Battelle Carbon Services

CCUS Overview

March, 2023

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Presentation Outline

- Basic Concepts
- CCUS Overview: Economic Considerations
- CCUS Overview: Subsurface Considerations & BCS Approach

What is a Tonne?

- American Ton = 2,000 lbs
- Metric Tonne = 2,204.6 lbs
- 1 Tonne CO_2 = 19.3 mcf

- At standard conditions, 1 tonne of CO_2 is 27-ft cube
- At supercritical conditions, 1 tonne of CO_2 is 680 gals

- Global Annual CO_2 Emissions = 33.5 BMT
- U.S. Annual CO_2 Emissions = 5.1 BMT
- U.S. Annual 45Q-Eligible CO_2 Emissions = 2.3 BMT

Inflation Reduction Act of 2022

- Two-tiered credit structure
- Need to satisfy prevailing wage and apprenticeship requirements to take full credit (otherwise 20%) – guideline being written by IRS
- More monetization options:
  - Direct Pay option limited to certain tax exempt and government entities, except first 5 years of 45 Q/V/X/Z
  - Transferability of credits 45 Q/V/X/Z

    Q – CCUS

    V – Hydrogen

    X – Batteries

    Z – Clean Fuel

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Carbon Capture and Sequestration Tax Credit 45Q

- 12-year payout period
- Extends beginning construction deadline to Jan 1, 2033
- Increases tax credit to:
  - **$85** for saline geologic storage
  - **$60** for EOR, zero-carbon fuel, chemicals, building materials, other products
  - $180 for DAC for saline storage
  - $130 for DAC for EOR or utilization
- Decreases plant facility size to:
  - 1,000 tonnes for DAC
  - 18,750 tonnes for power plants capturing >75% emissions from unit (not facility)
  - 12,500 tonnes for other facilities
- Reduction of tax credit if tax-exempt bonds used to finance the facility
- Prevailing wage and apprenticeship requirements apply

Permitting Overview

- U.S. EPA's **Underground Injection Control (UIC) Class VI Permitting** seeks to ensure the protection of underground sources of drinking water (USDWs) [40 §146.81 *et seq.*]

- U.S. EPA's greenhouse gas reporting program requires all CO_2 sequestration facilities to prepare and submit **Monitoring, Reporting, and Verification (MRV) plans** for the CO_2 injected, transported, and lost in a sequestration process [40 §98 subpart RR]

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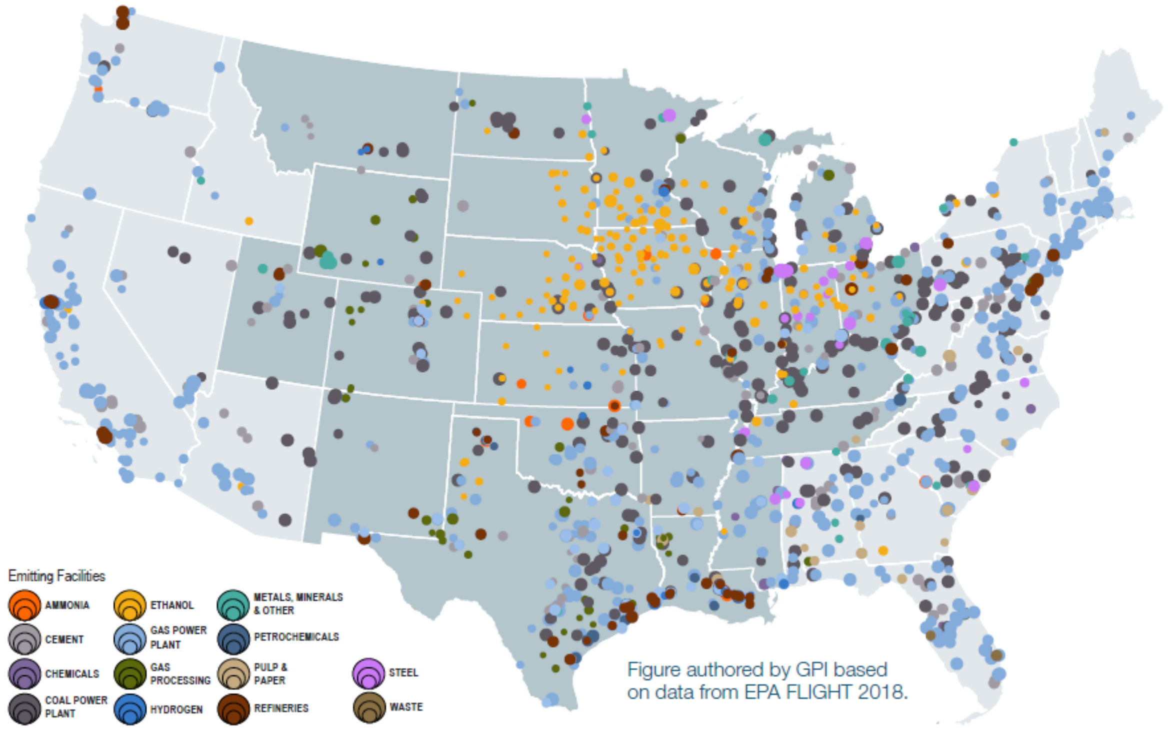
U.S. Emission Sources

Table 4. 45Q-eligible facilities by industry and emissions

Industry	Number of Facilities	Share of 45Q-Eligible Emissions	CO_2	Biogenic CO_2	Methane	Nitrous Oxide
Coal Power Plant	308	53.8%	1,269.6	0.3	3.0	6.2
Gas Power Plant	571	23.8%	565.4	0.7	0.4	0.4
Refineries	78	6.9%	163.3	-	0.6	0.4
Cement	135	3.7%	88.8	0.9	0.1	0.2
Hydrogen	57	2.7%	64.3	-	0.1	0.1
Steel	31	2.3%	54.0	-	0.2	-
Ethanol	173	1.3%	31.0	8.97	0.1	0.1
Ammonia	21	1.2%	25.1	0.0	0.0	4.1
Petrochemicals	30	1.1%	26.0	0.1	0.4	0.1
Metals, Minerals & Other	37	0.9%	19.5	-	0.4	-
Gas Processing	40	0.9%	19.9	-	0.7	-
Chemicals	16	0.8%	8.7	-	0.0	10.4
Pulp & Paper	18	0.4%	7.8	25.5	2.4	0.1
Waste	2	0.1%	0.8	1.2	0.6	-
Grand Total	**1,517**	**100%**	**2,344.2**	**29.3**	**9.1**	**22.1**

All emissions are in million metric tons.

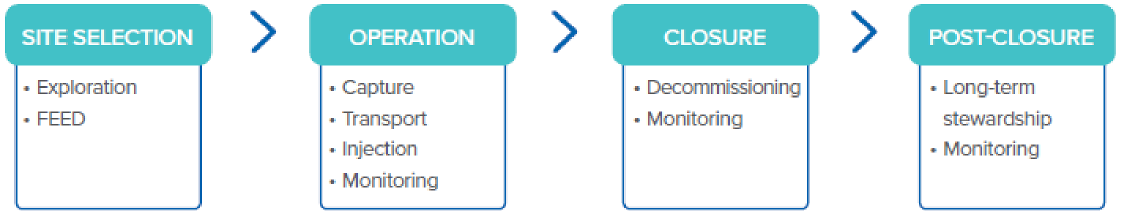
Figure 3. 45Q-eligible facilities by industry and emissions



Credit: Great Plains Institute

CCS Components

- Components of CCS Chain:
  - CO_2 capture from anthropogenic sources e.g. power generation, industrial plants
  - CO_2 capture from natural sources e.g. direct air capture
  - Transport of CO_2 including compression/ pumping
  - Injection of CO_2 into suitable geologic storage or utilization of CO_2 in products
  - If injected, long-term monitoring and site care
  - If utilized, life cycle analysis



CCS project lifecycle
Credit: GCCSI, 2019

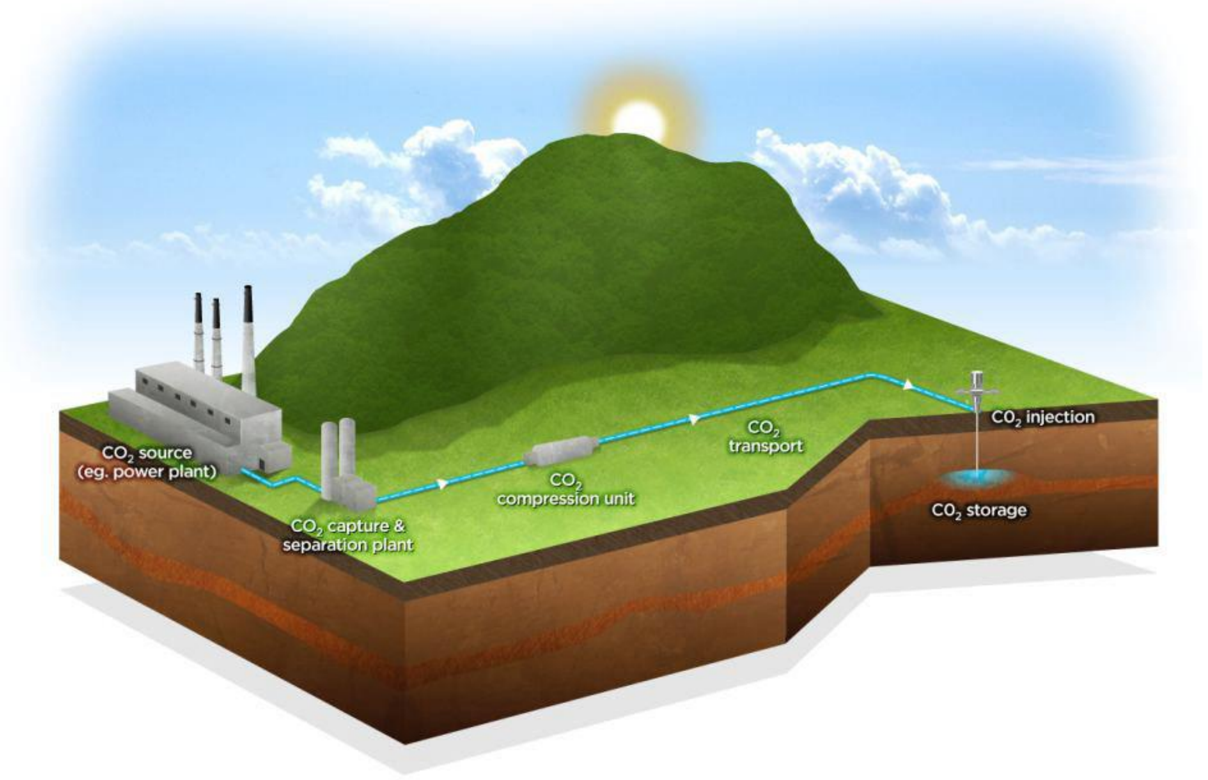


Illustration of a Simplified CCS Network with One Capture Unit and One Storage Facility
Credit: U.S. DOE

CO_2 Capture – Key Concepts

- Key Concepts to Efficient Capture:
  - CO_2 concentration
  - Economy of scale
  - Energy penalty
- Secondary Factors:
  - Technology maturity
  - 1st or nth of a kind
  - Modularization
  - Plant process optimization

Typical CO2 concentration in emissions
Credit: U.S. DOE

Separation Process	Absorption	Adsorption	Membranes	Cryogenic	Compress and Dehydrate
Electric Power Generation	X		R	T	X
Petroleum and Coal Products	X		Z	T	X
Pulp and Paper	R			T	X
Cement Manufacturing	X		R	T	X
Chemical Manufacturing	X	Z		T	X
Iron and Steel	X		Z	T	X
Oil and Natural Gas Processing	X	Z	Z	T	X
Pesticide, Fertilizer, Agricultural Chemical Manufacturing	X	Z			X
Bioethanol Fermentation					X

Key: X = primary, Z = secondary, R = research/demo, T = theoretical.

Application of Various Separation/Capture Processes in Selected Industries
Credit: National Petroleum Council, 2021

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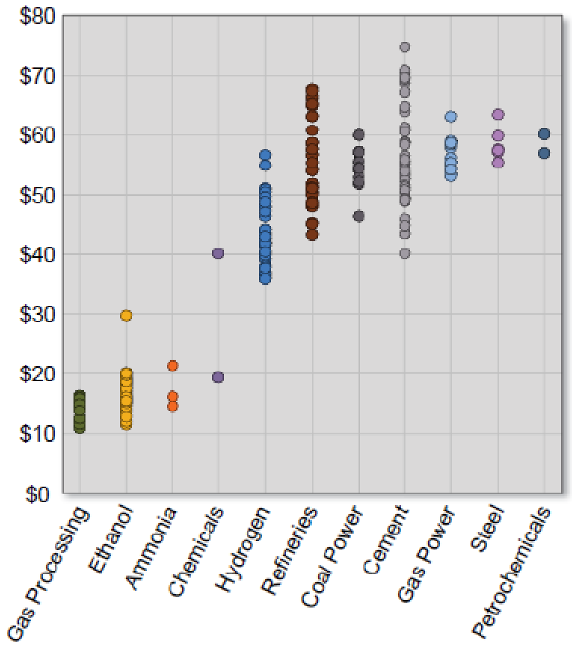
Economics – Key Challenges

- CCS requires large capital investment and long investment horizon.
- Capture is most costly component. Key concepts are concentration, scale, contaminants (excluding direct air capture).
- Transport and storage have limited room for cost improvement. Savings from volume aggregation.
- Hubs can lower unit cost across CCS chain. Capture fits individual plants - no economy of scale.
- Specialized CCS Operators can lower unit cost.
- Government incentives are key for demonstration and initial commercial deployment.

Figure 5 & Table 6. Estimated capture cost per industry for near-term facilities in study area



Industry	Average Estimated Cost $/ton	Range of Cost Estimates $/ton
Gas Processing	$14	$11 - $16
Ethanol	$17	$12 - $30
Ammonia	$17	$15 - $21
Chemicals	$30	$19 - $40
Hydrogen	$44	$36 - $57
Refineries	$56	$43 - $68
Coal Power Plant	$56	$46 - $60
Cement	$56	$40 - $75
Gas Power Plant	$57	$53 - $63
Steel	$59	$55 - $64
Petrochemicals	$59	$57 - $60

Figure authored by GPI based on data from EPA FLIGHT 2018.

Estimated capture cost per industry for near-term facilities in study area (closest to commercialization in U.S.)
Credit: Great Plains Institute, 2020

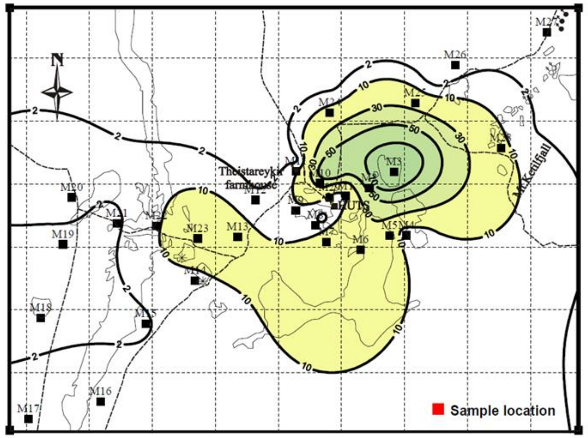
Midwest Carbon Express (Summit)

- Planned 12 Mtpa pipeline system. CO_2 from 31+ biofuel plants in 5 states in Midwest U.S. for storage.
- Expected construction in 2023, in-service 2024.
- 3200-km, USD $4.5 billion budget.
- 4-inch to 12-inch diameter lateral pipelines.
- 8-inch to 20-inch trunk pipeline. Design pressure 2183 psig (150 barg).
- Terrain is flat, mostly farmland and rural.
- 8 initial pump stations on trunk line.

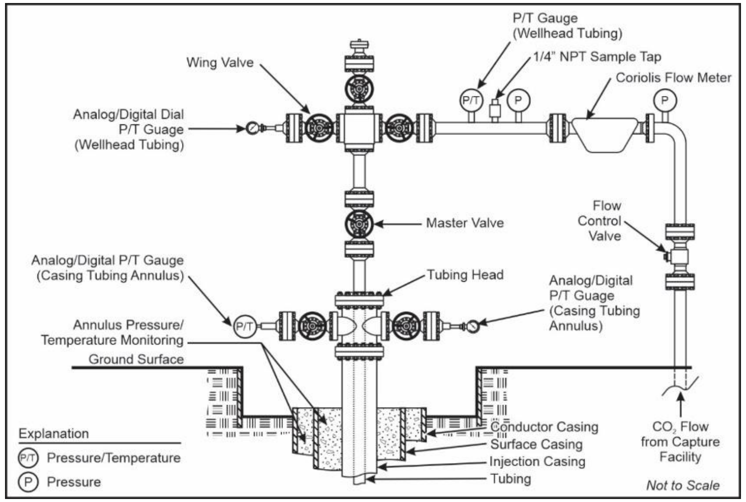
Midwest Carbon Express Pipeline in Midwest, U.S.
Credit: Summit Carbon Solutions

Injection and Well Site Monitoring

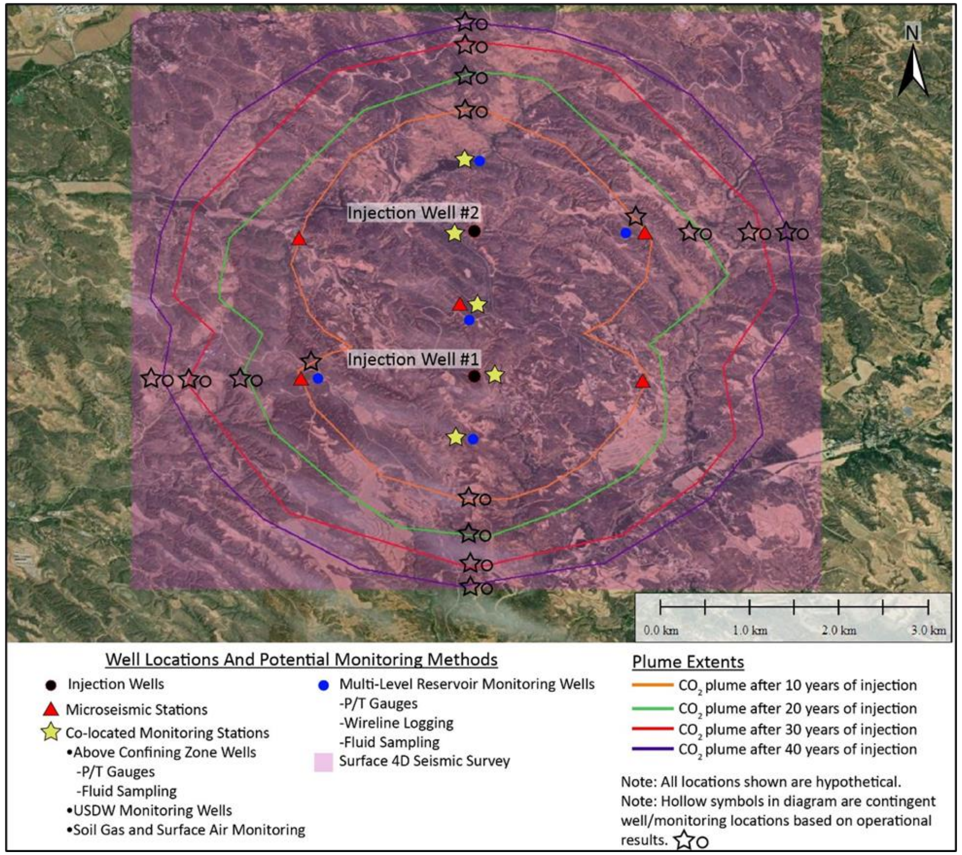
- Credit validation, lifecycle analysis, accounting.
- Class VI permit protects drinking water.
- Surface
  - Injection parameters, air, soil/gas, groundwater, corrosion
- Subsurface
  - CO_2 plume, pressure front, model validation, well integrity testing, pressure fall-off, seismic



Illustrative air dispersion model output



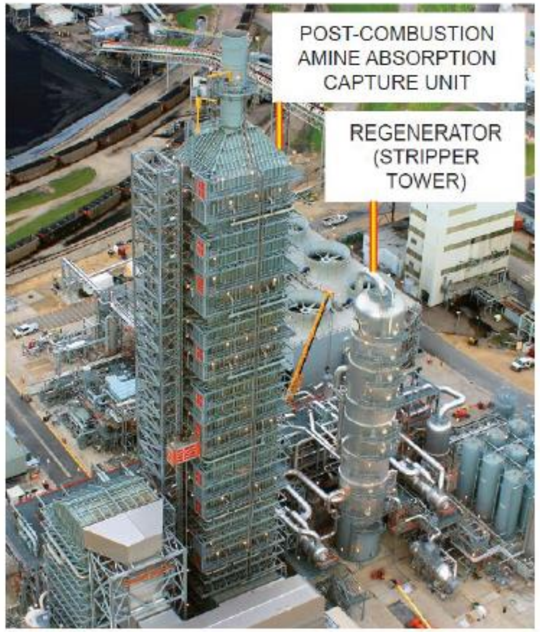
Simplified diagram of surface monitoring at injection wellhead(s)
Credit: Battelle

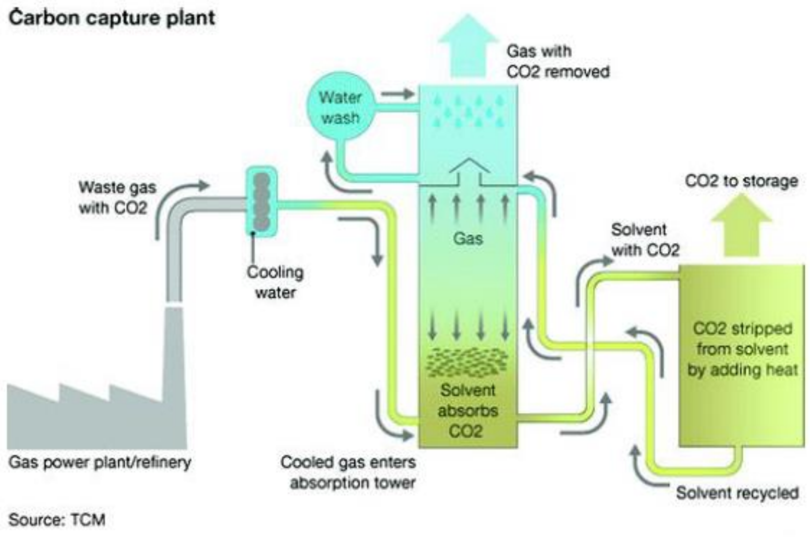


Illustrative CO_2 monitoring network
Credit: Battelle

Cost Components

- Capital expenditure:
  - Capture facility
  - Pipeline
  - Injection facility
  - Wells and monitoring infrastructure
  - Land use, pore space leasing
  - Project development and management
- Operating expenditure:
  - Labor and overhead
  - Electricity/Fuel
  - Chemicals
  - Maintenance and repair
  - Monitoring and site care
  - Taxation
- Financing cost





Schematic of solvent-based CO2 capture
Credit: U.S. DOE

The NRG/JX Petra Nova CO2 Capture Project Near Houston, Texas
Credit: National Petroleum Council

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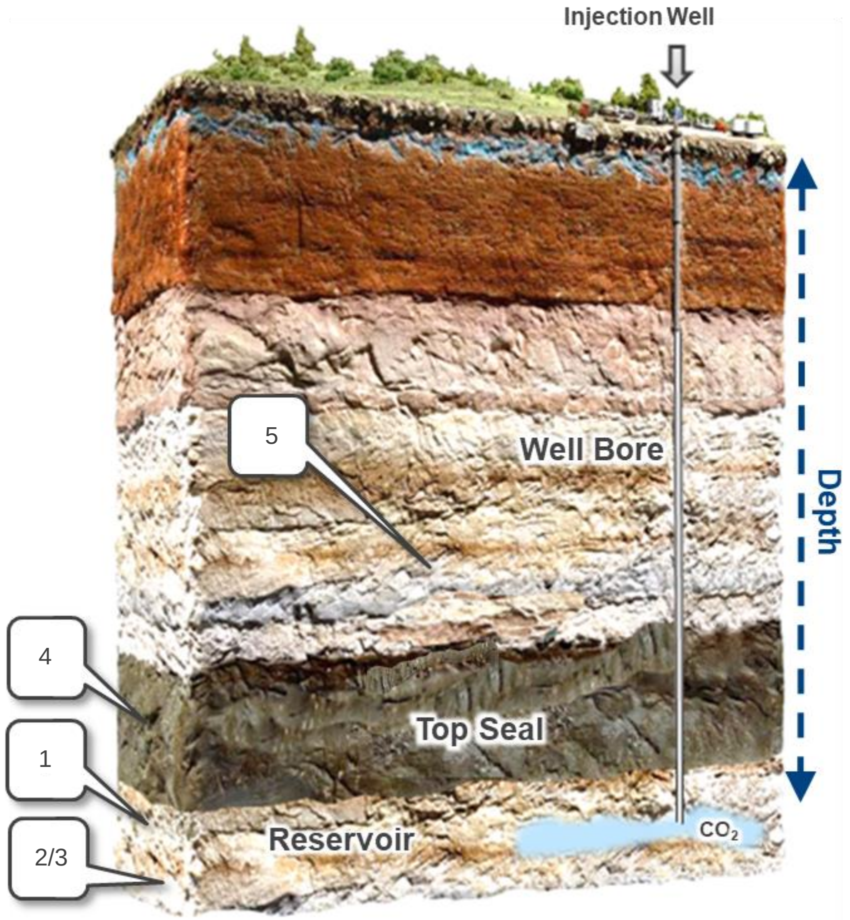
Our Phased Development Approach

- Starting with short timeframe, accessibly priced studies
- Methodical, proven approach
- Minimizing occurrence of “surprises”
- Each Phase builds upon knowledge gained in previous Phase
- Increasing confidence
- Even projects that end at Phase 1 are of value

Phase 1 Feasibility: Determine if a site has geological potential for carbon storage.	4 Weeks	RISK
Phase 2 Modeling: Perform detailed geologic assessment, analyze economic benefits, and begin the permitting plan.	4 Months	RISK
Phase 3 Characterization and Permitting: Drill a test well to sample and characterize the rock.	6 - 12 Months	RISK
Phase 4 Construction: Build the capture and injection systems.	2 Years	RISK
Phase 5 Operation and Monitoring: Begin injection of CO_2 and monitor the progress.	Ongoing	RISK

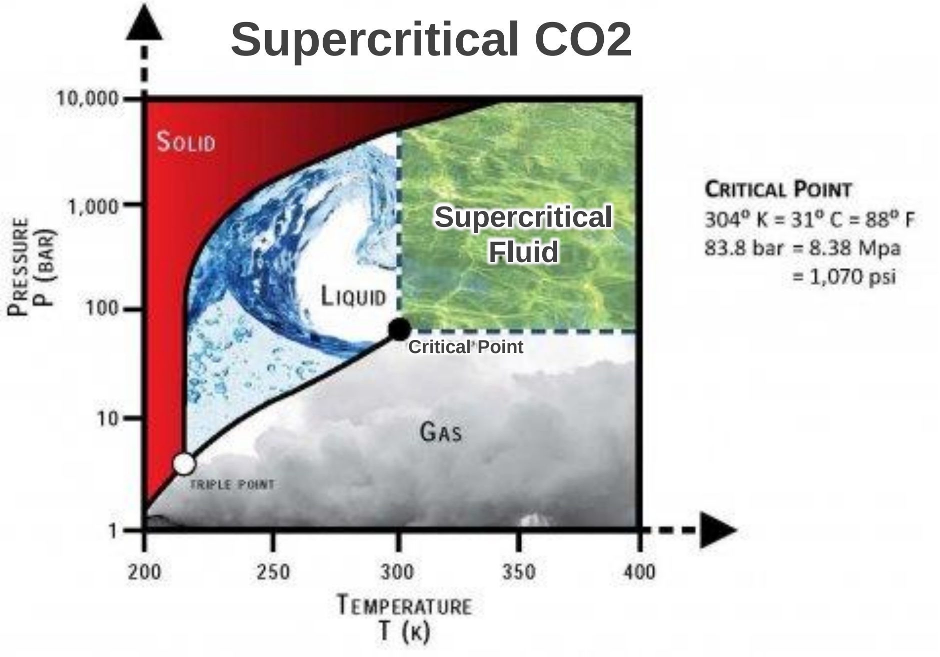
CO_2 Storage- Geologic Requirements

1	**Reservoir**	The presence of a rock, typically sandstone or carbonate, that meets the minimum depth threshold (>2,600 ft), reservoir characteristics (>1,070 psi and > 88F), and is not classified as USDW aquifer (>10,000 TDS)
2	**Capacity**	Reservoir rock has the thickness and lateral continuity to meet CO_2 storage requirements
3	**Injectivity/ Effectiveness**	The ability of the reservoir rock to allow the flow of supercritical CO_2 (permeability)
4	**Confinement/ Top Seal**	The presence of a rock that forms a barrier between the sequestered CO_2 and US drinking water
5	**Containment**	The reservoir is sealed laterally when applicable and any potential pathways for CO_2 leakage, such as faults, fractures, are either absent or the risk is mitigated



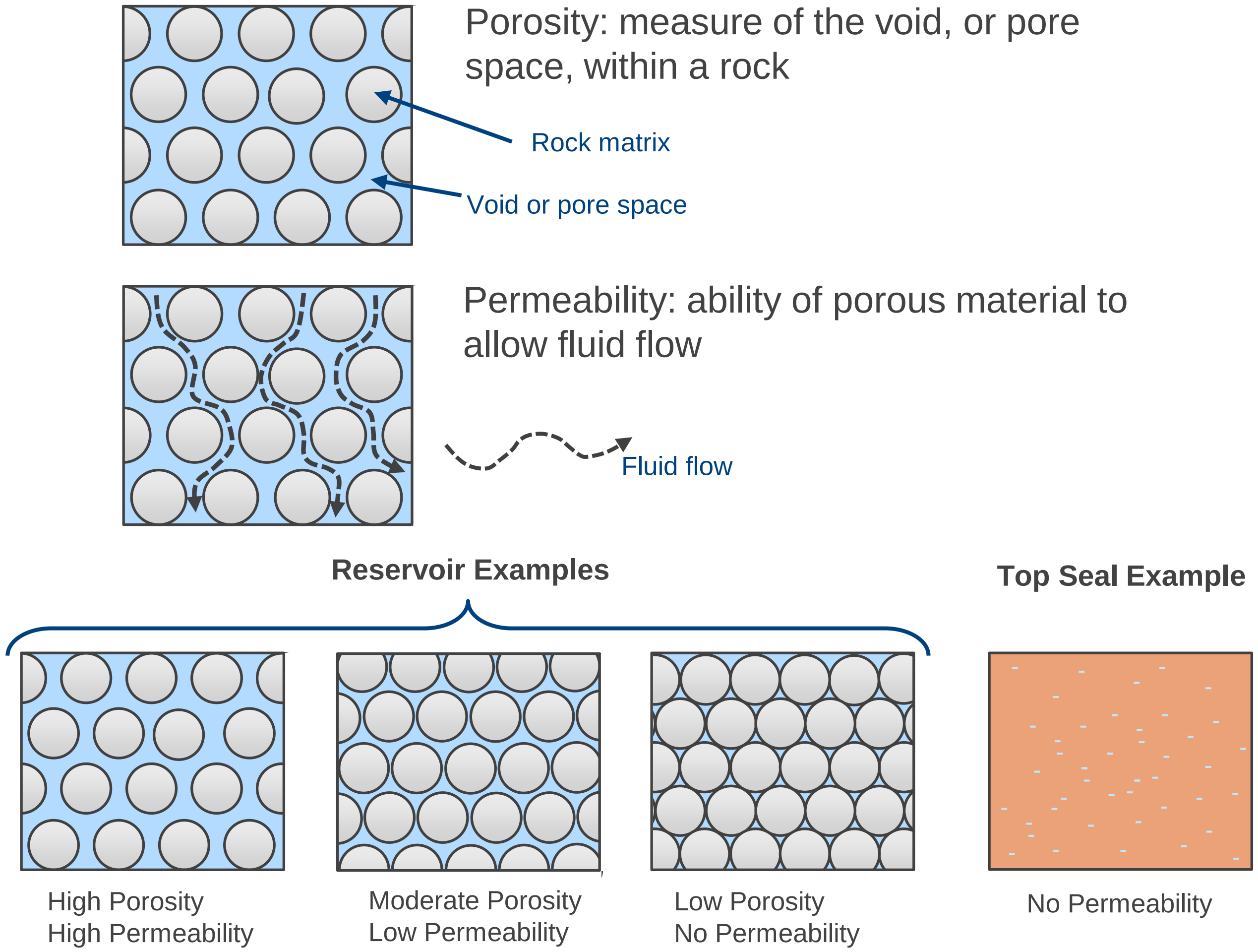
CO_2 Storage

Supercritical CO2



- CO2 has four states depending on Pressure and Temperature
- Supercritical CO_2 is fourth phase having density of liquid, but viscosity of gas
- State occurs at pressures and temperatures commonly found in deep, geologic formations
- Supercritical CO_2 state for plume management and maintenance

Reservoir & Containment/Top Seal



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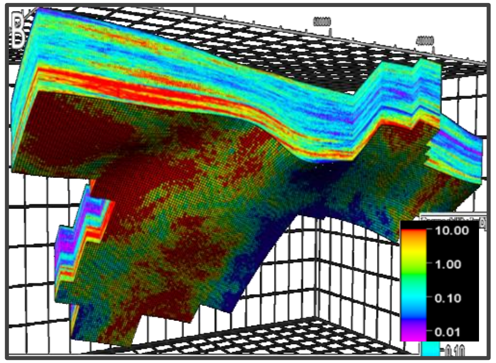
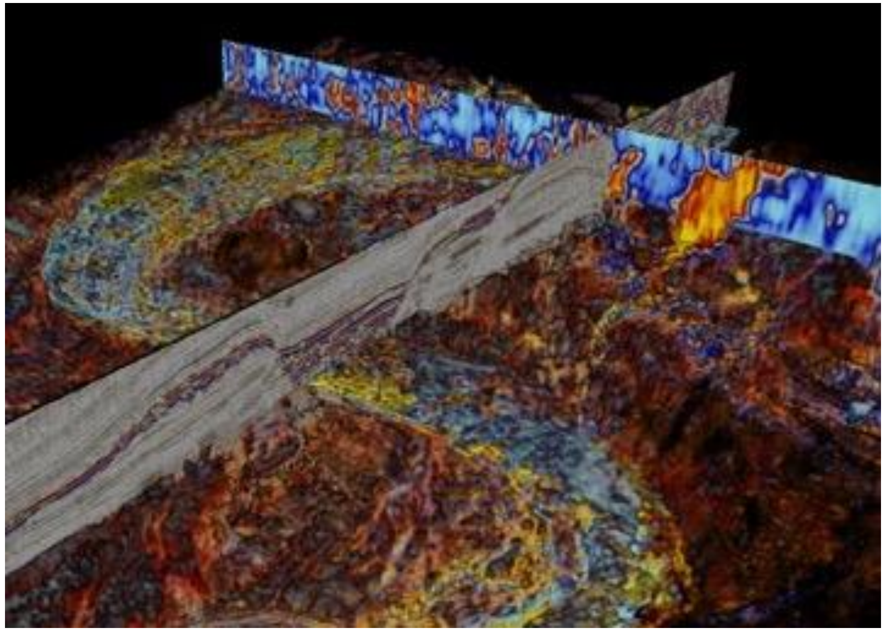
Potential Saline Storage

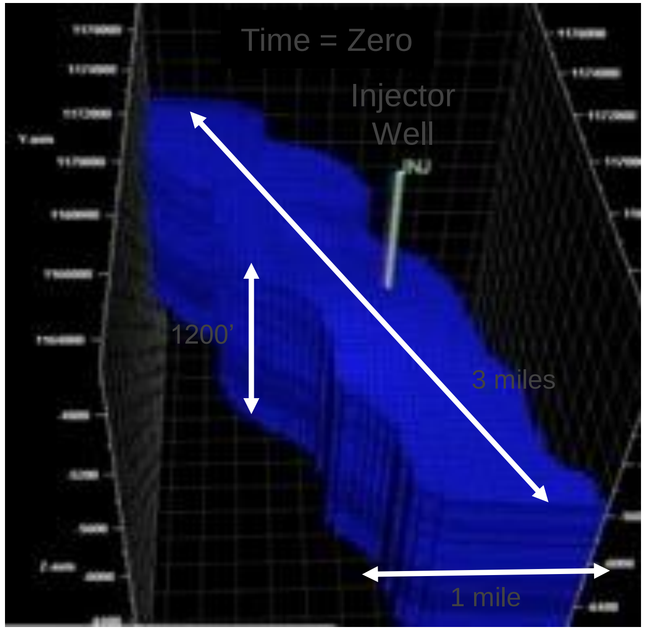
Predicting the CO_2 Plume Evolution with Models

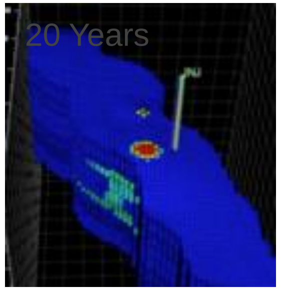


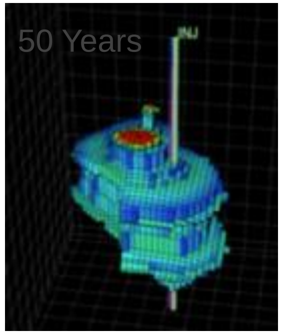
- time of arrival
- location
- CO_2 saturation 



Static Model

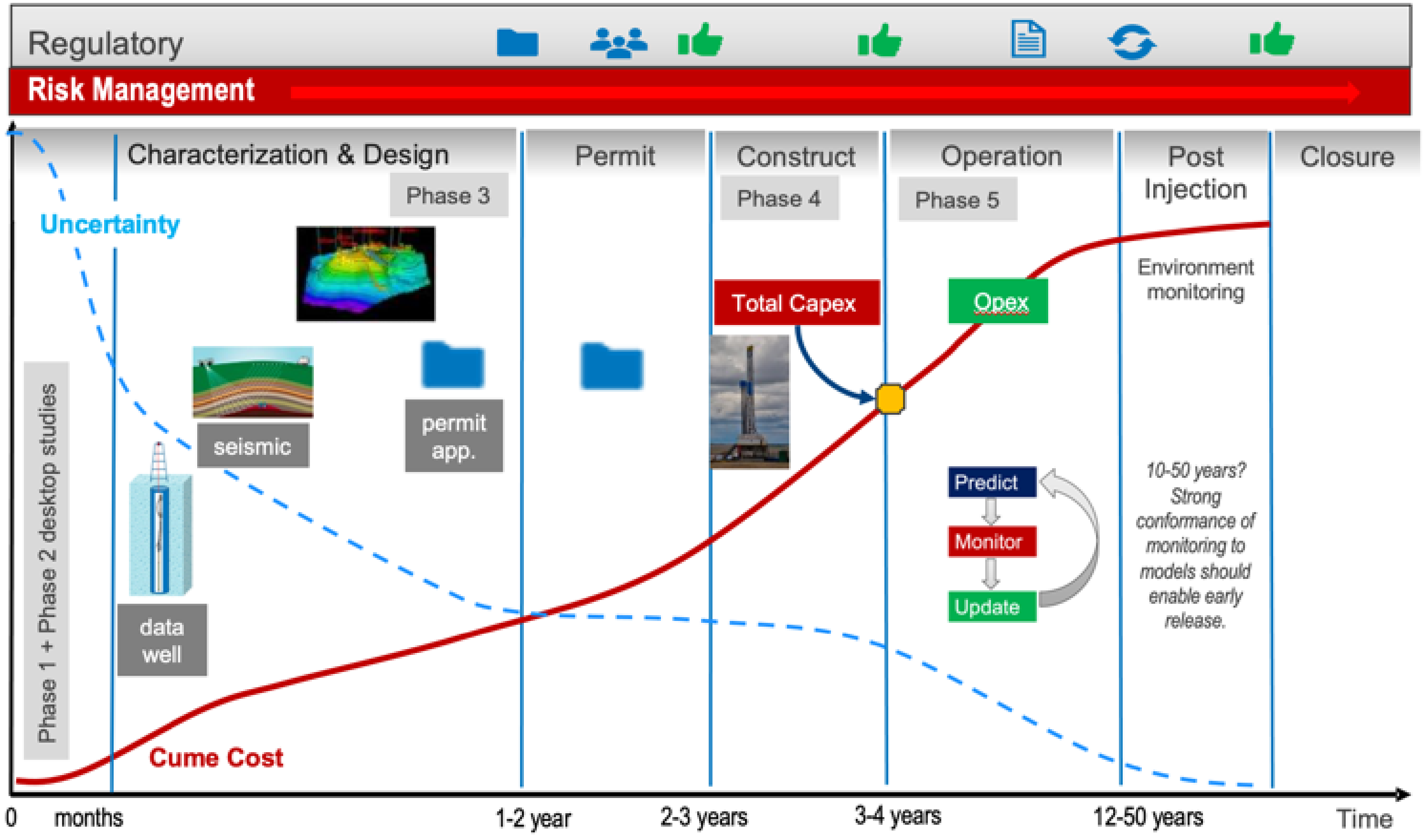






Dynamic Model

Project Lifecycle & Risk



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Questions?

It can be done

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