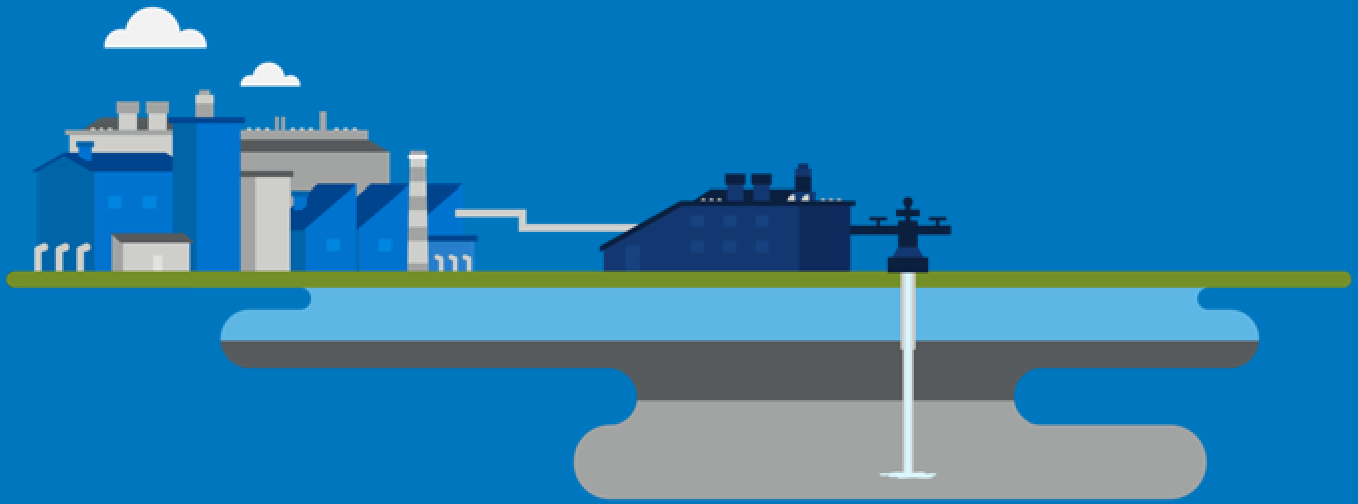
CCUS and Kentucky

Battelle Carbon Services



Evan Zeller
Subsurface Manager
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Presentation Outline

- Introduction/Battelle
- EPA and Class VI
- CCUS Project Considerations
- Kentucky and CCUS

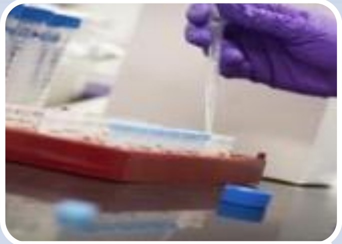
Battelle Innovates for the Future

We recognize global trends and help address the greatest and most challenging needs


Climate Resilience


Space & Hypersonics

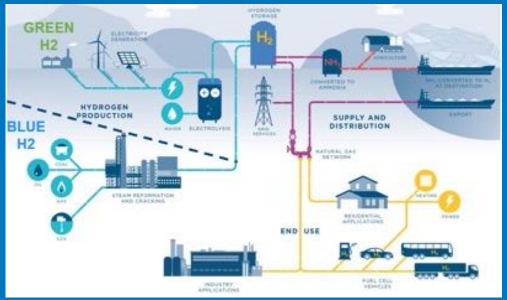

Neurotechnology


PFAS


Research Infrastructure


Microelectronics Trust & Assurance


CCS



H2 at Scale


Enhanced Geothermal

REE / CM


Plastics Upcycling/Recycling

Project Cypress Overview (DAC)

climeworks

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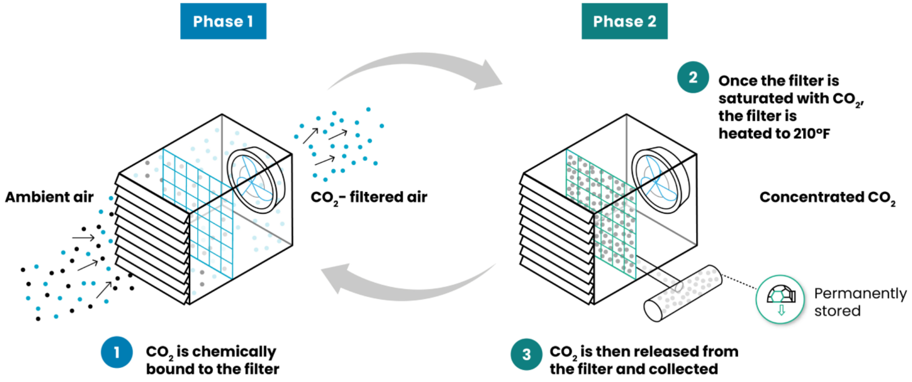
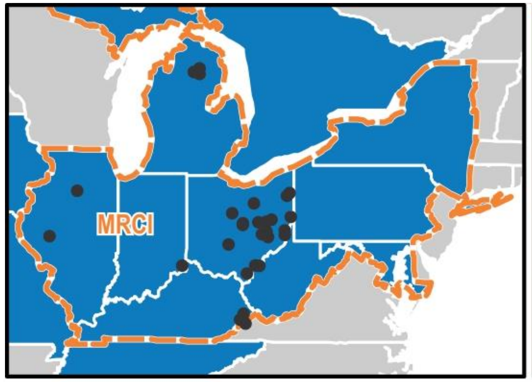
Heirloom

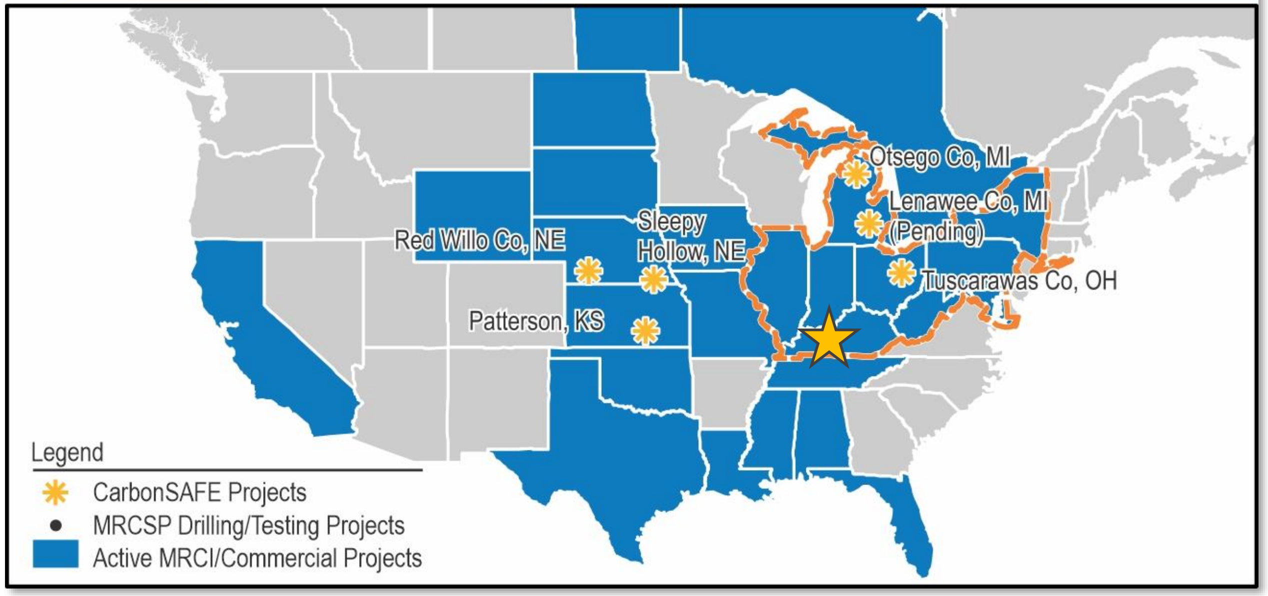



ARCH2
APPALACHIAN REGIONAL
CLEAN HYDROGEN HUB
Re-energizing Appalachia
Economically • Socially • Environmentally
www.ARCH2Hub.com

CCS Experience



Project	Location	Project Type	CO 2 Injected (Mt)
Appalachian Basin Geologic Test at R.E. Burger Power Plant	Shadyside, OH	Saline	50
Duke Energy—East Bend Well Site	Rabbit Hash, KY	Saline	910
Michigan Basin Geologic Test	Otsego Co., MI	Saline	60,000
Michigan Basin Niagaran Reef	Otsego Co., MI	EOR	1,900,000
AEP Mountaineer	Mason Co., WV	Saline	37,000



Description	Count
No. Wells Drilled	18
No. Wells Logged/Tested	52
No. Class V Permits Approved	3
No. Class VI Permits Approved	4
No. Class VI Permits in Process	8
No. CarbonSAFE Projects	7
Tonnes of CO_2 Injected	1,997,960

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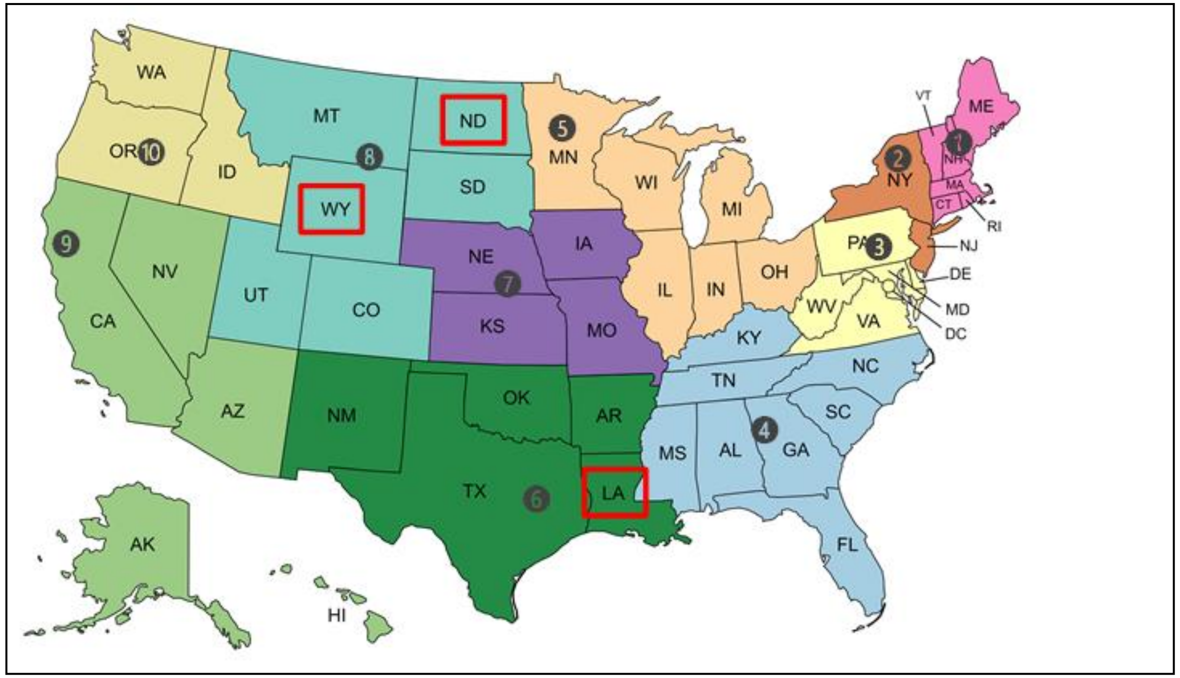
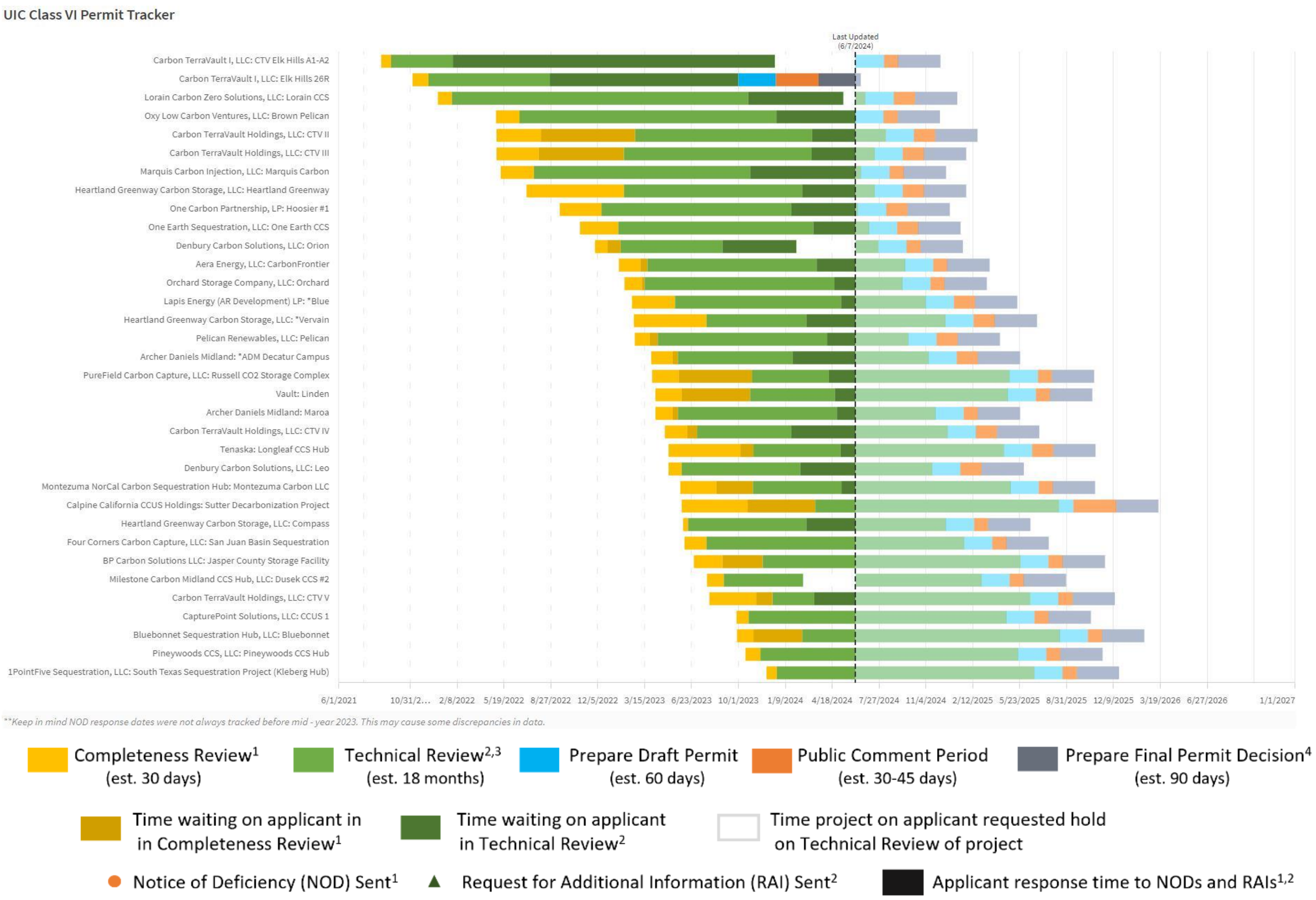
EPA Class VI

Region	Projects Under Review	Wells Under Review	# Issued
3	1	2	0
4	4	16	0
5	11	27	4
6	16	39	0
7	3	3	0
8	2	2	0
9	11	50	0
TOTAL	**48**	**139**	**4**



- 4 approved – (2) ADM, (2) Wabash

EPA Permit Tracker



- Wide range of sources and project types
- 2-3 years approval
  - Quality and completeness affect timing

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State Class VI Permits

State	Permits Under Review	Permits Issued
North Dakota	3	6
Wyoming	6	3
Louisiana	22	0
TOTAL	**31**	**9**

- Wide range of sources and project types
- ND approval 6-9 months

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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

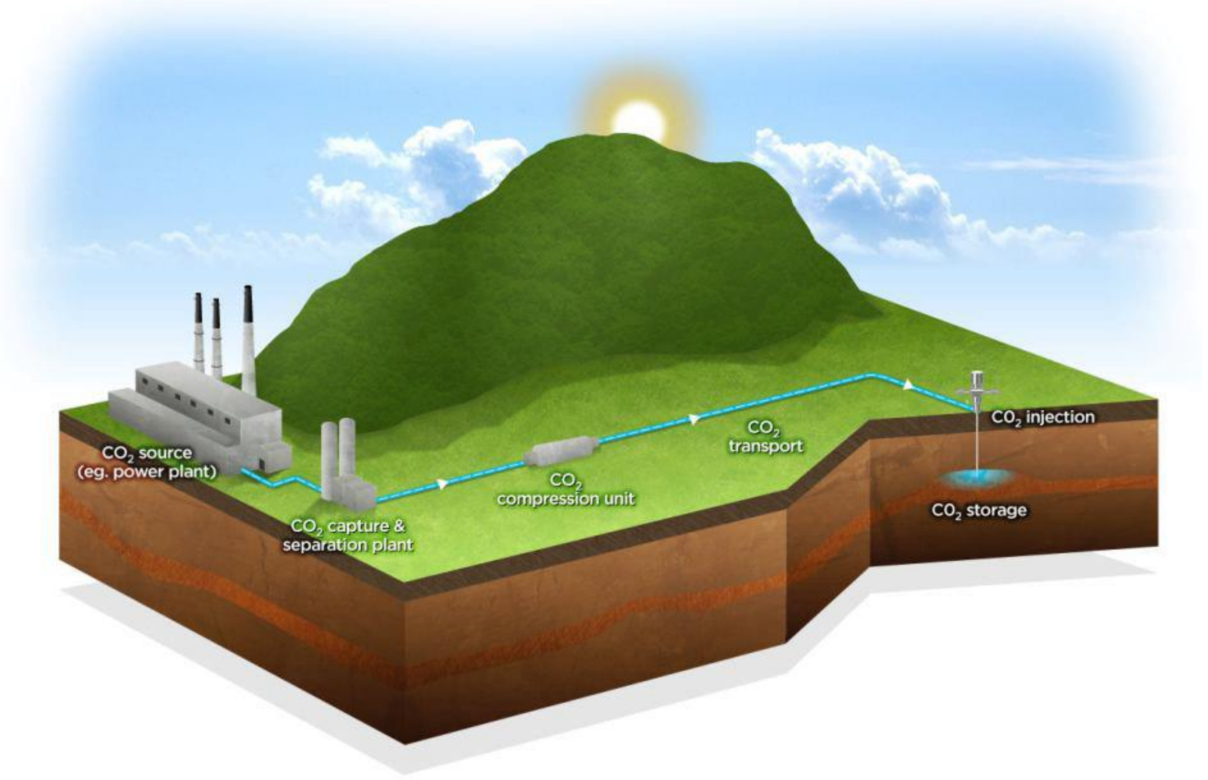
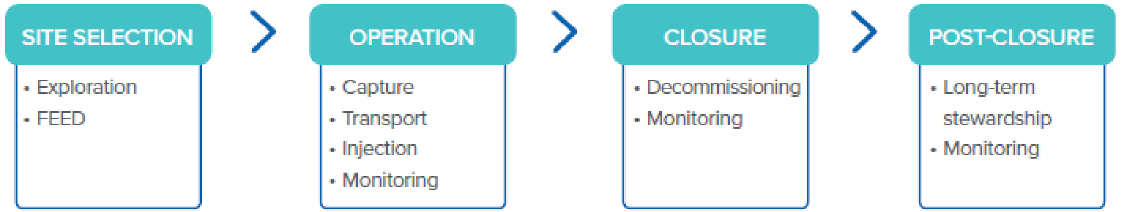


Illustration of a Simplified CCS Network with One Capture Unit and One Storage Facility
Credit: U.S. DOE



CCS project lifecycle
Credit: GCCSI, 2019

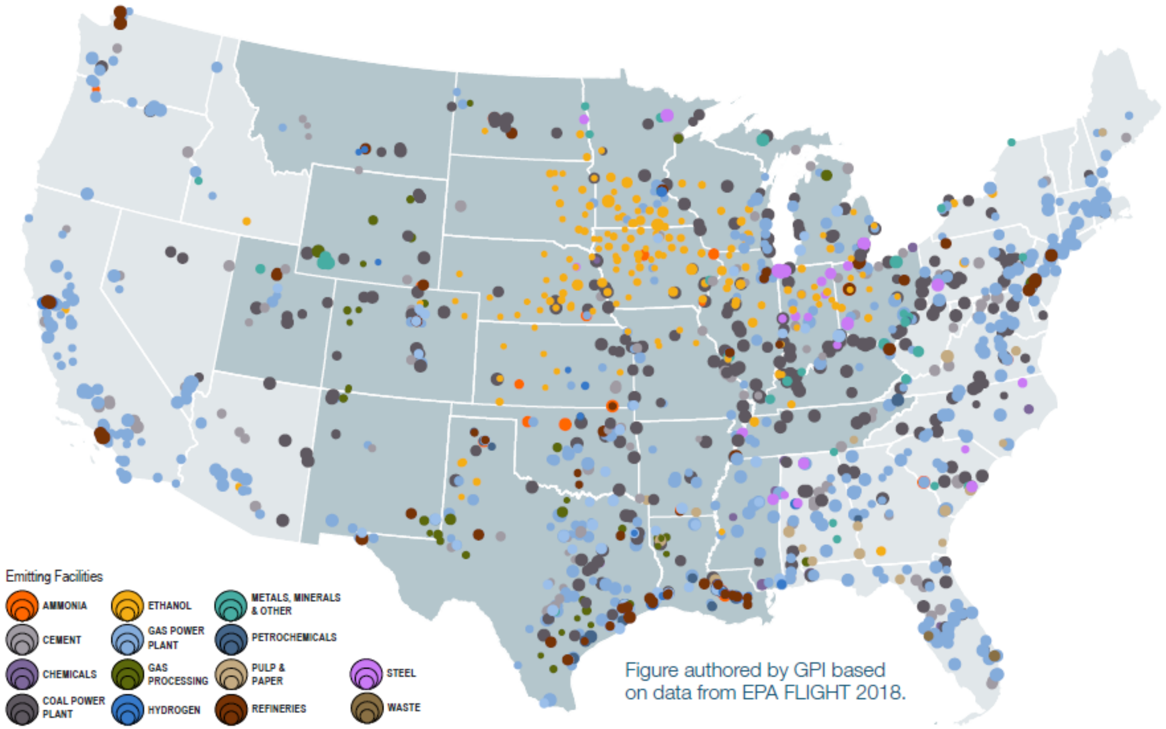
U.S. Emission Sources

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

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

Project Considerations

- Economics & uncertainty
  - Capture
    - CAPEX, purity, engineering, compatibility
  - Transport
    - ROW, distance, cost, community, future plans
  - Storage
    - Local geology, plume size and pore space, legacy wells, community

- Public acceptance/resistance
  - Engage early and often

State Regulatory Frameworks

- State regs reduce uncertainty for project investment
  - Test well permitting
  - Pore space ownership
  - Forced pooling
  - Local permitting (county/city)
  - Pipeline ROW
- States need explicit language for CCUS projects
- Class VI primacy reduces approval time

Example Regulations

- Illinois (SB3441)
  - Creates the Safety Moratorium on Carbon Dioxide Pipelines Act. Establishes a temporary statewide moratorium on construction of carbon dioxide pipelines until certain studies at the federal and State levels are conducted.

State	Statutory language
Indiana Code § 14-39-2-3	For split estate, "[a]fter June 30, 2022, the ownership of pore space is vested in the surface estate" unless express conveyance to contrary
Kentucky Rev. Stat. Ann. § 353.800	" 'Pore space owner' means the surface owner . . ."
Nebraska Rev. Stat. § 57-1604	Surface owner unless reservoir estate (containing underground voids/cavities) "has been severed and separately conveyed"
North Dakota Cent. Code § 47-31-03	"Title to pore space in all strata underlying the surface . . . is vested in the owner of the overlying surface estate."
Oklahoma Stat. tit. 60 § 6	"Land is the solid material of the earth, . . . and includes any pore space."
Utah Code Ann. § 40-6-20.5	"Title to pore space underlying the surface estate is vested in the owner of the surface estate."
West Virginia Code Ann. § 22-11B-18	"Title to pore space in all strata underlying the surface of lands and waters is vested in the owner of the overlying surface estate."
Wyoming Stat. Ann. § 34-1-152	"The ownership of all pore space in all strata below the surface lands and waters of this state is . . . vested in the several owners of the surface above the strata."

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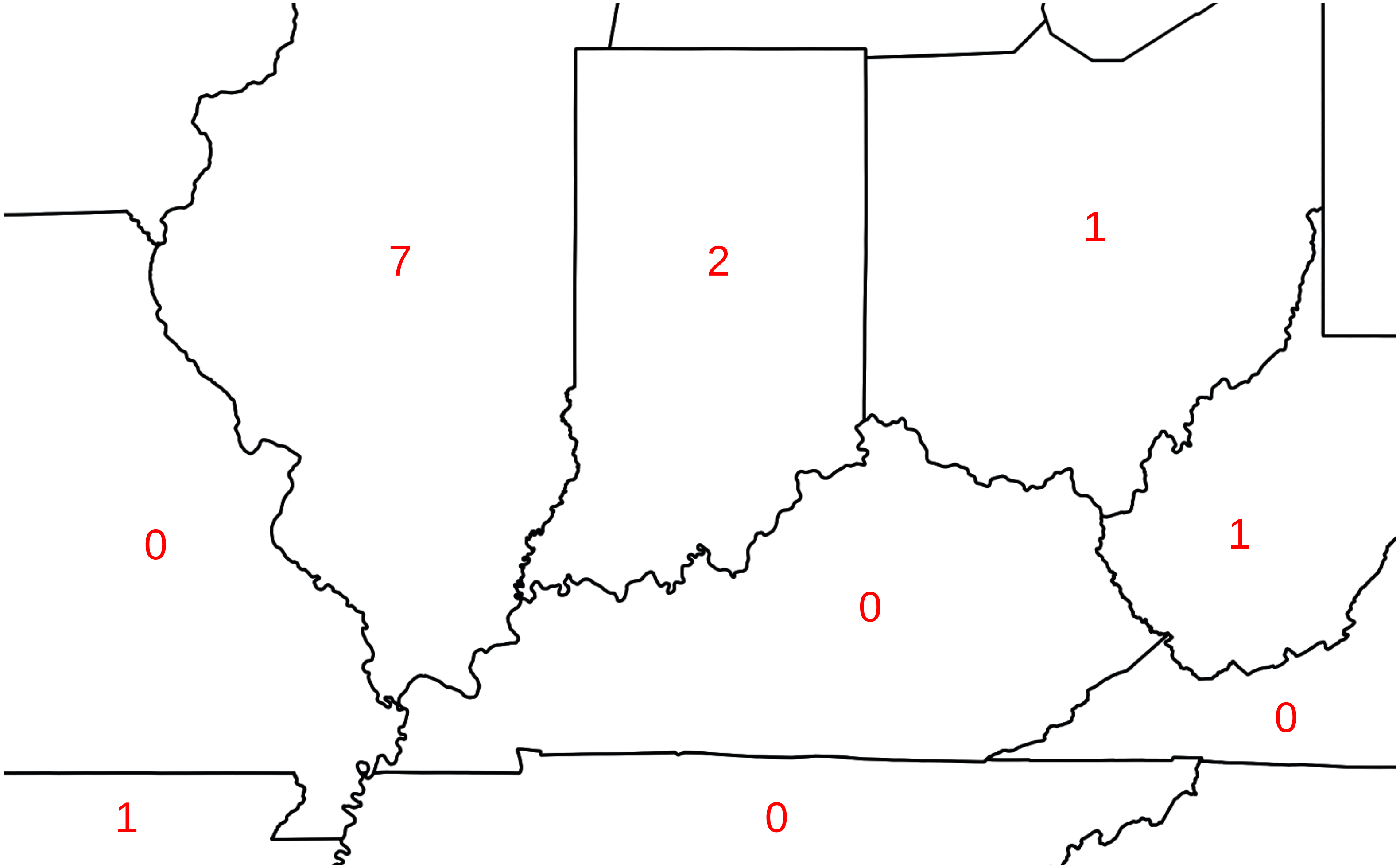
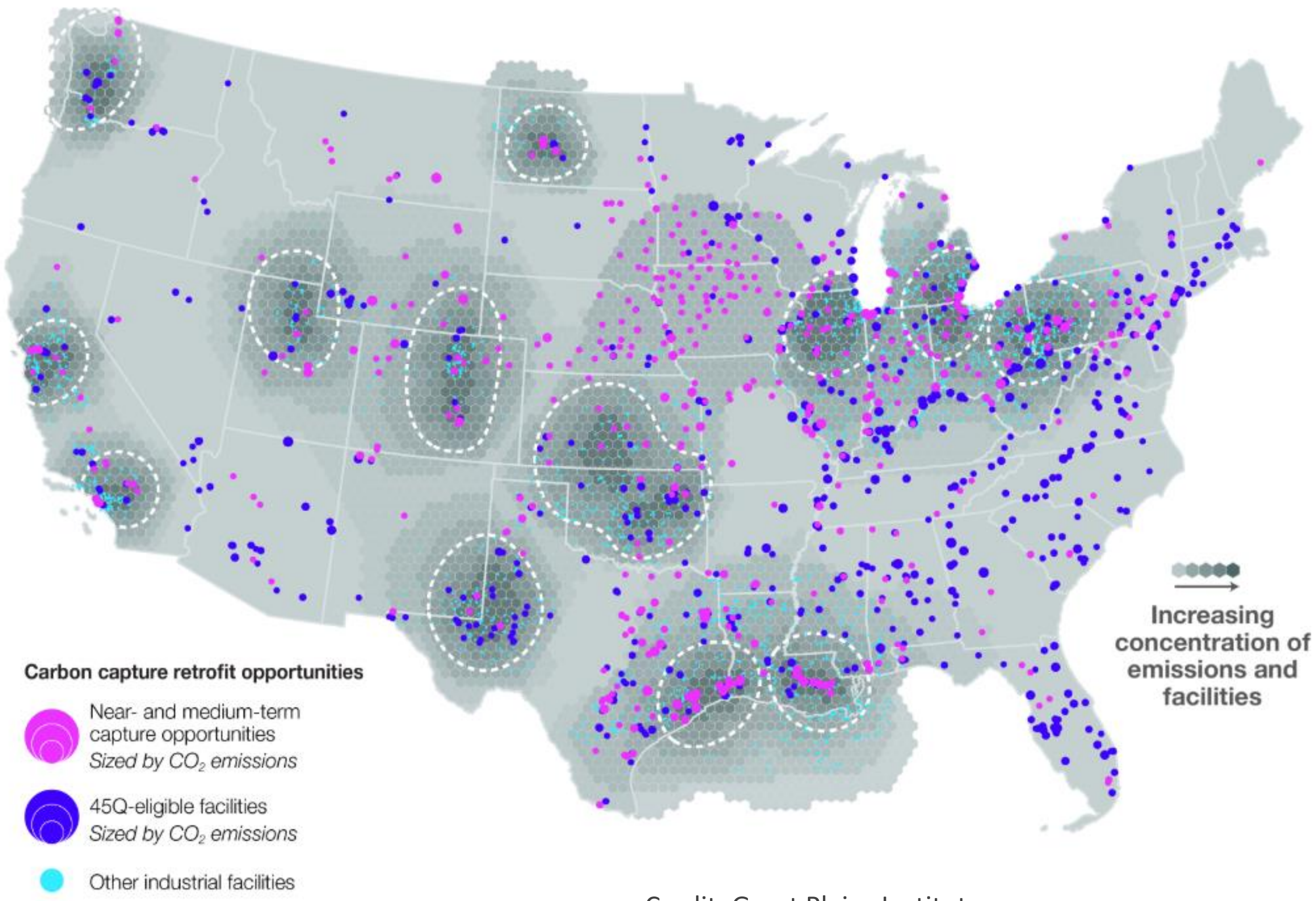
Class VI Applications

Why would we worry about CCUS?



Kentucky CCUS

- # Class VI permit applications = 0
- But we need to be ready…
  - Power plants
  - Blue hydrogen (SMR)
  - Heavy industry (metals)
- Well-defined regulations/statutes (primacy?)
- Public outreach



Credit: Great Plains Institute

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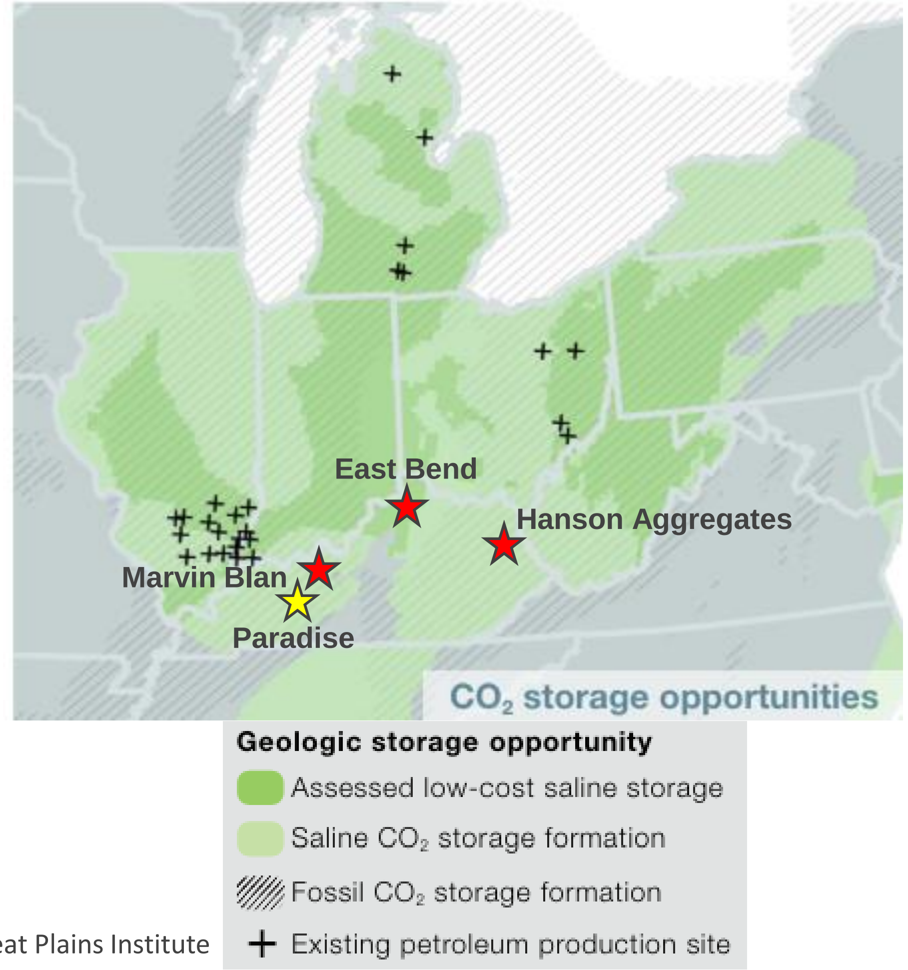
Geology

- We have the saline storage reservoirs
  - Need to prove up beyond regional strat wells
- North
  - Mt. Simon
- West
  - Knox
  - Shallower sands and carbonates
- East
  - Knox/Sub-Knox



Credit: Great Plains Institute

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DOE CarbonSafe Phase II: FOA2711

Facility

Paradise Combined Cycle Plant

Project Team

Battelle (prime)

KGS

Others

Location

Muhlenberg Co, KY

Scope

Storage complex feasibility

Phase II CarbonSafe

CCUS Outlook

- High purity (economic) CCUS projects going forward now
- As technology costs fall other industries will deploy CCUS
- To retain CCUS projects (along Ohio River) KY must enact CCUS regulations to remain viable partner
- KY CO_2 sources are later-stage projects – we have time but…

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It can be done

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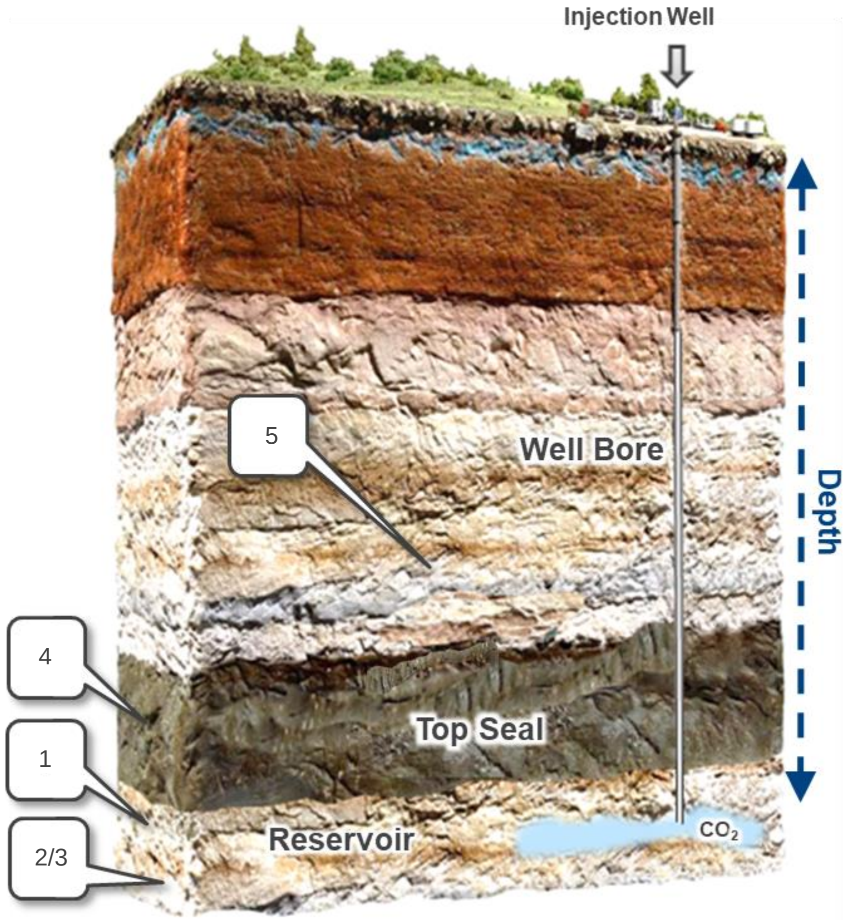
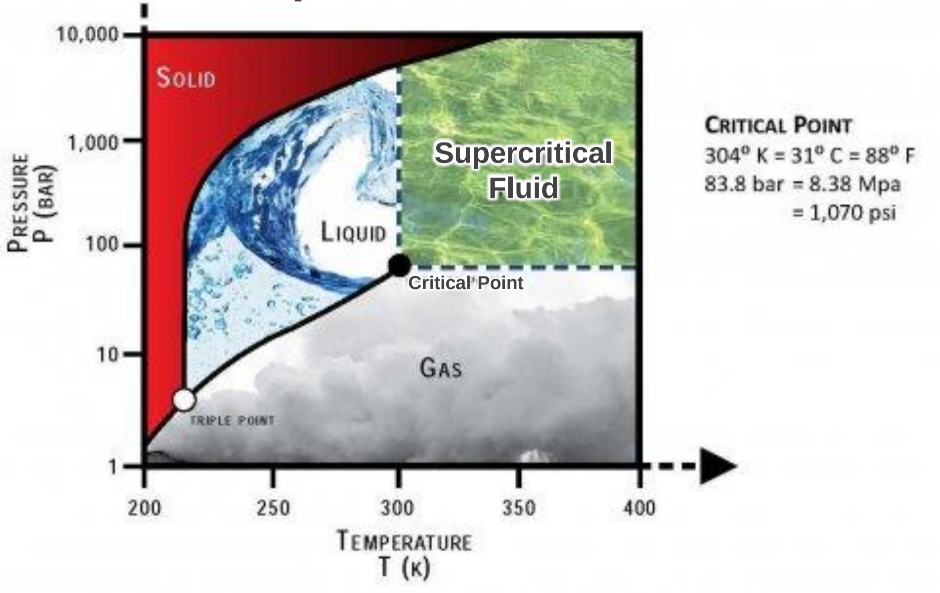
CO_2 Storage- Geologic Requirements

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



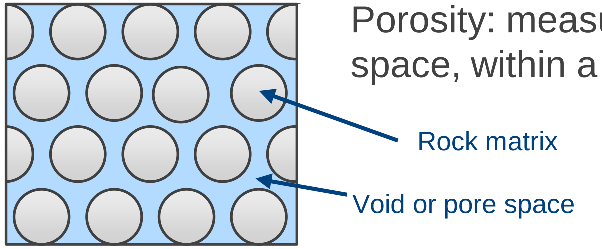
CO_2 Storage

Supercritical CO2

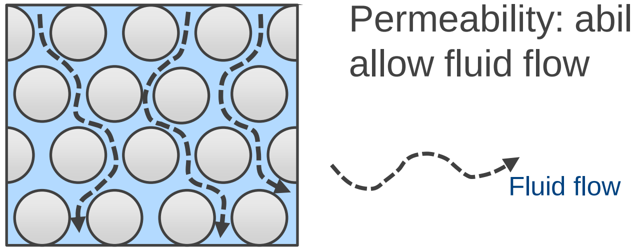


- CO2 has four states depending on Pressure and Temperature
- Supercritical CO_2 is fourth phase having density of liquid, but viscosity of gas
- State occurs at pressures and temperatures commonly found in deep, geologic formations
- Supercritical CO_2 state for plume management and maintenance

Reservoir & Containment/Top Seal

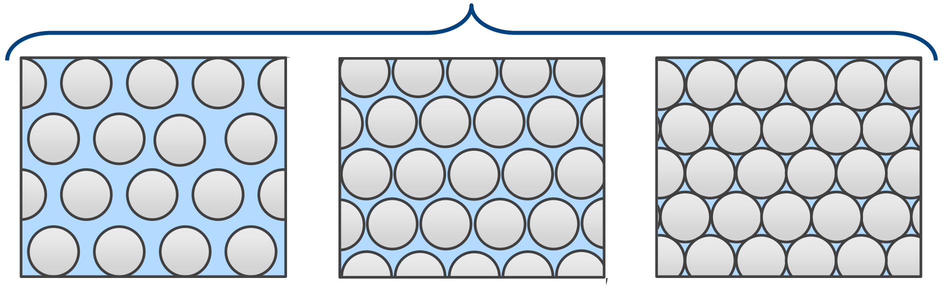


Porosity: measure of the void, or pore space, within a rock



Permeability: ability of porous material to allow fluid flow

Reservoir Examples

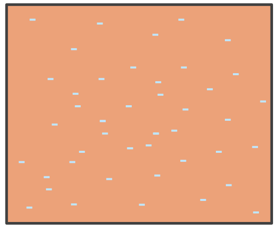


High Porosity
High Permeability

Moderate Porosity
Low Permeability

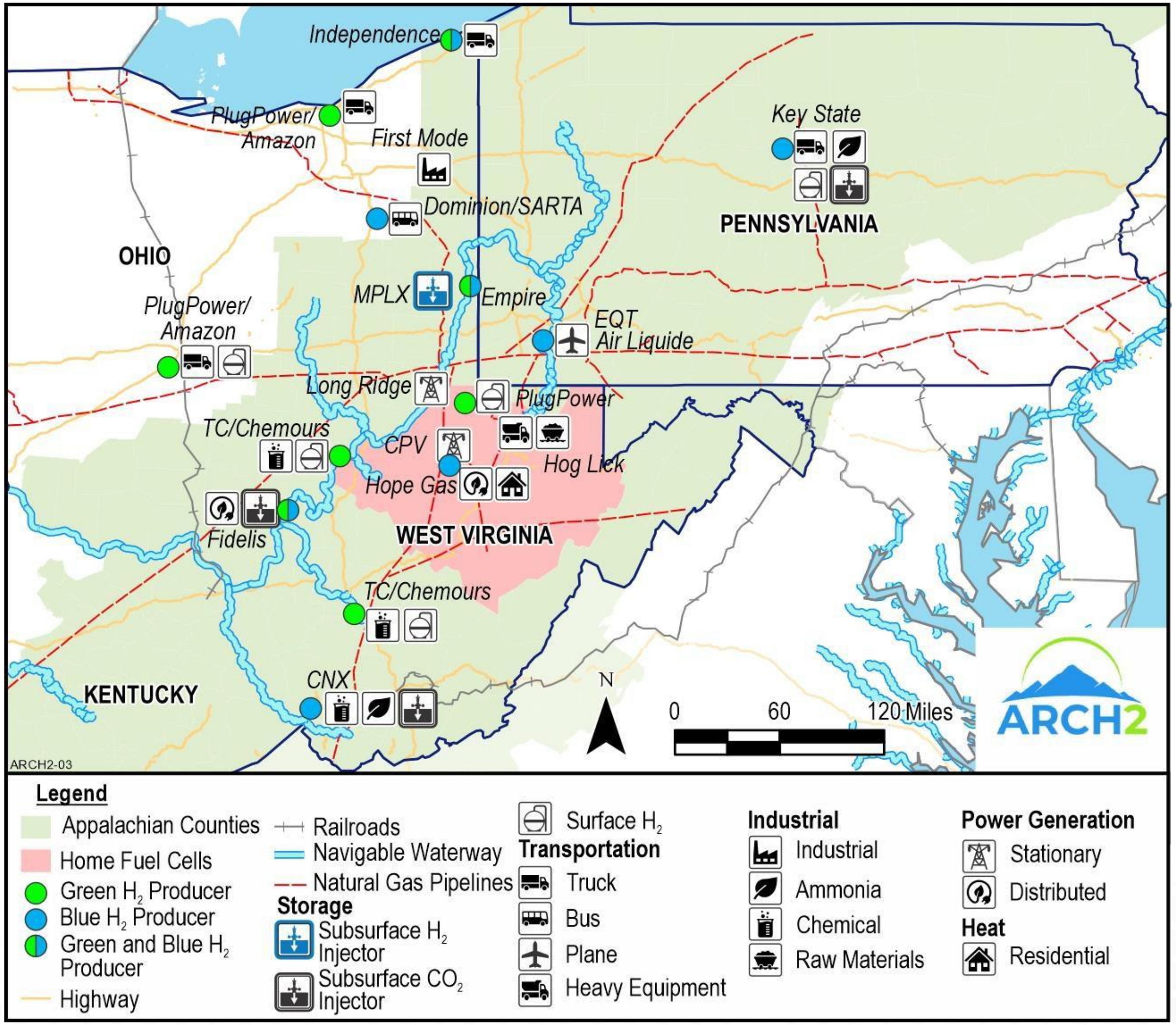
Low Porosity
No Permeability

Top Seal Example

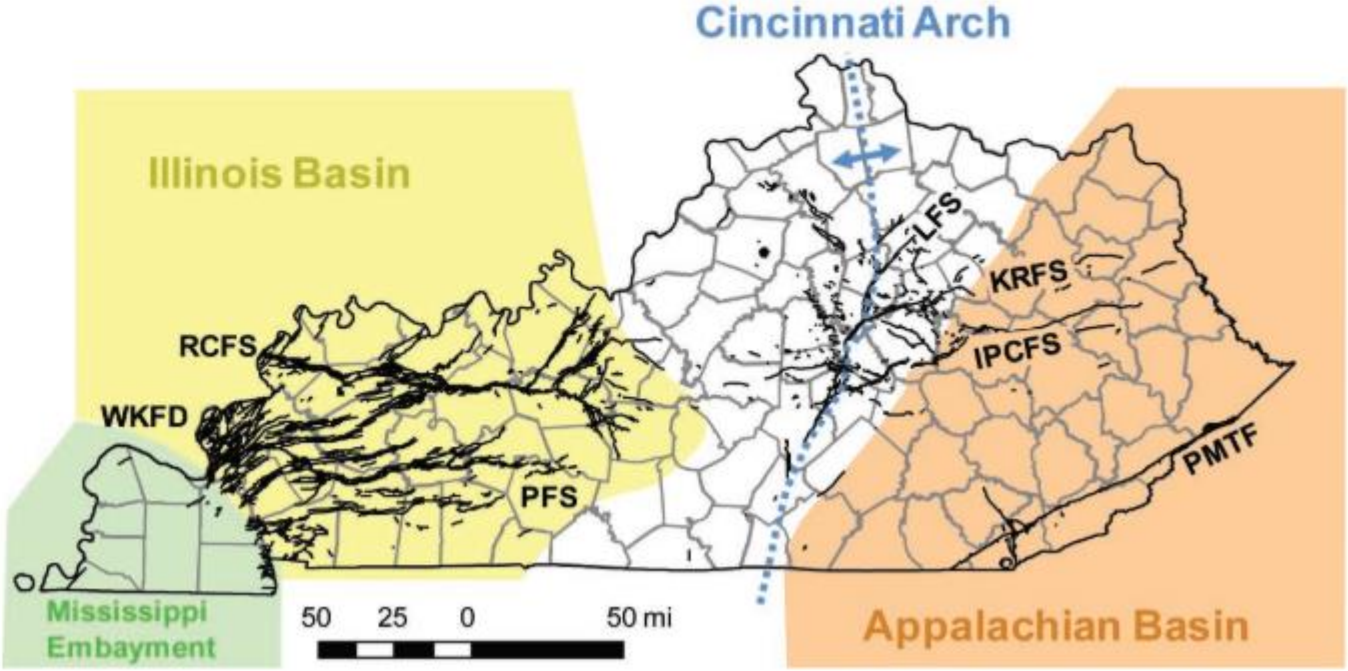


No Permeability

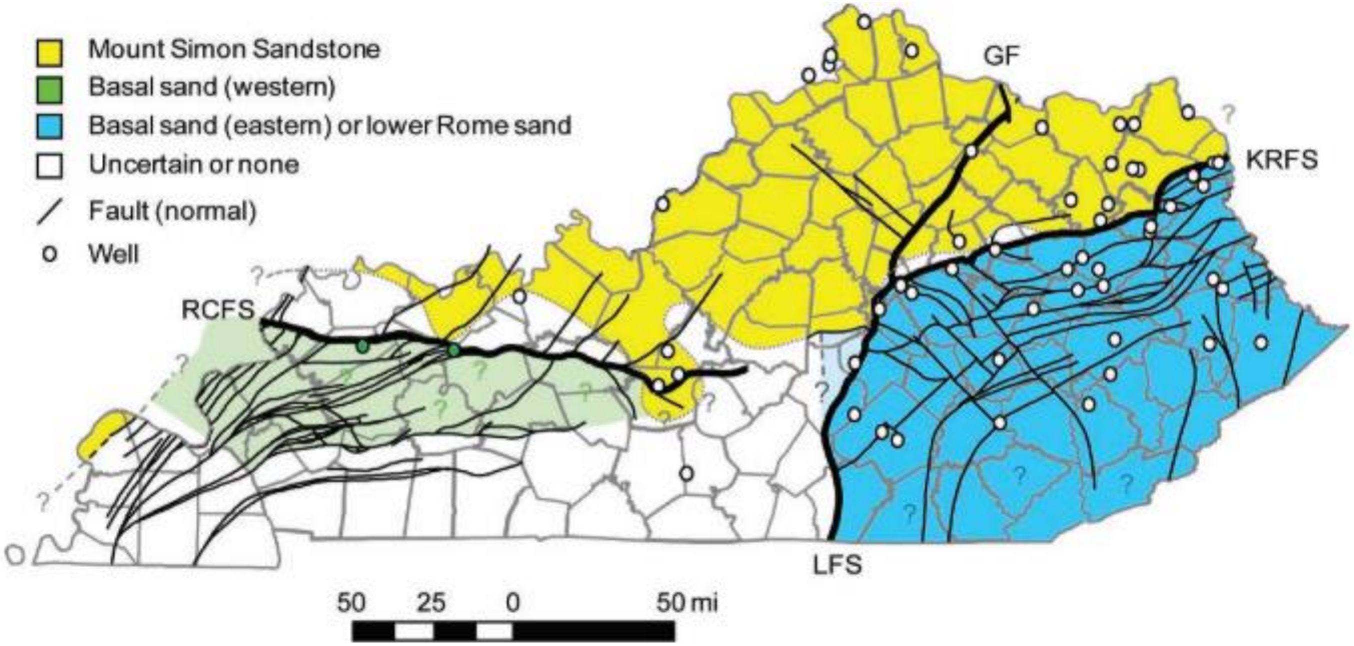
ARCH2 Overview



Note: Proposed project locations based on preliminary siting are subject to change during the detailed planning phase (phase 1).



Cincinnati Arch
Illinois Basin
LFS
KRFS
IPCFS
RCFS
WKFD
PFS
PMTF
Mississippi
Embayment
50 25 0 50 mi
Appalachian Basin


Mount Simon Sandstone
Basal sand (western)
Basal sand (eastern) or lower Rome sand
Uncertain or none
Fault (normal)
Well
GF
KRFS
RCFS
LFS
50 25 0 50 mi

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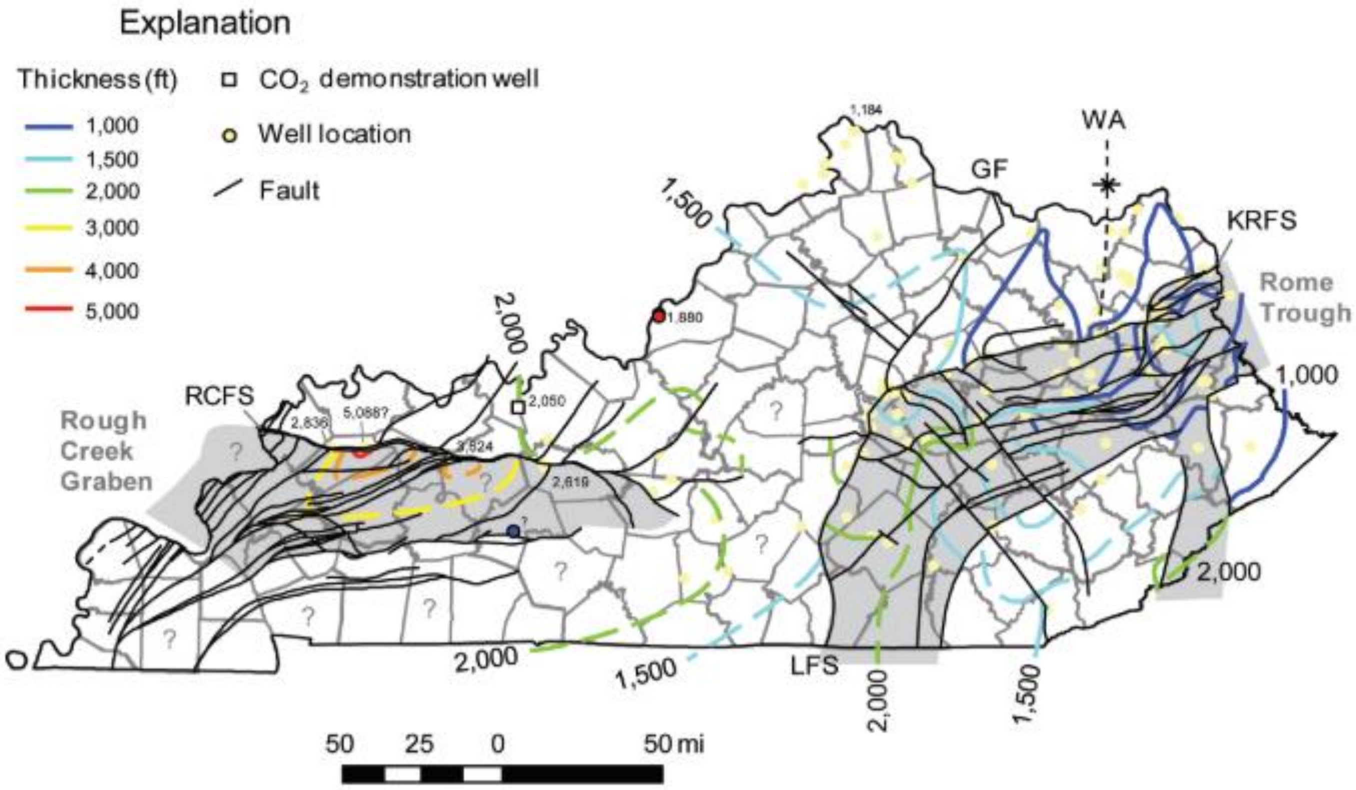
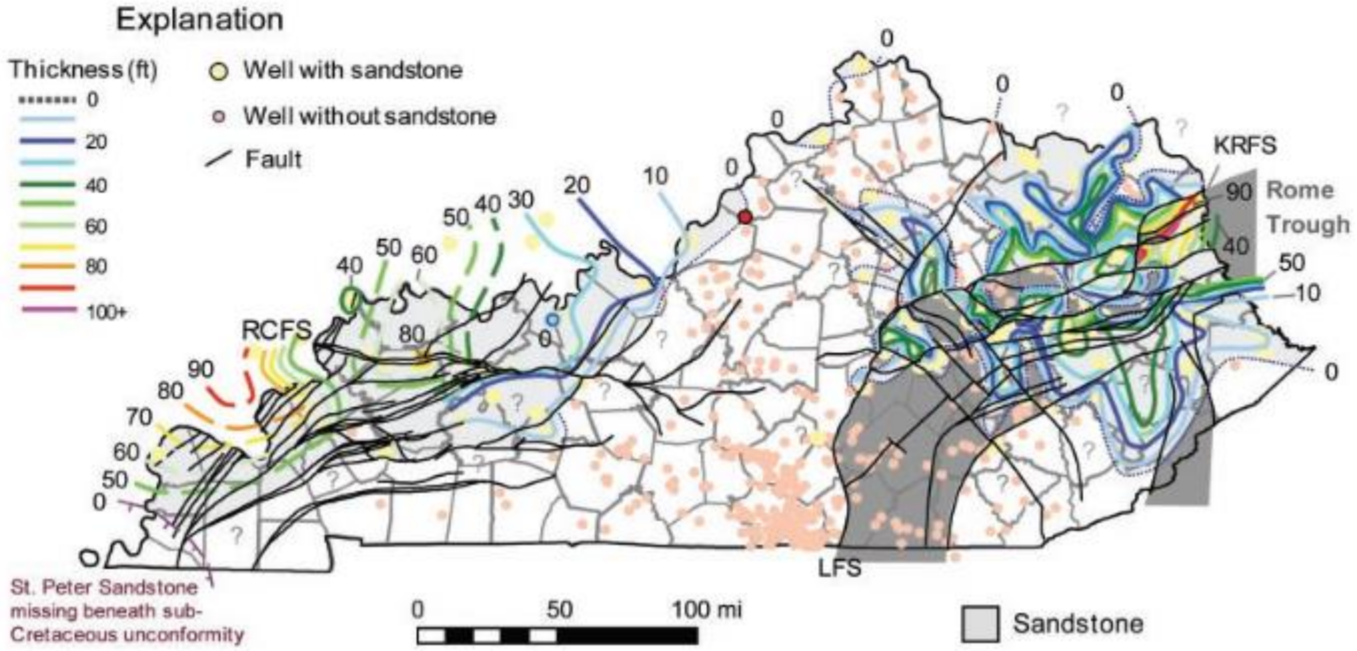

Explanation
Thickness (ft)
1,000
1,500
2,000
3,000
4,000
5,000
CO2 demonstration well
Well location
Fault
RCFS
Rough Creek Graben
WA
GF
KRFS
Rome Trough
LFS
1,000
1,500
2,000
50 25 0 50 mi


Explanation
Thickness (ft)
0
20
40
60
80
100+
Well with sandstone
Well without sandstone
Fault
RCFS
KRFS
Rome Trough
LFS
St. Peter Sandstone missing beneath sub-Cretaceous unconformity
0
50
100 mi
Sandstone