Comparative Economic Analysis of Capture, Transport, and Storage from a CO_2 Source Perspective

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Opportunity Landscape for CCS

CCS is expected to be a critical component in support of decarbonization targets.

Infrastructure Investment and Jobs Act (2022) is providing funding opportunities for large-scale CCS endeavors.

- Large-scale carbon capture pilot projects.
- Low-interest loans to large CO_2 pipeline projects.
- Large-scale carbon storage projects.
- Regional direct air capture hubs.

Inflation Reduction Act of 2022 improves economics of CCS via Section 45Q tax credit expansion.

Many U.S. states are implementing CCS-favorable policies.

CCS Deployment Hurdles

Integrating highly variable and often uncertain enabling elements makes CCS planning challenging.

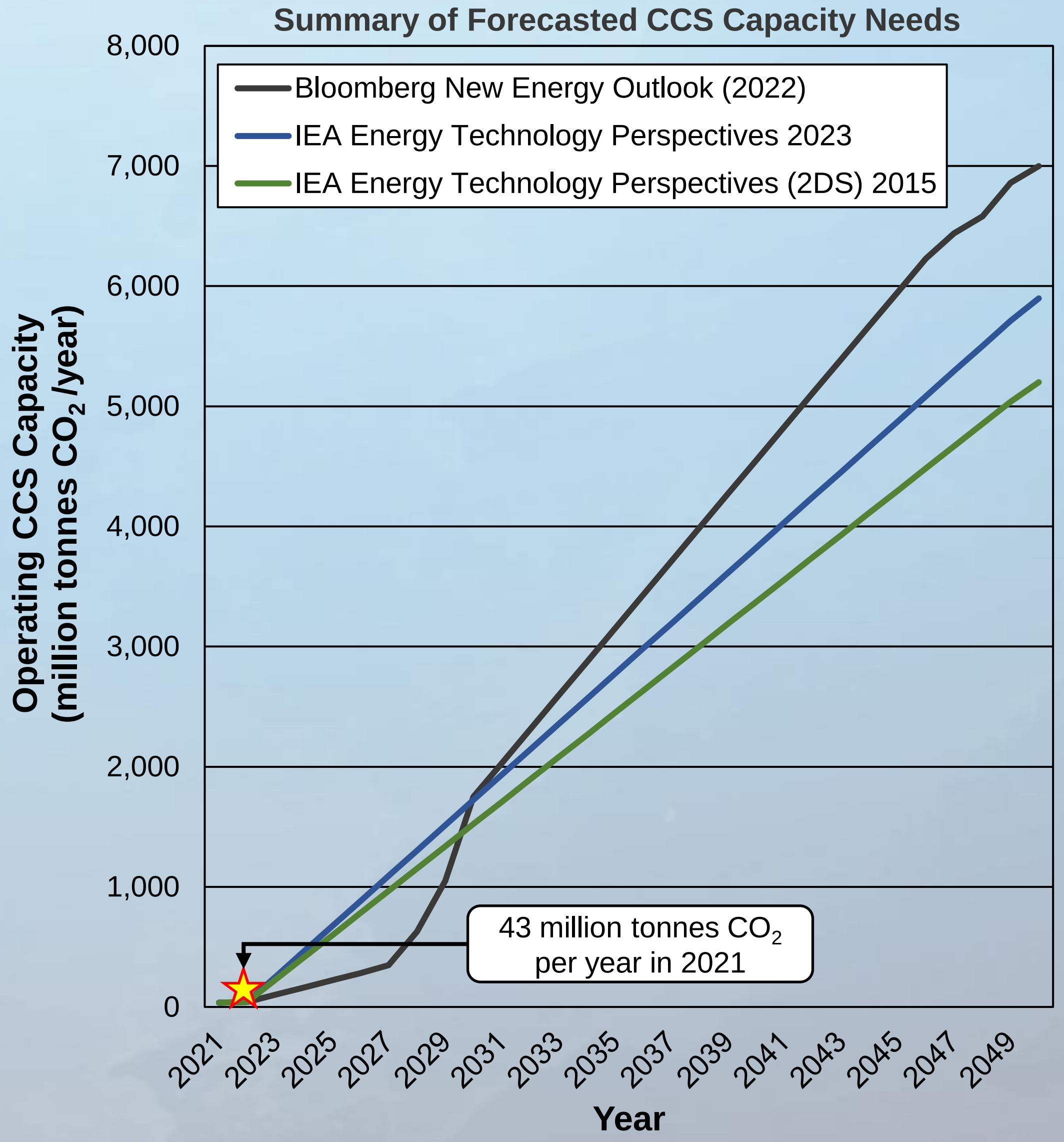
- CO_2 capture amenable to source type.
- CO_2 transport infrastructure.
- Storage options with suitable capacity, containment, and injectivity.
- Mature regulatory and economic policy support.
- Source-specific business case viability.

Enabling elements are known to vary substantially from region to region.

Keeping pace with decarbonization timelines will require rapid CCS scale-up.

Multiple options for CCS integration exist. Assessing and weighing options that are most beneficial to a given CO_2 source(s) remains a challenge.

- Single source-to-sink: e.g., ethanol facilities in North Dakota and Illinois.
- Hub and cluster: top-down demand-driven (e.g., Princeton University Net Zero and Great Plains Institute outlooks).



CCS Deployment Assessment

- **Approaches for broader CCS deployment must be applicable across different industries given unique business cases specific to CO_2 source types that may consider CCS.**
- **Techno-economic tools and analyses are key to providing clarity and insight into CCS development and for supporting broader deployment.**
  - NETL has developed techno-economic models and resources to assess the entire CCS value chain and support decision making.
  - NETL has also looked at CCS cost options across various U.S. regions from a CO_2 source's perspective.

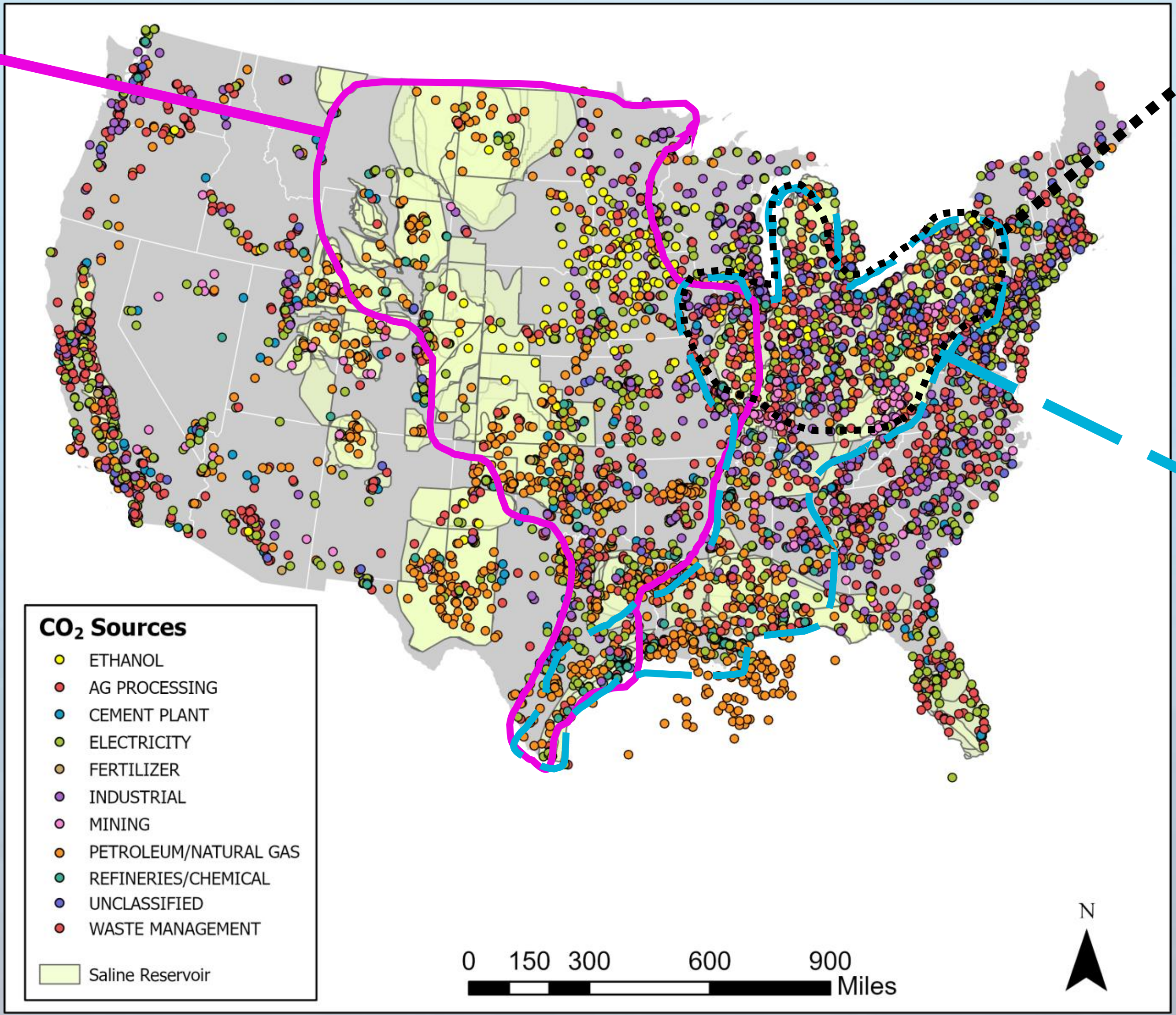
Assessing Regional CCS Opportunities

Phase III Study: U.S. Central

- Regionally relevant source types (industrial plants and electric power plants).
- Dedicated pipeline and trunkline.
- Denver, East Texas, Gulf Coast Onshore, Illinois, Ozark Plateau, Powder River, Williston, and Wind River basins.

U.S. Central Study Region CCS Landscape:

- CO_2 source type variety.
- Many sources not proximal to storage options.
- CO_2 storage operation regulatory primacy exists.
- State incentives and policies favorable for CCS exist.



Phase I Study: U.S. Eastern

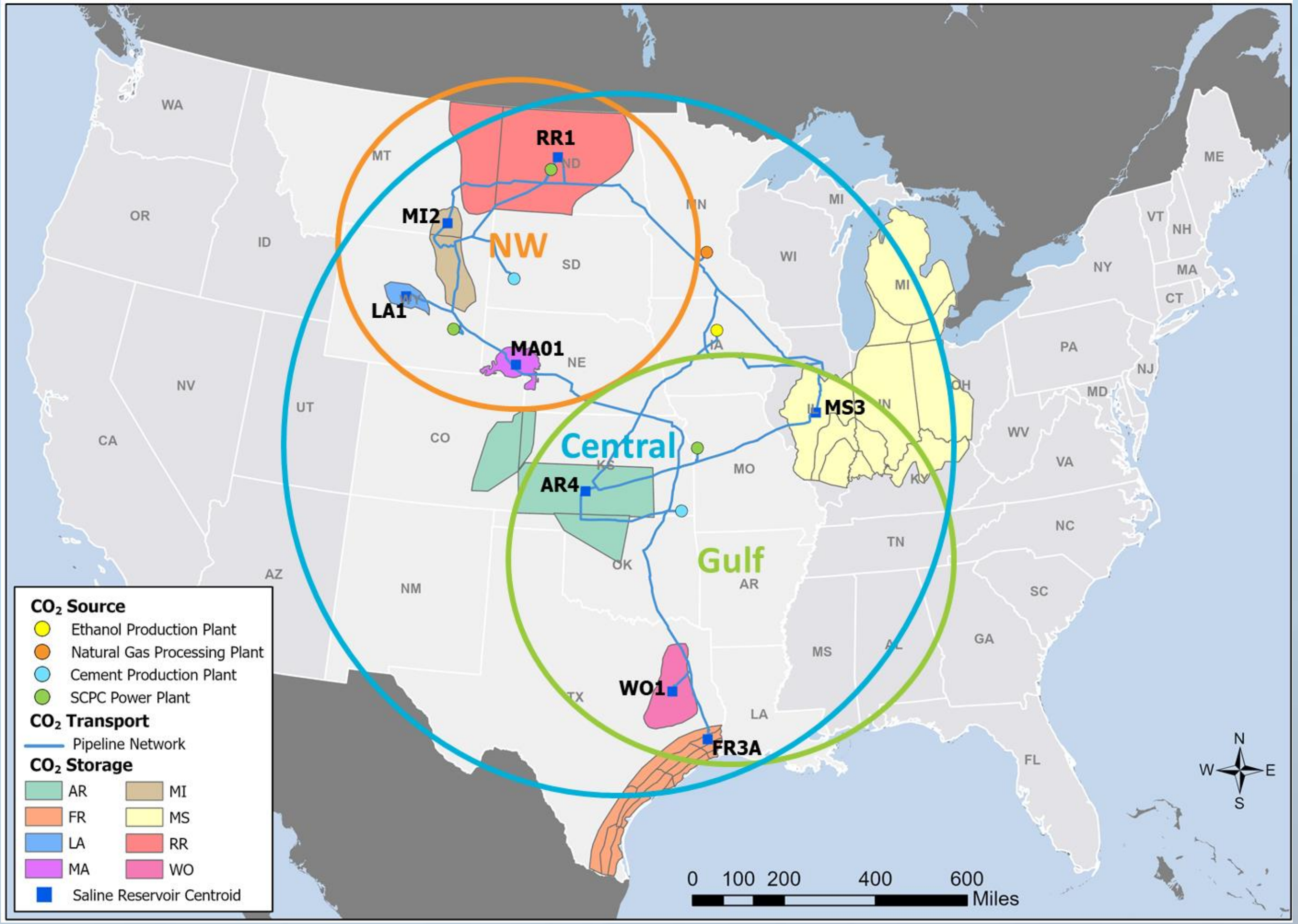
- Electric power plants.
- Dedicated pipeline.
- Appalachian and Illinois basins.

Phase II Study: U.S. Eastern II

- Industrial plants and electric power plants.
- Dedicated pipeline and trunkline.
- Appalachian, Gulf Coast Onshore, and Illinois basins.

Central United States Study Overview

- **Assessed management options for captured CO_2 faced by a CO_2 source from both economic and regional geologic perspectives.**
- **Integrated CCS costs for regionally relevant CO_2 sources in three regional impact areas using NETL-developed resources and techno-economic models specific to each value chain component.**
  - Impact areas enable exploration of the challenges facing and advantages of different areas within a region from the perspective of a CO_2 source.



Three regional impact areas considered: Central Impact Area, Northwest Impact Area, and Gulf Impact Area

CO_2 Capture, Transport, and Storage Cost Modeling Approach

CCS costs were evaluated from the perspective of various point sources using disparate techno-economic analysis resources developed by NETL.

Capture	Transport	Storage
NETL's Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity Revision 4 report for plant specifications Cost of Capturing CO_2 from Industrial Sources report for plant specifications	FECM/NETL CO_2 Transport Cost Model (CO2_T_COM) for estimating transport costs from source to sink	FECM/NETL CO_2 Saline Storage Cost Model (CO2_S_COM) for estimating geologic storage cost options
↓	↓	↓
Break-even cost for capturing CO_2 ($/tonne)	First year break-even price to transport CO_2 ($/tonne)	First year break-even price to store CO_2 ($/tonne)

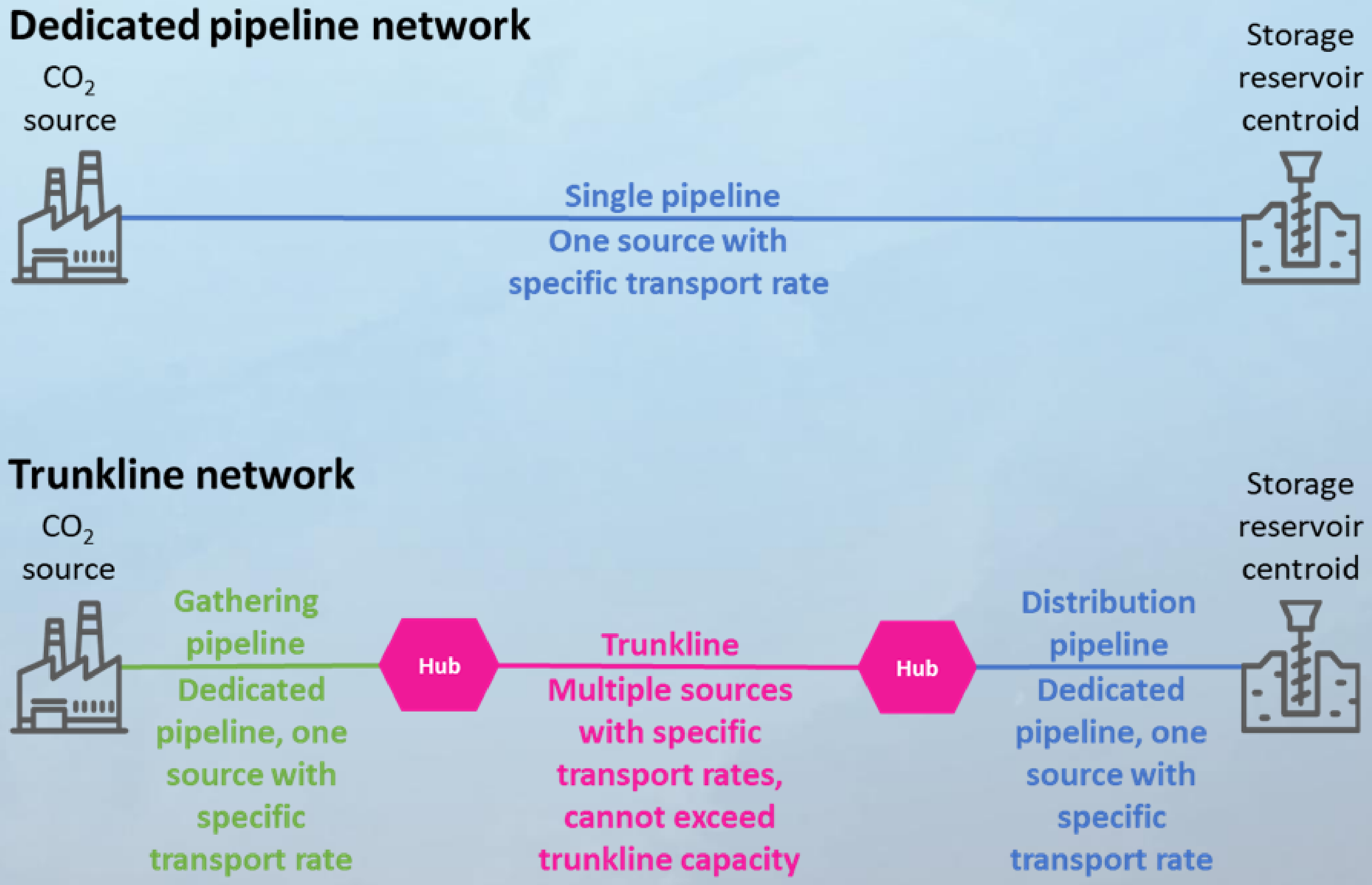
CO_2 Capture

- **Four hypothetical sources, each a different source type.**
- **Seven hypothetical locations:**
  - Iowa (ethanol).
  - Minnesota (natural gas processing plant [NGPP]).
  - Wyoming, North Dakota, and Missouri (supercritical pulverized coal [SCPC] electric power plant).
  - South Dakota and Kansas (cement plant).
- **Capture costs associated with Greenfield site.**

CO_2 Source Type	Net Power or Product Output	CO_2 Captured at 85% Capacity Factor (million tonnes/yr)	Capture Costs (2018$/tonne)
NGPP	500 MMscf/d	0.55	20.92
Ethanol Production Plant	50 Mgal/yr	0.12	35.22
SCPC Electric Power Plant	650 MW_{net}	4.33	65.50
Cement Production Plant	992,500 tonnes/yr	0.97	106.48

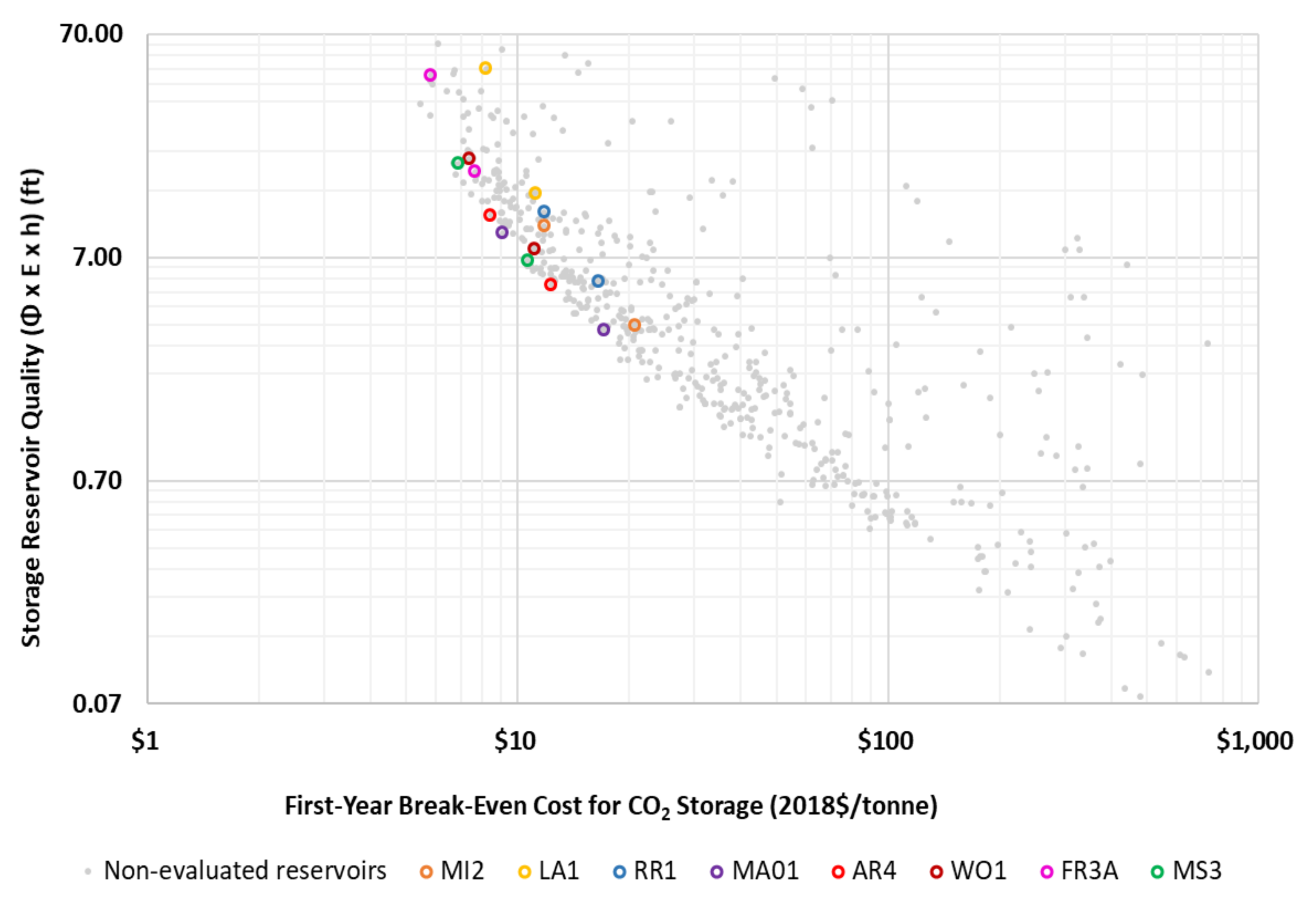
CO_2 Transport

- **Two transportation networks:**
  - Dedicated pipeline.
  - Trunkline.
    - Gathering and distribution pipelines of 30 miles each.
- **Pipeline networks follow existing natural gas pipeline rights-of-way.**



CO_2 Storage

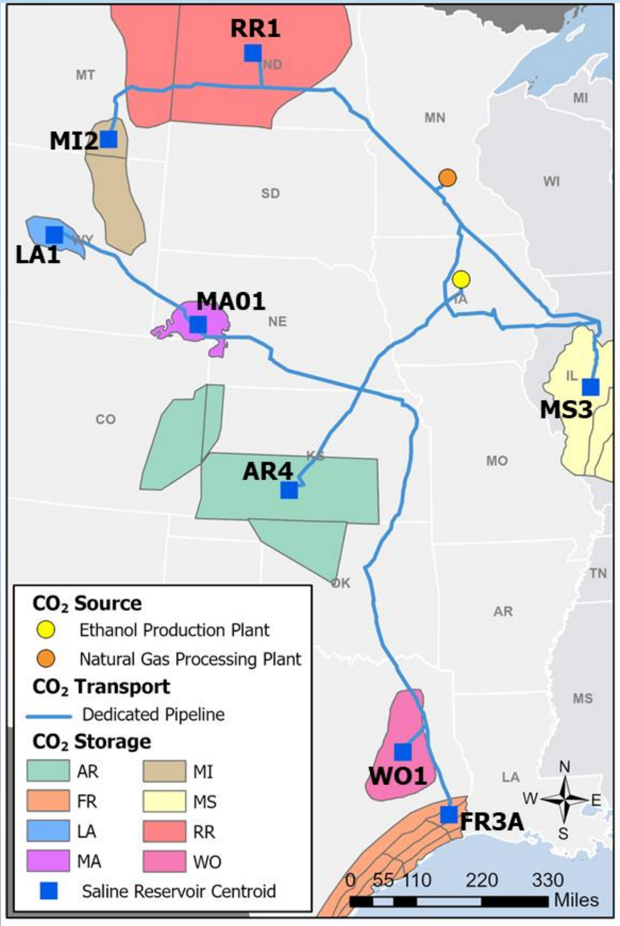
- **Regional storage reservoirs were screened and selected based on lowest cost and/or best reservoir quality options.**
- **Eight storage reservoirs:**
  - Arbuckle 4 (AR4) – Kansas.
  - Frio 3A (FR3A) – Texas.
  - Lance 1 (LA1) – Wyoming.
  - Maha 01 (MA01) – Nebraska.
  - Minnelusa 2 (MI2) – Montana.
  - Mt. Simon 3 (MS3) – Illinois.
  - Red River 1 (RR1) – North Dakota.
  - Woodbine 01 (WO1) – Texas.



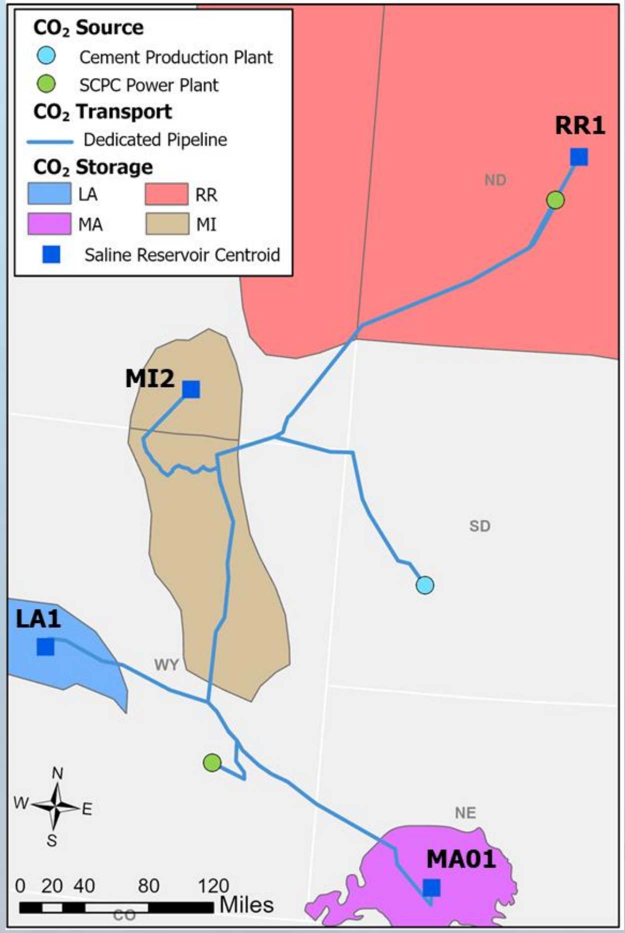
Regional Impact Areas Evaluated

Each regional impact area has a specifically designed CCS network.

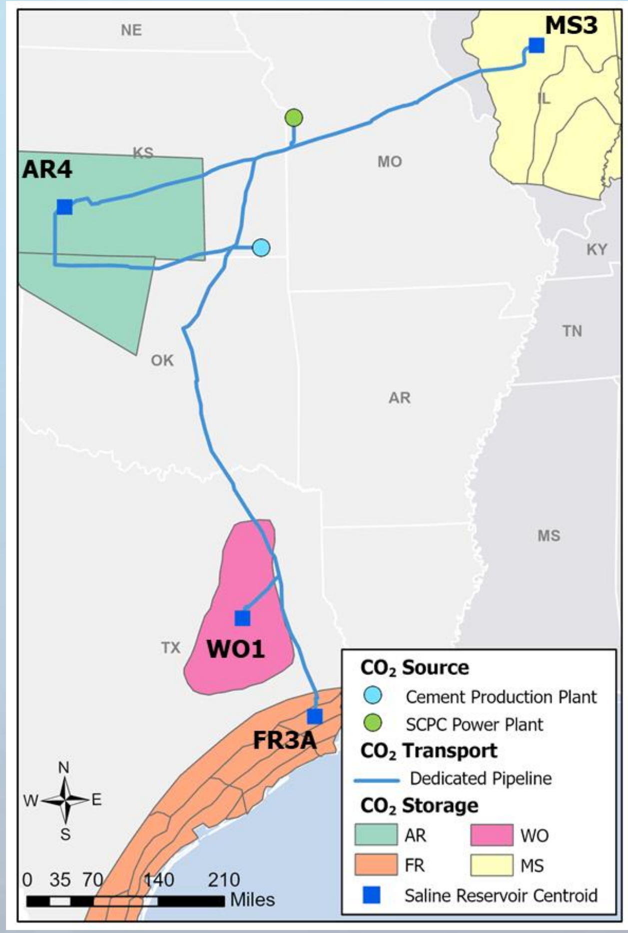
Central



Northwest

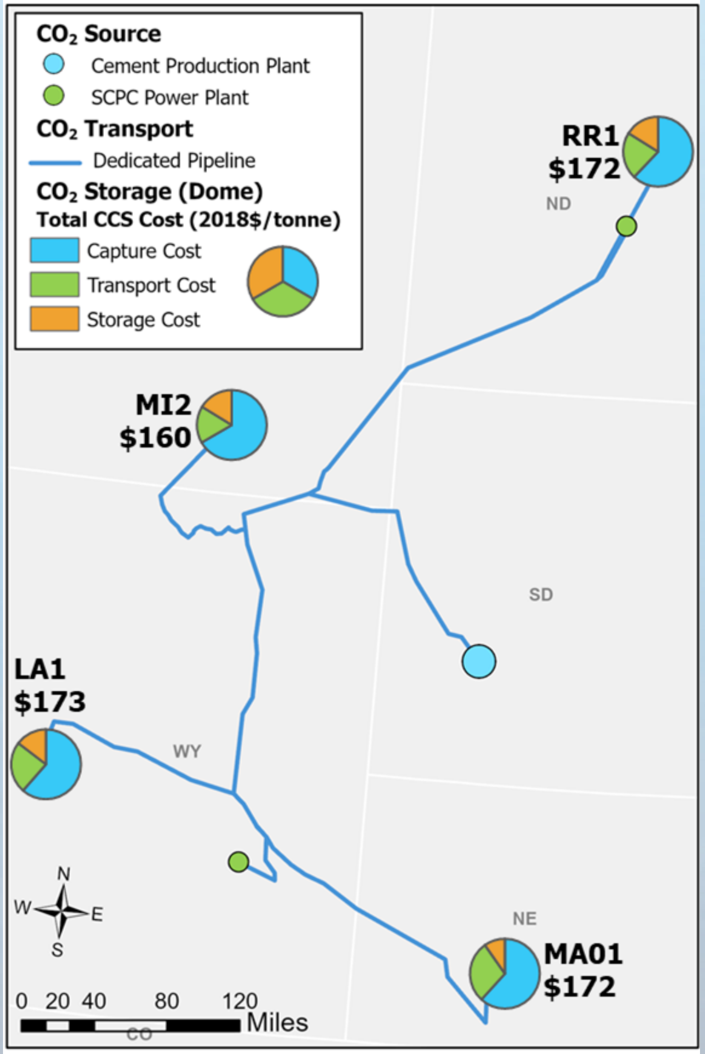


Gulf

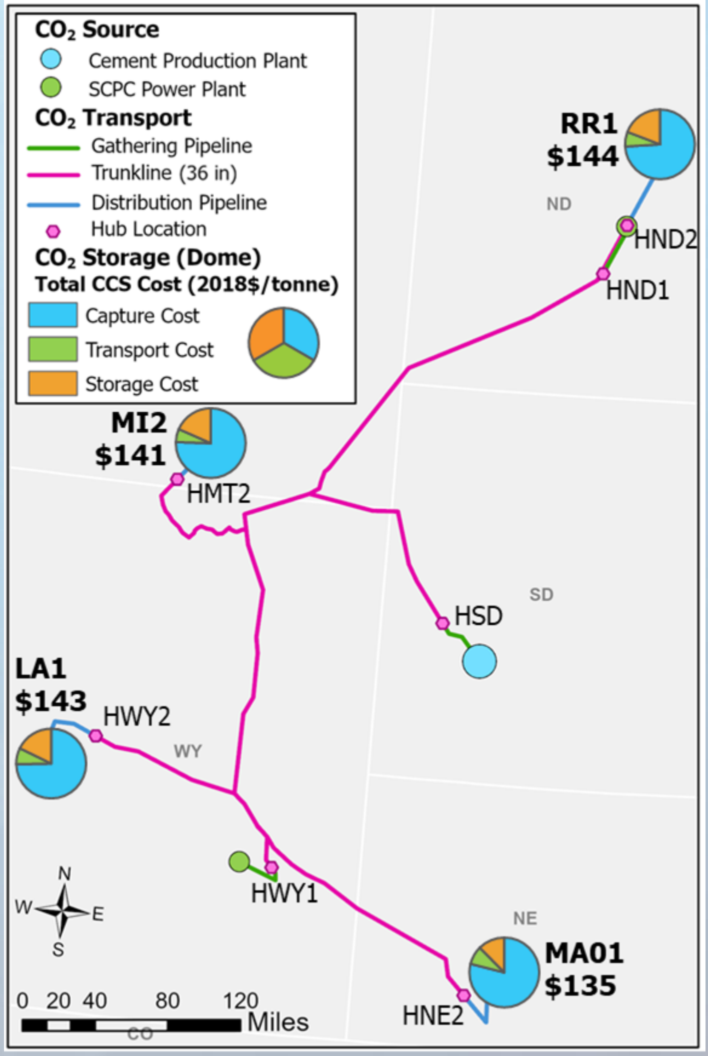


Northwest Impact Area – Cement Plant in South Dakota

- Capture is the highest CCS cost component in the dedicated pipeline network followed by transport and storage; transport and storage switch in the trunkline network.
- Closest storage reservoir (Minnelusa 2 [MI2]) is the lowest cost CCS option in the dedicated pipeline network.
- Furthest storage reservoir (Maha 01 [MA01]) becomes the lowest cost CCS option in the trunkline network.



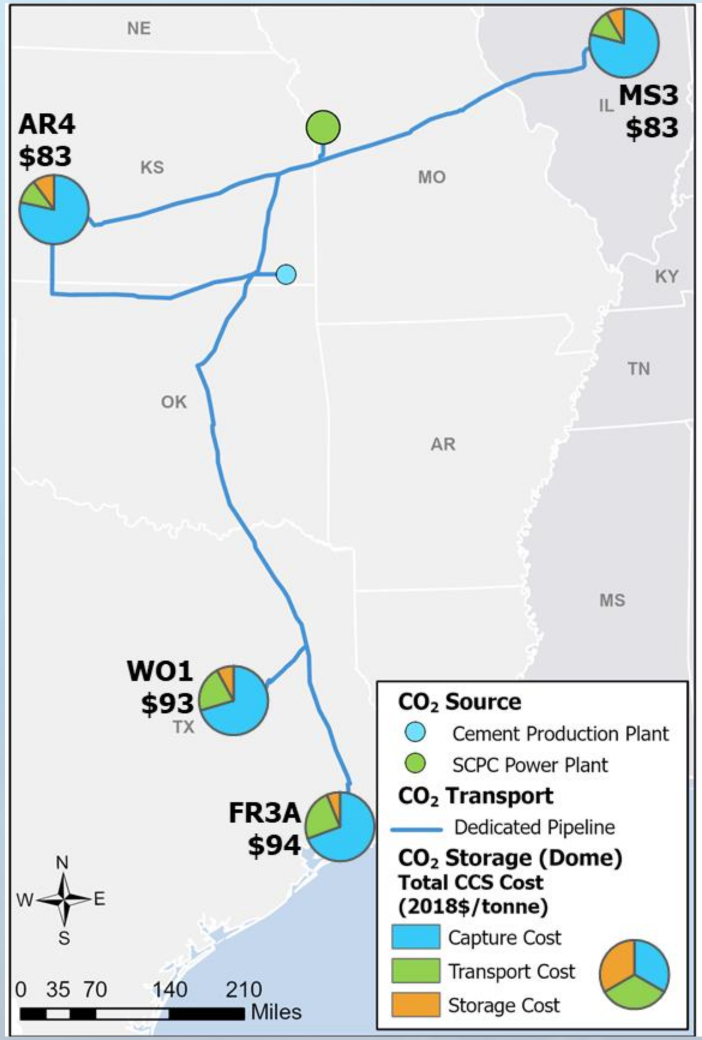
Dedicated Pipeline Network



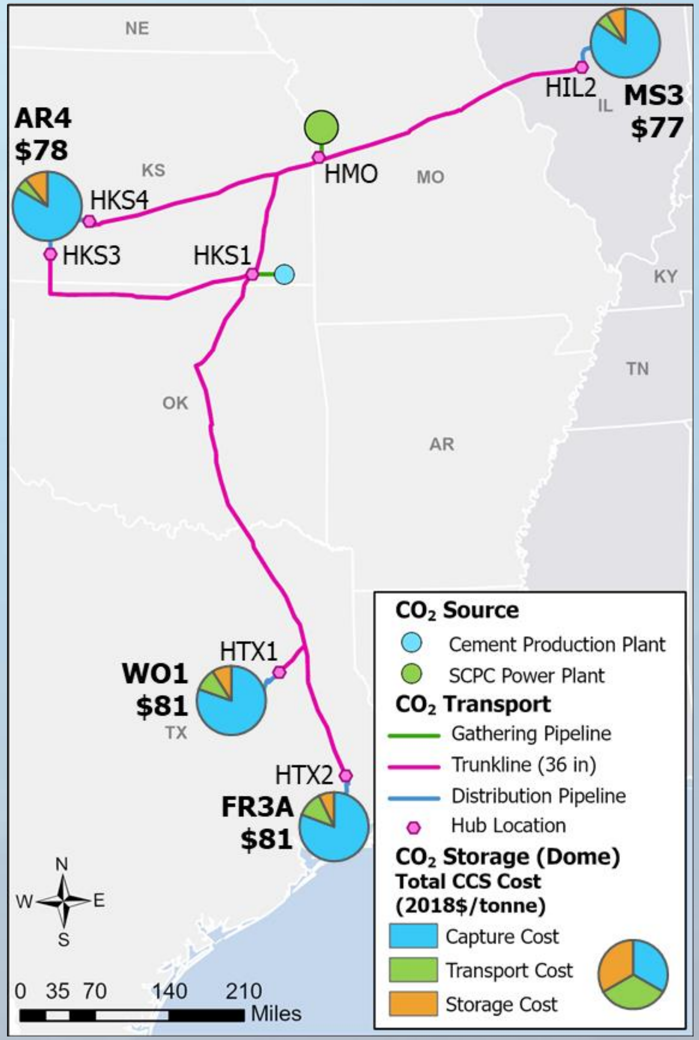
Trunkline Network

Gulf Impact Area – SCPC Plant in Missouri

- **Total CCS costs in the dedicated pipeline network are \$5–13/tonne more than in the trunkline network.**
  - Benefits the least from trunkline.
- **Capture is the highest CCS cost component for both networks followed by transport and storage.**
- **Arbuckle 4 (AR4) and Mt. Simon 3 (MS3) are the lowest cost CCS options in both networks and closest storage reservoirs.**
  - With similar CCS costs, additional factors such as storage potential, state incentives, etc., need to be considered.



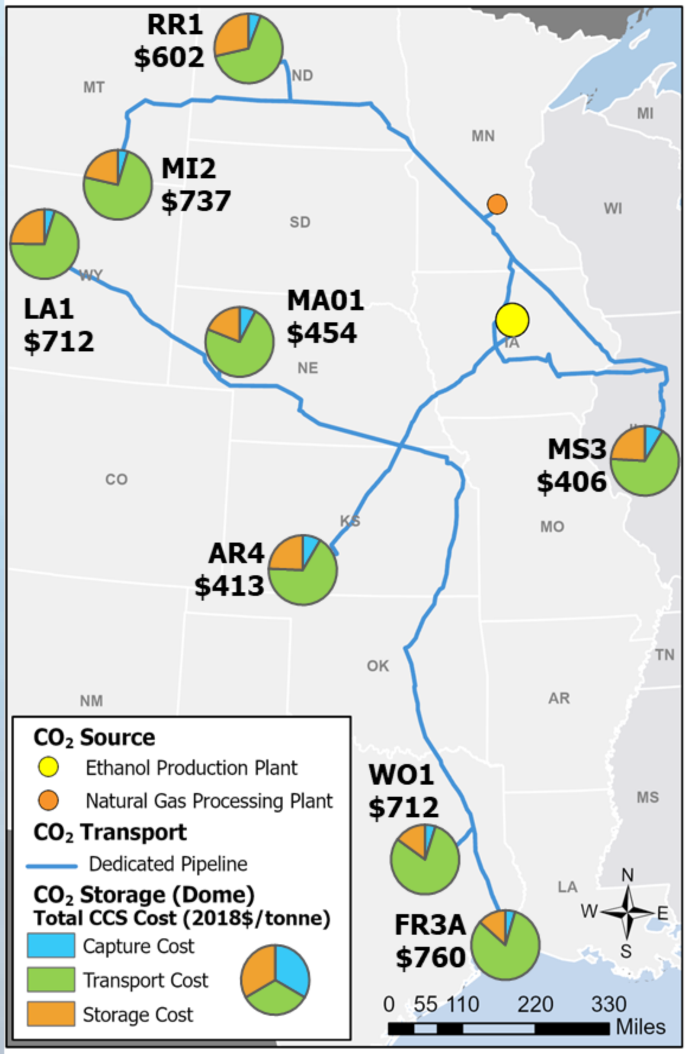
Dedicated Pipeline Network



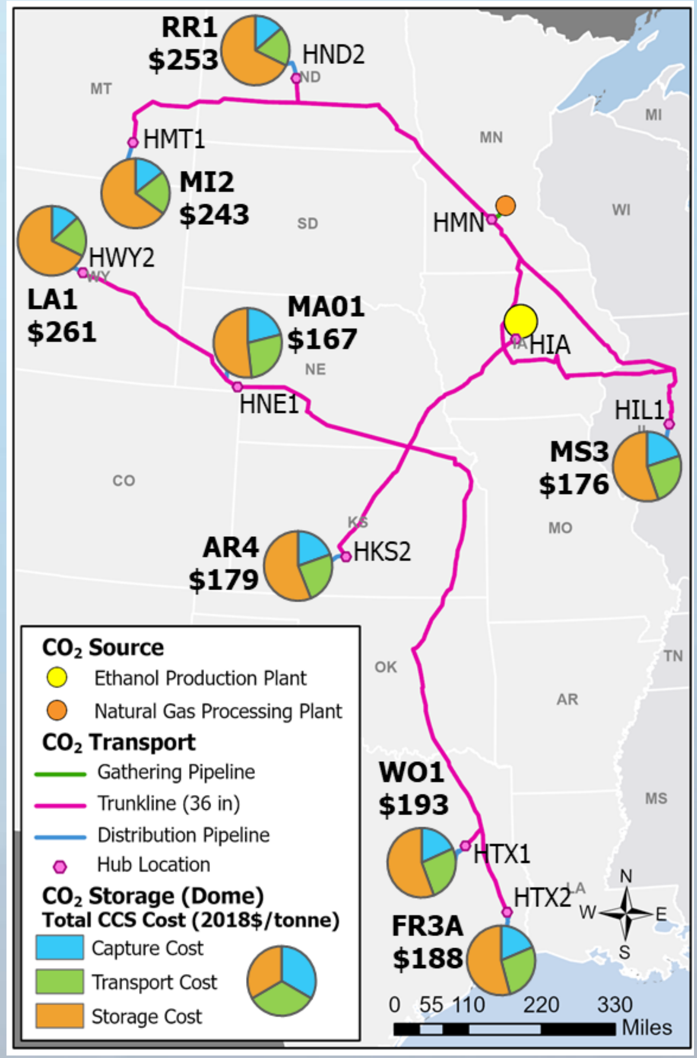
Trunkline Network

Central Impact Area – Ethanol Plant in Iowa

- **Total CCS costs in the dedicated pipeline network are $230–572/tonne more than in the trunkline network.**
  - Benefits most from trunkline.
- **Transport is the highest CCS cost component in the dedicated pipeline network followed by storage and capture; shifts in the trunkline network.**
- **Mt. Simon 3 (MS3) is the lowest cost CCS option in the dedicated pipeline network and closest storage reservoir.**
- **Maha 01 (MA01) is the lowest cost CCS option in the trunkline network.**
- **Frio 3a (FR3A) becomes more attractive than Woodbine 1 (WB1) in the trunkline network even though it is further away.**



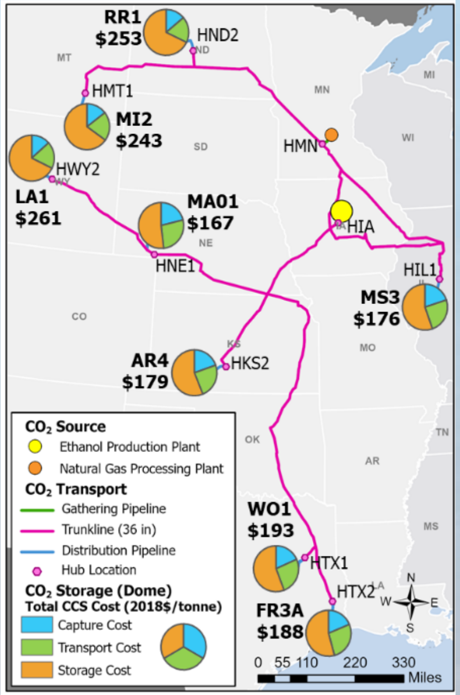
Dedicated Pipeline Network

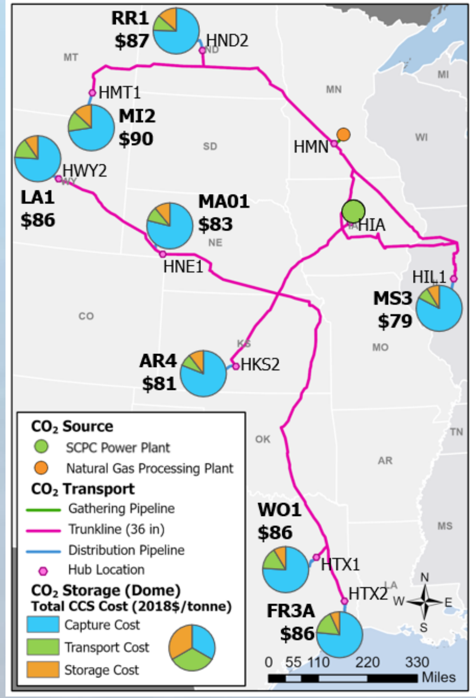


Trunkline Network

Economies of Scale

- **High capture rate helps decrease CCS costs across the CCS value chain.**
- **SCPC plant at the same location as the ethanol plant can save up to 83% on CCS unit costs in the dedicated pipeline network and 58% in the trunkline network.**
- **Ethanol hub capturing 4.33 million tonnes/yr collectively (~36 sources) can save up to 86% (dedicated network) and 67% (trunkline network) on CCS unit costs.**





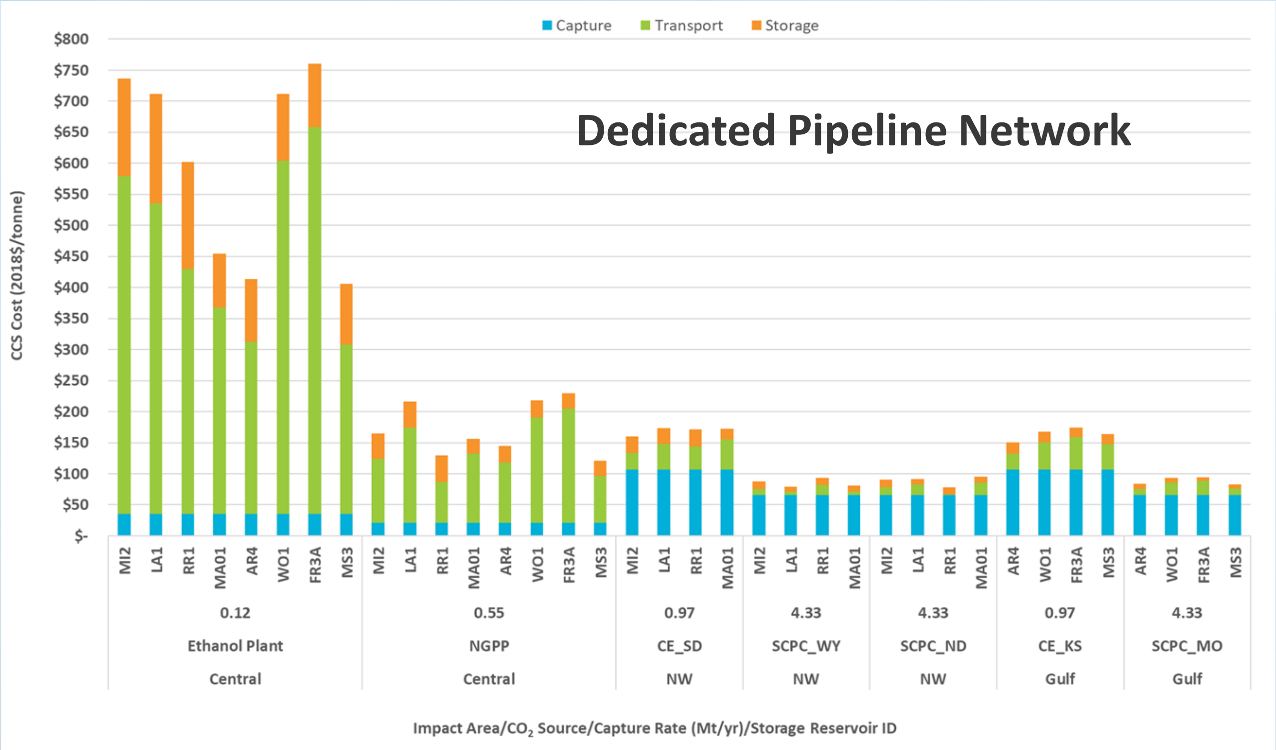
Central Impact Area – Ethanol plant (left) and SCPC plant (right) – Trunkline

Estimated CCS Costs for Ethanol Hub in Iowa

Storage Reservoir ID	Capture	Transport* (4.33 million tonnes/yr)	Storage (4.33 million tonnes/yr)	Total CCS
	2018$/tonne			
AR4	35.22	16.07	8.43	59.72
MA01	35.22	19.40	9.10	63.72
MS3	35.22	15.59	6.91	57.72

*Does not include gathering line costs.

Cost Comparison Across Regional Impact Areas



Regional Impact Area	CO_2 Source	Average CCS Cost Savings with Trunkline
Central	Ethanol	64%
	NGPP	57%
Northwest	CE_SD	17%
	SCPC_WY	6%
	SCPC_ND	7%
Gulf	CE_KS	18%
	SCPC_MO	10%

- **The SCPC plant has the lowest CCS unit costs followed by the cement plant, NGPP, and ethanol plant in the dedicated pipeline network.**
- **Storing CO_2 in the closest storage reservoir resulted in the lowest CCS unit costs in five of seven networks for the dedicated pipeline and three of seven for the trunkline pipeline.**
- **The trunkline network reduces CCS unit costs for sources, and, in particular, smaller sources.**

Conclusion

- **Assessed integrated CCS networks while meeting technical requirements and cost-effectiveness metrics through screening-level assessments.**
- **Illinois Basin provides a low-cost CCS option.**
  - High-quality reservoir providing low storage costs.
- **Costs are comparable within Northwest and Gulf regional impact areas.**
  - Not economical for plants to transport CO_2 to the Gulf, even though there are inexpensive, better-quality reservoirs.
- **Leveraging economies of scale can provide benefits.**
  - Project hubs linking multiple CO_2 emission sources to shared CO_2 transport and storage infrastructure significantly decrease project costs.
  - The trunkline network reduces costs for sources, with a larger reduction for smaller sources, thus eliminating economic barriers that would otherwise prevent smaller sources from employing CCS.
  - CCS costs for cement and SCPC plants are competitive.
- **Although this study considers several CCS project elements, additional key factors should be considered when executing a viable project.**
  - Other source types and static source capture rates.
  - Tax incentives/credits or effects of other polices such as Class VI primacy.
  - Alternative post-injection site care period (i.e., less than 50 years) and state-specific long-term liability laws.

Upcoming Resources

Forthcoming

- Central U.S. report.
- Capture, Transport, and Storage (CTS) Screening Tool.

USER INPUTS

SOURCE		Location Type Options	Locations	Centroid Coordinates	
	Source Location	State	NE	41.492537	latitude (decimal degrees)
			Detroit	-99.901813	longitude (decimal degrees)
			Cambridge Arch-Central Kansas		
CAPTURE		Source Options	CO2 Mass Flow Rate (MFR) [Average Mtpa]	Capacity Factor (CF) [%]	
	Source Technology	21. Ethanol	0.2	85	
	Intermediate Storage	No CIS			
	Source Cyclicity	Quarterly			
	Cycles per year	4			
	CIS required capacity [Mt]	0.009000	1.2x safety factor included		
TRANSPORT		Transport Options	Gathering Line CF	Trunkline CF	Distribution Line CF
	CO2 Pipeline Infrastructure	Trunkline	85	100	100
	Trunkline Route Total MFR [Mtpa]	5	0.2	5.0	6
	Route Tortuosity [%]	15%	Gathering Line MFR	Individual Trunkline MFR	Distribution Line MFR
STORAGE		Storage Project Options	Oil Price [$/STB]		
	CO2 Storage type	5+ Mtpa Saline Hub	75		
	Storage Hub Size [Mtpa]	6	5-10 Mtpa; 1Mtpa intervals		
INCENTIVES		Incentive Options			
	IRA-45Q	45Q with qualified labor			
	45Q Face Value	85	[$/t, in 2023]		
	Transferrable 45Q (yrs 6 - 12) discount [%]	8%	*this is the percent of the 45Q face value received by CCE owner when they transfer 45Q to another taxpayer with adequate tax liability.*		
	PISC	Default (50 years)	*Saline Storage Location State Dependent: LA, ND, MT have shortened PISC*		
	Capture Subsidy (agnostic) [$M]	0	*$0 is default; input is spread evenly across 30 operating years of CCE*		

OUTPUTS	Lowest CTS Cost	2nd Lowest CTS Cost
CTS TOTAL [2018$/tCO2]	20.83	22.61
FYBE Capture Cost [2018$/tCO2]	-0.61	-0.61
FYBE T&S Cost [2018$/tCO2]	21.45	23.22
FYBE Transport Cost [2018$/tCO2]	14.05	14.05
FYBE Storage Cost [2018$/tCO2]	7.40	9.17
Gathering Pipeline Mileage	20	20
Pipeline Mileage	Trunkline; 300	Trunkline; 200
Distribution Pipeline Mileage	20	20
Storage Formation, or oilfield #	Maha01	Arbuckle3
Shovel-ready Oilfield?	SALINE	SALINE
Storage Site State	NE	KS
Storage Site Province (if CO2 EOR)	SALINE	SALINE

Interface for Prototype CTS Screening Tool for low-cost source-to-sink matching.

Disclaimer

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Resources

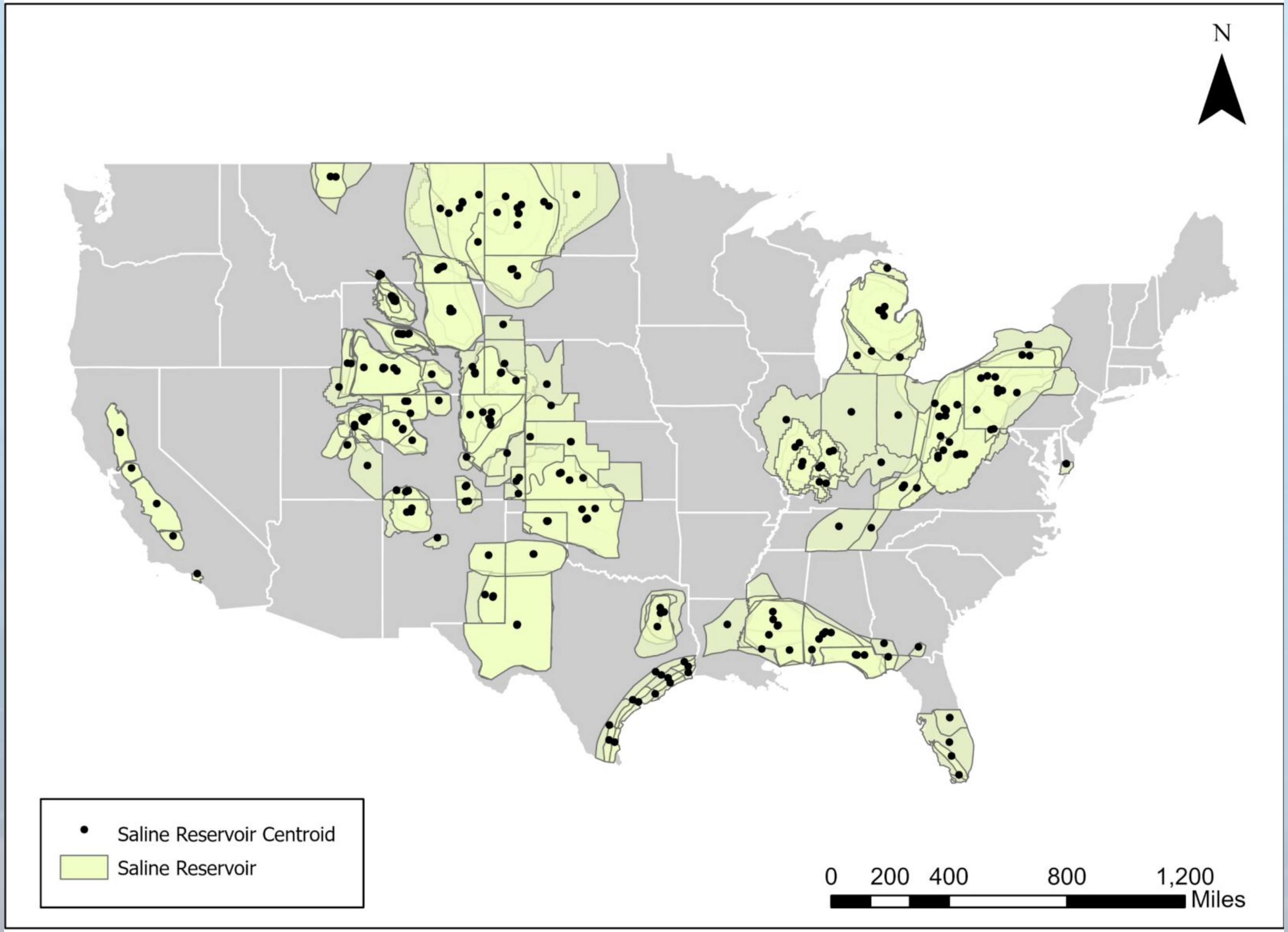
Techno-Economic Models

- FECM/NETL CO_2 Transport Cost Model (CO2_T_COM)
  https://netl.doe.gov/energy-analysis/search?search=CO2TransportCostModel
- FECM/NETL CO_2 Saline Storage Cost Model (CO2_S_COM)
  https://netl.doe.gov/energy-analysis/search?search=CO2SalineCostModel

Studies/Reports

- Which Reservoir for Low Cost Capture, Transportation, and Storage?
  https://doi.org/10.1016/j.egypro.2014.11.289
- Comparative Analysis of Transport and Storage Options from a CO_2 Source Perspective
  https://doi.org/10.1016/j.ijggc.2018.03.012
- Cost of Capturing CO_2 from Industrial Sources (2014)
  https://netl.doe.gov/energy-analysis/details?id=06cb9290-d7d2-42e1-89d8-be49d7e0f595
- Cost of Capturing CO_2 from Industrial Sources (2022)
  https://netl.doe.gov/energy-analysis/details?id=865aaad2-9252-44d9-a48a-95599b3072b4
- Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity (Revision 4, 2019)
  https://netl.doe.gov/energy-analysis/details?id=d4185e27-51ec-4a74-8351-cd6faad05c8a
- Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity (Revision 4A, 2022)
  https://netl.doe.gov/energy-analysis/details?id=e818549c-a565-4cbc-94db-442a1c2a70a9

CO2_S_COM Geologic Database



Map of 314 saline reservoirs in CO2_S_COM geologic database

CCS Cost Comparison Across Regional Impact Areas

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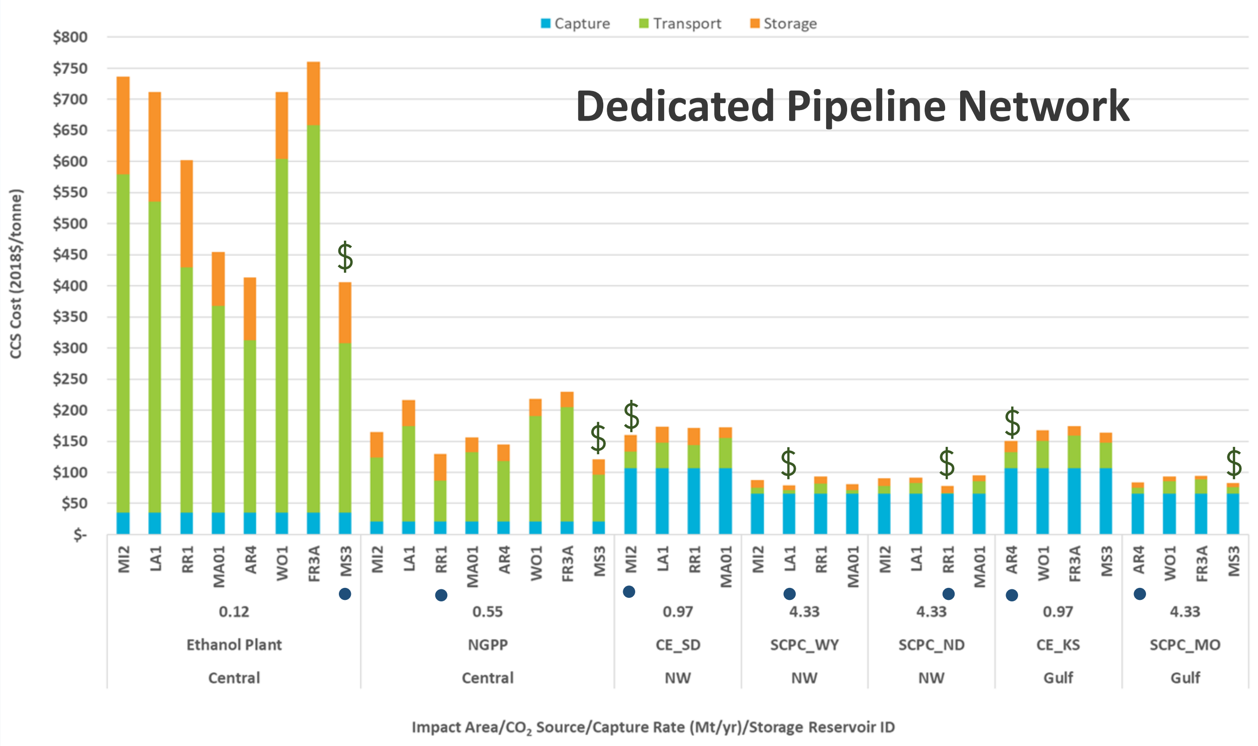
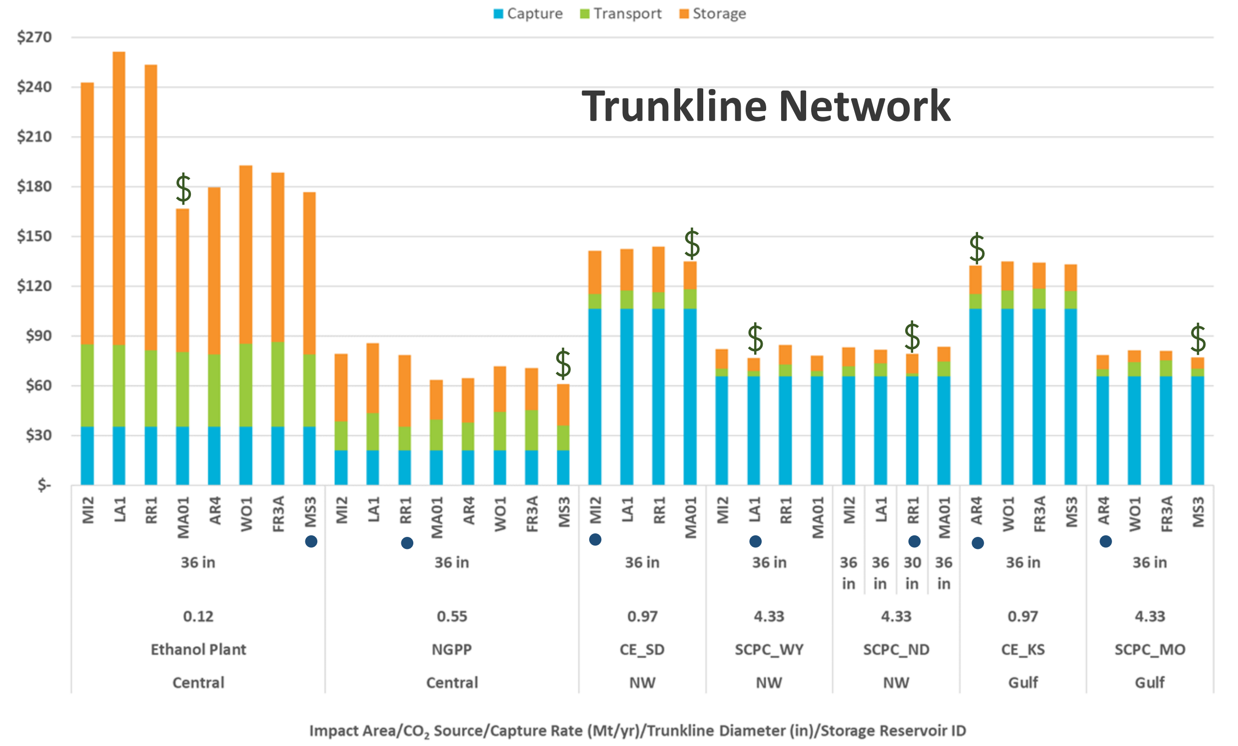
$ Lowest CCS unit cost per individual network
● Closest saline storage reservoir to source location





*Note: y-axis not on same scale