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CO_2 PIPELINE ANALYSIS FOR EXISTING COAL-FIRED POWER PLANTS

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Disclaimer

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Contents

1 INTRODUCTION

Previous studies have examined the needs for CO_2 transport and storage to achieve a net zero emissions economy by 2050 (Abramson and Christensen, 2021; Greig and Pascale, 2021; Chen and Pawar, 2023). This analysis examines the minimum CO_2 pipeline infrastructure necessary to transport and store CO_2 captured from coal-fired power plants. This analysis also examines an additional network configuration considering minimizing the number of state border crossings, reflecting non-economic considerations that may impact pipeline buildout.

2 CO_2 SOURCES AND STORAGE RESOURCES

2.1 Coal Power Plant Fleets

The decision to retrofit a coal unit with Carbon Capture and Storage (CCS) depends on many factors. In this analysis, we simplify announced retirement dates, facility age, and facility size.

- *Announced retirements*. Coal units that have announced and planned retirement dates are unlikely to install CCS given limited time remaining over which to recover capital costs.
- *Age*. Coal retirements in recent years have tended to come from older units: the capacity-weighted average age of coal-fired Electric Generating Units (EGUs) scheduled to retire in 2024 is almost 54 years (Ray and Tsai, 2024). Older coal facilities are more likely to retire, even if they have no announced retirement plans.
- *Size*. Capture costs on a dollar-per-ton basis tend to be higher for smaller capacity coal EGUs. An analysis of retrofit costs indicates that no coal plant with 50 MW of capacity or smaller operating at 70 percent capacity factor have capture costs less than $85 per metric ton CO_2 ($/t CO_2), the incentive provided by the 45Q tax credit (Hackett and Kuehn, 2023). These smaller units are unlikely to install CCS facilities due to higher costs.

Given the above, this analysis considers two scenarios for coal CCS retrofits:

- **Scenario 1:** All coal EGUs with no firm commitment to retire or convert to natural gas by 2040 install CCS facilities. This includes 202 coal-fired EGUs at 107 power plants with 72.3 GW of capacity (see ***Figure 1***). Deploying CCS at these plants could potentially sequester about 396 million metric tons of CO_2 per year.

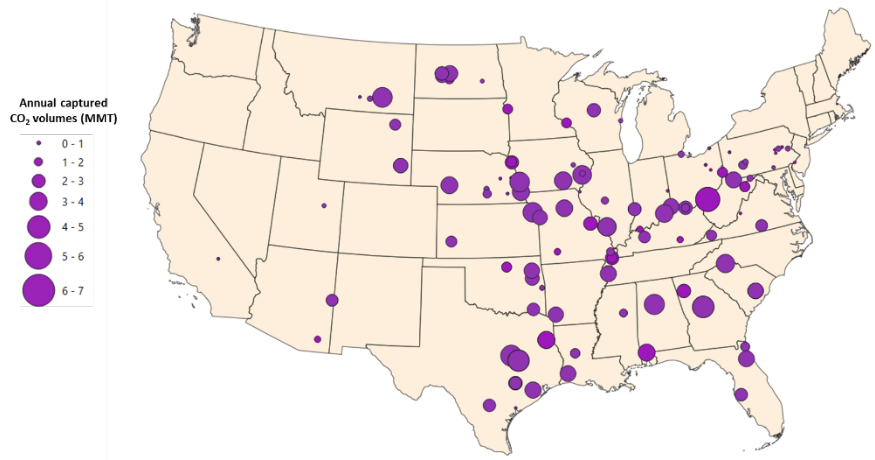


Figure 1: Locations and annual captured CO_2 volumes (in the unit of million metric tons or MMT) for the 202 coal-fired EGUs under Scenario 1. Note that certain locations may contain multiple generating units that overlap with each other.

- **Scenario 2:** Coal-fired EGUs with capacity greater than 50 MW and that will be less than 60 years old in 2040 will install CCS, consistent with data on coal fired EGU retirement age and capture cost trends. This includes 99 coal-fired EGUs at 67 power plants representing 42 GW of capacity (see ***Figure 2***). Deploying CCS at these plants could potentially sequester about 229 million metric tons of CO_2 per year.

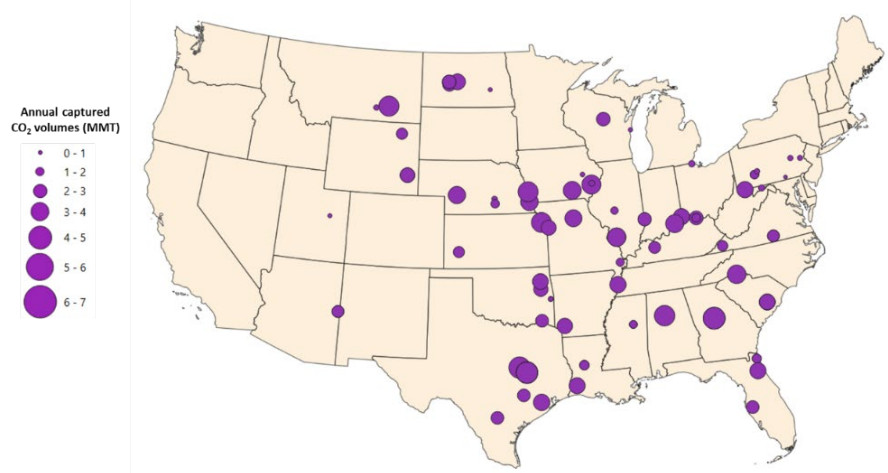


Figure 2: Locations and annual captured CO_2 volumes (in the unit of million metric tons or MMT) for the 99 coal-fired EGUs under Scenario 2. Note that some locations may contain multiple generating units that overlap with each other.

Data on coal unit characteristics was derived from the U.S. Environmental Protection Agency (EPA) National Electric Energy Data System (NEEDS) database (EPA, 2022). Annual captured CO_2 volumes were calculated assuming a 90% capture rate and a 70% capacity factor.

2.2 CO_2 Storage Resources

In this study, 314 geologic formations in the lower 48 states within the U.S. were considered for potential CO_2 storage (see ***Figure 3***). The geologic data used to define the storage formations comes primarily from National Carbon Sequestration Database and Geographic Information

System (NATCARB) although many other sources were also used (NETL, 2015; Morgan et al., 2024). The geologic properties for each storage formation include the areal extent, depth to the top of the storage formation, thickness, permeability, porosity, temperature, and hydrostatic pressure. To estimate the storage resources and costs, National Energy Technology Laboratory (NETL) has developed the CO_2 Saline Storage Cost Model (CO2_S_COM) (Morgan, 2022), and Los Alamos National Laboratory (LANL) has developed the Sequestration of CO_2 Tool (SCO_2T) (Meng et al., 2022). Based on the same geologic input data, these two models provide similar results for the storage resource and storage cost estimates for the 314 potential storage formations (Morgan et al., 2024). In this study, we used the storage resource and cost estimates from SCO_2T in the CO_2 pipeline network modeling. In addition, the transport cost is estimated with input data from the FECM/NETL CO_2 Transport Cost Model (CO2_T_COM) (Morgan et al., 2023).

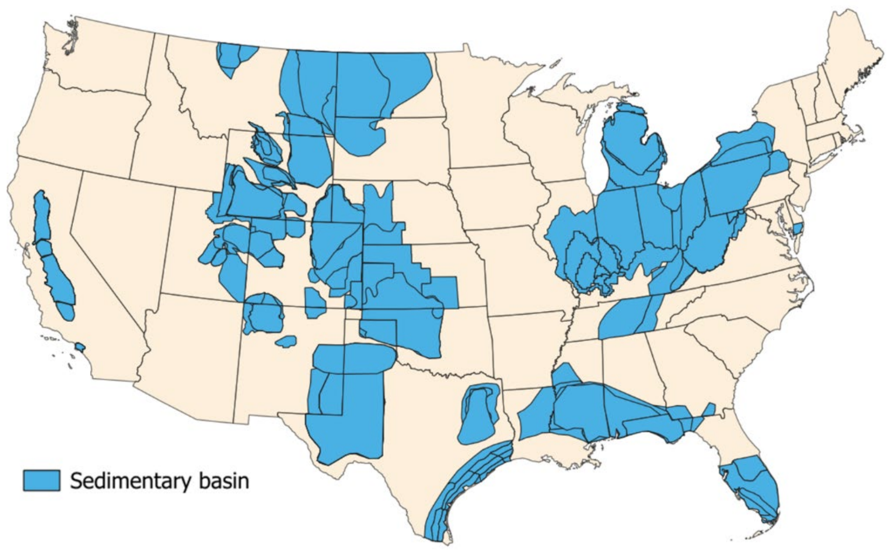


Figure 3: 314 geologic formations for potential CO_2 Storage (primarily based on NATCARB database).

For previous large-scale CO_2 pipeline network designs simulated (Chen et al., 2022; Shih et al., 2023), the centroids of geologic storage formations were assumed to represent sink locations. Although using this assumption can simplify the optimization process, the approach might only provide reserved solutions given the fact that some storage formations may extend to ~100s to ~1000s square miles. To address this issue and obtain optimal pipeline networks, Velasco-Lozano et al. (2024) proposed a novel geospatial splitting framework that partitions large formations into multiple sub-formations by considering physical, geographic, and demographic constraints. This new approach has been applied in this study to provide detailed and spatially refined CO_2 pipeline routes. The original 314 formations have been refined to 2,535 sub-formations for potential CO_2 storage (see ***Figure 4***).

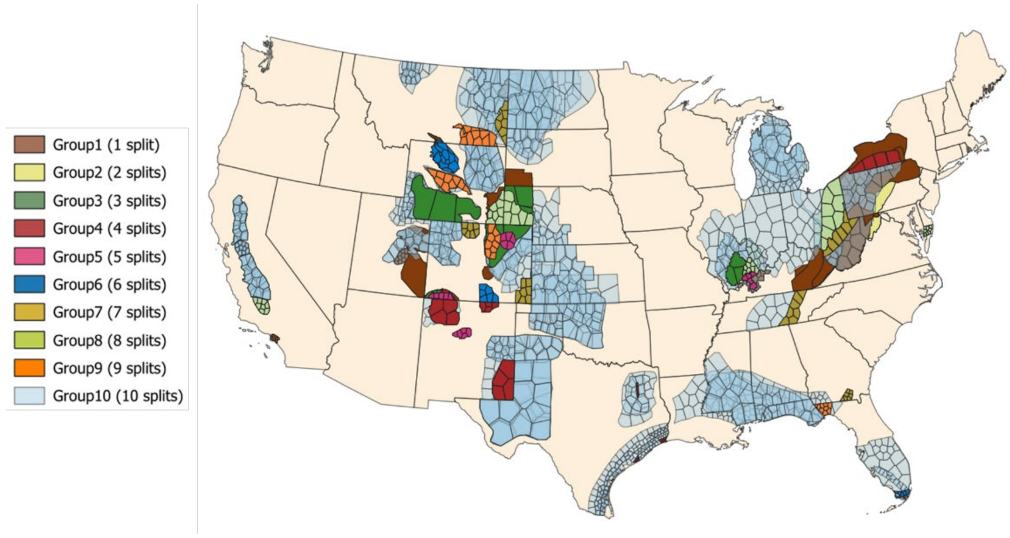


Figure 4: 2,535 sub-formations for potential CO_2 storage. Different groups have different number of splits; for example, "3 splits" indicates the original formation is split into three sub-formations.

3 CO_2 PIPELINE ANALYSIS

For both scenarios, the minimum pipeline network size was modeled to assess the size necessary to transport CO_2 captured from existing coal-fired power plants. This was modeled by assuming storage costs were zero, such that the model optimizes for the lowest transport cost resulting in minimum pipeline distances. For Scenario 2, recognizing the possible increase in costs and timeline resulting from segments that cross state boundaries, an additional case was run which limits state crossings by modeling state or groups of states independently as appropriate. For all pipeline modeling cases, we generally assumed that the pipelines avoid disadvantaged communities and tribal lands as much as possible, and other sensitive lands such as national parks. *SimCCS* version 3.0 was utilized for optimizing the CO_2 pipeline network under different scenarios (Ma et al., 2022; 2023).

3.1 Scenario 1: All Coal Units with No Retirement Dates

In this scenario, we included all 202 coal Electric Generating Units (EGUs) that have no firm commitment to retire or convert to natural gas by 2040 in the transport network modeling. We conducted a simulation minimizing total pipeline length (S1). ***Figure 5*** displays the optimized pipeline network under this scenario, with an estimated pipeline length of 6,812.5 miles. Additionally, ***Figure 5*** depicts over 5,300 miles of existing CO_2 pipelines. Considering the geographical spread of coal units and storage resources, the majority of the existing CO_2 pipelines in the Rocky Mountain, Permian Hub, and Gulf Coast regions may not be suitable for the reuse if only coal units were considered, without accounting for emissions from the other sectors such as natural gas power plants and ethanol plants.

This scenario results in a number of short pipelines with length less than 25 miles, particularly in Montana, Wyoming, Indiana, Ohio, Pennsylvania, and Kentucky, as demonstrated in ***Figure 6***. The size (diameter) of pipelines ranges from 4” to 30”, with 12”, 16”, and 20” being the most common sizes (see ***Figure 7***). The total number of pipelines crossing state boundaries is also reported at 41.

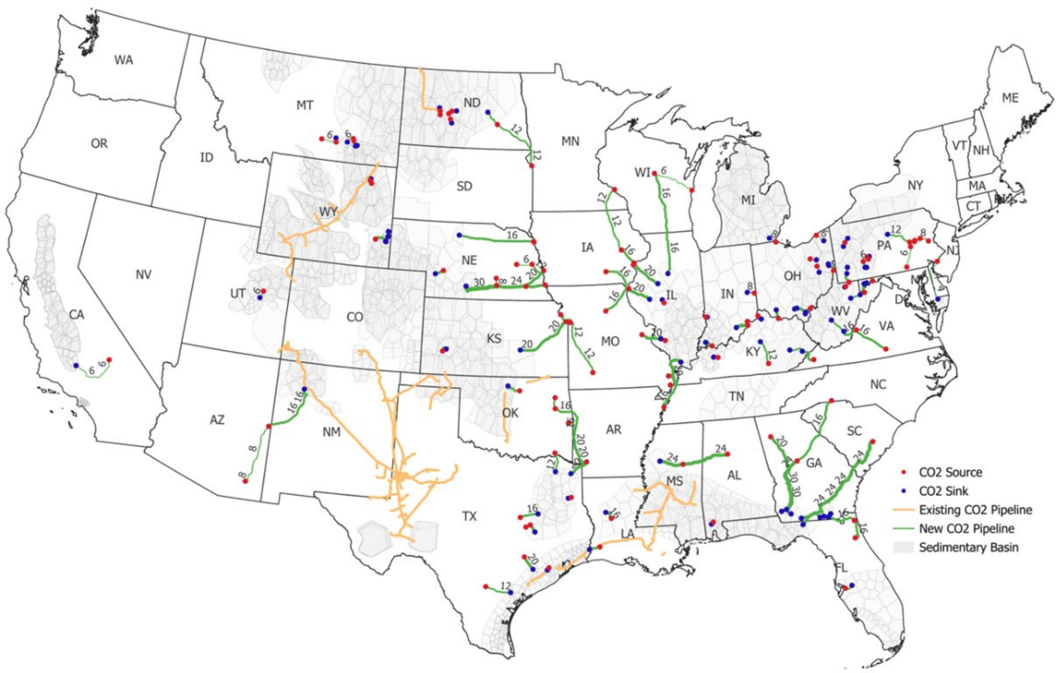


Figure 5: Minimum pipeline networks for Scenario 1. The numbers along the new CO_2 pipeline indicate the diameter of the optimized pipeline in the unit of inches.

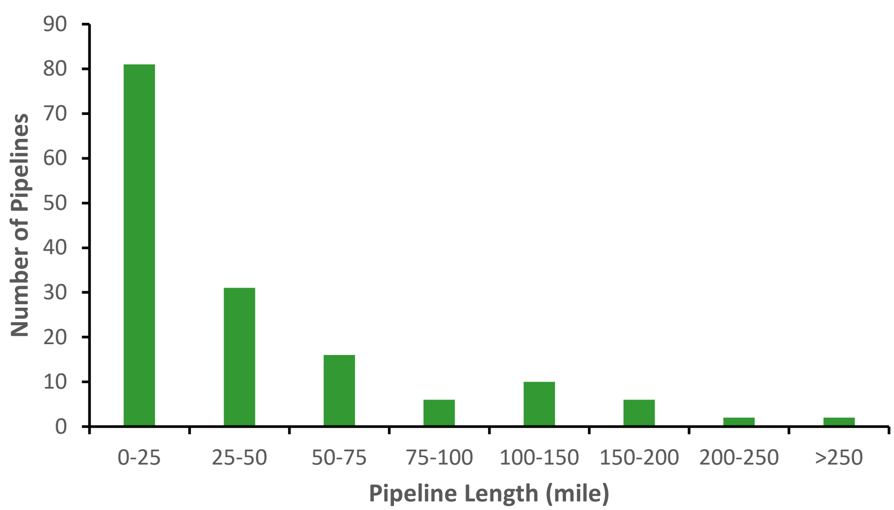


Figure 6: Number of pipelines by segment length in Scenario 1.

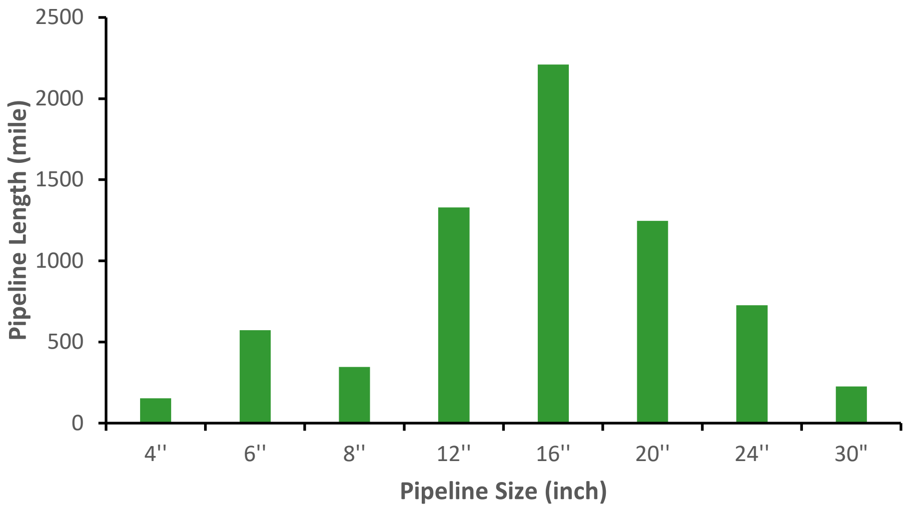
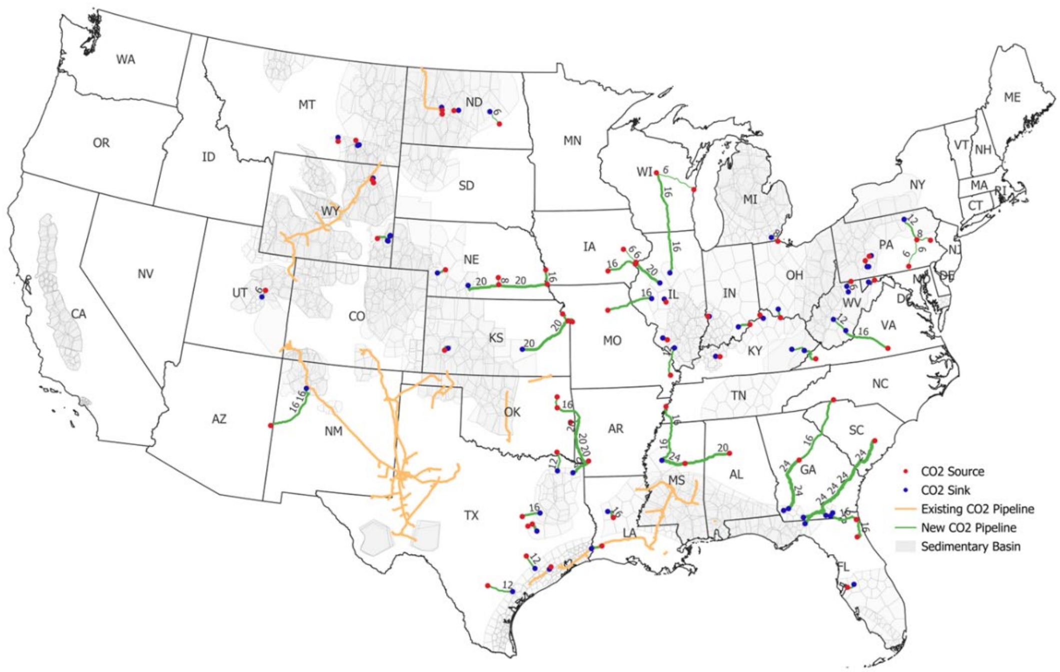


Figure 7: Total length under each pipeline size (diameter) – Scenario 1.

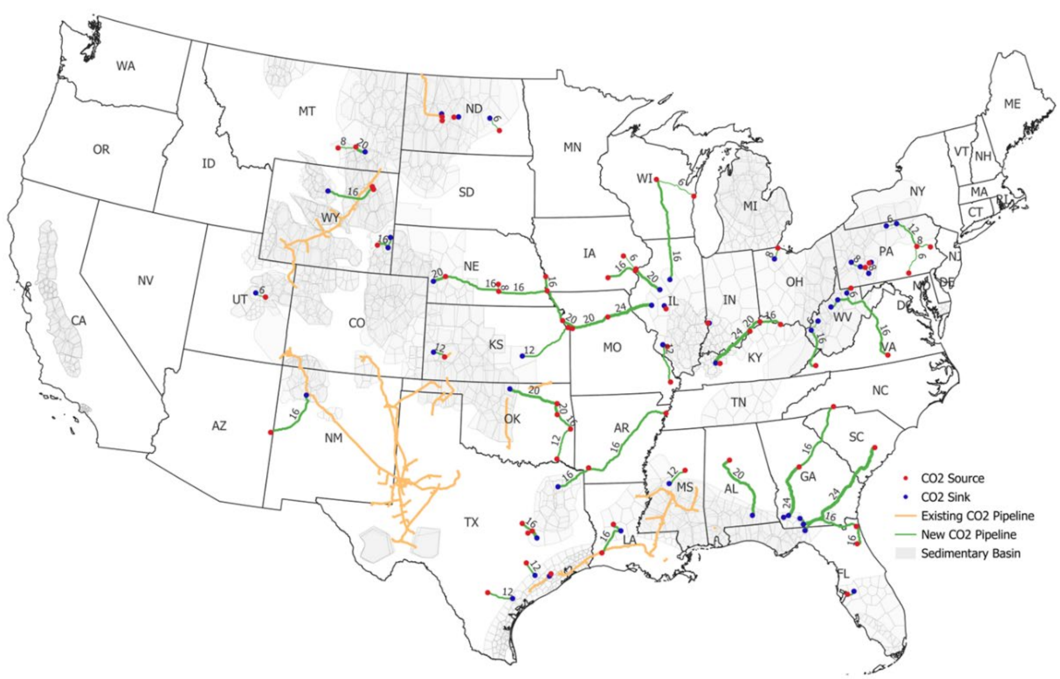
3.2 Scenario 2: Coal Units Unlikely to Retire by 2040

In this scenario, we focused on only 99 coal units unlikely to retire by 2040 for transport network modeling. We conducted simulations under two circumstances: minimizing total pipeline length (S2C1) and minimizing the number of pipelines crossing state boundaries (S2C2). ***Figure 8*** illustrates the optimized pipeline network under these two circumstances. The total pipeline length for S2C1 is 4,648 miles, a reduction of over 2,154 miles (31.6%) as compared to Scenario 1. Minimizing state crossing pipelines (S2C2) increases the total length by 1,332 miles compared to S2C1 but reduces the number of state crossing pipelines from 27 to 17.

Similar to Scenario 1, a greater number of shorter pipelines (less than 25 miles) are observed in Montana, Wyoming, Ohio, and Pennsylvania under case S2C1 where the total pipeline length is minimized. This trend is also evident in ***Figure 9***. Pipeline sizes range from 6” to 24” for both cases under Scenario 2, with a need for a 4” pipeline under S2C1 (see ***Figure 10***). The most common pipeline size (diameter) is 16” for both cases, followed by 12”, 20”, and 24”. As with Scenario 1, reusing existing CO_2 pipelines for transport is limited by the geospatial distribution of coal units and storage resources.



(a) S2C1 – Minimize pipeline length



(b) S2C2 – Minimize state crossing

Figure 8: Optimized pipeline networks by minimizing total pipeline length (a) and minimizing the number of pipeline state crossing (b) under Scenario 2. The numbers along the new CO_2 pipeline indicate the diameter of the optimized pipeline in the unit of inches.

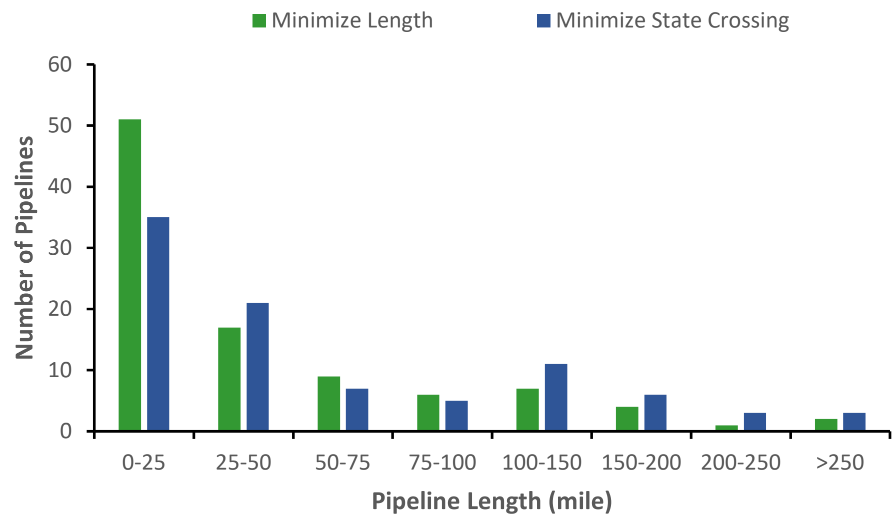


Figure 9: Number of pipelines by segment length – Scenario 2.

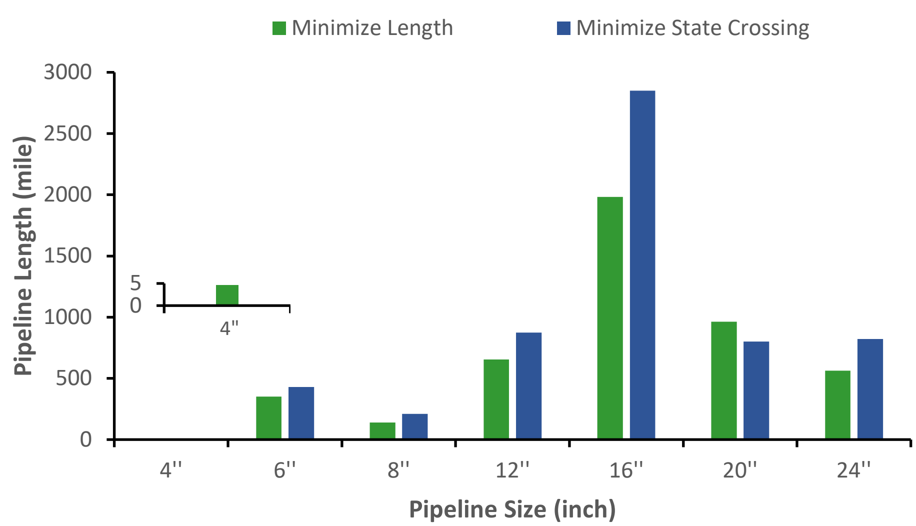


Figure 10: Total length under each pipeline size (diameter) – Scenario 2.

4 SUMMARY

The table below summarizes the key metrics obtained from the three modeling runs.

Table 1: Summary of the key metrics obtained from different case studies.

Scenario-Case	# of Coal Units	Total New Pipeline Length (miles)	% Segments < 25 miles	% Segments < 100 miles	# of State Crossings
Scenario 1 – Min length	202	6,812.5	52.60%	87.01%	41
Scenario 2 – Min length	99	4,658.0	52.58%	85.57%	27
Scenario 2 – Min state crossing	99	5,990.0	38.46%	74.73%	17

The key takeaways from this study are as follows:

- To transport captured CO_2 from all 202 coal units while avoiding tribal lands and disadvantaged communities, an estimated 6,812.5 miles of new CO_2 pipeline will be needed. Focusing only on the 99 coal units unlikely to retire by 2040, the required pipeline length ranges from 4,658 to 5,990 miles, depending on whether assessing the minimum pipelines length or minimum crossings of state boundaries. Interestingly, these total new pipeline lengths align closely with the existing CO_2 pipeline length of approximately 5,300 miles.
- The majority (over 70%) of pipeline segments in all investigated cases will span less than 100 miles, with more than 50% of segments being shorter than 25 miles in scenarios where total pipeline length is minimized.
- Common pipeline sizes for decarbonizing coal-fired power plants will include 12”, 16”, 20”, and 24”.
- Minimizing the total number of pipelines crossing state boundaries in Scenario 2, where 99 coal units are considered, can reduce the number of state-crossing pipelines from 27 to 17, with a moderate increase in total pipeline length.

It should be noted that the current transport network analysis focused solely on CO_2 emissions from coal-fired power plants. Future research will explore opportunities for pipeline co-development from other CO_2 sources such as natural gas power plants, ethanol plants, cement plants, and natural gas processing facilities, or the establishment of a common carrier pipeline network (e.g., hubs).

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