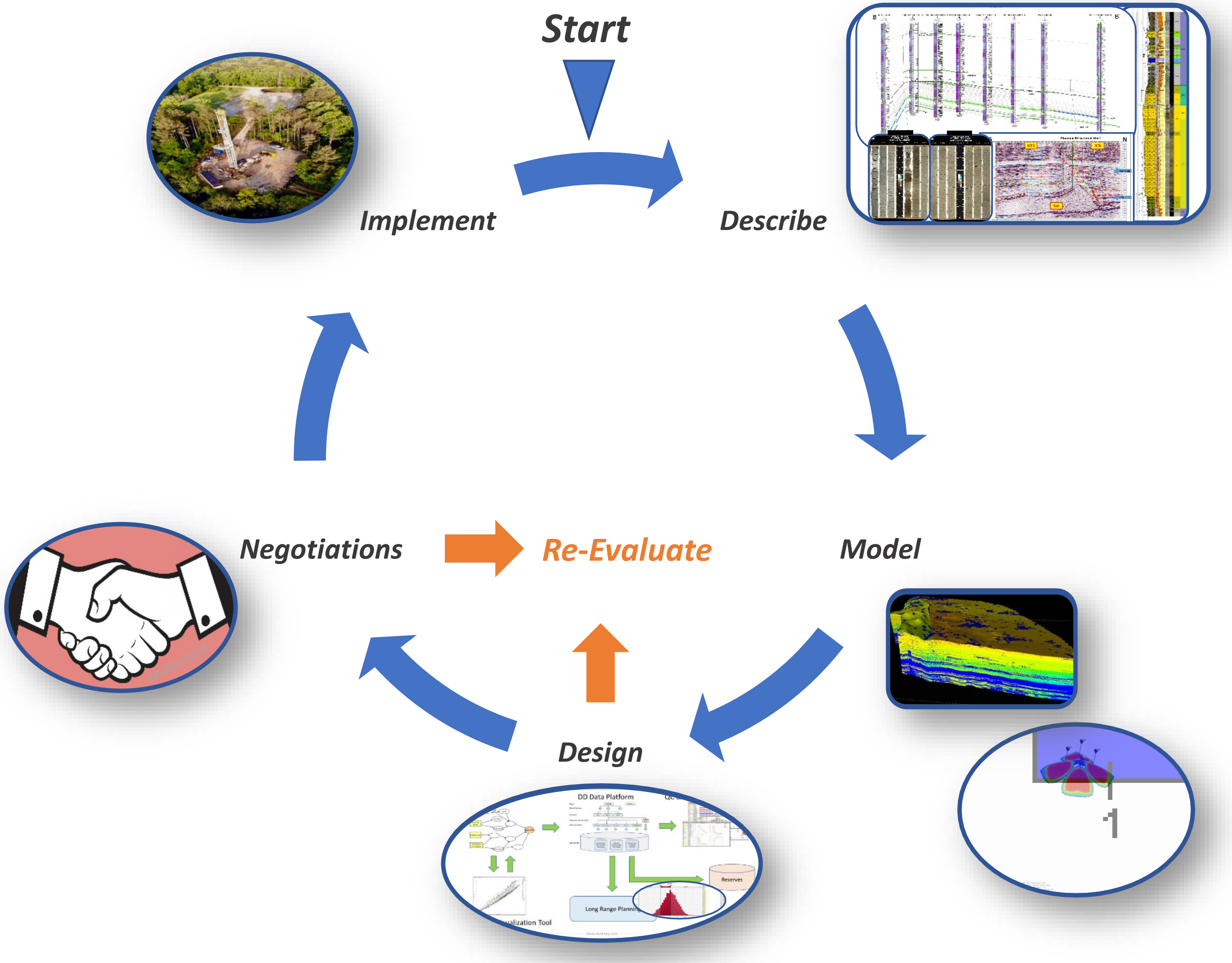


Start

Implement

Describe

Negotiations

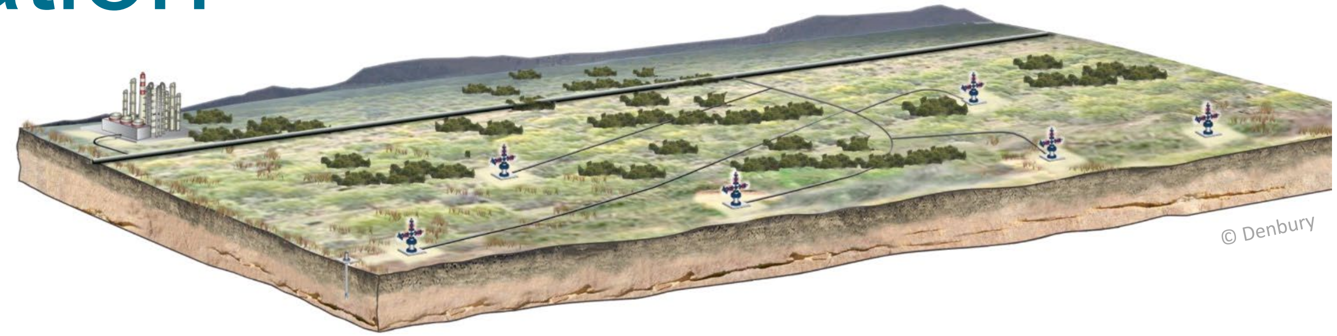
Re-Evaluate

Model

Design

Leasing/Unit Formation

- Requirements vary by state
  - Or don’t exist
- Surface
  - Surface ownership, pipeline ROW, pump stations,
  - Anchor owners and secondary ownership
  - How to draw AOI
- Subsurface
  - Mineral, pore space, water, cavern
  - Drill through rights, liability, depth intervals
- Philosophy
  - Lease/unitization sizing?
  - Lease staging/timing
  - Lease flexibility
  - How to mesh with ever-changing portfolio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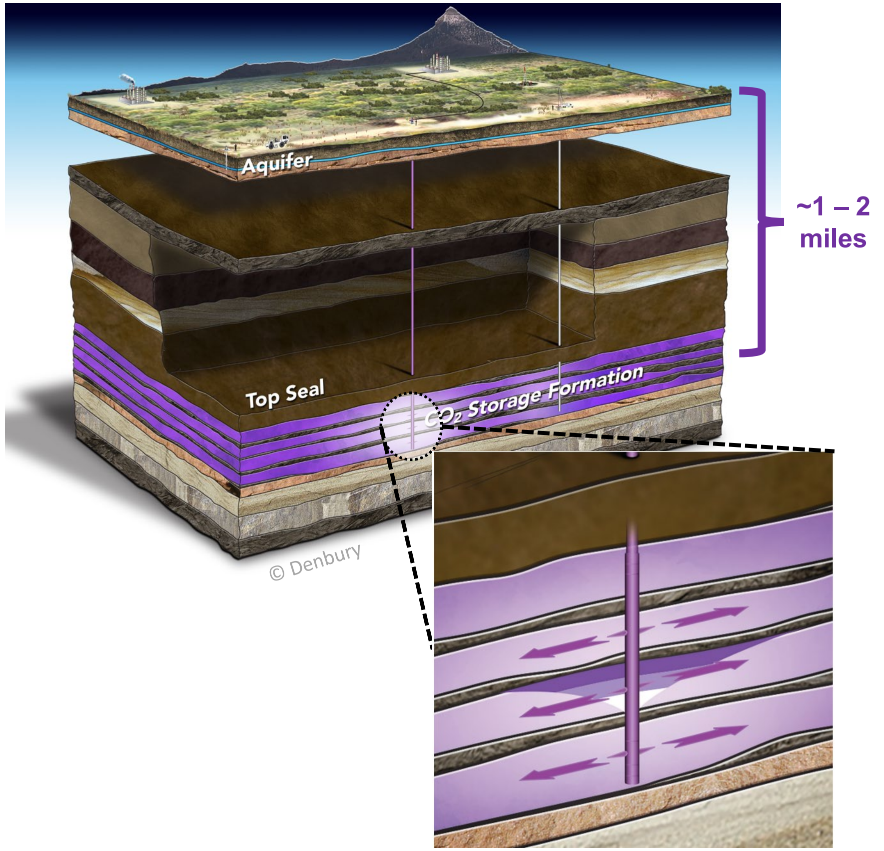

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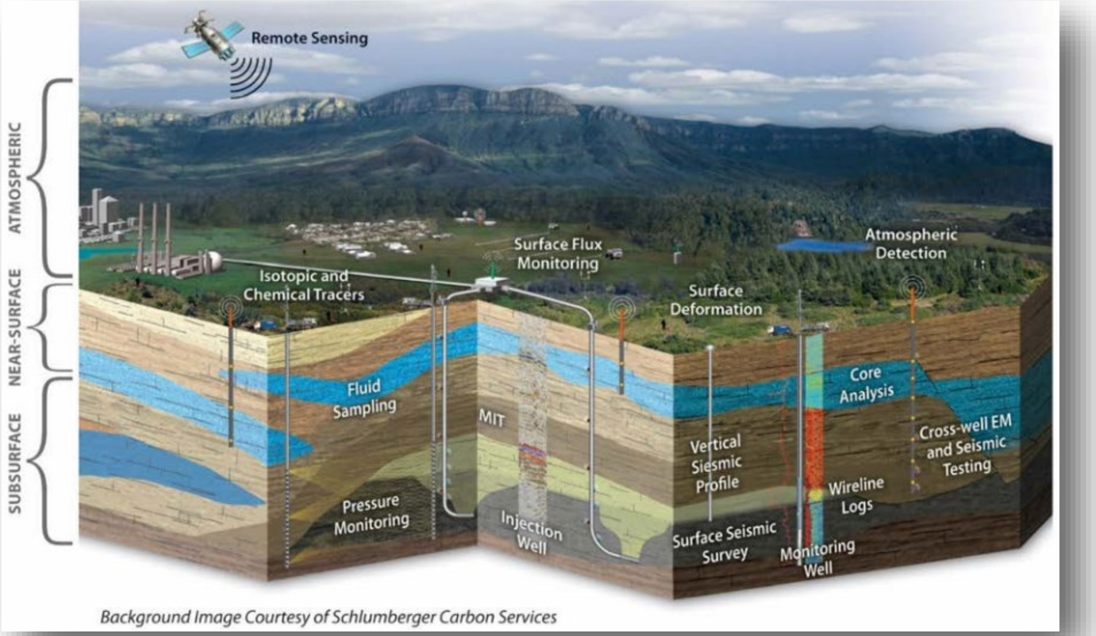
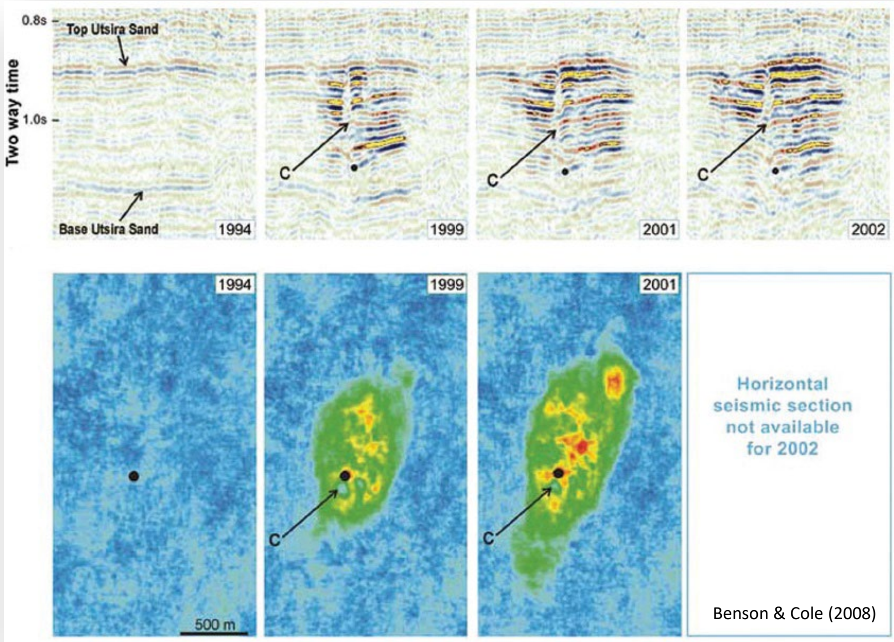
Monitoring

- Class VI Permits require more rigorous standards of reservoir characterization and site monitoring than Class II (EOR)
  - **Pre-Injection**- 4D modeling & characterization of reservoir, seal, plume size, plume movement, and pressure front
  - **Active-Injection**- 4D monitoring
    - 4D seismic, logging, pressure, groundwater, air, gravity, MITs
    - Pre-Injection modeling reviewed and updated at minimum every 5 years
  - **Post-Injection**- continued monitoring of site for minimum 10 years



Background Image Courtesy of Schlumberger Carbon Services



Benson & Cole (2008)

Post Injection Site Care (PISC) & Site Closure

- After sequestration, wells are plugged and project moves into the PISC & Site Closure phase
  - Activities during this phase may include, but are not limited to, the continual of:
    - Seismic Monitoring
    - Above-Ground Monitoring
    - In-Reservoir Monitoring
    - Above-Seal Monitoring
    - Ground-Water Monitoring
    - Vadose Zone Monitoring

- Post injection ownership and liability vary by state
  - Louisiana- ownership and liabilities transferred to state after 10 years if site receives “certificate of completion”
  - Wyoming- ownership and liabilities transferred to state after 20 years if site receives “certificate of completion”
  - Mississippi- ownership and liability stays with operator indefinitely

- “Trust Funds” funded through per-tonne fees during injection period used for PISC if operator is insolvent
  - Indiana- $0.08/tonne
  - Texas- proposing $0.25/tonne

Summary

- CCUS will be a key component to climate mitigation policy
- CCUS is an emerging industry and new economic incentives are attracting businesses to the space…..it's the new wild west!
- The best development strategies contain economic scenarios of each CCUS component while minimizing associated risks/uncertainties
- Coupling storage project evolution and geologic uncertainty to leasing/unit formation is not black and white and is likely to get more difficult as larger land positions are leased up (at least until state regulations catch up)
- CCS should be viewed as a win for landowners given minimal impact to the surface vs the economic opportunity

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QUESTIONS

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