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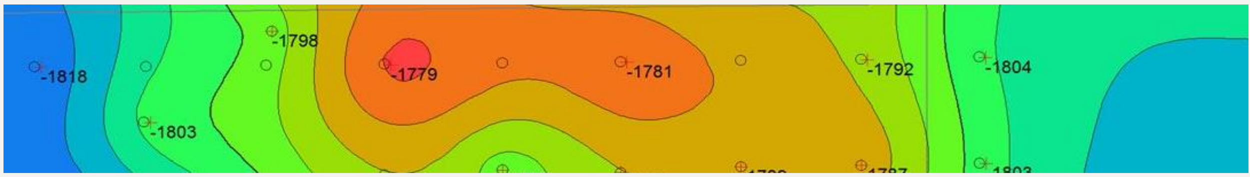

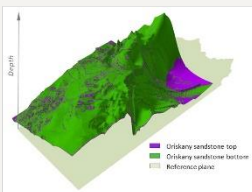

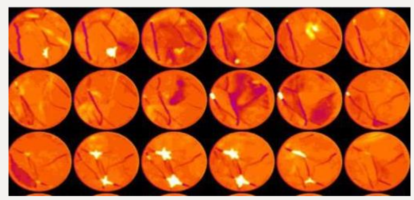

Comparative Analysis of Transport and Storage Options from a CO_2 Source Perspective

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ACRONYMS AND ABBREVIATIONS

CCS	Carbon capture and storage
CO_2	Carbon dioxide
d	day, days
DOE	Department of Energy
EPA	Environmental Protection Agency
FE	Fossil Energy
ft	Foot, feet
GC	Gulf Coast
ID	Identification
IGCC	Integrated gasification combined cycle
in	Inch, inches
IPCC	Intergovernmental Panel on Climate Change
km	Kilometer, kilometers
mD	Millidarcy, millidarcys
MESA	Mission Execution and Strategic Analysis
mi	Mile, miles
mi^2	Square mile, square miles
MMscf	Million standard cubic feet
Mt	Million tonnes
Mt.	Mount
MW_{net}	Net megawatt, net megawatts
N/A	Not applicable
NETL	National Energy Technology Laboratory
NG	Natural gas
NGCC	Natural gas combined cycle
O&M	Operation and maintenance
PISC	Post-injection site care
PC	Pulverized coal
ROW	Right-of-way, rights-of-way
SC	Supercritical
tonne	Metric ton (1,000 kilograms)
UIC	Underground Injection Control
U.S.	United States
yr, Yr	Year, years

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1 INTRODUCTION

Carbon capture and storage (CCS) is an important technology for reducing carbon dioxide (CO_2) emissions from anthropogenic sources. CCS involves a sequence of events, which collectively define the CCS value chain that includes: 1) capture—capturing CO_2 from industrial and power-generation facilities, purifying the CO_2 stream and compressing it for transport; 2) transport—transporting the CO_2 to a geologic storage site via pipeline for storage in a storage reservoir; and 3) storage—injecting the delivered CO_2 into a suitable geologic storage reservoir where the CO_2 can be isolated from the atmosphere. [1] CCS has been and continues to be successfully demonstrated throughout the world. Examples of successful CCS projects include the Sleipner Project (Norway), the Illinois Basin Decatur Project (United States [U.S.]), the Illinois Industrial Carbon Capture and Storage Project (United States), and several field demonstration projects implemented through the U.S. Department of Energy (DOE) Regional Carbon Sequestration Partnerships Initiative (United States and Canada). [2, 3] As research and development activities continue to advance CCS toward commercialization, demonstration projects that implement and validate safe and effective CO_2 injection and storage technologies become critically important. Successful demonstration and deployment of CCS technologies can contribute toward building confidence and reducing costs through new innovations and advances in capture, storage, and monitoring technology and protocols, [4] all towards helping push CCS towards commercial viability.

Large-scale CCS demonstrations have shown that significant CO_2 emissions reductions are capable; however, the technology itself is relatively high-cost. [5] Cost effective CCS depends on the total mass of CO_2 captured and stored which in turn depends on the annual rate of capture, transport distance, and project life. There is an economy of scale for each link of the CCS value chain which can impact the cost of each link differently; therefore, when considering all cost drivers related to CCS, it is important to ensure the entire CCS value chain is included, which consists of 1) the cost to capture CO_2, 2) the cost to transport CO_2, and 3) the cost to store CO_2.

From the perspective of an anthropogenic CO_2 source, capture, transport, and storage costs are critical in its effort to keep overall CCS costs at a minimum. The amount of CO_2 a power plant or industrial source captures and needs to store will play a significant role in increasing or decreasing overall capture and storage costs, respectively. Besides the amount of CO_2 for storage, reservoir quality will also affect storage costs. The distance from a CO_2 source to a storage site will factor into the transport costs along with the total mass of CO_2 being transported for sequestration. Ideally, the suitable storage site for captured CO_2 would be nearby if not onsite, minimizing transport cost and providing cost benefits to the CO_2 source; unfortunately, that scenario is not always possible.

The National Energy Technology Laboratory (NETL), part of the U.S. DOE's Office of Fossil Energy (FE), completed a study in 2014 [6] that looked at single CO_2 source-to-sink matching based on source-specific capture, varying levels of storage reservoir quality options (based on depth, formation, thickness, porosity, structure, and areal extent), and CO_2 transport via a dedicated pipeline based on distance from storage sites (focusing on saline-bearing formations). The 2014 study examined the cost of each CCS component focusing on CO_2 source locations and storage reservoir options within the Appalachian and Illinois basins. The study concluded that good quality storage reservoirs, even though they might be relatively far away to a given CO_2 source, could still be economically favorable over closer, lower quality storage reservoirs (thinner, deeper, less porous). However, building a dedicated pipeline system to a storage reservoir further away will increase the overall CCS cost for a project which might not be suitable or economically feasible for small CO_2 sources. Gulf Coast Basin storage reservoirs were not considered in NETL's 2014 study because modeling of trunklines was left for the next analysis.

This analysis evaluated integrated CCS costs (i.e., capture, transport, and storage) from the perspective of a CO_2 source. A source will have captured CO_2 requiring suitable storage and affordable transportation between source and storage. Capture costs were modeled for six hypothetical sources (three supercritical [SC] electric power plants and three industrial plants) with CO_2 capture rates ranging from 0.65 to 3.90 million tonnes per annum (Mt/Yr) and were based on two NETL reports. [7, 8] Two pipeline systems were evaluated as transport options: a dedicated pipeline system and a trunkline pipeline system. Transportation costs from source to storage reservoirs were evaluated using the FE/NETL CO_2 Transport Cost Model (CO_2 Transport Cost Model). [9] Storage reservoirs were limited to on-shore, saline-bearing formations. Seven storage reservoirs located in the Appalachian, Illinois, and Gulf Coast basins—and of various quality with respect to CO_2 storage—were modeled: two within the Rose Run Formation, three within the Mount (Mt.) Simon Formation, one in the Lower Tuscaloosa Formation, and one in the Frio Formation. Storage costs were calculated with the FE/NETL CO_2 Saline Storage Cost Model (CO_2 Storage Cost Model) [10] for the seven selected storage reservoirs under dome and regional dip structural settings. A total CCS cost was calculated for each source connected to each storage reservoir site by each pipeline system. The analysis methodology is founded on a modular approach for evaluating "per tonne of CO_2 costs" for a given CO_2 source, pipeline system, and storage options across the CCS value chain. This approach enables evaluation of many source-sink scenarios and facilitates straightforward CCS component integration to calculate total CCS costs across the evaluated scenarios. The objectives of this analysis were to see if Gulf Coast reservoirs were within the cost for northeast sources, how much a trunkline pipeline system would lower costs, and if storage options for industrial sources were like those for electric power plants. A paper with the same name and information as well as additional details on this study was published in *The International Journal of Greenhouse Gas Control* [11] along with a document that provides additional material (i.e., key parameters used in the models for obtaining transport and storage costs and CCS cost and pipeline results) to supplement the paper.

2 Literature Review

Total greenhouse gas emissions by economic sectors (i.e., electricity, transportation, industry, agriculture, and commercial & residential) in 2016 were 6,511 million metric tons (tonnes) of CO_2 equivalent, and emissions from electric and industrial sectors accounted for 50 percent of the total emissions. [12] CCS has been widely recognized as one of the key technologies to manage carbon emissions from various types of sources. [13] While several small- and large-scale CCS projects have been or are currently in operation [2, 14, 15] throughout the world, and have demonstrated that significant CO_2 emissions reductions are capable, policy-makers, pipeline operators, plant owners, and stakeholders continue to evaluate the costs associated with CCS. Calculating the cost of CCS is complex because it involves the estimation of capture, transport, and storage costs and the understanding of the specific cost drivers associated with each link of the CCS value chain. The contribution of each component at the same time is dependent upon each other. A low capture rate will affect all three types of cost. A good storage reservoir might not be close to the source and therefore affect transport costs. As a result, how to correctly estimate CCS cost and understand the effect of each component has become one of the most critical elements for researchers and organizations.

The three components of the CCS value chain historically have been researched separately or as combinations of the three. [16] When evaluating the capture cost of power generation systems, pulverized coal (PC) plants, coal-based integrated gasification combined cycle (IGCC) plants, and natural gas combined cycle (NGCC) plants are the three common systems studied. [17, 18, 19] Next-generation advanced fossil power systems (such as oxy-combustion and chemical looping) have also been studied by researchers and organizations including NETL. [20] NETL has been one of the leaders to document CO_2 capture cost and performance of fossil energy plants in their cost and performance baseline for fossil energy plants reports. [7, 21, 22, 23] These reports reflect cost and performance variations across different power generation and CO_2 capture systems and provide essential baseline information needed to understand and compare each system in detail.

Some studies addressed the cost of CO_2 transport and storage components of CCS in detail. Earlier work by Svensson et al. (2004) determined that among various transport approaches (pipeline, barge, and truck), pipeline transport is the most practical and cost-effective means of moving large amounts of CO_2. [24] The work by Zhang et al. (2006) supports the Svensson et al. (2004) study and concluded that the efficient transport of CO_2 by pipeline can be optimized by compressing and cooling CO_2 into a liquid state. [25] These types of studies laid a foundation for future studies exploring the CO_2 transport cost. For instance, McCoy and Rubin (2008) designed a CO_2 transport model to estimate the cost per tonne of CO_2 ($/tonne) by 1) varying the distance of transport, 2) varying the CO_2 flow rate (reflecting difference in power plant size), and 3) incorporating regional changes in costs. [26] Their study estimated a cost of $1.16/tonne to transport 5 Mt/Yr of CO_2 via a 100-kilometer (km) pipeline constructed in the Midwest. Depending on the region, pipeline construction costs can vary between 20 percent and 30 percent. Costs are also sensitive to the design capacity and the length of the pipeline. The cost per tonne of CO_2 will increase for a smaller design capacity and longer pipeline. By integrating studies from literature, NETL designed the CO_2 Transport Cost Model to optimize the break-even price of a tonne of CO_2 based on pipeline length, starting and ending elevations, and design capacity. [9] This model provides a flexible way to estimate the transport cost. It allows users to adjust project parameters (e.g., flowrate, operation duration, pipeline distances, elevations, etc.), financial parameters (e.g., interest rate), and other parameters. The most suitable pipeline diameter is selected by the model through an optimization process that incorporates user-defined inputs.

Estimating detailed CO_2 storage costs can be challenging because of the stages and time involved and because of geologic variation across potential storage reservoirs. [27, 28] For example, a typical storage project can be broken down into five stages: 1) site screening, 2) site selection and site characterization, 3) permitting and construction, 4) operations, and 5) post-injection site care (PISC) and site closure. [28] These stages can occur over different timeframes, and predictions for cost escalation and inflation over time can dramatically impact overall storage cost estimates for a given project. In addition, it has been noted that there can be a lack of consistency in cost categorization across project phases within publicly-available sources, making direct comparisons across different CCS studies a challenge. [29] The geologic variability of potential storage formation characteristics (i.e., depth, thickness, porosity, permeability, and overall capacity) are major drivers of site-to-site cost variability [11, 28, 30] and must be considered when estimating CO_2 storage costs. A study performed by Eccles et al. (2009) estimated the physical and economic potential of CO_2 storage in saline aquifers in the United States which included calculating the maximum CO_2 storage potential, injection rate, and storage cost of those reservoirs. [31] This analysis also estimated the capital cost and the operation and maintenance (O&M) cost of the wells. A study by Dahowski et al. (2005) summarized storage costs for different geological formations in Canada and the United States (contiguous 48 states), including deep saline formations. The average cost for storing CO_2 in deep saline formations was approximately \$13/tonne CO_2 but ranged from \$12 to \$15/tonne CO_2. [32] A more recent study by Vikara et al. (2017) indicated that there is potentially 559 to 3,042 gigatonnes (Gt) of CO_2 storage potential in the United States at or below a \$10/tonne CO_2 price point, and from 3,251 to 4,237 Gt at or under \$25/tonne CO_2. [27] To fully understand cost occurred in each stage and for wells compliant to the U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) Class VI regulations, [33] NETL designed the CO_2 Storage Cost Model to calculate a project's CO_2 break-even price. [10] This model provides a comprehensive list of various costs occurred in each stage. It also provides a flexible way to allow users to tailor the model to fit the requirements of each individual project by adjusting parameters in each stage (e.g., financial parameters or project lifetime). Moreover, the model has a built-in geologic database of formations in the United States as proxies for storage site assessment. The model has the capability to complete single- or multiple-formation storage cost estimates by leveraging this geologic database that has critical properties for saline-bearing formations that dictate subsurface CO_2 storage (porosity, permeability, depth, thickness, and areal extent).

The Intergovernmental Panel on Climate Change (IPCC) identified that many earlier cost studies either excluded transport and storage costs or used a constant cost, so they created a special CCS cost report comparing studies done on all three components: 1) capture costs of industrial processes and electricity power plants, 2) transport costs of pipeline and marine systems, and

3) costs of geologic storage. [16] The CCS costs within this report were examined at a generalized level showing possible cost ranges for each component. In a study done by Rubin et al. (2004), CCS costs of PC, IGCC, and NGCC plants were compared by adding fixed transport and storage costs to each system. [34] Employing a similar method used in IPCC's special CCS report, Rubin et al. (2015) updated the CCS costs of PC, IGCC, and NGCC in a 2015 study. [35] This evaluation concluded that the capital cost of power plants and CCS technologies have increased significantly since 2005.

While many CCS studies have been performed, it is apparent that difficulties in fully understanding the cost of CCS remain, especially from a fully-integrated (capture, transportation, and storage) perspective. [36, 37, 38] For example, different project lifetimes or financial considerations could drastically impact overall CCS cost estimates. Furthermore, location (for both the CO_2 source and storage reservoir site) is a critical CCS cost driver. From a CO_2 source's perspective, the ideal CO_2 storage site would be located nearby if not onsite, minimizing transportation cost. However, if an on-site storage reservoir was of lower quality and had a high associated storage cost, a more distant storage option of better quality and lower storage-related cost could be more favorable despite the added CO_2 transport-related cost. [6]

3 Study Methodology Overview and Assumptions

This study combined capture, transport, and storage costs into a collective evaluation of the CCS value chain and tested a methodology for analyzing these combined CCS costs. Economy of scale impacts costs of each link of the CCS value chain differently; therefore, when considering all cost drivers related to CCS, it is important to ensure the entire CCS value chain is included, which consists of 1) the cost to capture CO_2, 2) the cost to transport CO_2, and 3) the cost to store CO_2. In this analysis, costs for these components were estimated for different CO_2 sources, CO_2 transport types, and CO_2 storage options using data from NETL-developed, open-source models, databases, and publications. Modeling of each link of the CCS value chain is described in the following subsections.

Costs for each CCS value chain link were calculated for six sources that capture between 0.65 Mt/Yr and 3.90 Mt/Yr of CO_2 over a 30-year capture and injection period (Exhibit 3-1). This analysis modeled six hypothetical CO_2 sources types positioned in one of four hypothetical locations (Exhibit 3-2) in the northeastern United States. These locations established a range of transport distances between the sources and seven storage reservoir options. The source types were evaluated against two hypothetical CO_2 transportation options—dedicated pipelines or trunklines—for transporting captured CO_2 to the storage sites under dome or regional dip structural settings. For any source, the annual mass of CO_2 captured (and its capture cost) is fixed. Storage costs reflect storage reservoir quality and the mass of CO_2 injected over the life of the project. When connecting source and storage options, transportation costs depend on the mass of CO_2 transported and the distance to storage. The mass of CO_2 transported and transport distance affect the pipeline diameter and the number of booster pumps required, both of which impact transportation cost. Based on this methodology, results from modeling the integration of the unit cost to manage CO_2 within each step of the CCS value chain were combined to identify 1) total CCS costs on a per tonne of CO_2 basis across multiple source, transport, and storage options; 2) lowest-cost combinations for transporting and storing CO_2 based on a CO_2 source's type, CO_2 capture rate, and proximity to geologic storage options; and 3) if storage reservoirs closest to CO_2 sources provided a more favorable option. For this analysis, unit costs are expressed on a "per tonne of CO_2" basis (hereafter referred to as "per tonne").

3.1 CO_2 Capture Costs and CO_2 Source Types

Due to the large capital investment required for equipment and associated energy consumption, CO_2 capture is typically the largest cost component of an integrated CCS system. [39, 40] Three of the six sources evaluated in this study are newly built SCPC electric power plants with specifications based on work reported in NETL's "Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity" report. [7] Power plant capacity factor is 85 percent and rate of capture is 90 percent. The other three sources modeled are steel, cement, and natural gas (NG) processing industrial plants. The amount of CO_2 captured from each of these industrial plants is based on the amount of CO_2 available for capture. Specifications for these industrial plants are from the NETL 2014 report "Cost of Capturing CO_2 from Industrial Sources." [8] Net power or product outputs, annual capture rates of CO_2, and capture costs for the electric power plants and industrial plants are posted in Exhibit 3-1.

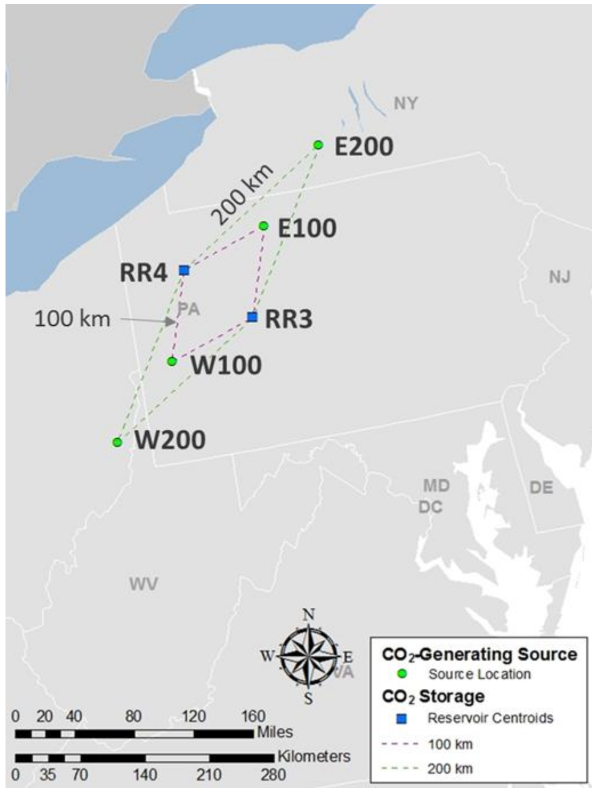
Exhibit 3-1 Annual rate of CO_2 capture, cost of capture, and net power or product output for CO_2 source types modeled

CO_2 Source Type		Net Power or Product Output	CO_2 Captured Mt/Yr	Capture Cost 2011$/tonne
Power Plant	SCPC electric power plant	550 MW_{net}	3.58	$57.82
		482 MW_{net}	3.14	$58.57
		400 MW_{net}	2.60	$61.21
Industrial Plant	Steel production plant	2.54 Mt/Yr	3.90	$99.00
	Cement production plant	992,500 tonnes/yr	1.14	$100.00
	NG processing plant	500 MMscf/d	0.65	$18.00

The northeastern United States was chosen as the study location for the evaluated CO_2 sources, whose types were chosen based on association with the area because of the abundance of CO_2 sources within the Northeast and Midwest regions of the United States (Pennsylvania, Ohio, Indiana, Illinois, and West Virginia. These source locations fall within the Appalachian Basin, one of the largest U.S. basins, consisting of several geologic formations with characteristics that make them suitable for CO_2 storage, including Rose Run. As seen in Exhibit 3-2, the sources were located 100 km east (E100) and west (W100) and 200 km east (E200) and west (W200) of the Rose Run storage reservoirs. The source locations were modeled equidistantly from the Rose Run storage reservoirs (e.g., E200 to Rose Run 3 was the same distance as its counterpart, W200 to Rose Run 3).[a] The CO_2 source locations of E100 and W100 are in northwest Pennsylvania and southwest Pennsylvania, respectively, E200 is in southwest New York, and W200 is in southeast Ohio. Electric power plants and industrial plants capturing varying amounts of CO_2 at specific costs were modeled at each of the CO_2 source locations.

[a] Other CCS cost studies such as NETL's "Quality Guidelines for Energy Systems Carbon Dioxide Transport and Storage Costs in NETL Studies" report [30] used fixed 100 km distances from a source to a storage site. To better determine the impacts of location on total CCS costs, 200 km was also evaluated as an additional distance parameter.

Exhibit 3-2 Source locations within northeastern United States used in this analysis

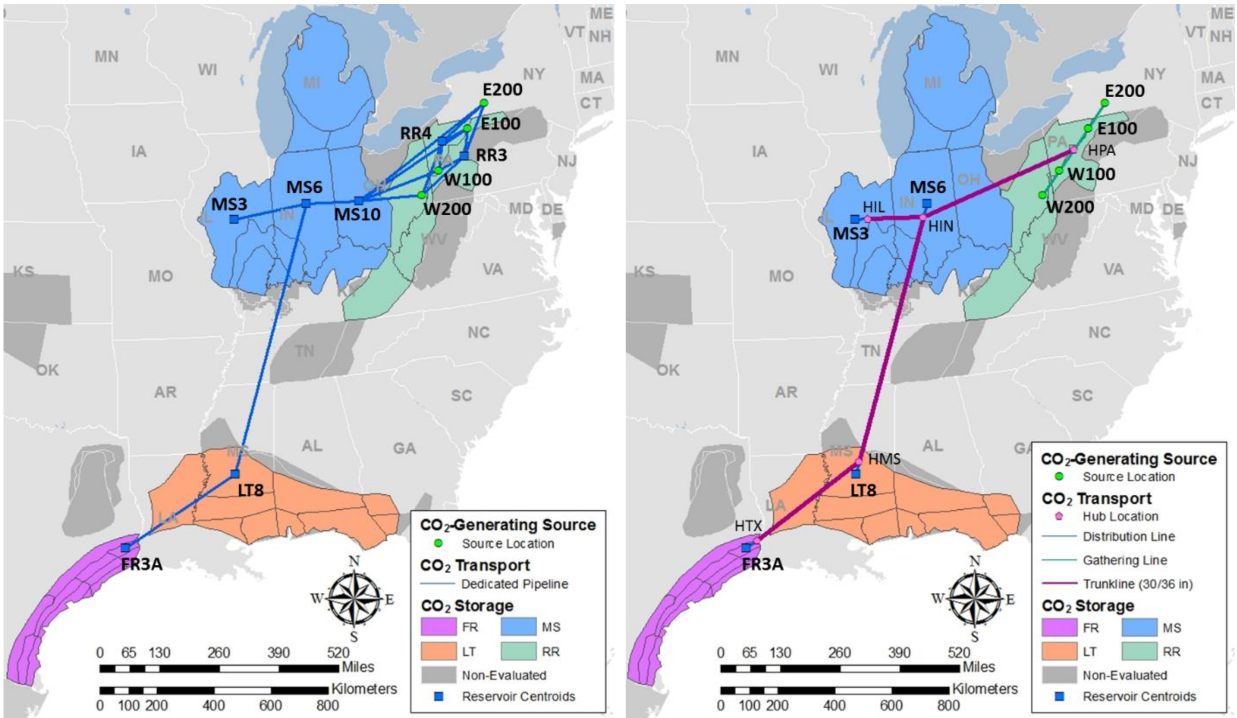


3.2 CO_2 Transport Costs

Two transportation options, a dedicated pipeline system and a trunkline pipeline system, were modeled for this study and are discussed more in Section 3.2.1 below. Exhibit 3-3 shows the dedicated (left) and trunkline (right) systems as part of the integrated hypothetical CCS networks modeled which also include areal extent of each formation in which a potential CO_2 storage reservoir may occur, CO_2 source locations, and storage reservoirs. All pipeline transportation costs were modeled with the CO_2 Transport Cost Model, [9] which is an Excel spreadsheet-based tool that estimates the cost, specifically, the first-year break-even price, of transporting CO_2 by pipeline. It is important to note that a previous version of the model was used for this analysis. Since then, the model has been updated to add pipeline diameters less than 8 inches (in) and modify the right-of-way (ROW)/damages capital cost category for the Parker equation, one of the equations used to calculate pipeline capital costs (i.e., materials, labor, ROW/damages, and miscellaneous). These edits have effects on cost.

The source delivers its captured CO_2 to the pipeline at pressure as a dense phase liquid and meets pipeline specification for purity. This price for transportation of CO_2 (in 2011 dollars [2011$]) covers all costs and provides project investors with their desired minimum return on investment. [41] A public version of the model as well as a detailed user manual describing assumptions, modules, and cost estimation methodology [41] are located at https://www.netl.doe.gov/research/energy-analysis/search-publications/vuesearch?search=netl&id=17&value=Analytical%20Tools%20%26%20Data.

Exhibit 3-3 Integrated hypothetical CCS networks modeled as part of this analysis



Pipeline modeling here utilizes a storage reservoir term: centroids as a junction point. Storage reservoirs are considered a subset of a larger storage formation (e.g., Mt. Simon 10 is a subset of Mt. Simon) (Exhibit 3-3). The areal extent of each formation is subdivided into sub-areas referred to as storage reservoirs. Each sub-area is defined by a centroid (with a unique latitude and longitude), which is the location for that particular storage reservoir. A centroid also represents a junction where two segments of a dedicated pipeline join.

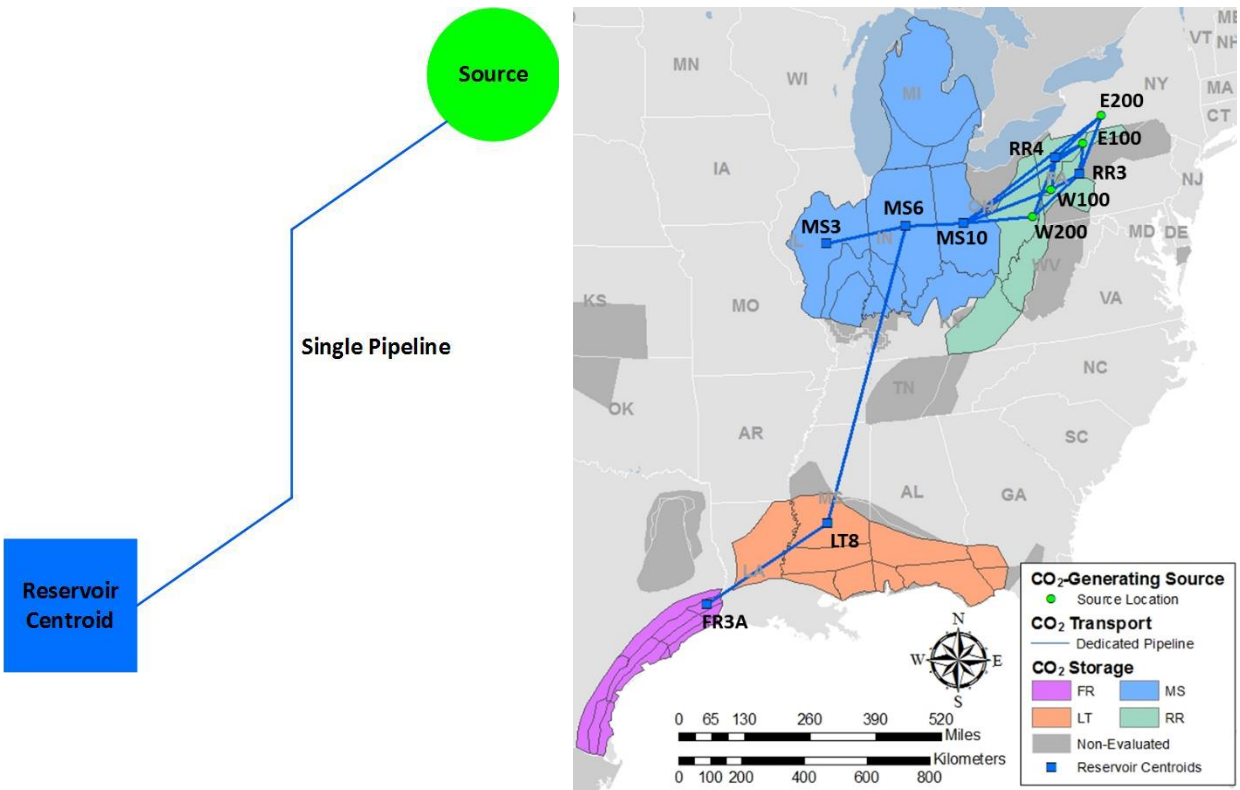
3.2.1 Pipeline Networks

Two pipeline networks, dedicated and trunkline, were modeled to track transport costs between a CO_2 source and storage site. Both pipeline systems connect to the same source locations. The Rose Run 3, Rose Run 4, and Mt. Simon 10 storage reservoirs are not included in the trunkline pipeline system due to their proximity to the source.

3.2.1.1 Dedicated Pipeline System

The dedicated pipeline system (dedicated system or dedicated network) transports CO_2 from a single source to a single storage reservoir site. All dedicated pipeline segments between a CO_2 source and its storage site connect at a centroid (right illustration in Exhibit 3-4). A source is connected directly to either the Rose Run storage reservoir or the Mt. Simon 10 storage reservoir. For the source to transport its captured CO_2 to the Mt. Simon 3 storage reservoir, the pipeline connects through the Mt. Simon 10 and Mt. Simon 6 centroids. The total distance between the source and the Mt. Simon 3 storage reservoir is the sum of each segment and is modeled as one dedicated pipeline. Transportation to the Gulf Coast storage reservoirs connects through the Mt. Simon 6 centroid. As can be seen in the left illustration in Exhibit 3-4, a single pipeline connects a source to a storage reservoir via a storage reservoir centroid. For example, if a CO_2 source at W200 wanted to transport CO_2 for storage in the Frio 3A storage reservoir, one pipeline would be routed through Mt. Simon 10, Mt. Simon 6, and Lower Tuscaloosa 8 centroid locations. The total distance of a dedicated pipeline is the summation of each individual pipeline segment. This total pipeline distance is used to calculate the transport cost for each combination of source and storage location. Exhibit 3-4 provides a schematic of the approach used for the dedicated system as well as a map illustrating the dedicated network with the source locations, storage reservoirs, and pipeline connections.

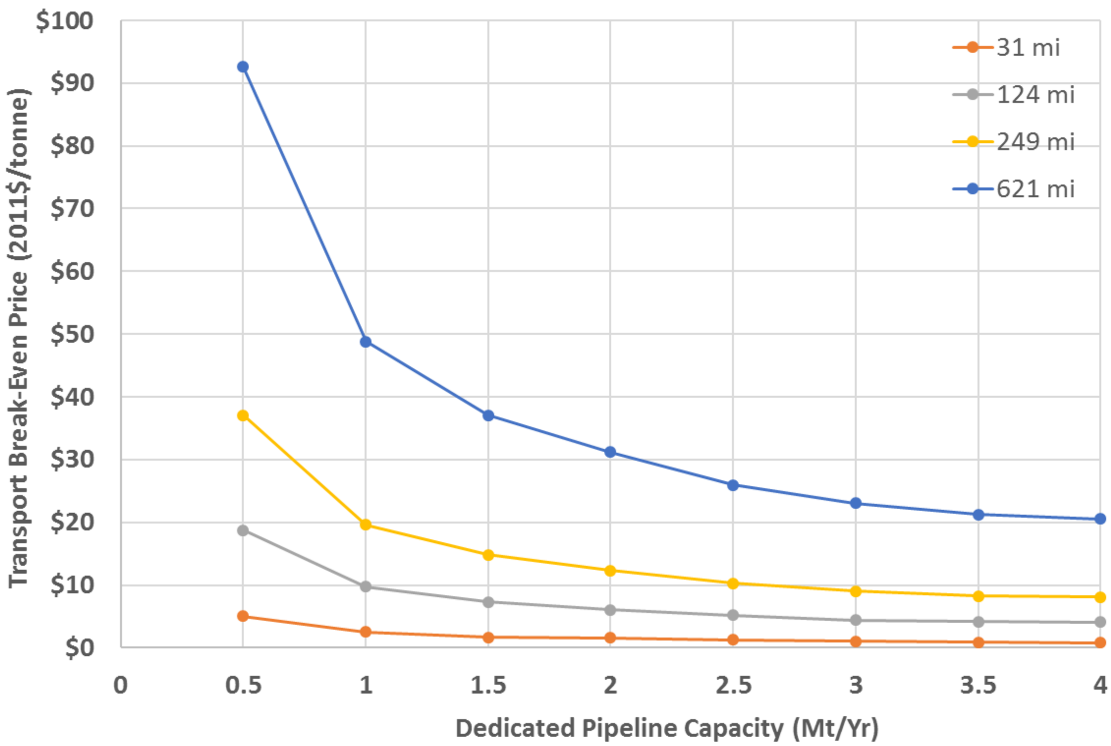
Exhibit 3-4 Schematic (left) depicting dedicated pipeline concept and map (right) illustrating dedicated network used for this analysis



Due to the range of the inlet and outlet pressures of a pipeline, CO_2 is transported as a dense phase liquid. Booster pumps are incorporated into the pipeline by the CO_2 Transport Cost Model as needed to maintain pressure over the length of the pipeline to assure the outlet pressure specified. Changes in elevation over the length of the pipeline is considered by the model. The annual mass of CO_2 transported and total transport distance are key factors in determining pipeline diameter and number of booster pumps, both driving CO_2 transportation costs.

Economies of scale for a dedicated pipeline are illustrated in Exhibit 3-5 and Exhibit 3-6. For each of the four distances plotted in Exhibit 3-5, the unit cost of transportation decreases with increasing annual mass of CO_2 transported. For a fixed annual mass of CO_2 transported, the unit cost of transportation increases with distance. Pipeline diameter for the dedicated systems modeled is either 8 in or 12, as can be seen in Exhibit 3-6. Because of the numerous source location, storage reservoir, and transport considerations evaluated in this analysis, results for the CO_2 source types at the E200 source location are shown in Exhibit 3-6 to simplify discussion. An 8-in pipeline will transport the captured CO_2 for the NG processing plant (0.65 Mt/Yr capture rate) and cement plant (1.14 Mt/Yr capture rate). A 12-in pipeline is needed for the electric power plants (2.60 Mt/Yr, 3.14 Mt/Yr, and 3.58 Mt/Yr capture rates) and steel plant (3.90 Mt/Yr capture rate).

Exhibit 3-5 Economies of scale for dedicated system



For each pipeline diameter, moving to the next larger source requires additional booster pumps to further compress the CO_2. The CO_2 Transport Cost Model determines the lowest cost option between increasing pipeline diameter or adding booster pumps with increasing annual mass of CO_2. Exhibit 3-6 illustrates the change in pipeline diameter and number of booster pumps with change in the mass of CO_2 transported to each possible storage site from the E200 location. In general, for each mass of CO_2 captured, the number of booster pumps needed along the pipeline increases with distance of transport. For each distance of transport and diameter of pipe, the number of booster pumps increase with increasing mass of CO_2 transported. When pipe diameter increases from 8 in to 12 in, the number of booster pumps needed drops. Additional raw booster pump data based on CO_2 transport rate for the pipeline segments in the dedicated system for other source locations can be found in Exhibit B-1 in Appendix B: Booster Pump Data.

Exhibit 3-6 Dedicated pipeline distance, pipeline diameter, number of booster pumps, and transport cost (2011$) per mass of CO_2 transported from E200

Dedicated Pipeline – from E200 Location			Mass CO_2 Transported					
Storage	**Distance mi**	**Parameters**	**0.65 Mt/Yr**	**1.14 Mt/Yr**	**2.60 Mt/Yr**	**3.14 Mt/Yr**	**3.58 Mt/Yr**	**3.90 Mt/Yr**
RR3	124	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	2	1	1	2	3
		Transport Cost 2011$/tonne	14.42	8.94	5.00	4.20	4.08	4.16
RR4	124	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	1	1	1	2	2
		Transport Cost 2011$/tonne	14.42	8.58	5.00	4.20	4.08	3.81
MS10	348	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	1	4	2	4	5	6
		Transport Cost 2011$/tonne	40.10	24.09	13.56	12.06	11.10	10.68
MS6	462	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	1	5	3	5	7	8
		Transport Cost 2011$/tonne	53.03	31.83	18.11	15.88	14.85	14.18

Dedicated Pipeline – from E200 Location			Mass CO_2 Transported					
Storage	Distance mi	Parameters	0.65 Mt/Yr	1.14 Mt/Yr	2.60 Mt/Yr	3.14 Mt/Yr	3.58 Mt/Yr	3.90 Mt/Yr
MS3	623	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	2	7	4	6	8	10
		Transport Cost 2011$/tonne	71.54	42.89	24.34	21.10	19.47	18.81
LT8	1,071	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	3	12	7	11	14	16
		Transport Cost 2011$/tonne	122.60	73.58	41.83	36.47	33.52	31.87
FR3A	1,358	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	4	14	8	12	16	19
		Transport Cost 2011$/tonne	155.52	92.86	52.74	45.56	41.89	39.96

3.2.1.2 Trunkline Pipeline System

The trunkline pipeline system (trunkline system or trunkline network) modeled has four segments with a connecting hub at each end. Each CO_2 source has its own gathering pipeline connecting to a gathering hub located in western Pennsylvania (HPA) where its CO_2 enters the trunkline system (right illustration in Exhibit 3-7). This dedicated gathering hub is equidistant from the W200/E200 and W100/E100 source locations. The gathering pipeline is either 8 in or 12 in in diameter depending on the mass of CO_2 transported (Exhibit 3-8). Because of the numerous source location, storage reservoir, and transport considerations evaluated in this analysis, results for the CO_2 source types at the E200 source location are shown in Exhibit 3-8 to simplify discussion. Additional raw booster pump data based on CO_2 transport rate for the trunkline segments in the trunkline system for other source locations can be found in Exhibit B-2 and Exhibit B-3 in Appendix B: Booster Pump Data. Distribution hubs are in Indiana (HIN), Illinois (HIL), Mississippi (HMS), and Texas (HTX) at the end of each trunkline segment. These distribution hubs are 30 miles (mi) from a storage reservoir and have a dedicated distribution pipeline, either 8 in or 12 in in diameter, transporting the source's CO_2 to the storage site for storage in a storage reservoir (i.e., centroid). Exhibit 3-7 displays a schematic of the approach used for the trunkline system and a map illustrating the overall trunkline network with source locations, hubs, storage reservoirs, and pipeline connections. As can be seen in the left illustration in Exhibit 3-7, several pipeline segments connect a CO_2 source to a storage reservoir via a storage reservoir centroid. For example, if a source at E200 wants to transport CO_2 for storage in the Mt. Simon 3 storage reservoir, four pipeline segments provide the connection (i.e., E200 – gathering hub in Pennsylvania (HPA) – hub in Indiana (HIN) – distribution hub in Illinois (HIL) – Mt. Simon 3 storage reservoir).

Exhibit 3-7 Schematic (left) depicting trunkline concept and map (right) illustrating trunkline network used for this analysis

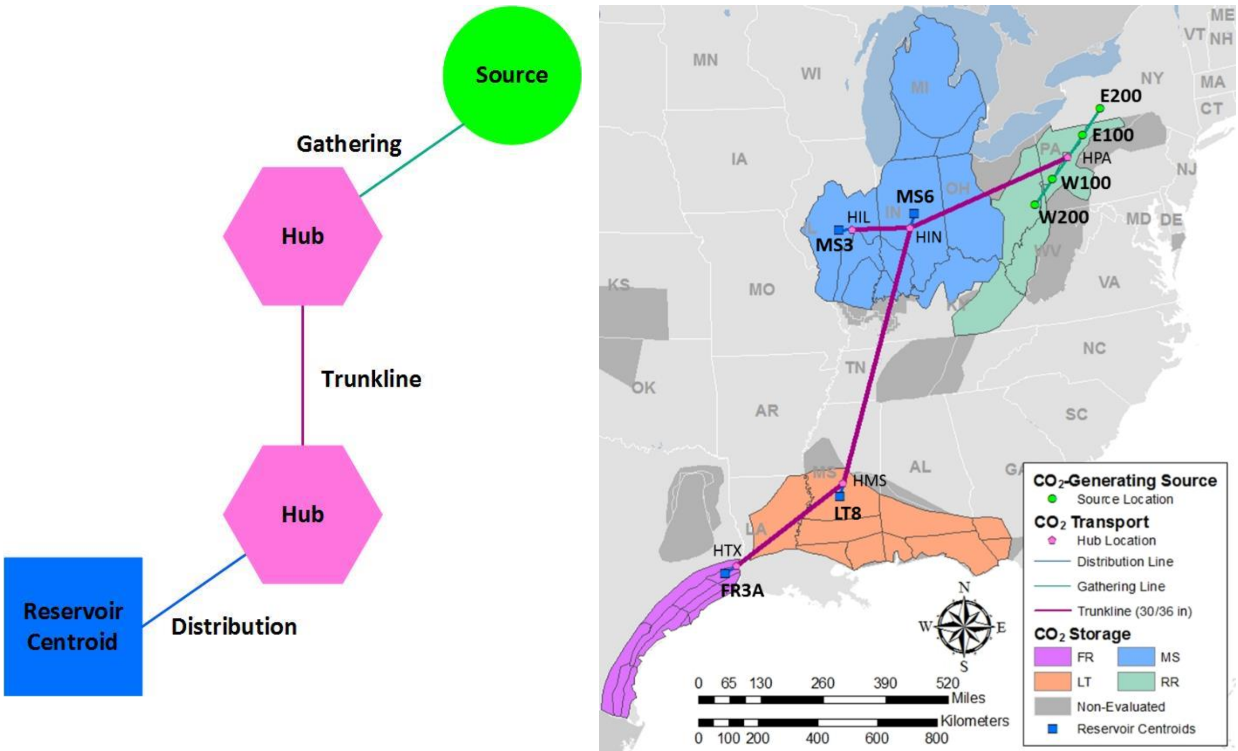


Exhibit 3-8 Gathering and distribution line distance, pipeline diameter, number of booster pumps, and transport cost (2011$) per mass of CO_2 transported from E200

Trunkline System – Gathering and Distribution Lines – from E200 Location			Mass CO_2 Transported					
Line	Distance mi	Parameters	0.65 Mt/Yr	1.14 Mt/Yr	2.60 Mt/Yr	3.14 Mt/Yr	3.58 Mt/Yr	3.90 Mt/Yr
E200 to HPA	122	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	1	2	2	2	3	3
		Transport Cost 2011$/tonne	14.43	8.74	5.24	4.46	4.35	4.08
HIN to MS6	30	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	0	0	0	0	0
		Transport Cost 2011$/tonne	3.73	2.13	1.19	0.98	0.86	0.79
HIL to MS3	30	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	0	0	0	0	0
		Transport Cost 2011$/tonne	3.73	2.13	1.19	0.98	0.86	0.79
HMS to LT8	30	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	0	0	0	0	0
		Transport Cost 2011$/tonne	3.73	2.13	1.19	0.98	0.86	0.79
HTX to FR3A	30	Diameter in	8	8	12	12	12	12
		No. of Booster Pumps	0	0	0	0	0	0
		Transport Cost 2011$/tonne	3.73	2.13	1.19	0.98	0.86	0.79

The trunkline system provides the capacity to transport CO_2 from multiple sources whereas a dedicated pipeline only has the capacity to transport CO_2 from a single source. Trunkline capacities were modeled based on the capture rate of a 550-net megawatt (MWnet) electric power plant (3.58 Mt/Yr capture rate). Pipe diameters for the trunkline system range from 12 in transporting 3.58 Mt/Yr to 36 in transporting 32.22 Mt/Yr. The 12-in trunkline is a dedicated pipeline for the larger sources (electric power plants and steel plant) but can provide trunkline opportunities for multiple smaller sources such as two cements plants and two NG processing plants. The economy of scale in the trunkline is due to the increase in mass of CO_2 transported, which reduces the unit cost of CO_2 transportation (Exhibit 3-9). This lower unit cost of transportation provides the CO_2 source options on selection of storage site and corresponding transportation.

As mentioned above, the smaller sources benefit from the 12-in diameter trunkline. A larger diameter is needed to accommodate multiple larger sources. The trunkline pipeline diameters modeled for the sources in this study are 12, 20, 24, 30, and 36 in (Exhibit 3-9). For reference, a 30-in diameter pipeline is the largest CO_2 pipeline in the CO_2 pipeline network supplying enhanced oil recovery projects. [42] Natural gas transmission pipeline diameters range from 6 in to 48 in. [43]

Exhibit 3-9 illustrates the change in unit cost of transportation, trunkline diameter, and number of booster pumps with change in mass of CO_2 transported over each trunkline segment. As with a dedicated pipeline, pipeline diameter and number of booster pumps needed increase with an increase in mass of CO_2 transported. If the pipeline diameter remains constant, then more booster pumps are provided with an increase in mass of CO_2 transported. At the end of each trunkline segment, the CO_2 will either enter the next segment or enter a distribution pipeline. The entry pressure of the CO_2 here is the same as the initial entry pressure from the source, and the number of booster pumps needed to maintain this pressure are accounted for by the model.

Exhibit 3-9 Trunkline segment distance, pipeline diameter, number of booster pumps, and transport cost per mass of CO_2 transported

Trunkline System			Mass CO_2 Transported				
Segment	**Distance mi**	**Parameters**	**3.58 Mt/Yr**	**10.74 Mt/Yr**	**17.90 Mt/Yr**	**25.06 Mt/Yr**	**32.22 Mt/Yr**
Pennsylvania to Indiana (HPA to HIN)	360	Diameter in	12	20	24	30	30
		No. of Booster Pumps	6	5	6	4	6
		Transport Cost 2011$/tonne	11.78	7.61	6.67	5.84	5.55
Indiana to Illinois (HIN to HIL)	119	Diameter in	12	24	30	30	36
		No. of Booster Pumps	3	1	1	2	1
		Transport Cost 2011$/tonne	4.30	2.89	2.42	2.18	1.86
Indiana to Mississippi (HIN to HMS)	548	Diameter in	12	20	24	30	36
		No. of Booster Pumps	10	9	9	6	4
		Transport Cost 2011$/tonne	18.21	12.06	10.09	8.84	8.30
Mississippi to Texas (HMS to HTX)	281	Diameter in	12	20	24	30	36
		No. of Booster Pumps	6	5	5	3	2
		Transport Cost 2011$/tonne	9.66	6.32	5.31	4.51	4.24

Unlike a dedicated pipeline where the segments are summed for a total distance to be modeled for transportation cost, each segment of the trunkline pipeline system was modeled separately, from the gathering segment to the distribution segment. The transportation cost for each segment is summed to determine total transportation cost for a trunkline pipeline system (see Exhibit 3-15).

3.3 CO_2 Storage Costs

As can be seen in Exhibit 3-10, seven storage reservoirs of varying quality and location from the geologic database within the CO_2 Storage Cost Model [10] were selected for storage cost modeling in this analysis: Rose Run 3 (RR3), Rose Run 4 (RR4), Mt. Simon 10 (MS10), Mt. Simon

6 (MS6), Mt. Simon 3 (MS3), Lower Tuscaloosa 8 (LT8), and Frio 3A (FR3A). Rose Run 3 and Rose Run 4 are in the Appalachian Basin in western Pennsylvania. Mt. Simon 10 is on the western flank of the Appalachian Basin in western Ohio, Mt. Simon 6 is in central Indiana on the arch between the Illinois and Appalachian basins, and furthest west is Mt. Simon 3 in central Illinois in the Illinois Basin. Two storage reservoirs are south in the Gulf Coast Basin: Lower Tuscaloosa 8 in southcentral Mississippi and Frio 3A in the northeastern Gulf Coast area of Texas. The storage reservoirs evaluated were selected because they represent some of the best storage reservoirs in their respective basins as well as provide a range of storage reservoir quality (Exhibit 3-11) for this analysis. Also, their proximal distribution among the modeled CO_2 sources in the northeastern United States varied. Both Gulf Coast Basin storage reservoirs provide a high-quality storage option but are 1,500 to 2,000 km from the eastern most source location in Pennsylvania; Mt. Simon 3 in Illinois is 1,000 km from the eastern most source in Pennsylvania. While Rose Run is a nearby storage option for each source at each of the four locations modeled, more distant storage reservoir options may be preferred due to the comparatively low storage reservoir quality and storage capacity limitations of the Rose Run formation. The reservoir identification (ID) shown in Exhibit 3-11 is used in tables and charts throughout this report for simplicity.

Exhibit 3-10 Seven storage reservoirs evaluated for this analysis

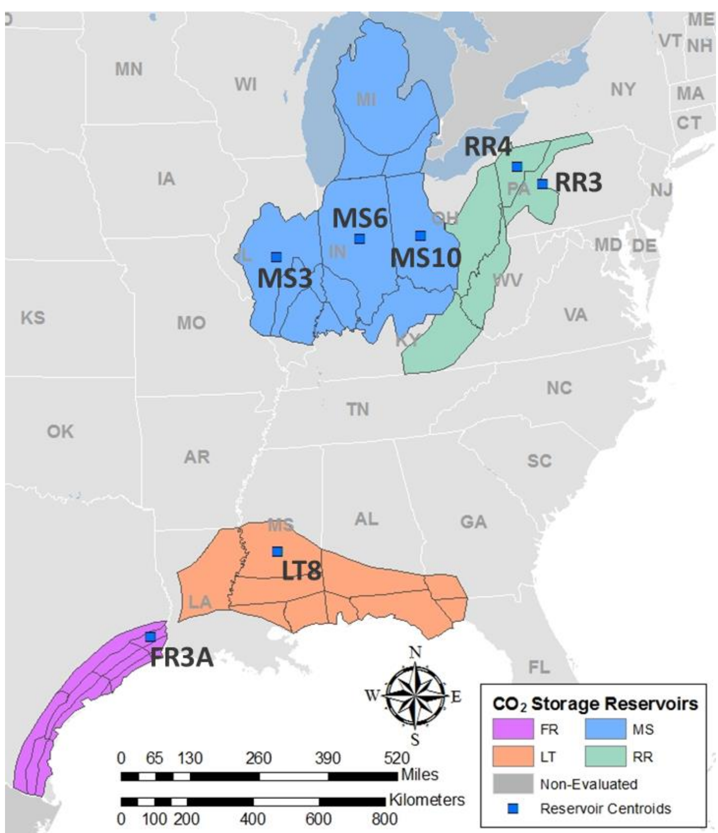


Exhibit 3-11 Geologic characteristics for the seven storage reservoirs evaluated

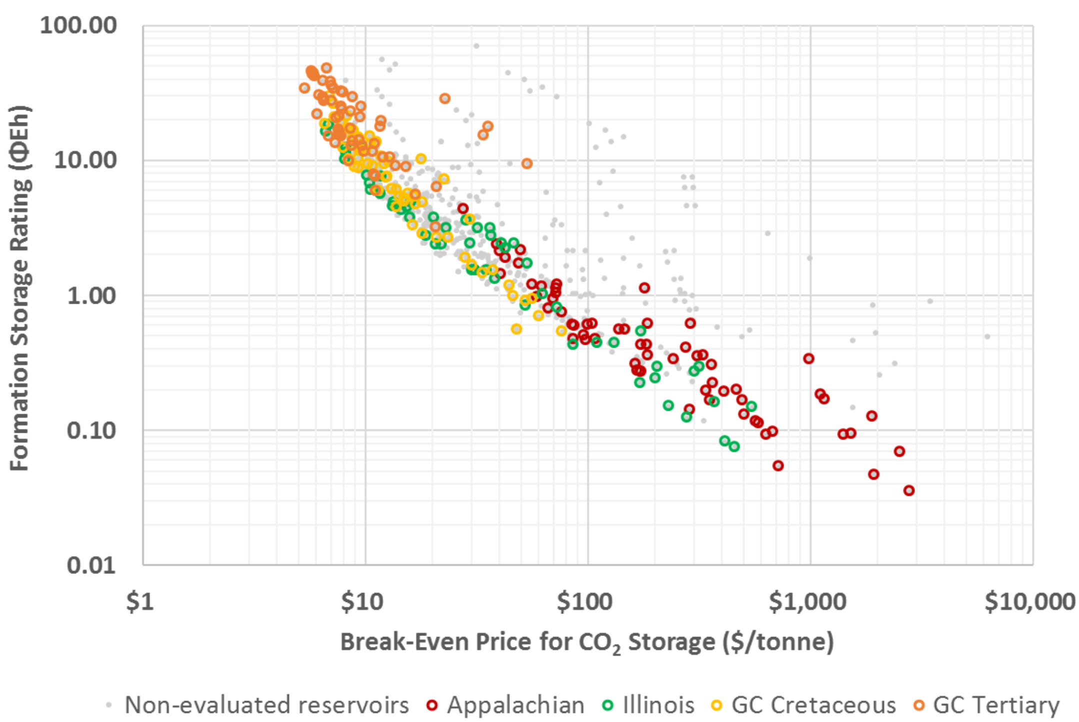
Formation	Storage Reservoir ID	Depth ft	Thickness ft	Porosity %	Permeability mD	Storage Coefficient %	
						Dome	Regional Dip
Mt. Simon	MS6	4,700	982	11	100	15.28	5.63
	MS3	4,270	1,000	12	125	15.28	5.63
	MS10	3,000	200	12	125	15.28	5.63
Lower Tuscaloosa	LT8	4,500	350	23	500	15.51	5.57
Frio	FR3A	5,000	1,000	30	460	15.28	5.63
Rose Run	RR3	13,822	320	8	3	16.97	4.71
	RR4	9,344	158	8	4	16.97	4.71

The CO_2 Storage Cost Model [10] was used to calculate the first-year break-even price to store a tonne of CO_2 for each storage reservoir modeled based on the mass of CO_2 received from each source over 30 years of capture. It is important to note that the study was completed using a previous version of the model; since then, the model has been updated with edits—such as changing the fluid recovery technology cost for a groundwater monitoring well and updating the database—which have effects on cost. In the CO_2 Storage Cost Model, a typical CO_2 storage project modeled has 30 years of injection operations followed by 50 years of PISC and then site closure, a period of time required by the U.S. EPA UIC Class VI regulations. [33] Up front years are for site selection, characterization, permitting, and construction. Overall storage project life is 86 years. The CO_2 Storage Cost Model is an Excel spreadsheet-based tool with a design based on the U.S. EPA UIC Class VI regulations. Capital, operating, and labor costs and a range of technologies applicable to CO_2 storage operations are included in the model, some of which are based on EPA's economic analysis of the Class VI regulations. Projects modeled within the CO_2 Storage Cost Model are assumed to be in compliance with the U.S. EPA UIC Class VI regulations. [33] The baseline CO_2 storage scenarios modeled for this analysis used the default settings in the model [10] with the exceptions of CO_2 injection rate (which were assumed to be the same as the capture rates), structure availability, and nominal maximum service area. A public version of the model as well as a detailed user manual describing assumptions, modules, and cost estimation methodology [28] are located at https://www.netl.doe.gov/research/energy-analysis/search-publications/vuesearch?search=netl&id=17&value=Analytical%20Tools%20%26%20Data.

The geologic database of the CO_2 Storage Cost Model contains geographical and geological data for 64 formations that are partitioned into 228 distinct storage reservoirs scattered across 34 basins in 26 states. Properties, such as formation depth, thickness, porosity, and permeability, are contained within the database. These properties are specific to each formation and have a direct impact on the cost of storage for a potential storage project.

Exhibit 3-12 is a cross plot (log-log scale) of basin storage (product of formation porosity [ϕ], storage coefficient [E], and height [h]) and the first-year break-even storage price ($/tonne) that illustrates the range of quality of the formations evaluated for this study. While the modeled formations are in three basins, the Gulf Coast (GC) Basin was divided into Tertiary for the Frio and Cretaceous for the Lower Tuscaloosa. Data plotted reflects modeling for the largest electric power plant with a 3.58 Mt/Yr capture rate.[b] Each storage reservoir was modeled for three storage structure types: anticline, regional dip, and dome. The better formations are represented by the lower cost, higher storage value data points (i.e., GC tertiary) while high cost, low storage value data points represent poor formations (i.e., Appalachian). From the three basins within Exhibit 3-12, seven storage reservoirs were selected for this analysis that represent a range in storage qualities and CO_2 break-even storage costs and present a source a range of possibilities depending on transportation costs. A cross plot of storage reservoir quality (product of storage reservoir porosity, storage coefficient, and height) and the first-year break-even storage price ($/tonne) that illustrates the range of quality of these storage reservoirs is shown in Exhibit 3-13. Each storage reservoir in Exhibit 3-13 has two data points representing the two structures discussed and compared in this analysis. The lower cost, higher reservoir quality value data point for a given storage reservoir is the dome structural setting, the other is the regional dip structural setting. Frio 3A is the best storage reservoir overall with respect to formation height, permeability, and porosity but is the furthest from the source locations evaluated. Both Rose Run storage reservoirs have poor permeability, though their porosity is adequate. Rose Run 4 is the poorest quality storage reservoir evaluated in this analysis, but both Rose Run storage reservoirs are closet to the evaluated source locations.

Exhibit 3-12 Basin characteristic against CO_2 break-even storage price for electric power plant (3.58 Mt/Yr capture rate)



[b] All CO_2 captured is assumed stored. Therefore, capture rate = storage rate.

Exhibit 3-13 Reservoir characteristic against CO_2 break-even storage price for electric power plant (3.58 Mt/Yr capture rate)

The areal extent of the CO_2 plume in the storage reservoir is a cost driver of storage costs and has other important cost considerations. The CO_2 Storage Cost Model can constrain the plume size to account for anthropogenic limitations at the surface; the constraint is not geologically associated within the subsurface. [28] The plume uncertainty boundary limit can raise concerns regarding the ability to secure sufficient pore space rights over a large area. It provides a reference on the areal extent a CO_2 plume can reach, which is an important consideration in selecting a potential storage site. This limit impacts storage projects using storage reservoirs in which the mass of total CO_2 injected over the user-defined injection duration would push the extent of the CO_2 plume beyond the estimated capacity of a desired storage reservoir.

The cost of storage for each storage reservoir modeled for the mass of CO_2 captured by each source over 30 years is posted in Exhibit 3-14. For each storage reservoir, the unit cost of storage decreases with increasing mass of CO_2 stored, illustrating an economy of scale. Storage costs are lowest for Frio 3A under a dome structural setting. The highest cost storage reservoir is Rose Run 4 under a regional dip structural setting. Due to volumetric limitations, the larger sources (2.60 Mt/Yr to 3.90 Mt/Yr capture rates) cannot use the Rose Run 4 storage reservoir because it cannot accommodate the captured CO_2 from these sources over 30 years. Therefore, in Exhibit 3-14, only cost data for the Rose Run 4 dome structural setting is posted for the two smaller sources, 0.65 Mt/Yr and 1.14 Mt/Yr.

Exhibit 3-14 Storage costs (2011$) and areal extent of CO_2 plume for the storage reservoirs modeled

	Annual Mass of CO_2 Injected (Mt)	0.65	1.14	2.60	3.14	3.58	3.90
	Total Mass of CO_2 Stored (Mt)	20	34	78	94	107	117
MS6	Dome Structure Area = 367 mi^2						
	Storage Cost (2011$/tonne)	17.80	11.93	7.58	6.98	6.65	6.50
	Uncertainty Area (mi^2)	4	6	14	17	20	22
	Regional Dip Structure Area = 28,636 mi^2						
	Storage Cost (2011$/tonne)	21.75	16.26	11.52	10.85	10.62	10.35
	Uncertainty Area (mi^2)	10	17	39	47	54	58
MS3	Dome Structure Area = 258 mi^2						
	Storage Cost (2011$/tonne)	19.23	12.53	7.80	7.02	6.86	6.53
	Uncertainty Area (mi^2)	3	6	13	16	18	20
	Regional Dip Structure Area = 20,117 mi^2						
	Storage Cost (2011$/tonne)	22.98	16.37	11.41	10.74	10.52	10.23
	Uncertainty Area (mi^2)	9	16	36	43	49	53
MS10	Dome Structure Area = 268 mi^2						
	Storage Cost (2011$/tonne)	24.60	19.40	15.95	15.39	15.11	14.98
	Uncertainty Area (mi^2)	20	35	81	97	111	121
	Regional Dip Structure Area = 20,865 mi^2						
	Storage Cost (2011$/tonne)	43.62	38.69	34.29	33.82	33.50	33.26
	Uncertainty Area (mi^2)	55	96	219	264	302	328
LT8	Dome Structure Area = 167 mi^2						
	Storage Cost (2011$/tonne)	19.32	13.20	8.83	8.17	7.93	7.63
	Uncertainty Area (mi^2)	5	9	21	26	29	32
	Regional Dip Structure Area = 13,045 mi^2						
	Storage Cost (2011$/tonne)	25.81	19.80	14.70	14.02	13.82	13.58
	Uncertainty Area (mi^2)	15	26	59	72	82	89
FR3A	Dome Structure Area = 15 mi^2						
	Storage Cost (2011$/tonne)	19.30	12.12	6.74	6.04	5.73	5.54
	Uncertainty Area (mi^2)	1	3	6	7	8	9
	Regional Dip Structure Area = 1,163 mi^2						
	Storage Cost (2011$/tonne)	20.82	13.74	8.51	7.83	7.58	7.26
	Uncertainty Area (mi^2)	4	7	15	19	21	23

	Annual Mass of CO_2 Injected (Mt)	0.65	1.14	2.60	3.14	3.58	3.90
	Total Mass of CO_2 Stored (Mt)	20	34	78	94	107	117
RR3	Dome Structure Area = 103 mi^2						
	Storage Cost (2011$/tonne)	49.61	38.79	29.41	28.09	27.60	27.15
	Uncertainty Area (mi^2)	14	24	55	66	75	82
	Regional Dip Structure Area = 7,996 mi^2						
	Storage Cost (2011$/tonne)	82.46	69.32	58.61	56.79	56.28	55.61
	Uncertainty Area (mi^2)	49	86	197	238	271	296
RR4	Dome Structure Area = 84 mi^2						
	Storage Cost (2011$/tonne)	52.32	44.89	N/A	N/A	N/A	N/A
	Uncertainty Area (mi^2)	29	50	N/A	N/A	N/A	N/A
	Regional Dip Structure Area = 6,524 mi^2						
	Storage Cost (2011$/tonne)	104.04	95.67	88.19	87.40	86.88	86.41
	Uncertainty Area (mi^2)	103	181	412	497	567	618

3.4 Integrating CCS Costs

As previously mentioned, the methodology for this analysis is founded on a modular approach for evaluating the unit cost ($/tonne) for a given CO_2 source, pipeline segments, and storage options across the CCS value chain (i.e., capture, transport, and storage). Total CCS costs were calculated for each source connected to each storage site via the two different pipeline systems of various distances by summing the CO_2 unit costs within each link of the CCS value chain. Exhibit 3-15 demonstrates this summation of the costs for all three components of the CCS value chain by using the NG processing plant (0.65 Mt/Yr capture rate) and the 550-MWnet electric power plant (3.58 Mt/Yr capture rate) as examples. Both sources are transporting CO_2 from the E200 location to the Frio 3A storage reservoir with either a dome or regional dip structure. This side-by-side comparison of a dedicated system and trunkline system illustrates the modular method for assessing capture, transport, and storage component costs.

CCS cost data for the NG processing plant is posted in the top half of Exhibit 3-15. Cost of capture and storage for this source is the same whether or not a dedicated or trunkline system is utilized; however, the method of obtaining the transport cost is inherently different. The dedicated system has one pipeline connecting the NG processing plant to the Frio 3A storage reservoir providing a single cost for transportation. With an 8-in dedicated pipeline, the cost to the NG processing plant operator is $155.52/tonne to transport its captured CO_2 1,358 mi to the Frio 3A storage reservoir. If the NG processing plant operator uses a trunkline system, which connects the NG processing plant to the Frio 3A storage reservoir through five pipe segments, the operator can reduce transportation costs to $36.25/tonne, a $119.27/tonne savings. To utilize this trunkline pipeline system, a 121-mi, 8-in dedicated gathering pipeline (E200 – HPA route in Exhibit 3-15) connects the source to the entry hub (HPA) of the trunkline. At the other end of the trunkline, from the HTX distribution hub, the source will also have a 30-

mi, 8-in dedicated distribution pipeline (HTX – FR3A route in Exhibit 3-15) to the Frio 3A storage reservoir. Between the entry hub and distribution hub, the trunkline system utilized by the NG processing plant has three segments or routes: the HPA – HIN route with a 360-mi, 30-in pipeline; the HIN – HMS route with a 549-mi, 36-in pipeline; and the HMS – HTX route with a 281-mi, 36-in pipeline. Total distance covered by the trunkline system is 1,341 mi. This discussion also applies to the 550-MWnet electric power plant data posted in the bottom half of Exhibit 3-15. Use of a trunkline system reduced overall CCS costs for the NG processing plant by 61 percent for regional dip and 62 percent for dome. The cost savings for the electric power plant is 17 percent for regional dip and 18 percent for dome.

Exhibit 3-15 CCS cost for dedicated and trunkline systems transporting 0.65 Mt/Yr (NG processing plant – top) and 3.58 Mt/Yr (550-MW$_{net}$ electric power plant – bottom) from the source at E200 to storage at Frio 3A

Dedicated Pipeline System			Cost $/tonne	Trunkline Pipeline System			Cost $/tonne
Capture (0.65 Mt/Yr)			18.00	**Capture** (0.65 Mt/Yr)			18.00
Transport				**Transport**			
Route	Diameter (in)	Distance (mi)		Route	Diameter (in)	Distance (mi)	
				E200 – HPA	8	121	14.43
				HPA – HIN	30	360	5.55
E200 – FR3A	8	1,358	155.52	HIN – HMS	36	549	8.30
				HMS – HTX	36	281	4.24
				HTX – FR3A	8	30	3.73
Total		1,358	155.52	*Total*		1,341	36.25
Storage	FR3A			**Storage**	FR3A		
Dome			19.30	Dome			19.30
Regional Dip			20.82	Regional Dip			20.82
CCS				**CCS**			
Dome			192.82	Dome			73.55
Regional Dip			194.34	Regional Dip			75.07

Dedicated Pipeline System			Cost $/tonne	Trunkline Pipeline System			Cost $/tonne
Capture (3.58 Mt/Yr)			57.82	**Capture** (3.58 Mt/Yr)			57.82
Transport				**Transport**			
Route	Diameter (in)	Distance (mi)		Route	Diameter (in)	Distance (mi)	
				E200 – HPA	12	121	4.35
				HPA – HIN	30	360	5.55
E200 – FR3A	12	1,358	41.89	HIN – HMS	36	549	8.30
				HMS – HTX	36	281	4.24
				HTX – FR3A	12	30	0.86
Total		1,358	41.89	*Total*		1,341	23.30
Storage	FR3A			**Storage**	FR3A		
Dome			5.73	Dome			5.73
Regional Dip			7.58	Regional Dip			7.58
CCS				**CCS**			
Dome			105.44	Dome			86.85
Regional Dip			107.29	Regional Dip			88.70

4 STUDY FINDINGS AND RESULTS

This section provides an overview of the results of this analysis with explanatory text. Raw data calculated for all components of the CCS costs under all analyzed scenarios are in Exhibit A-1 through Exhibit A-16 in Appendix A: CCS Costs for Source-Sink Combinations. All costs discussed in this section and in Appendix A: CCS Costs for Source-Sink Combinations refer to the unit cost ($/tonne) in 2011$. Since different amounts of CO_2 are sequestrated (based on capture rate), comparing the unit cost for all components of the CCS cost is more straightforward. Booster pump data for pipeline/trunkline segments in the dedicated and trunkline systems is in Appendix B: Booster Pump Data. Additional charts of modeling results can be found in Appendix C: Additional Charts.

A source's CO_2 capture rate and its location relative to a potential storage site are important factors for transport costs and overall CCS cost. For instance, transport-related costs for all scenarios were found to range from 1 percent to 80 percent of overall CCS related costs; where the higher portion (>70 percent) of transport-related costs were under dedicated system with low capture rate. Storage costs are not a function of CO_2 source location and remain the same for each specific rate of capture regardless of the source location or transportation option and distance. The reservoir location and impact of trunkline system and dedicated system are discussed in Section 4.1.

Capture costs are 9 percent to 87 percent of overall CCS cost across all scenarios. Thus, all variables (source location, storage formation, capture rate, and transportation system) dramatically change the quantity of CCS cost itself as well as the percentage of each component of CCS cost. Discussion on the CCS cost changes with different capture rates is in Section 4.2.

Storage-related costs for all scenarios are 4 percent to 80 percent of overall CCS cost, resulting from a wide range of storage reservoir characteristics of the selected formations as illustrated in Section 4.3. In this analysis, dome structure and regional dip structure are chosen for each reservoir. The impact of different reservoir structures is addressed in Section 4.3.

For Sections 4.1 through 4.3, to simplify discussion, some results and findings are focused on two CO_2 sources: the smallest industrial plant (small source, NG processing plant with capture rate of 0.65 Mt/Yr) NG processing plant and the largest electric power plant (large source, 550 MWnet with a capture rate of 3.58 Mt/Yr). These sources were chosen to illustrate the range of source types and CO_2 capture rates. For all results, E200 was chosen to illustrate the location impact on CCS costs since it gives nearby storage reservoirs with poor storage reservoir characteristics more advantages. Comparison charts and results for different scenarios among the four source locations modeled are in Section 4.4.

A pie chart identifies the location of the candidate storage reservoir centroid of each storage site on the maps for Exhibit 4-1, Exhibit 4-3, Exhibit 4-6, and Exhibit 4-7. These pie charts have three colors representing the cost of each link in the CCS value chain as a percentage of total CCS costs. The cost items for each of the links are summed to a single value representing the cost of CCS (see Exhibit 3-15 for an example). This CCS cost value is posted at the storage reservoir next to the pie chart in each of the maps. The size of the pie chart represents the CCS cost to the storage reservoir; the larger the pie chart, the higher the CCS cost.

4.1 COMPARING DEDICATED SYSTEM VS. TRUNKLINE SYSTEM

Exhibit 4-1 compares the CCS cost results for the electric power plant (3.58 Mt/Yr capture rate) at E200 transporting CO_2 using the dedicated or trunkline systems to storage sites in regional dip structure. The costs for the trunkline system are for the largest trunkline capacity (trunkline diameter of 30/36 in). The 30/36-in diameter trunkline is used for comparison against the 12-in dedicated pipeline for this source to illustrate the cost differences between the two pipeline networks modeled (see Exhibit 3-15 for an example). The pie charts on the map illustrate the reduction in transportation cost between the dedicated and trunkline systems.

CCS costs posted in Exhibit 4-1 show that a trunkline significantly reduces the transport cost to those reservoirs in both the trunkline and pipeline systems, especially those located furthest from the source. Transportation costs to the Frio 3A and Lower Tuscaloosa 8 are reduced by \$18.59/tonne and \$14.46/tonne, respectively, making their CCS costs much cheaper than those for the dedicated system. The difference in CCS costs between Mt. Simon 6 and Frio 3A dropped from \$24/tonne in the dedicated system to \$10/tonne in the trunkline system. In both systems, Mt. Simon 6 has the lowest CCS cost followed by Mt. Simon 3. Additional charts showing the effect of the dedicated and trunkline systems on CCS cost can be found in Appendix C: Additional Charts.

Exhibit 4-1 Maps showing total CCS cost and percent of each component for the electric power plant in the dedicated (left) and trunkline (right) systems (regional dip, E200)

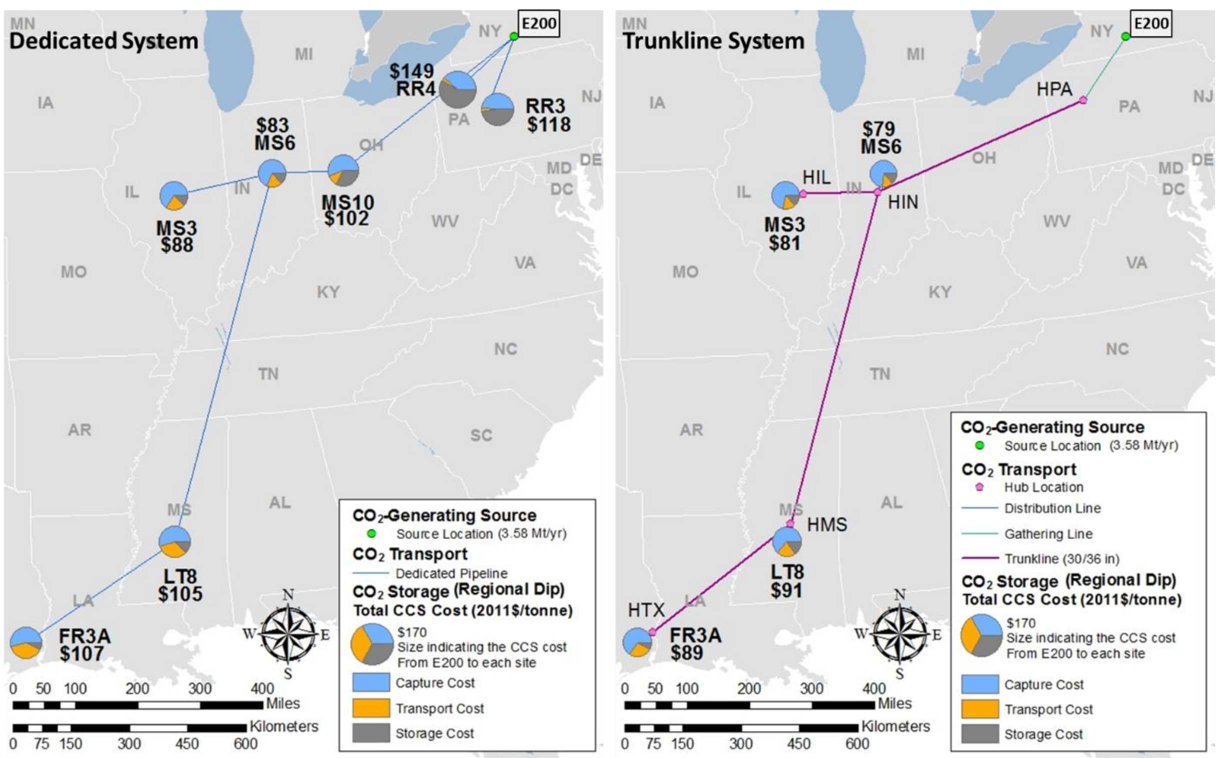
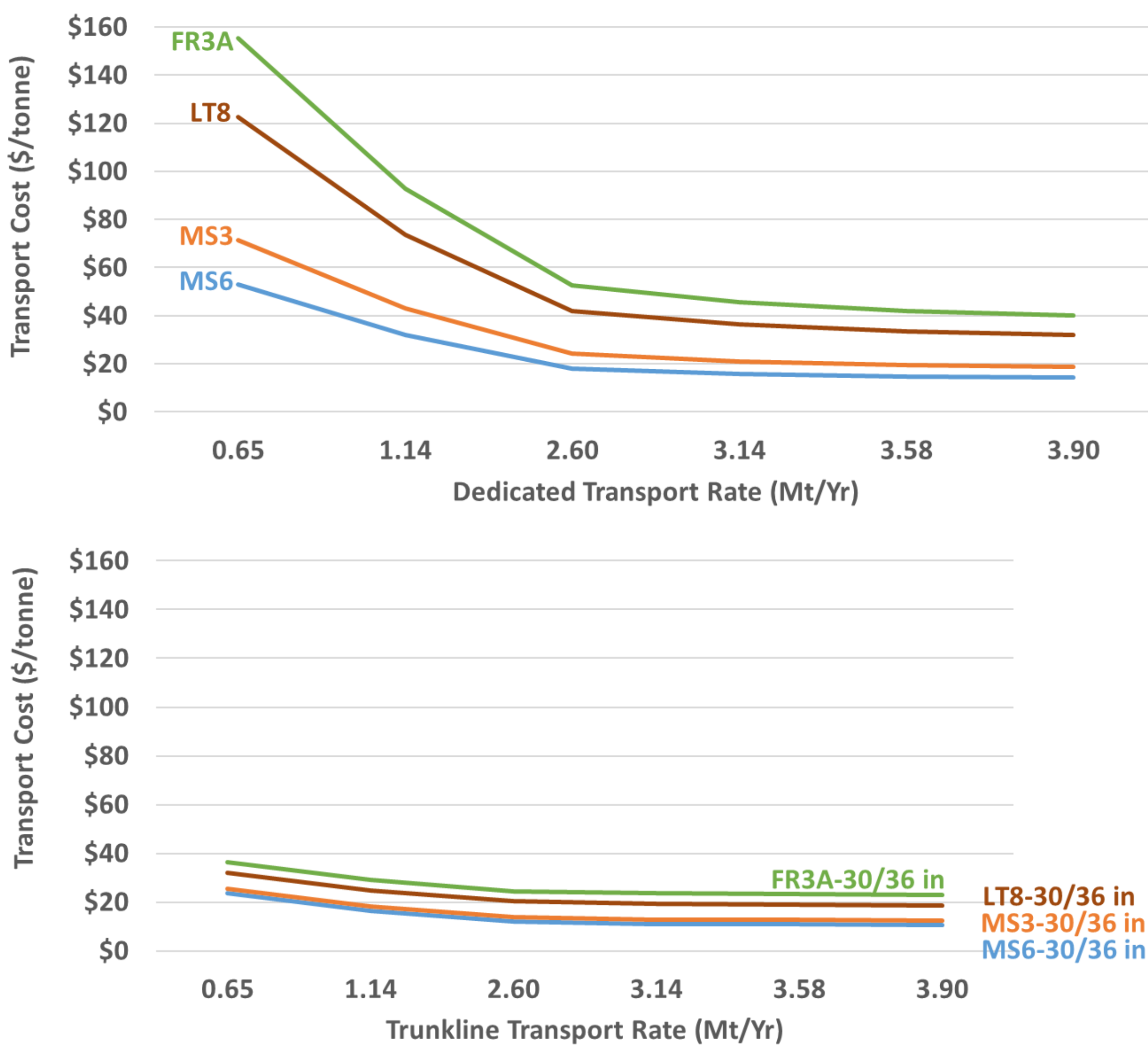


Exhibit 4-2 illustrates an economy of scale in the transport cost between the dedicated system (top graph) and the trunkline system (bottom graph) for the E200 location and all sources. The transport cost significantly drops between the dedicated system and trunkline system for the small sources, much less for the larger sources. A trunkline is less sensitive to the transport rate of a source since it provides the same transport cost per its diameter and total capacity regardless of the size of the source. A source, especially a small source, can take advantage of the lower unit transport costs of a trunkline for its CCS project because a trunkline's overall capital and operating expenses are shared by multiple sources. With a dedicated pipeline, these costs are covered by the transportation fee to a single source.

Unit costs for each of the four trunkline segments differ depending on pipeline diameter. Unit costs for the 30/36-in trunkline segments range from \$1.86/tonne to \$8.30/tonne of CO_2 transported while these costs range between \$4.30/tonne and \$18.21/tonne for a 12-in trunkline (Exhibit 3-9). Looking at the smallest source modeled, it will cost the NG processing plant \$156/tonne to transport its CO_2 via an 8-in dedicated pipeline from E200 to Frio 3A or \$36/tonne to utilize a 30/36-in trunkline. Bubble charts depicting the transport difference between the dedicated and trunkline systems can be found in Appendix C: Additional Charts.

Exhibit 4-2 Transport cost comparison across all capture rates for dedicated (top) and trunkline (bottom) systems (E200)



4.2 CCS Cost Changes with Different Capture Rates

Unlike changing the pipeline system (from dedicated to trunkline) which only affects transport rate, a change of capture rate changes the transport rate and total mass of CO_2 injected and stored. It has a major effect on all CCS component costs. Exhibit 4-3 shows the results for a NG processing plant (0.65 Mt/Yr capture rate) at E200 using the dedicated or trunkline systems to transport CO_2 to storage sites with regional dip structure. As in Exhibit 4-1, the costs for the trunkline system are for the largest trunkline capacity (trunkline diameter of 30/36 in). Only the capture rate changes (from 3.58 Mt/Yr to 0.65 Mt/Yr) between Exhibit 4-1 and Exhibit 4-3; however, both the total CCS cost and the percentage of each CCS component changes reflecting the different rates of capture for the second largest and smallest sources modeled. This change in the cost of capture as a percentage of overall CCS cost is illustrated in blue in the pie charts in each map. The capture cost of the electric power plant is a larger percentage of overall CCS cost in Exhibit 4-1. The CCS cost of Frio 3A for the NG processing plant at E200 decreases from $194/tonne in the dedicated system to $75/tonne in the trunkline system. This price drop is much larger than the $107/tonne to $89/tonne change for the electric power plant (Exhibit 4-1). This again shows that the NG processing plant benefits more from the trunkline system. The NG processing plant is a high purity source with a very low cost of capture which gives it a distinct advantage when comparing capture costs. This low cost of capture contributes to the lower CCS cost of $75/tonne at Frio 3A versus the electric power plant with $89/tonne in the trunkline system. As in Exhibit 4-1, Mt. Simon 6 is still the low-cost reservoir for both systems.

The next smallest source is the cement plant with $100/tonne of CO_2 capture costs (Exhibit 3-1). Its CCS cost at all storage sites will be greater than that for either the NG processing plant or the 550-MWnet electric power plant for both pipeline systems modeled due to its high capture cost.

Exhibit 4-3 Maps showing total CCS cost and percent of each component for the NG processing plant in the dedicated (left) and trunkline (right) systems (regional dip, E200)

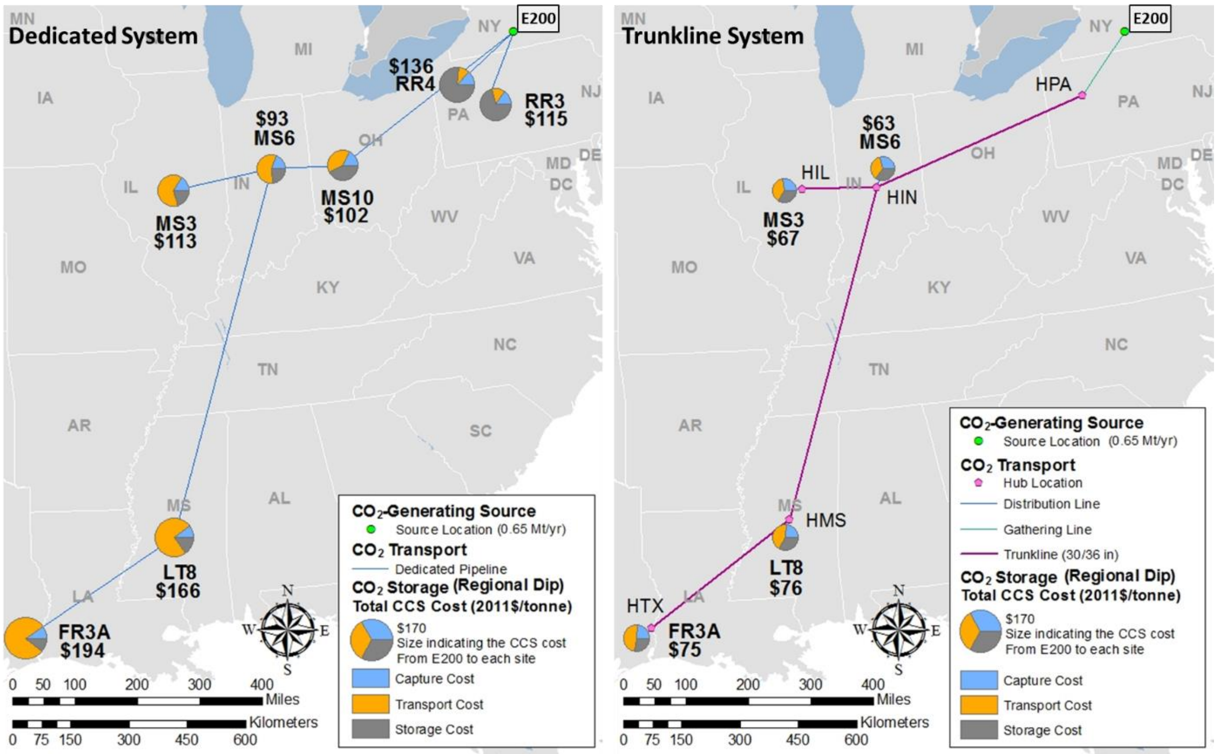
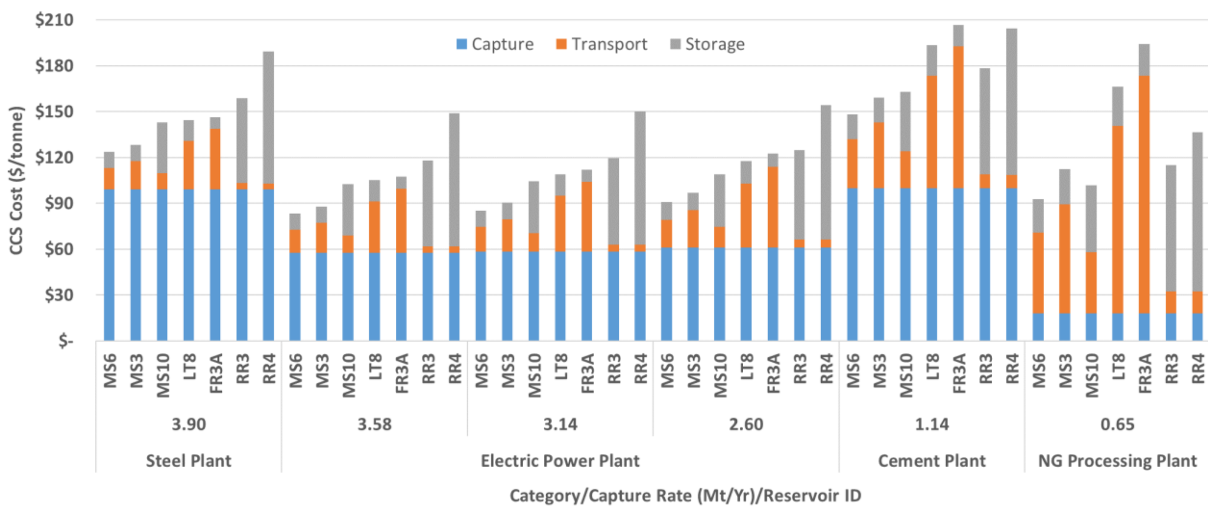


Exhibit 4-4 illustrates which components have the most impact on the overall CCS cost for electric power plants and industrial plants at E200 in the dedicated system under regional dip structural setting for storage reservoirs. Capture costs are at the bottom of each bar, transportation in the middle, and storage at the top. The NG processing plant has the lowest capture cost among all the capture rates since it is a high purity and high concentration CO_2 source. The three electric power plants have very close capture costs which are more expensive than the NG processing plant but cheaper than the other two industrial sources. The cement plant has the most expensive capture cost, and the capture cost of the steel plant is very close to it. For the electric power plants, the cost of capture differential is $3.39/tonne across the three plants modeled, presenting a consistent cost of capture for all three. The cost of capture for the steel plant and cement plant is more than $30/tonne higher; for the NG processing plant about $40/tonne cheaper. There is a distinct shift in CCS costs between electric power plants and even between industrial plants. This difference is mostly due to the composition of the CO_2 flue stream for each source and the applied technology for capture.

Storage costs in Exhibit 4-4 are for a regional dip reservoir. For all sources at E200, the Mt. Simon 6 reservoir is the low-cost CCS destination for their captured CO_2. Capture costs dominate overall CCS costs for all sources except the NG processing plant. Transport costs influence overall CCS costs for the NG processing plant for all reservoirs except Rose Run 3 and Rose Run 4 which are affected by storage costs. The low cost of storage at the Frio 3A reservoir cannot offset the cost of transportation from any of the sources modeled. The low cost of transportation offsets the poor storage reservoir quality of Mt. Simon 10 making it cost competitive with the better Gulf Coast storage reservoirs for all sources. For the two small sources, the Rose Run 3 storage reservoir is more cost effective for total CCS costs than the Gulf Coast storage reservoirs.

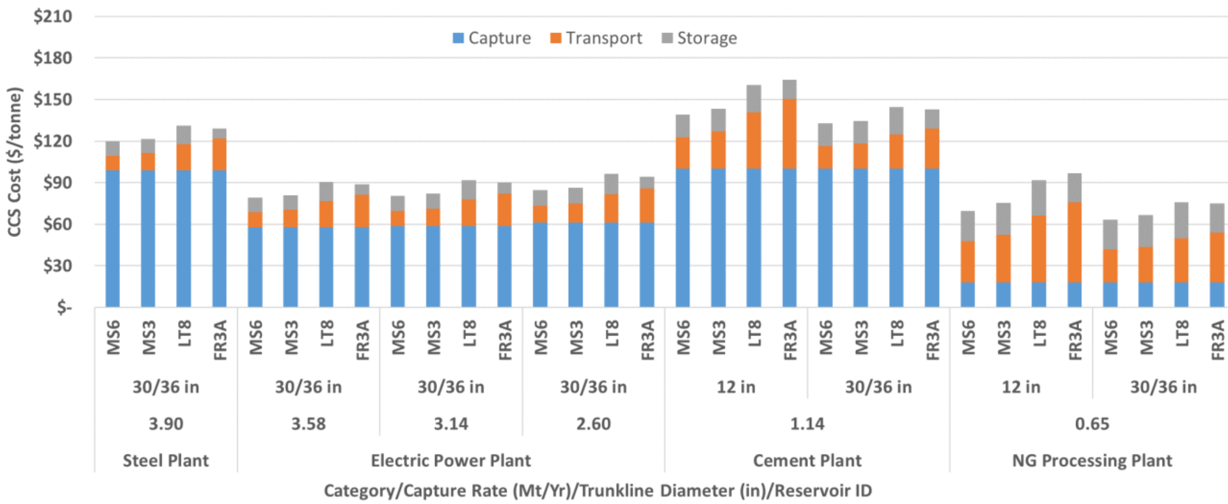
Exhibit 4-4 Bar chart showing CCS costs for electric power plants and industrial sources by capture rate for dedicated system (regional dip, E200)



Use of a trunkline reduces transportation costs and therefore CCS costs across all sources modeled. CCS costs with the largest diameter trunkline (30/36 in) are plotted in Exhibit 4-5 for all sources. While a 12-in pipeline is a dedicated pipeline for the larger sources, it can act as a trunkline for the smaller sources. CCS cost data for this diameter trunkline is also shown in Exhibit 4-5.

In Exhibit 4-5, the Mt. Simon 6 reservoir is still the low-cost CCS option for storage for all sources modeled and both trunkline pipeline diameters. Compared to the dedicated pipeline system in Exhibit 4-4, the cost of transportation to all reservoirs is lower for all sources. Also, the storage cost differential across the four storage reservoirs modeled is tighter.

Exhibit 4-5 Bar chart showing CCS costs for power plants and industrial sources by capture rate for trunkline system (regional dip, E200)



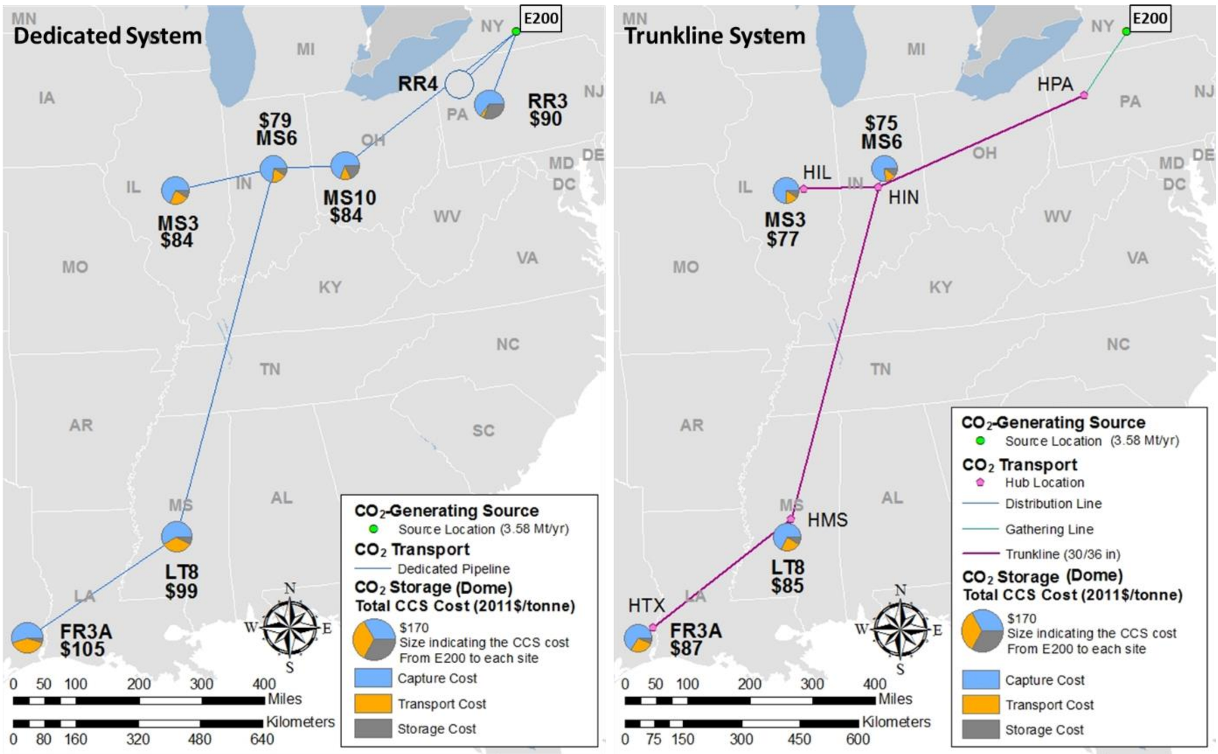
For trends regarding all sources at the E200 location using a dedicated system or trunkline system under a dome structure for storage, refer to Exhibit C-3 or Exhibit C-4, respectively, in Appendix C: Additional Charts.

4.3 Storage Cost Difference Between Dome and Regional Dip

Dome and regional dip structures are modeled for each formation. Although regional dip structure provides more storage capacity, storage cost for the dome structure is lower.

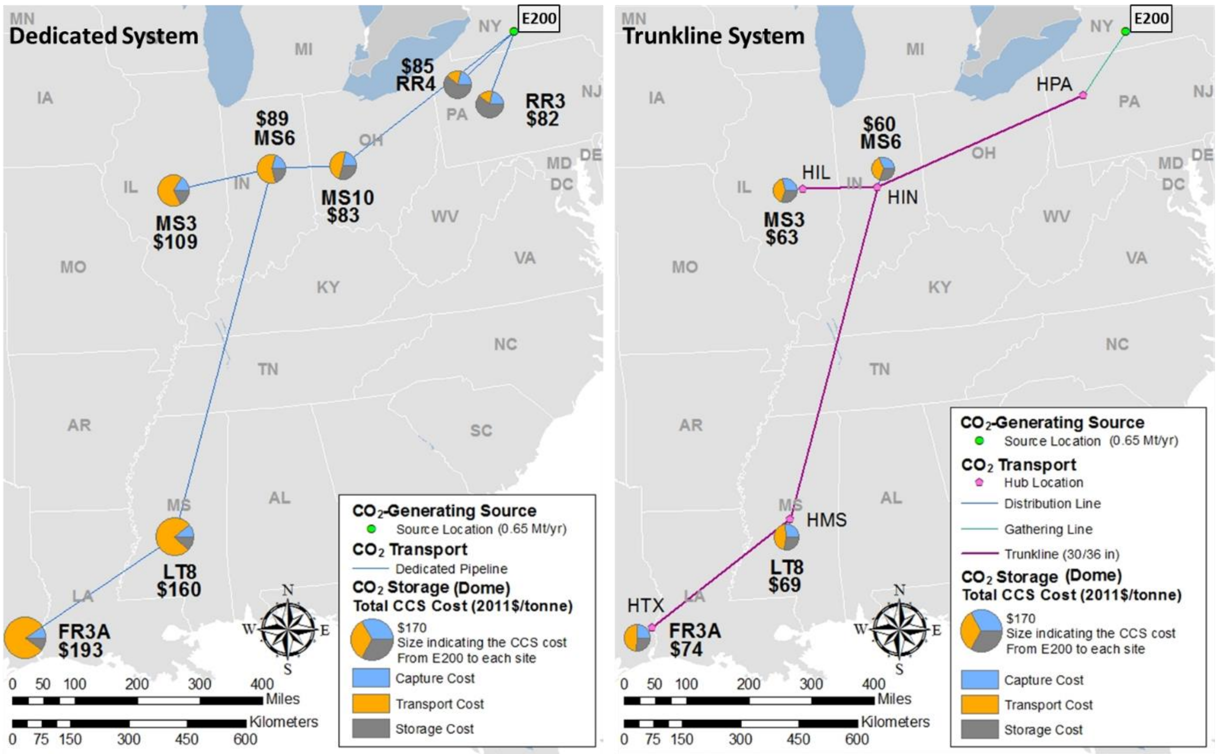
CCS costs for a dedicated and trunkline system utilizing a dome structure for an electric power plant with a 3.58 Mt/Yr capture rate is illustrated in Exhibit 4-6. This map is a complement to the one using regional dip storage in Exhibit 4-1. CCS costs are lower for dome structure storage primarily due to a better storage coefficient associated with structural closure (Exhibit 3-11). This higher storage coefficient reduces the overall areal extent of the CO_2 plume lowering storage cost (capture and transport costs remain the same between these two exhibits). The difference in CCS costs between a dome structure and regional dip structure is largest for Rose Run 3 and least for Frio 3A. Rose Run 4 does not have sufficient capacity to store 3.58 Mt/Yr in dome structure. The CCS cost for Frio 3A in the dome structure is $2/tonne cheaper than the regional dip structure, whereas its $28/tonne cheaper for Rose Run 3. This reflects the effect of storage reservoir quality. This cost improvement gives the Rose Run 3 an advantage over both Frio 3A and Lower Tuscaloosa 8. However, the Mt. Simon 6 reservoir is still the lowest-cost storage site. Both the Mt. Simon 3 and 10 storage reservoirs are close behind with identical CCS costs. In the trunkline system, CCS costs are reduced by $2/tonne to $6/tonne from regional dip structure to dome.

Exhibit 4-6 Maps showing total CCS cost and percent of each component for the electric power plant in the dedicated (left) and trunkline (right) systems (dome, E200)



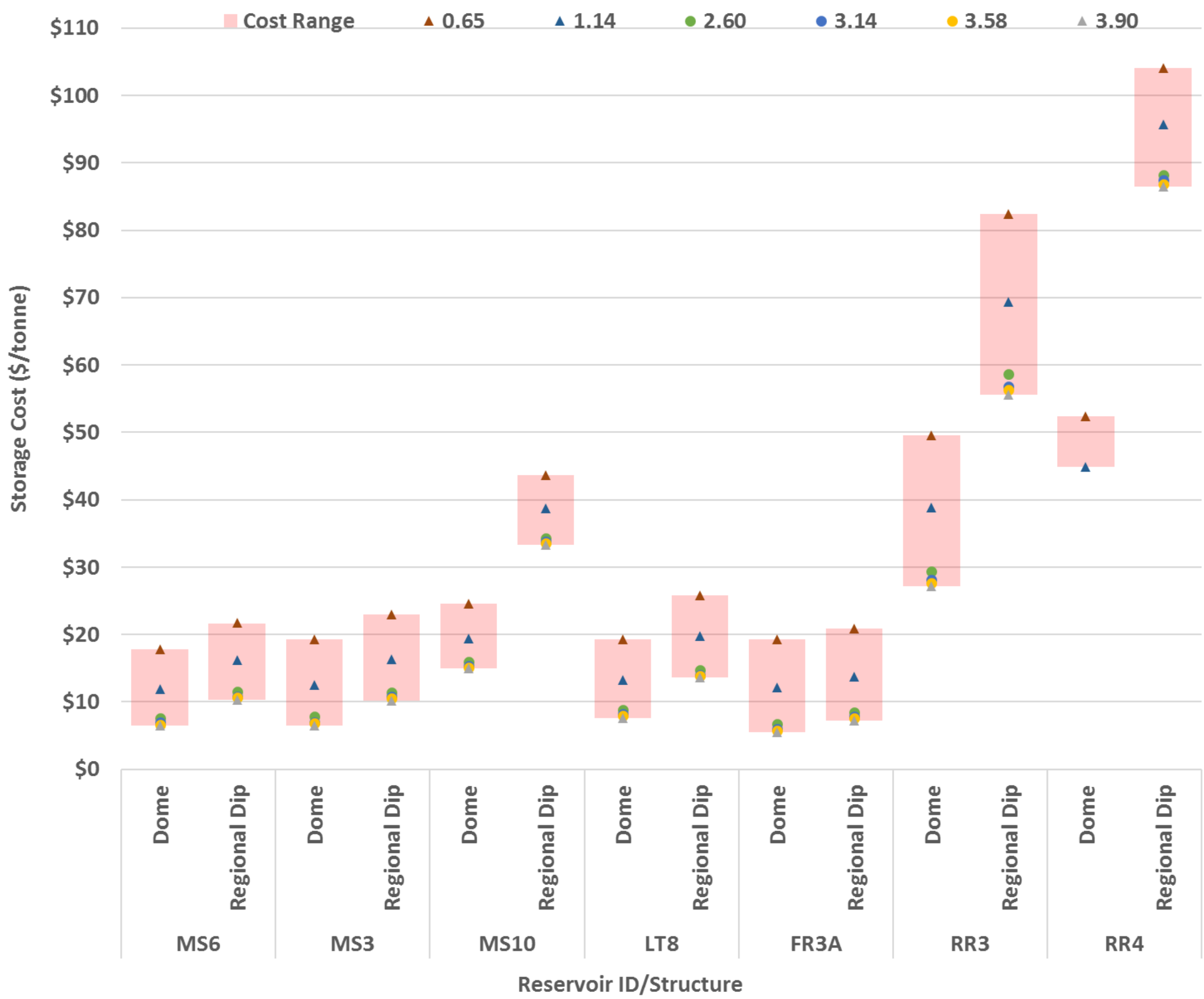
The change in cost of CCS between regional dip structure (Exhibit 4-3) and dome structure (Exhibit 4-7) for the NG processing plant with a 0.65 Mt/Yr capture rate is comparable to that illustrated for the electric power plant with a 3.58 Mt/Yr capture rate. As can be seen in Exhibit 4-7 for the NG processing plant, the Rose Run 3 storage reservoir in a dome structural setting is the lowest CCS cost location. This CCS cost undercuts the Mt. Simon 6 by $7/tonne. CCS costs at the Mt. Simon 10, Rose Run 3, and Rose Run 4 storage reservoirs are all lower than the Mt. Simon 6 storage reservoir. For the small source using a dedicated pipeline, proximity of suitable storage with short transportation distance provides affordable CCS; higher quality storage is too far. With access to a trunkline network, the NG processing plant can utilize the Mt. Simon 6 storage reservoir at $60/tonne of CO_2, a savings of $29/tonne (Exhibit 4-7).

Exhibit 4-7 Maps showing total CCS cost and percent of each component for the NG processing plant in the dedicated (left) and trunkline (right) systems (dome, E200)



The storage cost for both dome and regional dip structures across all capture rates is shown in Exhibit 4-8. It becomes clear that dome structure provides lower storage costs than regional dip structure across all capture rates. Again, the storage cost difference between dome structure and regional dip structure for formations with good storage reservoir characteristics (like Frio 3A and Mt. Simon 6) are much smaller than the difference for formations with poor storage reservoir characteristics (like Rose Run 3 and Rose Run 4). Generally, storage reservoirs with good characteristics have small cost differentials due to change in structure type. It is also worth pointing out that the smaller sources (0.65 Mt/Yr and 1.14 Mt/Yr) have a wider spread in storage costs than the larger sources regardless of structural setting (dome or regional dip). Because of volumetric limitations, data points for the electric power plants and steel plant are not shown in Exhibit 4-8 for Rose Run 4.

Exhibit 4-8 Cost-range plot showing storage costs for all storage reservoirs across all capture rates (regional dip and dome, E200)



4.4 CCS Costs Changes for Different Source Locations

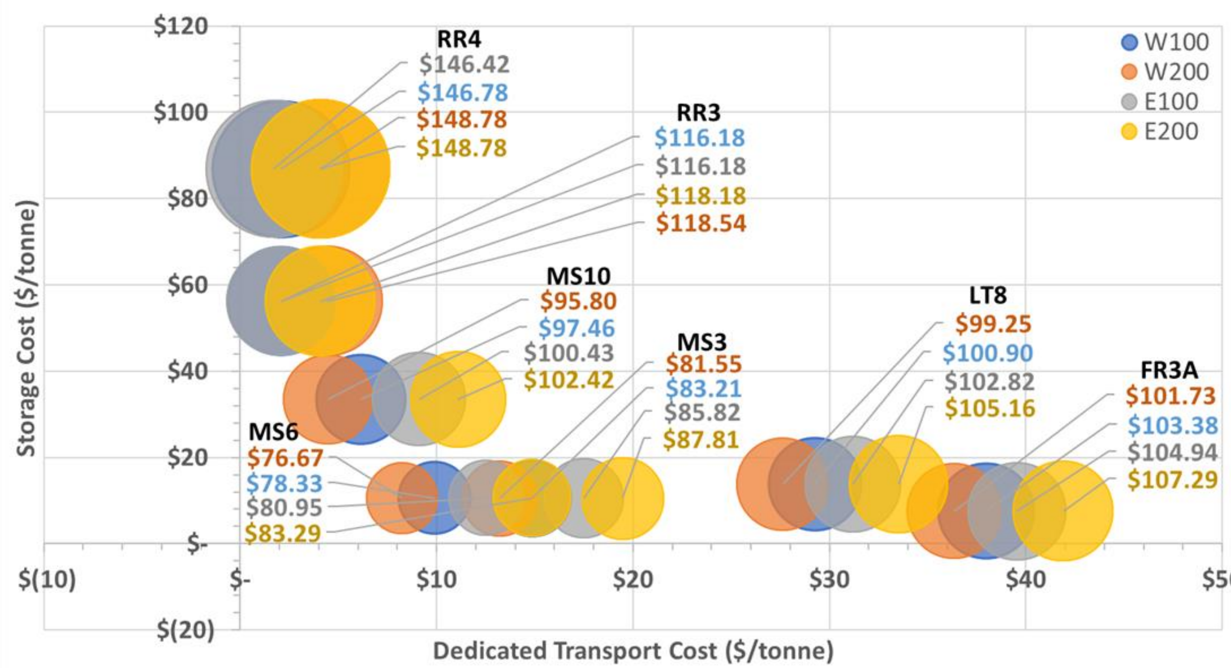
As mentioned before, all the charts and scenarios discussed from Section 4.1 to Section 4.3 are from the perspective of a source at E200. The bubble charts below illustrate the CCS cost from different source locations under different scenarios. CCS costs are represented by the relative size of the bubble (the larger the bubble, the higher the CCS cost). The source locations will only change the transport cost, while the storage and capture costs remain the same.

Exhibit 4-9 compares the CCS costs for the electric power plant (capture rate 3.58 Mt/Yr) at all source locations in the dedicated system (top graph) and trunkline system (bottom graph) using regional dip storage. In the dedicated system, the furthest source, E200, has a higher transport cost than other source locations thus generally obtaining the highest CCS costs of all source locations. When comparing different source locations to storage reservoirs within the Illinois and Gulf Coast basins, W200 achieves the cheapest CCS cost because of the shorter distance. The CCS costs increase for the other source locations because the distance to these reservoirs inherently increases. Therefore, W100 provides the second lowest cost followed by E100 and then E200. Since Rose Run 3 and 4 are closer to W100 and E100, those locations can attain lower CCS costs than sources at W200 or E200. Although the distance between E100 to Rose Run 4 is the same for a source at W100, the elevation differences impact transport cost and thus result in different total CCS costs. This same trend is shown for W200 and E200 to Rose Run 4.

In the trunkline graph, cost data for the largest trunkline diameter (30/36 in) is plotted. The W100/E100 and W200/E200 source locations are equal distance from the gathering hub in Pennsylvania. The distribution pipelines from the distribution hubs to the modeled storage locations are also of equal distance. In the trunkline system, E100 provides the cheapest CCS cost because of its location to the storage reservoirs.

When comparing the dedicated and trunkline systems, E200 provides the most expensive CCS costs except at Rose Run 3 in the dedicated system due to elevation differences between W200 and E200 impacting transport cost. For both systems, the Mt. Simon 6 storage reservoir is the most attractive. Rose Run 4 and Lower Tuscaloosa 8/Frio 3A are the least attractive in the dedicated system and trunkline system, respectively. Unlike the dedicated system, Frio 3A becomes more attractive than Lower Tuscaloosa 8 in the trunkline system even though it does not have the cheapest CCS cost.

Exhibit 4-9 Bubble charts depicting the relative CCS costs for electric power plant with 3.58 Mt/Yr capture rate in dedicated (top) and trunkline (bottom) systems (regional dip, all source locations)



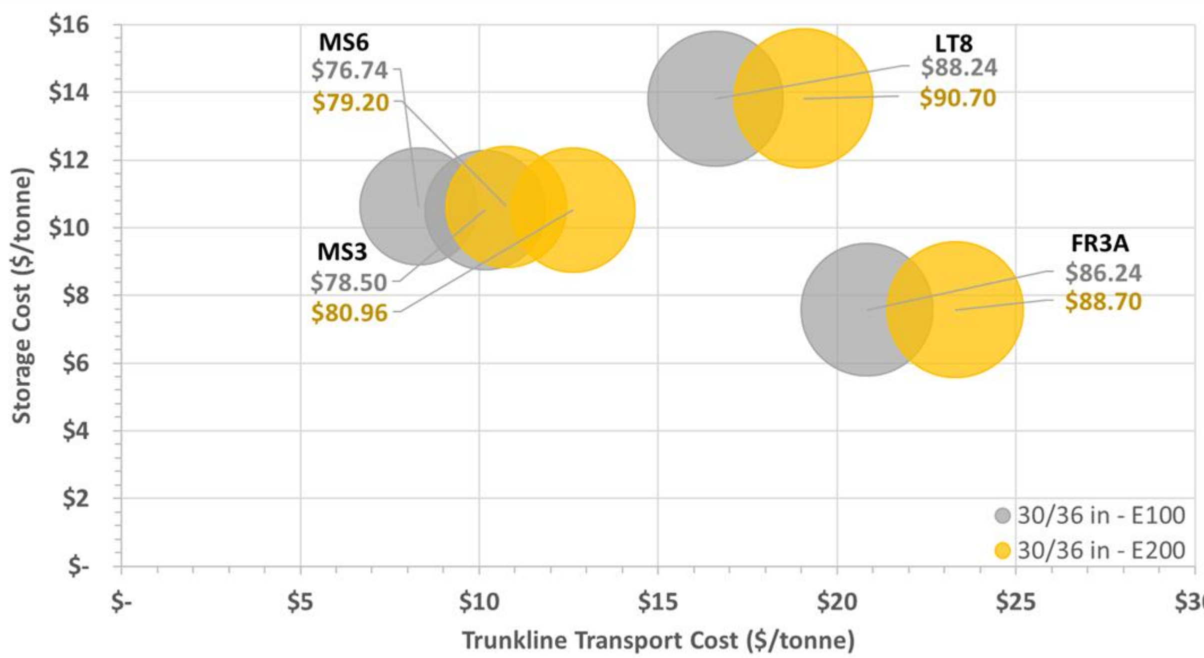
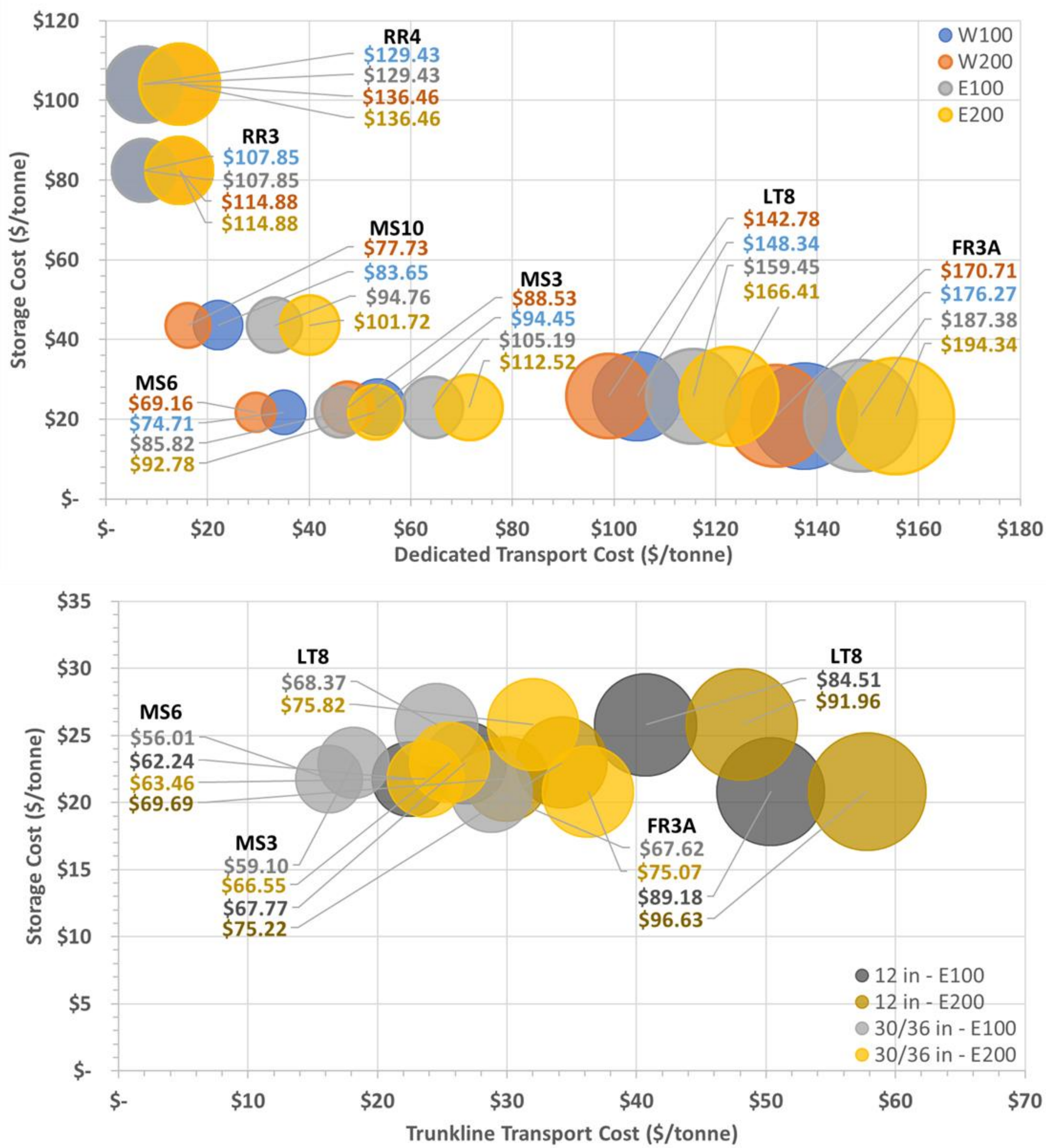


Exhibit 4-10 compares the CCS costs for the NG processing plant (capture rate 0.65 Mt/Yr) at all source locations in the dedicated system (top graph) and trunkline system (bottom graph) using regional dip storage. Similar trends for source locations occur between the electric power plant and NG processing plant. In the dedicated system, the furthest source, E200, has the highest CCS costs of all source locations due to its high transport cost. Further storage reservoirs (Lower Tuscaloosa 8, Mt. Simon 3, and Frio 3A) are less attractive; thus, the source may utilize the closer storage reservoirs. It would be a cost advantage for the NG processing plant to transport CO_2 to the closer storage reservoirs than pay the higher transport cost to transport to the better-quality storage reservoirs no matter the location of the source.

In the trunkline graph, cost data for the smallest (12 in) and largest (30/36 in) trunkline diameters are plotted. Unlike the electric power plant, the 12-in trunkline can provide transportation for multiple smaller sources; a 12-in diameter pipeline is a dedicated pipeline for the electric power plant. CCS costs were only plotted for E200 in the bottom chart in Exhibit 4-10 since W100/E100 and W200/E200 source locations are equal distance from the gathering hub in Pennsylvania. The distribution pipelines from the distribution hubs to the modeled storage locations are also of equal distance. The trunkline system helps decrease prices for the NG processing plant making CCS costs relatively close; thus, giving the source more options. When comparing CCS costs for E100 and E200 across both diameters, E100 for the largest diameter has the lowest costs. E100 and E200 have higher transport costs for the smallest diameter pipeline thus generally providing the highest CCS costs.

When comparing the dedicated and trunkline systems, E200 provides the most expensive CCS costs. For both systems, the Mt. Simon 6 storage reservoir is the most attractive, while the Gulf Coast storage reservoirs are the least attractive. Unlike the dedicated system, Frio 3A becomes more attractive than Lower Tuscaloosa 8 in the trunkline system even though it does not have the cheapest CCS cost and is furthest from the source locations. Similar bubble charts for scenarios with dome structure can be found in Appendix C: Additional Charts.

Exhibit 4-10 Bubble charts depicting the relative CCS costs for NG processing plant with 0.65 Mt/Yr capture rate in dedicated (top) and trunkline (bottom) systems (regional dip, all source locations)



5 CONCLUSION

This study evaluated CO_2 storage source-to-sink connections utilizing hypothetical CO_2 sources in the northeastern United States and regional geology providing potential storage reservoir options in the Midwestern and Gulf Coast regions. It provides a better understanding of the challenges a CO_2 source has in selecting an optimal combination of transportation and storage for their captured CO_2 and in keeping their overall CCS cost low. For the electric power plants, there is some economy of scale in that capturing more CO_2 provides for lower unit cost of capture. This is not true for the industrial sources. The NG processing plant had the lowest rate of capture and the lowest unit cost of capture. This is due to its high CO_2 purity flue stream. The next lowest capture rate source modeled, the cement plant, had the highest cost of capture. Each source has its own burden with respect to capture of CO_2. Storage reservoir quality determines storage cost for a given mass of CO_2 stored. A good quality storage reservoir, however, might not be close enough, and the lower storage cost might not be enough to compensate for the cost of transportation adversely impacting overall CCS cost. This analysis shows how different CO_2 storage and transportation options influence total CCS costs for a CO_2 source. It also illustrates the importance of a source's location and the annual mass of CO_2 captured for a particular source.

A CO_2 source (unless siting a new facility) cannot change its location relative to viable CO_2 storage options or, for that matter, alter the amount of CO_2 it produces. However, a CO_2 source has options with respect to two of the three links in the CCS value chain: 1) selection of a suitable storage reservoir with sufficient volume for the captured CO_2 and 2) selection of transportation—either a dedicated or trunkline pipeline system—to the storage site.

This study modeled six source types at four distinct locations, with an option to store CO_2 in one of seven geologic storage reservoirs using one of two types of CO_2 pipeline configurations. storage sites connected by two different pipeline systems Exhibit 3-3). To simplify discussion of some modeling results, the largest electric power plant (large source, 550 MW_{net} with a capture rate of 3.58 Mt/Yr) and the smallest industrial plant (small source, NG processing plant with capture rate of 0.65 Mt/Yr) were chosen to illustrate the range of CCS cost options a source needs to consider. The E200 location was featured since it is the furthest source location from all storage reservoirs beyond the Rose Run storage reservoirs. Trunkline discussion is limited to the largest diameter trunkline modeled.

Overall, the results of this study indicated that the lowest CCS cost option may not be the highest quality storage reservoirs via a trunkline connection. A CO_2 source's proximal location to lower quality storage options or its low cost of capture can provide unique CCS options. Economies of scale enable unit CCS cost reductions for higher CO_2 volumes. Key outcomes from the study results that support these findings include:

1. **Cost of a dedicated system increases as the amount of transported CO_2 decreases:** Distance and the amount of CO_2 transported are two key variables impacting the cost per tonne of CO_2 transported. However, these two parameters affect the cost differently. Distance has a linear relationship upon transport cost; the longer the distance, the higher the cost. On the other hand, the amount of CO_2 transported has an

inverse relationship to transport cost; the smaller the amount, the higher the unit cost. As the amount of transported CO_2 decreases, the transport cost using a dedicated system can increase rapidly. Therefore, the transport cost using a dedicated system can be extremely expensive for a small CO_2 emission source transporting CO_2 to a distant storage reservoir.

A trunkline system has similar cost trends of a dedicated system; however, a trunkline has an advantage in its ability to accommodate multiple sources at a lower unit cost of transport for all sources using it. In this study, a 30/36-in trunkline is designed to accommodate nine sources each with a capture rate of 3.58 Mt/Yr. The cost of transport is based on the total mass from nine sources, not just one. This large capacity results in a low break-even CO_2 transport cost, which is also the price each source needs to pay from their perspective. Transport cost difference between sources using the same trunkline system is due to the dedicated gathering and distribution pipelines each source must build. However, even with these cost differences, overall transport cost using a trunkline system is still less than using a dedicated system.

2. **Cost-effective storage options are limited for smaller CO_2 sources using a dedicated system:** While high quality storage reservoirs are favorable for all sizes of CO_2 sources, the options are usually limited for small sources. The cost to build a small capacity dedicated pipeline to a storage reservoir further away can be substantially higher than that of a large capacity dedicated pipeline. For instance, the transport cost difference between either the Rose Run 3 or Rose Run 4 storage reservoirs and the Frio 3A storage reservoir for a large source (capture rate of 3.58 Mt/Yr) at E200 is $37.81/tonne. This cost difference for a small source (capture rate of 0.65 Mt/Yr) is $141.10. In this case, the transport cost difference for a small source is 3.7 times more than that for a large source. Using storage reservoirs nearby usually is the only option for small sources unless the farther storage reservoirs have low storage costs.

3. **Storage reservoir structure type affects poor quality storage reservoirs more than good quality storage reservoirs:** Due to a better storage coefficient, a dome structure provides better storage quality than a regional dip structure for a storage reservoir in the same formation. It also provides a lower storage cost. The cost difference between dome and regional dip for storage reservoirs in formations with good storage qualities is less than that for storage reservoirs in formations with poor storage qualities. For example, the CCS costs for a small source (capture rate of 0.65 Mt/Yr) at E200 utilizing a Rose Run 3 storage reservoir in either a regional dip or dome structural setting is $115/tonne or $82/tonne, respectively. The CCS cost difference is $33/tonne. On the other hand, the CCS costs for the same source transporting CO_2 to Mt. Simon 6 using regional dip or dome are $93/tonne or $89/tonne, respectively. The CCS cost difference is only $4/tonne. In this case, the proximity of the Rose Run 3 storage reservoir to the source and its sufficient reservoir quality in dome structure allows it to be the low-cost CCS destination with a cost of $82/tonne. In a regional dip structural setting, the better quality of the Mt. Simon 6 storage reservoir provides lower storage and CCS costs, a savings of $22/tonne. Depending on the structural setting for the Rose Run 3 storage

reservoir, a small source can save $11/tonne in overall CCS costs over the Mt. Simon 6 in a regional dip structural setting, $7/tonne for a dome structural setting.

4. **Storage quality of the Gulf Coast storage reservoirs is not sufficient to overcome the cost of transportation:** One of the research questions in this analysis was to determine if Gulf Coast storage reservoirs can provide cost effective storage for sources located in the northeastern United States. Modeling results showed that, while use of a trunkline system can significantly lower transportation costs to the Gulf Coast storage reservoirs, the best storage option for a large source (e.g., 3.58 Mt/Yr) is usually the Mt. Simon 6 due to its good storage quality and source-to-sink proximity. The Mt. Simon 3 storage reservoir further west in Illinois is a viable option when CCS costs are within $5 or less to those for the Mt. Simon 6. While Frio 3A has a lower storage cost than Mt. Simon 6 and Mt. Simon 3, the margin is not large enough to compensate for the additional transportation cost to the Gulf Coast. For a small source (e.g., 0.65 Mt/Yr) modeled, transport to the Frio 3A using a trunkline system is cheaper than to the Mt. Simon 6 using a dedicated system. However, lower CCS costs will still be in the Mt. Simon or Rose Run storage reservoirs for a small source depending on the pipeline network and structural setting of the storage reservoir. Modeling shows that a trunkline system would benefit small sources more than large sources.
5. **Economies of scale are present in each link of the CCS value chain:** An economy of scale is illustrated in the trend of unit cots for capture (Exhibit 3-1), transport (Exhibit 3-5), and storage of CO_2 (Exhibit 3-13). From a source's perspective, economies of scale can be realized in both transportation and storage components. For any particular source, there are limits here depending on the total mass of CO_2 captured and requiring storage. Within the same type of source, the unit cost of capture decreases with increasing amount of CO_2 captured. This trend is true for the electric power plants but not for the industrial sources modeled. Increasing the mass of CO_2 stored lowers the unit cost of storage. Over a fixed distance, increasing the mass of CO_2 transported lowers the unit cost of transportation for both a dedicated or trunkline pipeline. Generally, economies of scale benefit a larger source over a smaller source; however, the cost of capture for the NG processing plant, the smallest source modeled in this study, is low enough to give it the low-cost advantage over the large electric power plant for storage at the Frio 3A storage reservoir in the trunkline system. In a dedicated system, the large electric power plant has the low-cost advantage over the NG processing plant for storage at the Frio 3A since the cost of transportation for the NG processing plant is too high to offset its low capture cost. The cement plant, the next smallest source, has $100/tonne capture costs which is a distinct disadvantage proving no CCS cost advantage for this source.
6. **Source-to-sink proximity is a critical element when considering overall CCS cost:** In most scenarios for either source discussed (largest electric power plant and NG processing plant), the Mt. Simon storage reservoirs provide the best storage options for the hypothetical CO_2 source in New York (i.e., E200). Given the good storage quality of the Mt. Simon storage reservoirs and proximity to the source locations modeled, it is not economical to consider a storage reservoir past Mt. Simon. This trend is generally

true for the other sources modeled but not specifically discussed here. Under this analysis' modeling conditions, it is often more beneficial to transport CO_2 to further away storage reservoirs with high storage qualities than to nearby storage reservoirs with low storage qualities. However, it is all relative to the type of source, the volume of CO_2 to be stored, proximity to a given storage reservoir, and the quality of the storage reservoir. Changing the source location can significantly change the transport cost and the best storage option thus affecting total CCS cost.

The cost for each link the CCS value chain is unique to each source's specific attributes. Since capture of CO_2 is fixed for the source, transportation and storage are important CCS cost variables for a source to evaluate to attain the lowest integrated CCS cost. First, a good quality storage reservoir needs to be selected that will hold the mass of CO_2 captured over the operating life of the source. Once the storage site is known, a pipeline system (dedicated or trunkline) can be selected. The sum of the unit costs for each is the CCS cost for the overall project. Each CCS link has some level of economy of scale, but this is limited at some point, usually restricted by distance, which defined transportation costs. If the modeled sources of this study were in the Gulf Coast area, none of them would have considered transportation north to any of the Mt. Simon storage reservoirs. If these sources were in Indiana or Illinois, they would not have considered a Rose Run storage reservoir. Considering use of the Gulf Coast storage reservoirs would have depended on capture costs and trunkline pipeline costs. Efforts to reduce storage or capture costs will lower overall CCS cost, favorably impacting proximal storage or making more distal storage cost effective.

6 REFERENCES

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Appendix A: CCS Costs for Source-Sink Combinations

This appendix shows cost data of all components in the carbon capture and storage (CCS) value chain (i.e., capture, transport, and storage) as well as total CCS costs for all scenarios in the analysis in Exhibit A-1 through Exhibit A-16. Costs are listed by source location and are reported in 2011$/tonne. Pipeline/trunkline distances and diameters are also listed in the tables.

Exhibit A-1 Electric power plant CCS costs for dedicated system by source location (regional dip)

Electric Power Plant Capture Rate – Pipeline Diameter			3.58 Mt/Yr – 12-in pipeline				3.14 Mt/Yr – 12-in pipeline				2.60 Mt/Yr – 12-in pipeline			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	462	$57.82	$14.85	$10.62	$83.29	$58.57	$15.88	$10.85	$85.30	$61.21	$18.11	$11.52	$90.84
	MS3	623	$57.82	$19.47	$10.52	$87.81	$58.57	$21.10	$10.74	$90.41	$61.21	$24.34	$11.41	$96.96
	MS10	348	$57.82	$11.10	$33.50	$102.42	$58.57	$12.06	$33.82	$104.45	$61.21	$13.56	$34.29	$109.06
	LT8	1,071	$57.82	$33.52	$13.82	$105.16	$58.57	$36.47	$14.02	$109.06	$61.21	$41.83	$14.70	$117.74
	FR3A	1,358	$57.82	$41.89	$7.58	$107.29	$58.57	$45.56	$7.83	$111.96	$61.21	$52.74	$8.51	$122.46
	RR3	124	$57.82	$4.08	$56.28	$118.18	$58.57	$4.20	$56.79	$119.56	$61.21	$5.00	$58.61	$124.82
	RR4	124	$57.82	$4.08	$86.88	$148.78	$58.57	$4.20	$87.40	$150.17	$61.21	$5.00	$88.19	$154.40
E100	MS6	401	$57.82	$12.51	$10.62	$80.95	$58.57	$13.66	$10.85	$83.08	$61.21	$15.50	$11.52	$88.23
	MS3	561	$57.82	$17.48	$10.52	$85.82	$58.57	$18.88	$10.74	$88.19	$61.21	$21.73	$11.41	$94.35
	MS10	286	$57.82	$9.11	$33.50	$100.43	$58.57	$9.84	$33.82	$102.23	$61.21	$11.31	$34.29	$106.81
	LT8	1,009	$57.82	$31.18	$13.82	$102.82	$58.57	$33.90	$14.02	$106.49	$61.21	$39.22	$14.70	$115.13
	FR3A	1,297	$57.82	$39.54	$7.58	$104.94	$58.57	$43.34	$7.83	$109.74	$61.21	$50.13	$8.51	$119.85
	RR3	62	$57.82	$2.08	$56.28	$116.18	$58.57	$1.97	$56.79	$117.33	$61.21	$2.37	$58.61	$122.19
	RR4	62	$57.82	$1.72	$86.88	$146.42	$58.57	$1.97	$87.40	$147.94	$61.21	$2.37	$88.19	$151.77
W100	MS6	303	$57.82	$9.89	$10.62	$78.33	$58.57	$10.68	$10.85	$80.10	$61.21	$11.90	$11.52	$84.63
	MS3	463	$57.82	$14.87	$10.52	$83.21	$58.57	$16.25	$10.74	$85.56	$61.21	$18.49	$11.41	$91.11
	MS10	188	$57.82	$6.14	$33.50	$97.46	$58.57	$6.50	$33.82	$98.89	$61.21	$7.35	$34.29	$102.85
	LT8	911	$57.82	$29.26	$13.82	$100.90	$58.57	$31.62	$14.02	$104.21	$61.21	$35.98	$14.70	$111.89
	FR3A	1,199	$57.82	$37.98	$7.58	$103.38	$58.57	$41.06	$7.83	$107.46	$61.21	$47.23	$8.51	$116.95
	RR3	62	$57.82	$2.08	$56.28	$116.18	$58.57	$2.32	$56.79	$117.68	$61.21	$2.37	$58.61	$122.19
	RR4	62	$57.82	$2.08	$86.88	$146.78	$58.57	$2.32	$87.40	$148.29	$61.21	$2.37	$88.19	$151.77
W200	MS6	254	$57.82	$8.23	$10.62	$76.67	$58.57	$8.84	$10.85	$78.26	$61.21	$10.10	$11.52	$82.83
	MS3	414	$57.82	$13.21	$10.52	$81.55	$58.57	$14.41	$10.74	$83.72	$61.21	$16.33	$11.41	$88.95
	MS10	139	$57.82	$4.48	$33.50	$95.80	$58.57	$5.01	$33.82	$97.40	$61.21	$5.55	$34.29	$101.05
	LT8	862	$57.82	$27.61	$13.82	$99.25	$58.57	$29.78	$14.02	$102.37	$61.21	$34.18	$14.70	$110.09
	FR3A	1,150	$57.82	$36.33	$7.58	$101.73	$58.57	$39.22	$7.83	$105.62	$61.21	$45.08	$8.51	$114.80
	RR3	124	$57.82	$4.44	$56.28	$118.54	$58.57	$4.56	$56.79	$119.92	$61.21	$5.00	$58.61	$124.82
	RR4	124	$57.82	$4.08	$86.88	$148.78	$58.57	$4.56	$87.40	$150.53	$61.21	$5.00	$88.19	$154.40

Exhibit A-2 Electric power plant CCS costs for dedicated system by source location (dome)

Electric Power Plant Capture Rate – Pipeline Diameter			3.58 Mt/Yr – 12-in pipeline				3.14 Mt/Yr – 12-in pipeline				2.60 Mt/Yr – 12-in pipeline			
Source Location	Storage Reservoir ID[c]	Pipeline Distance mi	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	462	$57.82	$14.85	$6.65	$79.32	$58.57	$15.88	$6.98	$81.43	$61.21	$18.11	$7.58	$86.90
	MS3	623	$57.82	$19.47	$6.86	$84.15	$58.57	$21.10	$7.02	$86.69	$61.21	$24.34	$7.80	$93.35
	MS10	348	$57.82	$11.10	$15.11	$84.03	$58.57	$12.06	$15.39	$86.02	$61.21	$13.56	$15.95	$90.72
	LT8	1,071	$57.82	$33.52	$7.93	$99.27	$58.57	$36.47	$8.17	$103.21	$61.21	$41.83	$8.83	$111.87
	FR3A	1,358	$57.82	$41.89	$5.73	$105.44	$58.57	$45.56	$6.04	$110.17	$61.21	$52.74	$6.74	$120.69
	RR3	124	$57.82	$4.08	$27.60	$89.50	$58.57	$4.20	$28.09	$90.86	$61.21	$5.00	$29.41	$95.62
	RR4	124	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E100	MS6	401	$57.82	$12.51	$6.65	$76.98	$58.57	$13.66	$6.98	$79.21	$61.21	$15.50	$7.58	$84.29
	MS3	561	$57.82	$17.48	$6.86	$82.16	$58.57	$18.88	$7.02	$84.47	$61.21	$21.73	$7.80	$90.74
	MS10	286	$57.82	$9.11	$15.11	$82.04	$58.57	$9.84	$15.39	$83.80	$61.21	$11.31	$15.95	$88.47
	LT8	1,009	$57.82	$31.18	$7.93	$96.93	$58.57	$33.90	$8.17	$100.64	$61.21	$39.22	$8.83	$109.26
	FR3A	1,297	$57.82	$39.54	$5.73	$103.09	$58.57	$43.34	$6.04	$107.95	$61.21	$50.13	$6.74	$118.08
	RR3	62	$57.82	$2.08	$27.60	$87.50	$58.57	$1.97	$28.09	$88.63	$61.21	$2.37	$29.41	$92.99
	RR4	62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
W100	MS6	303	$57.82	$9.89	$6.65	$74.36	$58.57	$10.68	$6.98	$76.23	$61.21	$11.90	$7.58	$80.69
	MS3	463	$57.82	$14.87	$6.86	$79.55	$58.57	$16.25	$7.02	$81.84	$61.21	$18.49	$7.80	$87.50
	MS10	188	$57.82	$6.14	$15.11	$79.07	$58.57	$6.50	$15.39	$80.46	$61.21	$7.35	$15.95	$84.51
	LT8	911	$57.82	$29.26	$7.93	$95.01	$58.57	$31.62	$8.17	$98.36	$61.21	$35.98	$8.83	$106.02
	FR3A	1,199	$57.82	$37.98	$5.73	$101.53	$58.57	$41.06	$6.04	$105.67	$61.21	$47.23	$6.74	$115.18
	RR3	62	$57.82	$2.08	$27.60	$87.50	$58.57	$2.32	$28.09	$88.98	$61.21	$2.37	$29.41	$92.99
	RR4	62	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
W200	MS6	254	$57.82	$8.23	$6.65	$72.70	$58.57	$8.84	$6.98	$74.39	$61.21	$10.10	$7.58	$78.89
	MS3	414	$57.82	$13.21	$6.86	$77.89	$58.57	$14.41	$7.02	$80.00	$61.21	$16.33	$7.80	$85.34
	MS10	139	$57.82	$4.48	$15.11	$77.41	$58.57	$5.01	$15.39	$78.97	$61.21	$5.55	$15.95	$82.71
	LT8	862	$57.82	$27.61	$7.93	$93.36	$58.57	$29.78	$8.17	$96.52	$61.21	$34.18	$8.83	$104.22
	FR3A	1,150	$57.82	$36.33	$5.73	$99.88	$58.57	$39.22	$6.04	$103.83	$61.21	$45.08	$6.74	$113.03
	RR3	124	$57.82	$4.44	$27.60	$89.86	$58.57	$4.56	$28.09	$91.22	$61.21	$5.00	$29.41	$95.62
	RR4	124	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[c] Rose Run 4 does not have sufficient capacity under dome structure to store the amount of captured CO_2 from the three electric power plants.

Exhibit A-3 Industrial plant CCS costs for dedicated system by source location (regional dip)

Industrial Plant Capture Rate – Pipeline Diameter			3.90 Mt/Yr (Steel) – 12-in pipeline[d]				1.14 Mt/Yr (Cement) – 8-in pipeline				0.65 Mt/Yr (NG Processing) – 8-in pipeline			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	462	$99.00	$14.18	$10.35	$123.53	$100.00	$31.83	$16.26	$148.09	$18.00	$53.03	$21.75	$92.78
	MS3	623	$99.00	$18.81	$10.23	$128.04	$100.00	$42.89	$16.37	$159.26	$18.00	$71.54	$22.98	$112.52
	MS10	348	$99.00	$10.68	$33.26	$142.94	$100.00	$24.09	$38.69	$162.78	$18.00	$40.10	$43.62	$101.72
	LT8	1,071	$99.00	$31.87	$13.58	$144.45	$100.00	$73.58	$19.80	$193.38	$18.00	$122.60	$25.81	$166.41
	FR3A	1,358	$99.00	$39.96	$7.26	$146.22	$100.00	$92.86	$13.74	$206.60	$18.00	$155.52	$20.82	$194.34
	RR3	124	$99.00	$4.16	$55.61	$158.77	$100.00	$8.94	$69.32	$178.26	$18.00	$14.42	$82.46	$114.88
	RR4	124	$99.00	$3.81	$86.41	$189.22	$100.00	$8.58	$95.67	$204.25	$18.00	$14.42	$104.04	$136.46
E100	MS6	401	$99.00	$11.98	$10.35	$121.33	$100.00	$27.50	$16.26	$143.76	$18.00	$46.07	$21.75	$85.82
	MS3	561	$99.00	$16.60	$10.23	$125.83	$100.00	$38.20	$16.37	$154.57	$18.00	$64.21	$22.98	$105.19
	MS10	286	$99.00	$8.48	$33.26	$140.74	$100.00	$19.76	$38.69	$158.45	$18.00	$33.14	$43.62	$94.76
	LT8	1,009	$99.00	$29.67	$13.58	$142.25	$100.00	$68.90	$19.80	$188.70	$18.00	$115.64	$25.81	$159.45
	FR3A	1,297	$99.00	$37.76	$7.26	$144.02	$100.00	$88.18	$13.74	$201.92	$18.00	$148.56	$20.82	$187.38
	RR3	62	$99.00	$1.94	$55.61	$156.55	$100.00	$4.22	$69.32	$173.54	$18.00	$7.39	$82.46	$107.85
	RR4	62	$99.00	$1.94	$86.41	$187.35	$100.00	$4.22	$95.67	$199.89	$18.00	$7.39	$104.04	$129.43
W100	MS6	303	$99.00	$9.58	$10.35	$118.93	$100.00	$21.16	$16.26	$137.42	$18.00	$34.96	$21.75	$74.71
	MS3	463	$99.00	$14.55	$10.23	$123.78	$100.00	$32.22	$16.37	$148.59	$18.00	$53.47	$22.98	$94.45
	MS10	188	$99.00	$6.08	$33.26	$138.34	$100.00	$13.43	$38.69	$152.12	$18.00	$22.03	$43.62	$83.65
	LT8	911	$99.00	$28.32	$13.58	$140.90	$100.00	$63.28	$19.80	$183.08	$18.00	$104.53	$25.81	$148.34
	FR3A	1,199	$99.00	$36.41	$7.26	$142.67	$100.00	$82.56	$13.74	$196.30	$18.00	$137.45	$20.82	$176.27
	RR3	62	$99.00	$2.17	$55.61	$156.78	$100.00	$4.57	$69.32	$173.89	$18.00	$7.39	$82.46	$107.85
	RR4	62	$99.00	$1.94	$86.41	$187.35	$100.00	$4.57	$95.67	$200.24	$18.00	$7.39	$104.04	$129.43
W200	MS6	254	$99.00	$8.02	$10.35	$117.37	$100.00	$17.64	$16.26	$133.90	$18.00	$29.41	$21.75	$69.16
	MS3	414	$99.00	$13.00	$10.23	$122.23	$100.00	$28.70	$16.37	$145.07	$18.00	$47.55	$22.98	$88.53
	MS10	139	$99.00	$4.52	$33.26	$136.78	$100.00	$9.90	$38.69	$148.59	$18.00	$16.11	$43.62	$77.73
	LT8	862	$99.00	$26.42	$13.58	$139.00	$100.00	$59.75	$19.80	$179.55	$18.00	$98.97	$25.81	$142.78
	FR3A	1,150	$99.00	$34.86	$7.26	$141.12	$100.00	$79.03	$13.74	$192.77	$18.00	$131.89	$20.82	$170.71
	RR3	124	$99.00	$4.16	$55.61	$158.77	$100.00	$8.94	$69.32	$178.26	$18.00	$14.42	$82.46	$114.88
	RR4	124	$99.00	$4.16	$86.41	$189.57	$100.00	$8.94	$95.67	$204.61	$18.00	$14.42	$104.04	$136.46

[d] A 16-in diameter pipeline was used for transporting 3.90 Mt/Yr of CO_2 from the W100 location to the Rose Run 3 storage reservoir for storage.

Exhibit A-4 Industrial plant CCS costs for dedicated system by source location (dome)

Industrial Plant Capture Rate – Pipeline Diameter			3.90 Mt/Yr (Steel) – 12-in pipeline[e]				1.14 Mt/Yr (Cement) – 8-in pipeline				0.65 Mt/Yr (NG Processing) – 8-in pipeline			
Source Location	Storage Reservoir ID[f]	Pipeline Distance mi	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	462	$99.00	$14.18	$6.50	$119.68	$100.00	$31.83	$11.93	$143.76	$18.00	$53.03	$17.80	$88.83
	MS3	623	$99.00	$18.81	$6.53	$124.34	$100.00	$42.89	$12.53	$155.42	$18.00	$71.54	$19.23	$108.77
	MS10	348	$99.00	$10.68	$14.98	$124.66	$100.00	$24.09	$19.40	$143.49	$18.00	$40.10	$24.60	$82.70
	LT8	1,071	$99.00	$31.87	$7.63	$138.50	$100.00	$73.58	$13.20	$186.78	$18.00	$122.60	$19.32	$159.92
	FR3A	1,358	$99.00	$39.96	$5.54	$144.50	$100.00	$92.86	$12.12	$204.98	$18.00	$155.52	$19.30	$192.82
	RR3	124	$99.00	$4.16	$27.15	$130.31	$100.00	$8.94	$38.79	$147.73	$18.00	$14.42	$49.61	$82.03
	RR4	124	N/A	N/A	N/A	N/A	$100.00	$8.58	$44.89	$153.47	$18.00	$14.42	$52.32	$84.74
E100	MS6	401	$99.00	$11.98	$6.50	$117.48	$100.00	$27.50	$11.93	$139.43	$18.00	$46.07	$17.80	$81.87
	MS3	561	$99.00	$16.60	$6.53	$122.13	$100.00	$38.20	$12.53	$150.73	$18.00	$64.21	$19.23	$101.44
	MS10	286	$99.00	$8.48	$14.98	$122.46	$100.00	$19.76	$19.40	$139.16	$18.00	$33.14	$24.60	$75.74
	LT8	1,009	$99.00	$29.67	$7.63	$136.30	$100.00	$68.90	$13.20	$182.10	$18.00	$115.64	$19.32	$152.96
	FR3A	1,297	$99.00	$37.76	$5.54	$142.30	$100.00	$88.18	$12.12	$200.30	$18.00	$148.56	$19.30	$185.86
	RR3	62	$99.00	$1.94	$27.15	$128.09	$100.00	$4.22	$38.79	$143.01	$18.00	$7.39	$49.61	$75.00
	RR4	62	N/A	N/A	N/A	N/A	$100.00	$4.22	$44.89	$149.11	$18.00	$7.39	$52.32	$77.71
W100	MS6	303	$99.00	$9.58	$6.50	$115.08	$100.00	$21.16	$11.93	$133.09	$18.00	$34.96	$17.80	$70.76
	MS3	463	$99.00	$14.55	$6.53	$120.08	$100.00	$32.22	$12.53	$144.75	$18.00	$53.47	$19.23	$90.70
	MS10	188	$99.00	$6.08	$14.98	$120.06	$100.00	$13.43	$19.40	$132.83	$18.00	$22.03	$24.60	$64.63
	LT8	911	$99.00	$28.32	$7.63	$134.95	$100.00	$63.28	$13.20	$176.48	$18.00	$104.53	$19.32	$141.85
	FR3A	1,199	$99.00	$36.41	$5.54	$140.95	$100.00	$82.56	$12.12	$194.68	$18.00	$137.45	$19.30	$174.75
	RR3	62	$99.00	$2.17	$27.15	$128.32	$100.00	$4.57	$38.79	$143.36	$18.00	$7.39	$49.61	$75.00
	RR4	62	N/A	N/A	N/A	N/A	$100.00	$4.57	$44.89	$149.46	$18.00	$7.39	$52.32	$77.71
W200	MS6	254	$99.00	$8.02	$6.50	$113.52	$100.00	$17.64	$11.93	$129.57	$18.00	$29.41	$17.80	$65.21
	MS3	414	$99.00	$13.00	$6.53	$118.53	$100.00	$28.70	$12.53	$141.23	$18.00	$47.55	$19.23	$84.78
	MS10	139	$99.00	$4.52	$14.98	$118.50	$100.00	$9.90	$19.40	$129.30	$18.00	$16.11	$24.60	$58.71
	LT8	862	$99.00	$26.42	$7.63	$133.05	$100.00	$59.75	$13.20	$172.95	$18.00	$98.97	$19.32	$136.29
	FR3A	1,150	$99.00	$34.86	$5.54	$139.40	$100.00	$79.03	$12.12	$191.15	$18.00	$131.89	$19.30	$169.19
	RR3	124	$99.00	$4.16	$27.15	$130.31	$100.00	$8.94	$38.79	$147.73	$18.00	$14.42	$49.61	$82.03
	RR4	124	N/A	N/A	N/A	N/A	$100.00	$8.94	$44.89	$153.83	$18.00	$14.42	$52.32	$84.74

[e] A 16-in diameter pipeline was used for transporting 3.90 Mt/Yr of CO_2 from the W100 location to the Rose Run 3 storage reservoir for storage.

[f] Rose Run 4 does not have sufficient capacity under dome structure to store the amount of captured CO_2 from the steel plant (3.90 Mt/Yr capture rate).

Exhibit A-5 Electric power plant CCS costs for trunkline system by source location (regional dip)

Electric Power Plant Capture Rate				3.58 Mt/Yr				3.14 Mt/Yr				2.60 Mt/Yr			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	512	30/36	$57.82	$10.76	$10.62	$79.20	$58.57	$10.99	$10.85	$80.41	$61.21	$11.98	$11.52	$84.71
	MS6	512	30	$57.82	$11.05	$10.62	$79.49	$58.57	$11.28	$10.85	$80.70	$61.21	$12.27	$11.52	$85.00
	MS6	512	24/30	$57.82	$11.88	$10.62	$80.32	$58.57	$12.11	$10.85	$81.53	$61.21	$13.10	$11.52	$85.83
	MS6	512	20/24	$57.82	$12.82	$10.62	$81.26	$58.57	$13.05	$10.85	$82.47	$61.21	$14.04	$11.52	$86.77
	MS3	631	30/36	$57.82	$12.62	$10.52	$80.96	$58.57	$12.85	$10.74	$82.16	$61.21	$13.84	$11.41	$86.46
	MS3	631	30	$57.82	$13.23	$10.52	$81.57	$58.57	$13.46	$10.74	$82.77	$61.21	$14.45	$11.41	$87.07
	MS3	631	24/30	$57.82	$14.30	$10.52	$82.64	$58.57	$14.53	$10.74	$83.84	$61.21	$15.52	$11.41	$88.14
	MS3	631	20/24	$57.82	$15.71	$10.52	$84.05	$58.57	$15.94	$10.74	$85.25	$61.21	$16.93	$11.41	$89.55
	LT8	1,061	30/36	$57.82	$19.06	$13.82	$90.70	$58.57	$19.29	$14.02	$91.88	$61.21	$20.28	$14.70	$96.19
	LT8	1,061	30	$57.82	$19.89	$13.82	$91.53	$58.57	$20.12	$14.02	$92.71	$61.21	$21.11	$14.70	$97.02
	LT8	1,061	24/30	$57.82	$21.97	$13.82	$93.61	$58.57	$22.20	$14.02	$94.79	$61.21	$23.19	$14.70	$99.10
	LT8	1,061	20/24	$57.82	$24.88	$13.82	$96.52	$58.57	$25.11	$14.02	$97.70	$61.21	$26.10	$14.70	$102.01
	FR3A	1,342	30/36	$57.82	$23.30	$7.58	$88.70	$58.57	$23.53	$7.83	$89.93	$61.21	$24.52	$8.51	$94.24
	FR3A	1,342	30	$57.82	$24.40	$7.58	$89.80	$58.57	$24.63	$7.83	$91.03	$61.21	$25.62	$8.51	$95.34
	FR3A	1,342	24/30	$57.82	$27.28	$7.58	$92.68	$58.57	$27.51	$7.83	$93.91	$61.21	$28.50	$8.51	$98.22
	FR3A	1,342	20/24	$57.82	$31.20	$7.58	$96.60	$58.57	$31.43	$7.83	$97.83	$61.21	$32.42	$8.51	$102.14
E100	MS6	446	30/36	$57.82	$8.30	$10.62	$76.74	$58.57	$8.64	$10.85	$78.06	$61.21	$9.22	$11.52	$81.95
	MS6	446	30	$57.82	$8.59	$10.62	$77.03	$58.57	$8.93	$10.85	$78.35	$61.21	$9.51	$11.52	$82.24
	MS6	446	24/30	$57.82	$9.42	$10.62	$77.86	$58.57	$9.76	$10.85	$79.18	$61.21	$10.34	$11.52	$83.07
	MS6	446	20/24	$57.82	$10.36	$10.62	$78.80	$58.57	$10.70	$10.85	$80.12	$61.21	$11.28	$11.52	$84.01
	MS3	565	30/36	$57.82	$10.16	$10.52	$78.50	$58.57	$10.50	$10.74	$79.81	$61.21	$11.08	$11.41	$83.70
	MS3	565	30	$57.82	$10.77	$10.52	$79.11	$58.57	$11.11	$10.74	$80.42	$61.21	$11.69	$11.41	$84.31
	MS3	565	24/30	$57.82	$11.84	$10.52	$80.18	$58.57	$12.18	$10.74	$81.49	$61.21	$12.76	$11.41	$85.38
	MS3	565	20/24	$57.82	$13.25	$10.52	$81.59	$58.57	$13.59	$10.74	$82.90	$61.21	$14.17	$11.41	$86.79
	LT8	994	30/36	$57.82	$16.60	$13.82	$88.24	$58.57	$16.94	$14.02	$89.53	$61.21	$17.52	$14.70	$93.43
	LT8	994	30	$57.82	$17.43	$13.82	$89.07	$58.57	$17.77	$14.02	$90.36	$61.21	$18.35	$14.70	$94.26
	LT8	994	24/30	$57.82	$19.51	$13.82	$91.15	$58.57	$19.85	$14.02	$92.44	$61.21	$20.43	$14.70	$96.34
	LT8	994	20/24	$57.82	$22.42	$13.82	$94.06	$58.57	$22.76	$14.02	$95.35	$61.21	$23.34	$14.70	$99.25
	FR3A	1,275	30/36	$57.82	$20.84	$7.58	$86.24	$58.57	$21.18	$7.83	$87.58	$61.21	$21.76	$8.51	$91.48
	FR3A	1,275	30	$57.82	$21.94	$7.58	$87.34	$58.57	$22.28	$7.83	$88.68	$61.21	$22.86	$8.51	$92.58
	FR3A	1,275	24/30	$57.82	$24.82	$7.58	$90.22	$58.57	$25.16	$7.83	$91.56	$61.21	$25.74	$8.51	$95.46
	FR3A	1,275	20/24	$57.82	$28.74	$7.58	$94.14	$58.57	$29.08	$7.83	$95.48	$61.21	$29.66	$8.51	$99.38

Exhibit A-6 Electric power plant CCS costs for trunkline system by source location (regional dip) - continued

Electric Power Plant Capture Rate				3.58 Mt/Yr				3.14 Mt/Yr				2.60 Mt/Yr			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W100	MS6	446	30/36	$57.82	$8.66	$10.62	$77.10	$58.57	$8.99	$10.85	$78.41	$61.21	$9.22	$11.52	$81.95
	MS6	446	30	$57.82	$8.95	$10.62	$77.39	$58.57	$9.28	$10.85	$78.70	$61.21	$9.51	$11.52	$82.24
	MS6	446	24/30	$57.82	$9.78	$10.62	$78.22	$58.57	$10.11	$10.85	$79.53	$61.21	$10.34	$11.52	$83.07
	MS6	446	20/24	$57.82	$10.72	$10.62	$79.16	$58.57	$11.05	$10.85	$80.47	$61.21	$11.28	$11.52	$84.01
	MS3	565	30/36	$57.82	$10.52	$10.52	$78.86	$58.57	$10.85	$10.74	$80.16	$61.21	$11.08	$11.41	$83.70
	MS3	565	30	$57.82	$11.13	$10.52	$79.47	$58.57	$11.46	$10.74	$80.77	$61.21	$11.69	$11.41	$84.31
	MS3	565	24/30	$57.82	$12.20	$10.52	$80.54	$58.57	$12.53	$10.74	$81.84	$61.21	$12.76	$11.41	$85.38
	MS3	565	20/24	$57.82	$13.61	$10.52	$81.95	$58.57	$13.94	$10.74	$83.25	$61.21	$14.17	$11.41	$86.79
	LT8	994	30/36	$57.82	$16.96	$13.82	$88.60	$58.57	$17.29	$14.02	$89.88	$61.21	$17.52	$14.70	$93.43
	LT8	994	30	$57.82	$17.79	$13.82	$89.43	$58.57	$18.12	$14.02	$90.71	$61.21	$18.35	$14.70	$94.26
	LT8	994	24/30	$57.82	$19.87	$13.82	$91.51	$58.57	$20.20	$14.02	$92.79	$61.21	$20.43	$14.70	$96.34
	LT8	994	20/24	$57.82	$22.78	$13.82	$94.42	$58.57	$23.11	$14.02	$95.70	$61.21	$23.34	$14.70	$99.25
	FR3A	1,275	30/36	$57.82	$21.20	$7.58	$86.60	$58.57	$21.53	$7.83	$87.93	$61.21	$21.76	$8.51	$91.48
	FR3A	1,275	30	$57.82	$22.30	$7.58	$87.70	$58.57	$22.63	$7.83	$89.03	$61.21	$22.86	$8.51	$92.58
	FR3A	1,275	24/30	$57.82	$25.18	$7.58	$90.58	$58.57	$25.51	$7.83	$91.91	$61.21	$25.74	$8.51	$95.46
	FR3A	1,275	20/24	$57.82	$29.10	$7.58	$94.50	$58.57	$29.43	$7.83	$95.83	$61.21	$29.66	$8.51	$99.38
W200	MS6	512	30/36	$57.82	$10.76	$10.62	$79.20	$58.57	$11.35	$10.85	$80.77	$61.21	$11.98	$11.52	$84.71
	MS6	512	30	$57.82	$11.05	$10.62	$79.49	$58.57	$11.64	$10.85	$81.06	$61.21	$12.27	$11.52	$85.00
	MS6	512	24/30	$57.82	$11.88	$10.62	$80.32	$58.57	$12.47	$10.85	$81.89	$61.21	$13.10	$11.52	$85.83
	MS6	512	20/24	$57.82	$12.82	$10.62	$81.26	$58.57	$13.41	$10.85	$82.83	$61.21	$14.04	$11.52	$86.77
	MS3	631	30/36	$57.82	$12.62	$10.52	$80.96	$58.57	$13.21	$10.74	$82.52	$61.21	$13.84	$11.41	$86.46
	MS3	631	30	$57.82	$13.23	$10.52	$81.57	$58.57	$13.82	$10.74	$83.13	$61.21	$14.45	$11.41	$87.07
	MS3	631	24/30	$57.82	$14.30	$10.52	$82.64	$58.57	$14.89	$10.74	$84.20	$61.21	$15.52	$11.41	$88.14
	MS3	631	20/24	$57.82	$15.71	$10.52	$84.05	$58.57	$16.30	$10.74	$85.61	$61.21	$16.93	$11.41	$89.55
	LT8	1,061	30/36	$57.82	$19.06	$13.82	$90.70	$58.57	$19.65	$14.02	$92.24	$61.21	$20.28	$14.70	$96.19
	LT8	1,061	30	$57.82	$19.89	$13.82	$91.53	$58.57	$20.48	$14.02	$93.07	$61.21	$21.11	$14.70	$97.02
	LT8	1,061	24/30	$57.82	$21.97	$13.82	$93.61	$58.57	$22.56	$14.02	$95.15	$61.21	$23.19	$14.70	$99.10
	LT8	1,061	20/24	$57.82	$24.88	$13.82	$96.52	$58.57	$25.47	$14.02	$98.06	$61.21	$26.10	$14.70	$102.01
	FR3A	1,342	30/36	$57.82	$23.30	$7.58	$88.70	$58.57	$23.89	$7.83	$90.29	$61.21	$24.52	$8.51	$94.24
	FR3A	1,342	30	$57.82	$24.40	$7.58	$89.80	$58.57	$24.99	$7.83	$91.39	$61.21	$25.62	$8.51	$95.34
	FR3A	1,342	24/30	$57.82	$27.28	$7.58	$92.68	$58.57	$27.87	$7.83	$94.27	$61.21	$28.50	$8.51	$98.22
	FR3A	1,342	20/24	$57.82	$31.20	$7.58	$96.60	$58.57	$31.79	$7.83	$98.19	$61.21	$32.42	$8.51	$102.14

Exhibit A-7 Electric power plant CCS costs for trunkline system by source location (dome)

Electric Power Plant Capture Rate				3.58 Mt/Yr				3.14 Mt/Yr				2.60 Mt/Yr			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	512	30/36	$57.82	$10.76	$6.65	$75.23	$58.57	$10.99	$6.98	$76.54	$61.21	$11.98	$7.58	$80.77
	MS6	512	30	$57.82	$11.05	$6.65	$75.52	$58.57	$11.28	$6.98	$76.83	$61.21	$12.27	$7.58	$81.06
	MS6	512	24/30	$57.82	$11.88	$6.65	$76.35	$58.57	$12.11	$6.98	$77.66	$61.21	$13.10	$7.58	$81.89
	MS6	512	20/24	$57.82	$12.82	$6.65	$77.29	$58.57	$13.05	$6.98	$78.60	$61.21	$14.04	$7.58	$82.83
	MS3	631	30/36	$57.82	$12.62	$6.86	$77.30	$58.57	$12.85	$7.02	$78.44	$61.21	$13.84	$7.80	$82.85
	MS3	631	30	$57.82	$13.23	$6.86	$77.91	$58.57	$13.46	$7.02	$79.05	$61.21	$14.45	$7.80	$83.46
	MS3	631	24/30	$57.82	$14.30	$6.86	$78.98	$58.57	$14.53	$7.02	$80.12	$61.21	$15.52	$7.80	$84.53
	MS3	631	20/24	$57.82	$15.71	$6.86	$80.39	$58.57	$15.94	$7.02	$81.53	$61.21	$16.93	$7.80	$85.94
	LT8	1,061	30/36	$57.82	$19.06	$7.93	$84.81	$58.57	$19.29	$8.17	$86.03	$61.21	$20.28	$8.83	$90.32
	LT8	1,061	30	$57.82	$19.89	$7.93	$85.64	$58.57	$20.12	$8.17	$86.86	$61.21	$21.11	$8.83	$91.15
	LT8	1,061	24/30	$57.82	$21.97	$7.93	$87.72	$58.57	$22.20	$8.17	$88.94	$61.21	$23.19	$8.83	$93.23
	LT8	1,061	20/24	$57.82	$24.88	$7.93	$90.63	$58.57	$25.11	$8.17	$91.85	$61.21	$26.10	$8.83	$96.14
	FR3A	1,342	30/36	$57.82	$23.30	$5.73	$86.85	$58.57	$23.53	$6.04	$88.14	$61.21	$24.52	$6.74	$92.47
	FR3A	1,342	30	$57.82	$24.40	$5.73	$87.95	$58.57	$24.63	$6.04	$89.24	$61.21	$25.62	$6.74	$93.57
	FR3A	1,342	24/30	$57.82	$27.28	$5.73	$90.83	$58.57	$27.51	$6.04	$92.12	$61.21	$28.50	$6.74	$96.45
	FR3A	1,342	20/24	$57.82	$31.20	$5.73	$94.75	$58.57	$31.43	$6.04	$96.04	$61.21	$32.42	$6.74	$100.37
E100	MS6	446	30/36	$57.82	$8.30	$6.65	$72.77	$58.57	$8.64	$6.98	$74.19	$61.21	$9.22	$7.58	$78.01
	MS6	446	30	$57.82	$8.59	$6.65	$73.06	$58.57	$8.93	$6.98	$74.48	$61.21	$9.51	$7.58	$78.30
	MS6	446	24/30	$57.82	$9.42	$6.65	$73.89	$58.57	$9.76	$6.98	$75.31	$61.21	$10.34	$7.58	$79.13
	MS6	446	20/24	$57.82	$10.36	$6.65	$74.83	$58.57	$10.70	$6.98	$76.25	$61.21	$11.28	$7.58	$80.07
	MS3	565	30/36	$57.82	$10.16	$6.86	$74.84	$58.57	$10.50	$7.02	$76.09	$61.21	$11.08	$7.80	$80.09
	MS3	565	30	$57.82	$10.77	$6.86	$75.45	$58.57	$11.11	$7.02	$76.70	$61.21	$11.69	$7.80	$80.70
	MS3	565	24/30	$57.82	$11.84	$6.86	$76.52	$58.57	$12.18	$7.02	$77.77	$61.21	$12.76	$7.80	$81.77
	MS3	565	20/24	$57.82	$13.25	$6.86	$77.93	$58.57	$13.59	$7.02	$79.18	$61.21	$14.17	$7.80	$83.18
	LT8	994	30/36	$57.82	$16.60	$7.93	$82.35	$58.57	$16.94	$8.17	$83.68	$61.21	$17.52	$8.83	$87.56
	LT8	994	30	$57.82	$17.43	$7.93	$83.18	$58.57	$17.77	$8.17	$84.51	$61.21	$18.35	$8.83	$88.39
	LT8	994	24/30	$57.82	$19.51	$7.93	$85.26	$58.57	$19.85	$8.17	$86.59	$61.21	$20.43	$8.83	$90.47
	LT8	994	20/24	$57.82	$22.42	$7.93	$88.17	$58.57	$22.76	$8.17	$89.50	$61.21	$23.34	$8.83	$93.38
	FR3A	1,275	30/36	$57.82	$20.84	$5.73	$84.39	$58.57	$21.18	$6.04	$85.79	$61.21	$21.76	$6.74	$89.71
	FR3A	1,275	30	$57.82	$21.94	$5.73	$85.49	$58.57	$22.28	$6.04	$86.89	$61.21	$22.86	$6.74	$90.81
	FR3A	1,275	24/30	$57.82	$24.82	$5.73	$88.37	$58.57	$25.16	$6.04	$89.77	$61.21	$25.74	$6.74	$93.69
	FR3A	1,275	20/24	$57.82	$28.74	$5.73	$92.29	$58.57	$29.08	$6.04	$93.69	$61.21	$29.66	$6.74	$97.61

Exhibit A-8 Electric power plant CCS costs for trunkline system by source location (dome) - continued

Electric Power Plant Capture Rate				3.58 Mt/Yr				3.14 Mt/Yr				2.60 Mt/Yr			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W100	MS6	446	30/36	$57.82	$8.66	$6.65	$73.13	$58.57	$8.99	$6.98	$74.54	$61.21	$9.22	$7.58	$78.01
	MS6	446	30	$57.82	$8.95	$6.65	$73.42	$58.57	$9.28	$6.98	$74.83	$61.21	$9.51	$7.58	$78.30
	MS6	446	24/30	$57.82	$9.78	$6.65	$74.25	$58.57	$10.11	$6.98	$75.66	$61.21	$10.34	$7.58	$79.13
	MS6	446	20/24	$57.82	$10.72	$6.65	$75.19	$58.57	$11.05	$6.98	$76.60	$61.21	$11.28	$7.58	$80.07
	MS3	565	30/36	$57.82	$10.52	$6.86	$75.20	$58.57	$10.85	$7.02	$76.44	$61.21	$11.08	$7.80	$80.09
	MS3	565	30	$57.82	$11.13	$6.86	$75.81	$58.57	$11.46	$7.02	$77.05	$61.21	$11.69	$7.80	$80.70
	MS3	565	24/30	$57.82	$12.20	$6.86	$76.88	$58.57	$12.53	$7.02	$78.12	$61.21	$12.76	$7.80	$81.77
	MS3	565	20/24	$57.82	$13.61	$6.86	$78.29	$58.57	$13.94	$7.02	$79.53	$61.21	$14.17	$7.80	$83.18
	LT8	994	30/36	$57.82	$16.96	$7.93	$82.71	$58.57	$17.29	$8.17	$84.03	$61.21	$17.52	$8.83	$87.56
	LT8	994	30	$57.82	$17.79	$7.93	$83.54	$58.57	$18.12	$8.17	$84.86	$61.21	$18.35	$8.83	$88.39
	LT8	994	24/30	$57.82	$19.87	$7.93	$85.62	$58.57	$20.20	$8.17	$86.94	$61.21	$20.43	$8.83	$90.47
	LT8	994	20/24	$57.82	$22.78	$7.93	$88.53	$58.57	$23.11	$8.17	$89.85	$61.21	$23.34	$8.83	$93.38
	FR3A	1,275	30/36	$57.82	$21.20	$5.73	$84.75	$58.57	$21.53	$6.04	$86.14	$61.21	$21.76	$6.74	$89.71
	FR3A	1,275	30	$57.82	$22.30	$5.73	$85.85	$58.57	$22.63	$6.04	$87.24	$61.21	$22.86	$6.74	$90.81
	FR3A	1,275	24/30	$57.82	$25.18	$5.73	$88.73	$58.57	$25.51	$6.04	$90.12	$61.21	$25.74	$6.74	$93.69
	FR3A	1,275	20/24	$57.82	$29.10	$5.73	$92.65	$58.57	$29.43	$6.04	$94.04	$61.21	$29.66	$6.74	$97.61
W200	MS6	512	30/36	$57.82	$10.76	$6.65	$75.23	$58.57	$11.35	$6.98	$76.90	$61.21	$11.98	$7.58	$80.77
	MS6	512	30	$57.82	$11.05	$6.65	$75.52	$58.57	$11.64	$6.98	$77.19	$61.21	$12.27	$7.58	$81.06
	MS6	512	24/30	$57.82	$11.88	$6.65	$76.35	$58.57	$12.47	$6.98	$78.02	$61.21	$13.10	$7.58	$81.89
	MS6	512	20/24	$57.82	$12.82	$6.65	$77.29	$58.57	$13.41	$6.98	$78.96	$61.21	$14.04	$7.58	$82.83
	MS3	631	30/36	$57.82	$12.62	$6.86	$77.30	$58.57	$13.21	$7.02	$78.80	$61.21	$13.84	$7.80	$82.85
	MS3	631	30	$57.82	$13.23	$6.86	$77.91	$58.57	$13.82	$7.02	$79.41	$61.21	$14.45	$7.80	$83.46
	MS3	631	24/30	$57.82	$14.30	$6.86	$78.98	$58.57	$14.89	$7.02	$80.48	$61.21	$15.52	$7.80	$84.53
	MS3	631	20/24	$57.82	$15.71	$6.86	$80.39	$58.57	$16.30	$7.02	$81.89	$61.21	$16.93	$7.80	$85.94
	LT8	1,061	30/36	$57.82	$19.06	$7.93	$84.81	$58.57	$19.65	$8.17	$86.39	$61.21	$20.28	$8.83	$90.32
	LT8	1,061	30	$57.82	$19.89	$7.93	$85.64	$58.57	$20.48	$8.17	$87.22	$61.21	$21.11	$8.83	$91.15
	LT8	1,061	24/30	$57.82	$21.97	$7.93	$87.72	$58.57	$22.56	$8.17	$89.30	$61.21	$23.19	$8.83	$93.23
	LT8	1,061	20/24	$57.82	$24.88	$7.93	$90.63	$58.57	$25.47	$8.17	$92.21	$61.21	$26.10	$8.83	$96.14
	FR3A	1,342	30/36	$57.82	$23.30	$5.73	$86.85	$58.57	$23.89	$6.04	$88.50	$61.21	$24.52	$6.74	$92.47
	FR3A	1,342	30	$57.82	$24.40	$5.73	$87.95	$58.57	$24.99	$6.04	$89.60	$61.21	$25.62	$6.74	$93.57
	FR3A	1,342	24/30	$57.82	$27.28	$5.73	$90.83	$58.57	$27.87	$6.04	$92.48	$61.21	$28.50	$6.74	$96.45
	FR3A	1,342	20/24	$57.82	$31.20	$5.73	$94.75	$58.57	$31.79	$6.04	$96.40	$61.21	$32.42	$6.74	$100.37

Exhibit A-9 Industrial plant CCS costs for trunkline system by source location (regional dip)

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[g]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	512	30/36	$99.00	$10.42	$10.35	$119.77	$100.00	$16.42	$16.26	$132.68	$18.00	$23.71	$21.75	$63.46
	MS6	512	30	$99.00	$10.71	$10.35	$120.06	$100.00	$16.71	$16.26	$132.97	$18.00	$24.00	$21.75	$63.75
	MS6	512	24/30	$99.00	$11.54	$10.35	$120.89	$100.00	$17.54	$16.26	$133.80	$18.00	$24.83	$21.75	$64.58
	MS6	512	20/24	$99.00	$12.48	$10.35	$121.83	$100.00	$18.48	$16.26	$134.74	$18.00	$25.77	$21.75	$65.52
	MS6	512	12	N/A	N/A	N/A	N/A	$100.00	$22.65	$16.26	$138.91	$18.00	$29.94	$21.75	$69.69
	MS3	631	30/36	$99.00	$12.28	$10.23	$121.51	$100.00	$18.28	$16.37	$134.65	$18.00	$25.57	$22.98	$66.55
	MS3	631	30	$99.00	$12.89	$10.23	$122.12	$100.00	$18.89	$16.37	$135.26	$18.00	$26.18	$22.98	$67.16
	MS3	631	24/30	$99.00	$13.96	$10.23	$123.19	$100.00	$19.96	$16.37	$136.33	$18.00	$27.25	$22.98	$68.23
	MS3	631	20/24	$99.00	$15.37	$10.23	$124.60	$100.00	$21.37	$16.37	$137.74	$18.00	$28.66	$22.98	$69.64
	MS3	631	12	N/A	N/A	N/A	N/A	$100.00	$26.95	$16.37	$143.32	$18.00	$34.24	$22.98	$75.22
	LT8	1,061	30/36	$99.00	$18.72	$13.58	$131.30	$100.00	$24.72	$19.80	$144.52	$18.00	$32.01	$25.81	$75.82
	LT8	1,061	30	$99.00	$19.55	$13.58	$132.13	$100.00	$25.55	$19.80	$145.35	$18.00	$32.84	$25.81	$76.65
	LT8	1,061	24/30	$99.00	$21.63	$13.58	$134.21	$100.00	$27.63	$19.80	$147.43	$18.00	$34.92	$25.81	$78.73
	LT8	1,061	20/24	$99.00	$24.54	$13.58	$137.12	$100.00	$30.54	$19.80	$150.34	$18.00	$37.83	$25.81	$81.64
	LT8	1,061	12	N/A	N/A	N/A	N/A	$100.00	$40.86	$19.80	$160.66	$18.00	$48.15	$25.81	$91.96
	FR3A	1,342	30/36	$99.00	$22.96	$7.26	$129.22	$100.00	$28.96	$13.74	$142.70	$18.00	$36.25	$20.82	$75.07
	FR3A	1,342	30	$99.00	$24.06	$7.26	$130.32	$100.00	$30.06	$13.74	$143.80	$18.00	$37.35	$20.82	$76.17
	FR3A	1,342	24/30	$99.00	$26.94	$7.26	$133.20	$100.00	$32.94	$13.74	$146.68	$18.00	$40.23	$20.82	$79.05
	FR3A	1,342	20/24	$99.00	$30.86	$7.26	$137.12	$100.00	$36.86	$13.74	$150.60	$18.00	$44.15	$20.82	$82.97
	FR3A	1,342	12	N/A	N/A	N/A	N/A	$100.00	$50.52	$13.74	$164.26	$18.00	$57.81	$20.82	$96.63

[g] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-10 Industrial plant CCS costs for trunkline system by source location (regional dip) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[h]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E100	MS6	446	30/36	$99.00	$8.46	$10.35	$117.81	$100.00	$11.81	$16.26	$128.07	$18.00	$16.26	$21.75	$56.01
	MS6	446	30	$99.00	$8.75	$10.35	$118.10	$100.00	$12.10	$16.26	$128.36	$18.00	$16.55	$21.75	$56.30
	MS6	446	24/30	$99.00	$9.58	$10.35	$118.93	$100.00	$12.93	$16.26	$129.19	$18.00	$17.38	$21.75	$57.13
	MS6	446	20/24	$99.00	$10.52	$10.35	$119.87	$100.00	$13.87	$16.26	$130.13	$18.00	$18.32	$21.75	$58.07
	MS6	446	12	N/A	N/A	N/A	N/A	$100.00	$18.04	$16.26	$134.30	$18.00	$22.49	$21.75	$62.24
	MS3	565	30/36	$99.00	$10.32	$10.23	$119.55	$100.00	$13.67	$16.37	$130.04	$18.00	$18.12	$22.98	$59.10
	MS3	565	30	$99.00	$10.93	$10.23	$120.16	$100.00	$14.28	$16.37	$130.65	$18.00	$18.73	$22.98	$59.71
	MS3	565	24/30	$99.00	$12.00	$10.23	$121.23	$100.00	$15.35	$16.37	$131.72	$18.00	$19.80	$22.98	$60.78
	MS3	565	20/24	$99.00	$13.41	$10.23	$122.64	$100.00	$16.76	$16.37	$133.13	$18.00	$21.21	$22.98	$62.19
	MS3	565	12	N/A	N/A	N/A	N/A	$100.00	$22.34	$16.37	$138.71	$18.00	$26.79	$22.98	$67.77
	LT8	994	30/36	$99.00	$16.76	$13.58	$129.34	$100.00	$20.11	$19.80	$139.91	$18.00	$24.56	$25.81	$68.37
	LT8	994	30	$99.00	$17.59	$13.58	$130.17	$100.00	$20.94	$19.80	$140.74	$18.00	$25.39	$25.81	$69.20
	LT8	994	24/30	$99.00	$19.67	$13.58	$132.25	$100.00	$23.02	$19.80	$142.82	$18.00	$27.47	$25.81	$71.28
	LT8	994	20/24	$99.00	$22.58	$13.58	$135.16	$100.00	$25.93	$19.80	$145.73	$18.00	$30.38	$25.81	$74.19
	LT8	994	12	N/A	N/A	N/A	N/A	$100.00	$36.25	$19.80	$156.05	$18.00	$40.70	$25.81	$84.51
	FR3A	1,275	30/36	$99.00	$21.00	$7.26	$127.26	$100.00	$24.35	$13.74	$138.09	$18.00	$28.80	$20.82	$67.62
	FR3A	1,275	30	$99.00	$22.10	$7.26	$128.36	$100.00	$25.45	$13.74	$139.19	$18.00	$29.90	$20.82	$68.72
	FR3A	1,275	24/30	$99.00	$24.98	$7.26	$131.24	$100.00	$28.33	$13.74	$142.07	$18.00	$32.78	$20.82	$71.60
	FR3A	1,275	20/24	$99.00	$28.90	$7.26	$135.16	$100.00	$32.25	$13.74	$145.99	$18.00	$36.70	$20.82	$75.52
	FR3A	1,275	12	N/A	N/A	N/A	N/A	$100.00	$45.91	$13.74	$159.65	$18.00	$50.36	$20.82	$89.18

[h] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-11 Industrial plant CCS costs for trunkline system by source location (regional dip) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[i]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W100	MS6	446	30/36	$99.00	$8.46	$10.35	$117.81	$100.00	$12.17	$16.26	$128.43	$18.00	$16.26	$21.75	$56.01
	MS6	446	30	$99.00	$8.75	$10.35	$118.10	$100.00	$12.46	$16.26	$128.72	$18.00	$16.55	$21.75	$56.30
	MS6	446	24/30	$99.00	$9.58	$10.35	$118.93	$100.00	$13.29	$16.26	$129.55	$18.00	$17.38	$21.75	$57.13
	MS6	446	20/24	$99.00	$10.52	$10.35	$119.87	$100.00	$14.23	$16.26	$130.49	$18.00	$18.32	$21.75	$58.07
	MS6	446	12	N/A	N/A	N/A	N/A	$100.00	$18.40	$16.26	$134.66	$18.00	$22.49	$21.75	$62.24
	MS3	565	30/36	$99.00	$10.32	$10.23	$119.55	$100.00	$14.03	$16.37	$130.40	$18.00	$18.12	$22.98	$59.10
	MS3	565	30	$99.00	$10.93	$10.23	$120.16	$100.00	$14.64	$16.37	$131.01	$18.00	$18.73	$22.98	$59.71
	MS3	565	24/30	$99.00	$12.00	$10.23	$121.23	$100.00	$15.71	$16.37	$132.08	$18.00	$19.80	$22.98	$60.78
	MS3	565	20/24	$99.00	$13.41	$10.23	$122.64	$100.00	$17.12	$16.37	$133.49	$18.00	$21.21	$22.98	$62.19
	MS3	565	12	N/A	N/A	N/A	N/A	$100.00	$22.70	$16.37	$139.07	$18.00	$26.79	$22.98	$67.77
	LT8	994	30/36	$99.00	$16.76	$13.58	$129.34	$100.00	$20.47	$19.80	$140.27	$18.00	$24.56	$25.81	$68.37
	LT8	994	30	$99.00	$17.59	$13.58	$130.17	$100.00	$21.30	$19.80	$141.10	$18.00	$25.39	$25.81	$69.20
	LT8	994	24/30	$99.00	$19.67	$13.58	$132.25	$100.00	$23.38	$19.80	$143.18	$18.00	$27.47	$25.81	$71.28
	LT8	994	20/24	$99.00	$22.58	$13.58	$135.16	$100.00	$26.29	$19.80	$146.09	$18.00	$30.38	$25.81	$74.19
	LT8	994	12	N/A	N/A	N/A	N/A	$100.00	$36.61	$19.80	$156.41	$18.00	$40.70	$25.81	$84.51
	FR3A	1,275	30/36	$99.00	$21.00	$7.26	$127.26	$100.00	$24.71	$13.74	$138.45	$18.00	$28.80	$20.82	$67.62
	FR3A	1,275	30	$99.00	$22.10	$7.26	$128.36	$100.00	$25.81	$13.74	$139.55	$18.00	$29.90	$20.82	$68.72
	FR3A	1,275	24/30	$99.00	$24.98	$7.26	$131.24	$100.00	$28.69	$13.74	$142.43	$18.00	$32.78	$20.82	$71.60
	FR3A	1,275	20/24	$99.00	$28.90	$7.26	$135.16	$100.00	$32.61	$13.74	$146.35	$18.00	$36.70	$20.82	$75.52
	FR3A	1,275	12	N/A	N/A	N/A	N/A	$100.00	$46.27	$13.74	$160.01	$18.00	$50.36	$20.82	$89.18

[i] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-12 Industrial plant CCS costs for trunkline system by source location (regional dip) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[j]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W200	MS6	512	30/36	$99.00	$10.77	$10.35	$120.12	$100.00	$16.78	$16.26	$133.04	$18.00	$23.71	$21.75	$63.46
	MS6	512	30	$99.00	$11.06	$10.35	$120.41	$100.00	$17.07	$16.26	$133.33	$18.00	$24.00	$21.75	$63.75
	MS6	512	24/30	$99.00	$11.89	$10.35	$121.24	$100.00	$17.90	$16.26	$134.16	$18.00	$24.83	$21.75	$64.58
	MS6	512	20/24	$99.00	$12.83	$10.35	$122.18	$100.00	$18.84	$16.26	$135.10	$18.00	$25.77	$21.75	$65.52
	MS6	512	12	N/A	N/A	N/A	N/A	$100.00	$23.01	$16.26	$139.27	$18.00	$29.94	$21.75	$69.69
	MS3	631	30/36	$99.00	$12.63	$10.23	$121.86	$100.00	$18.64	$16.37	$135.01	$18.00	$25.57	$22.98	$66.55
	MS3	631	30	$99.00	$13.24	$10.23	$122.47	$100.00	$19.25	$16.37	$135.62	$18.00	$26.18	$22.98	$67.16
	MS3	631	24/30	$99.00	$14.31	$10.23	$123.54	$100.00	$20.32	$16.37	$136.69	$18.00	$27.25	$22.98	$68.23
	MS3	631	20/24	$99.00	$15.72	$10.23	$124.95	$100.00	$21.73	$16.37	$138.10	$18.00	$28.66	$22.98	$69.64
	MS3	631	12	N/A	N/A	N/A	N/A	$100.00	$27.31	$16.37	$143.68	$18.00	$34.24	$22.98	$75.22
	LT8	1,061	30/36	$99.00	$19.07	$13.58	$131.65	$100.00	$25.08	$19.80	$144.88	$18.00	$32.01	$25.81	$75.82
	LT8	1,061	30	$99.00	$19.90	$13.58	$132.48	$100.00	$25.91	$19.80	$145.71	$18.00	$32.84	$25.81	$76.65
	LT8	1,061	24/30	$99.00	$21.98	$13.58	$134.56	$100.00	$27.99	$19.80	$147.79	$18.00	$34.92	$25.81	$78.73
	LT8	1,061	20/24	$99.00	$24.89	$13.58	$137.47	$100.00	$30.90	$19.80	$150.70	$18.00	$37.83	$25.81	$81.64
	LT8	1,061	12	N/A	N/A	N/A	N/A	$100.00	$41.22	$19.80	$161.02	$18.00	$48.15	$25.81	$91.96
	FR3A	1,342	30/36	$99.00	$23.31	$7.26	$129.57	$100.00	$29.32	$13.74	$143.06	$18.00	$36.25	$20.82	$75.07
	FR3A	1,342	30	$99.00	$24.41	$7.26	$130.67	$100.00	$30.42	$13.74	$144.16	$18.00	$37.35	$20.82	$76.17
	FR3A	1,342	24/30	$99.00	$27.29	$7.26	$133.55	$100.00	$33.30	$13.74	$147.04	$18.00	$40.23	$20.82	$79.05
	FR3A	1,342	20/24	$99.00	$31.21	$7.26	$137.47	$100.00	$37.22	$13.74	$150.96	$18.00	$44.15	$20.82	$82.97
	FR3A	1,342	12	N/A	N/A	N/A	N/A	$100.00	$50.88	$13.74	$164.62	$18.00	$57.81	$20.82	$96.63

[j] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-13 Industrial plant CCS costs for trunkline system by source location (dome)

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[k]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E200	MS6	512	30/36	$99.00	$10.42	$6.50	$115.92	$100.00	$16.42	$11.93	$128.35	$18.00	$23.71	$17.80	$59.51
	MS6	512	30	$99.00	$10.71	$6.50	$116.21	$100.00	$16.71	$11.93	$128.64	$18.00	$24.00	$17.80	$59.80
	MS6	512	24/30	$99.00	$11.54	$6.50	$117.04	$100.00	$17.54	$11.93	$129.47	$18.00	$24.83	$17.80	$60.63
	MS6	512	20/24	$99.00	$12.48	$6.50	$117.98	$100.00	$18.48	$11.93	$130.41	$18.00	$25.77	$17.80	$61.57
	MS6	512	12	N/A	N/A	N/A	N/A	$100.00	$22.65	$11.93	$134.58	$18.00	$29.94	$17.80	$65.74
	MS3	631	30/36	$99.00	$12.28	$6.53	$117.81	$100.00	$18.28	$12.53	$130.81	$18.00	$25.57	$19.23	$62.80
	MS3	631	30	$99.00	$12.89	$6.53	$118.42	$100.00	$18.89	$12.53	$131.42	$18.00	$26.18	$19.23	$63.41
	MS3	631	24/30	$99.00	$13.96	$6.53	$119.49	$100.00	$19.96	$12.53	$132.49	$18.00	$27.25	$19.23	$64.48
	MS3	631	20/24	$99.00	$15.37	$6.53	$120.90	$100.00	$21.37	$12.53	$133.90	$18.00	$28.66	$19.23	$65.89
	MS3	631	12	N/A	N/A	N/A	N/A	$100.00	$26.95	$12.53	$139.48	$18.00	$34.24	$19.23	$71.47
	LT8	1,061	30/36	$99.00	$18.72	$7.63	$125.35	$100.00	$24.72	$13.20	$137.92	$18.00	$32.01	$19.32	$69.33
	LT8	1,061	30	$99.00	$19.55	$7.63	$126.18	$100.00	$25.55	$13.20	$138.75	$18.00	$32.84	$19.32	$70.16
	LT8	1,061	24/30	$99.00	$21.63	$7.63	$128.26	$100.00	$27.63	$13.20	$140.83	$18.00	$34.92	$19.32	$72.24
	LT8	1,061	20/24	$99.00	$24.54	$7.63	$131.17	$100.00	$30.54	$13.20	$143.74	$18.00	$37.83	$19.32	$75.15
	LT8	1,061	12	N/A	N/A	N/A	N/A	$100.00	$40.86	$13.20	$154.06	$18.00	$48.15	$19.32	$85.47
	FR3A	1,342	30/36	$99.00	$22.96	$5.54	$127.50	$100.00	$28.96	$12.12	$141.08	$18.00	$36.25	$19.30	$73.55
	FR3A	1,342	30	$99.00	$24.06	$5.54	$128.60	$100.00	$30.06	$12.12	$142.18	$18.00	$37.35	$19.30	$74.65
	FR3A	1,342	24/30	$99.00	$26.94	$5.54	$131.48	$100.00	$32.94	$12.12	$145.06	$18.00	$40.23	$19.30	$77.53
	FR3A	1,342	20/24	$99.00	$30.86	$5.54	$135.40	$100.00	$36.86	$12.12	$148.98	$18.00	$44.15	$19.30	$81.45
	FR3A	1,342	12	N/A	N/A	N/A	N/A	$100.00	$50.52	$12.12	$162.64	$18.00	$57.81	$19.30	$95.11

[k] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-14 Industrial plant CCS costs for trunkline system by source location (dome) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[l]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
E100	MS6	446	30/36	$99.00	$8.46	$6.50	$113.96	$100.00	$11.81	$11.93	$123.74	$18.00	$16.26	$17.80	$52.06
	MS6	446	30	$99.00	$8.75	$6.50	$114.25	$100.00	$12.10	$11.93	$124.03	$18.00	$16.55	$17.80	$52.35
	MS6	446	24/30	$99.00	$9.58	$6.50	$115.08	$100.00	$12.93	$11.93	$124.86	$18.00	$17.38	$17.80	$53.18
	MS6	446	20/24	$99.00	$10.52	$6.50	$116.02	$100.00	$13.87	$11.93	$125.80	$18.00	$18.32	$17.80	$54.12
	MS6	446	12	N/A	N/A	N/A	N/A	$100.00	$18.04	$11.93	$129.97	$18.00	$22.49	$17.80	$58.29
	MS3	565	30/36	$99.00	$10.32	$6.53	$115.85	$100.00	$13.67	$12.53	$126.20	$18.00	$18.12	$19.23	$55.35
	MS3	565	30	$99.00	$10.93	$6.53	$116.46	$100.00	$14.28	$12.53	$126.81	$18.00	$18.73	$19.23	$55.96
	MS3	565	24/30	$99.00	$12.00	$6.53	$117.53	$100.00	$15.35	$12.53	$127.88	$18.00	$19.80	$19.23	$57.03
	MS3	565	20/24	$99.00	$13.41	$6.53	$118.94	$100.00	$16.76	$12.53	$129.29	$18.00	$21.21	$19.23	$58.44
	MS3	565	12	N/A	N/A	N/A	N/A	$100.00	$22.34	$12.53	$134.87	$18.00	$26.79	$19.23	$64.02
	LT8	994	30/36	$99.00	$16.76	$7.63	$123.39	$100.00	$20.11	$13.20	$133.31	$18.00	$24.56	$19.32	$61.88
	LT8	994	30	$99.00	$17.59	$7.63	$124.22	$100.00	$20.94	$13.20	$134.14	$18.00	$25.39	$19.32	$62.71
	LT8	994	24/30	$99.00	$19.67	$7.63	$126.30	$100.00	$23.02	$13.20	$136.22	$18.00	$27.47	$19.32	$64.79
	LT8	994	20/24	$99.00	$22.58	$7.63	$129.21	$100.00	$25.93	$13.20	$139.13	$18.00	$30.38	$19.32	$67.70
	LT8	994	12	N/A	N/A	N/A	N/A	$100.00	$36.25	$13.20	$149.45	$18.00	$40.70	$19.32	$78.02
	FR3A	1,275	30/36	$99.00	$21.00	$5.54	$125.54	$100.00	$24.35	$12.12	$136.47	$18.00	$28.80	$19.30	$66.10
	FR3A	1,275	30	$99.00	$22.10	$5.54	$126.64	$100.00	$25.45	$12.12	$137.57	$18.00	$29.90	$19.30	$67.20
	FR3A	1,275	24/30	$99.00	$24.98	$5.54	$129.52	$100.00	$28.33	$12.12	$140.45	$18.00	$32.78	$19.30	$70.08
	FR3A	1,275	20/24	$99.00	$28.90	$5.54	$133.44	$100.00	$32.25	$12.12	$144.37	$18.00	$36.70	$19.30	$74.00
	FR3A	1,275	12	N/A	N/A	N/A	N/A	$100.00	$45.91	$12.12	$158.03	$18.00	$50.36	$19.30	$87.66

[l] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-15 Industrial plant CCS costs for trunkline system by source location (dome) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[m]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W100	MS6	446	30/36	$99.00	$8.46	$6.50	$113.96	$100.00	$12.17	$11.93	$124.10	$18.00	$16.26	$17.80	$52.06
	MS6	446	30	$99.00	$8.75	$6.50	$114.25	$100.00	$12.46	$11.93	$124.39	$18.00	$16.55	$17.80	$52.35
	MS6	446	24/30	$99.00	$9.58	$6.50	$115.08	$100.00	$13.29	$11.93	$125.22	$18.00	$17.38	$17.80	$53.18
	MS6	446	20/24	$99.00	$10.52	$6.50	$116.02	$100.00	$14.23	$11.93	$126.16	$18.00	$18.32	$17.80	$54.12
	MS6	446	12	N/A	N/A	N/A	N/A	$100.00	$18.40	$11.93	$130.33	$18.00	$22.49	$17.80	$58.29
	MS3	565	30/36	$99.00	$10.32	$6.53	$115.85	$100.00	$14.03	$12.53	$126.56	$18.00	$18.12	$19.23	$55.35
	MS3	565	30	$99.00	$10.93	$6.53	$116.46	$100.00	$14.64	$12.53	$127.17	$18.00	$18.73	$19.23	$55.96
	MS3	565	24/30	$99.00	$12.00	$6.53	$117.53	$100.00	$15.71	$12.53	$128.24	$18.00	$19.80	$19.23	$57.03
	MS3	565	20/24	$99.00	$13.41	$6.53	$118.94	$100.00	$17.12	$12.53	$129.65	$18.00	$21.21	$19.23	$58.44
	MS3	565	12	N/A	N/A	N/A	N/A	$100.00	$22.70	$12.53	$135.23	$18.00	$26.79	$19.23	$64.02
	LT8	994	30/36	$99.00	$16.76	$7.63	$123.39	$100.00	$20.47	$13.20	$133.67	$18.00	$24.56	$19.32	$61.88
	LT8	994	30	$99.00	$17.59	$7.63	$124.22	$100.00	$21.30	$13.20	$134.50	$18.00	$25.39	$19.32	$62.71
	LT8	994	24/30	$99.00	$19.67	$7.63	$126.30	$100.00	$23.38	$13.20	$136.58	$18.00	$27.47	$19.32	$64.79
	LT8	994	20/24	$99.00	$22.58	$7.63	$129.21	$100.00	$26.29	$13.20	$139.49	$18.00	$30.38	$19.32	$67.70
	LT8	994	12	N/A	N/A	N/A	N/A	$100.00	$36.61	$13.20	$149.81	$18.00	$40.70	$19.32	$78.02
	FR3A	1,275	30/36	$99.00	$21.00	$5.54	$125.54	$100.00	$24.71	$12.12	$136.83	$18.00	$28.80	$19.30	$66.10
	FR3A	1,275	30	$99.00	$22.10	$5.54	$126.64	$100.00	$25.81	$12.12	$137.93	$18.00	$29.90	$19.30	$67.20
	FR3A	1,275	24/30	$99.00	$24.98	$5.54	$129.52	$100.00	$28.69	$12.12	$140.81	$18.00	$32.78	$19.30	$70.08
	FR3A	1,275	20/24	$99.00	$28.90	$5.54	$133.44	$100.00	$32.61	$12.12	$144.73	$18.00	$36.70	$19.30	$74.00
	FR3A	1,275	12	N/A	N/A	N/A	N/A	$100.00	$46.27	$12.12	$158.39	$18.00	$50.36	$19.30	$87.66

[m] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

Exhibit A-16 Industrial plant CCS costs for trunkline system by source location (dome) - continued

Industrial Plant Capture Rate				3.90 Mt/Yr (Steel)				1.14 Mt/Yr (Cement)				0.65 Mt/Yr (NG Processing)			
Source Location	Storage Reservoir ID	Pipeline Distance mi	Trunkline Diameter in[n]	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS	Capture	Transport	Storage	Total CCS
W200	MS6	512	30/36	$99.00	$10.77	$6.50	$116.27	$100.00	$16.78	$11.93	$128.71	$18.00	$23.71	$17.80	$59.51
	MS6	512	30	$99.00	$11.06	$6.50	$116.56	$100.00	$17.07	$11.93	$129.00	$18.00	$24.00	$17.80	$59.80
	MS6	512	24/30	$99.00	$11.89	$6.50	$117.39	$100.00	$17.90	$11.93	$129.83	$18.00	$24.83	$17.80	$60.63
	MS6	512	20/24	$99.00	$12.83	$6.50	$118.33	$100.00	$18.84	$11.93	$130.77	$18.00	$25.77	$17.80	$61.57
	MS6	512	12	N/A	N/A	N/A	N/A	$100.00	$23.01	$11.93	$134.94	$18.00	$29.94	$17.80	$65.74
	MS3	631	30/36	$99.00	$12.63	$6.53	$118.16	$100.00	$18.64	$12.53	$131.17	$18.00	$25.57	$19.23	$62.80
	MS3	631	30	$99.00	$13.24	$6.53	$118.77	$100.00	$19.25	$12.53	$131.78	$18.00	$26.18	$19.23	$63.41
	MS3	631	24/30	$99.00	$14.31	$6.53	$119.84	$100.00	$20.32	$12.53	$132.85	$18.00	$27.25	$19.23	$64.48
	MS3	631	20/24	$99.00	$15.72	$6.53	$121.25	$100.00	$21.73	$12.53	$134.26	$18.00	$28.66	$19.23	$65.89
	MS3	631	12	N/A	N/A	N/A	N/A	$100.00	$27.31	$12.53	$139.84	$18.00	$34.24	$19.23	$71.47
	LT8	1,061	30/36	$99.00	$19.07	$7.63	$125.70	$100.00	$25.08	$13.20	$138.28	$18.00	$32.01	$19.32	$69.33
	LT8	1,061	30	$99.00	$19.90	$7.63	$126.53	$100.00	$25.91	$13.20	$139.11	$18.00	$32.84	$19.32	$70.16
	LT8	1,061	24/30	$99.00	$21.98	$7.63	$128.61	$100.00	$27.99	$13.20	$141.19	$18.00	$34.92	$19.32	$72.24
	LT8	1,061	20/24	$99.00	$24.89	$7.63	$131.52	$100.00	$30.90	$13.20	$144.10	$18.00	$37.83	$19.32	$75.15
	LT8	1,061	12	N/A	N/A	N/A	N/A	$100.00	$41.22	$13.20	$154.42	$18.00	$48.15	$19.32	$85.47
	FR3A	1,342	30/36	$99.00	$23.31	$5.54	$127.85	$100.00	$29.32	$12.12	$141.44	$18.00	$36.25	$19.30	$73.55
	FR3A	1,342	30	$99.00	$24.41	$5.54	$128.95	$100.00	$30.42	$12.12	$142.54	$18.00	$37.35	$19.30	$74.65
	FR3A	1,342	24/30	$99.00	$27.29	$5.54	$131.83	$100.00	$33.30	$12.12	$145.42	$18.00	$40.23	$19.30	$77.53
	FR3A	1,342	20/24	$99.00	$31.21	$5.54	$135.75	$100.00	$37.22	$12.12	$149.34	$18.00	$44.15	$19.30	$81.45
	FR3A	1,342	12	N/A	N/A	N/A	N/A	$100.00	$50.88	$12.12	$163.00	$18.00	$57.81	$19.30	$95.11

[n] A 12-in diameter pipeline for the steel plant (3.90 Mt/Yr capture rate) is considered a dedicated pipeline since the pipeline capacity is reached with only that source. Therefore, the pipeline cannot accommodate another CO_2 source.

APPENDIX B: BOOSTER PUMP DATA

This appendix includes the number of booster pumps and the pipeline/trunkline distance for pipeline/trunkline segments for the dedicated and trunkline systems based on CO_2 transport rate or trunkline diameter.

Exhibit B-1 Pipeline distance and number of booster pumps for pipeline segments of dedicated system based on CO_2 transport rate

		Number of Pumps					
Pipeline Segment	Distance mi	3.58 Mt/Yr	3.14 Mt/Yr	2.60 Mt/Yr	3.90 Mt/Yr	1.14 Mt/Yr	0.65 Mt/Yr
E200 to MS6	462	7	5	3	8	5	1
E100 to MS6	401	5	4	2	6	4	1
W100 to MS6	303	5	4	2	6	4	1
W200 to MS6	254	4	3	2	5	3	1
E200 to MS3	623	8	6	4	10	7	2
E100 to MS3	561	7	5	3	8	5	1
W100 to MS3	463	7	6	4	9	6	2
W200 to MS3	414	6	5	3	8	5	1
E200 to MS10	348	5	4	2	6	4	1
E100 to MS10	286	4	3	2	4	3	1
W100 to MS10	188	3	2	1	4	3	1
W200 to MS10	139	2	2	1	3	2	0
E200 to LT8	1,071	14	11	7	16	12	3
E100 to LT8	1,009	12	9	6	14	10	3
W100 to LT8	911	14	11	7	17	12	3
W200 to LT8	862	13	10	7	15	11	3
E200 to FR3A	1,358	16	12	8	19	14	4
E100 to FR3A	1,297	14	11	7	17	12	4
W100 to FR3A	1,199	17	13	9	20	14	4
W200 to FR3A	1,150	16	12	8	19	13	4
E200 to RR3	124	2	1	1	3	2	0
E100 to RR3	62	1	0	0	1	0	0
W100 to RR3	62	1	1	0	0	1	0
W200 to RR3	124	3	2	1	3	2	0
E200 to RR4	124	2	1	1	2	1	0
E100 to RR4	62	0	0	0	1	0	0
W100 to RR4	62	1	1	0	1	1	0
W200 to RR4	124	2	2	1	3	2	0

Exhibit B-2 Pipeline distance and number of booster pumps for gathering and distribution lines of trunkline system based on CO_2 transport rate

			Number of Pumps					
Pipeline Segment	Line Type	Distance mi	3.58 Mt/Yr	3.14 Mt/Yr	2.60 Mt/Yr	3.90 Mt/Yr	1.14 Mt/Yr	0.65 Mt/Yr
E200 to HPA	Gathering	121	3	2	2	3	2	1
E100 to HPA	Gathering	121	1	1	1	2	1	1
W100 to HPA	Gathering	55	2	2	1	2	2	1
W200 to HPA	Gathering	55	3	3	2	4	3	1
HIN to MS6	Distribution	30	0	0	0	0	0	0
HIL to MS3	Distribution	30	0	0	0	0	0	0
HMS to LT8	Distribution	30	0	0	0	0	0	0
HTX to FR3A	Distribution	30	0	0	0	0	0	0

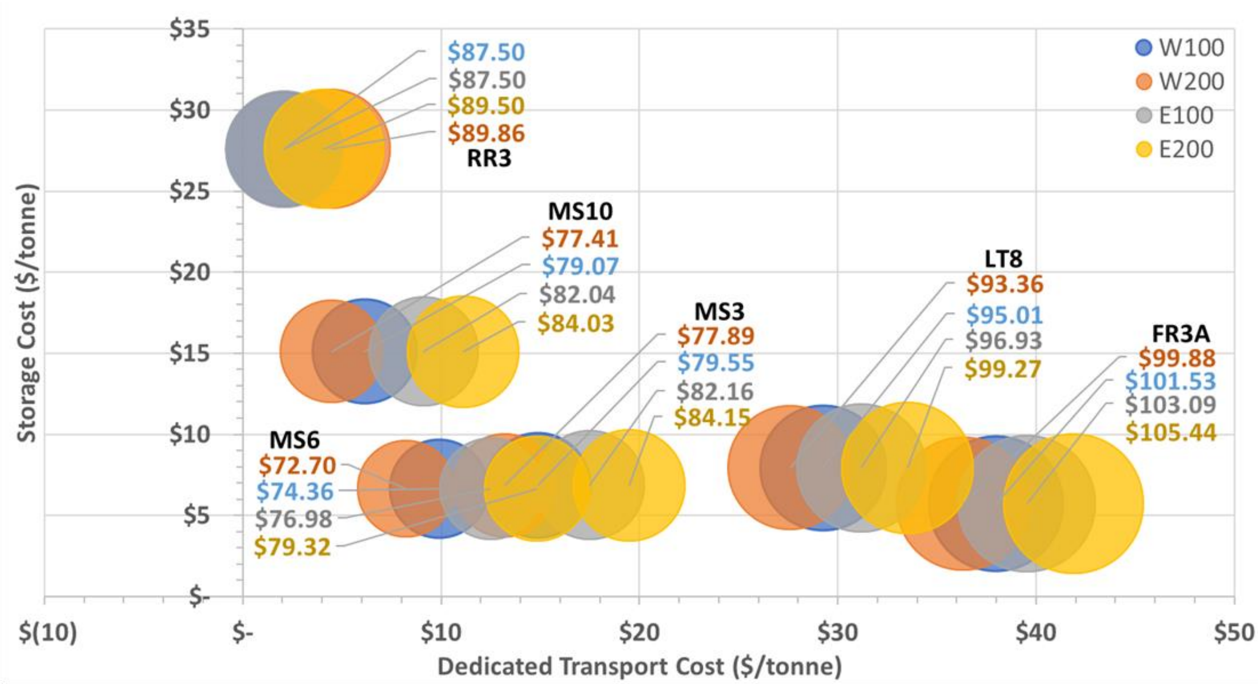
Exhibit B-3 Trunkline distance and number of booster pumps for trunkline segments of trunkline system based on trunkline diameter

		Number of Pumps				
Trunkline Segment	Distance mi	30/36 in	30 in	24/30 in	20/24 in	12 in
HPA-HIN	360	6	4	6	5	6
HIN-HIL	119	1	2	1	1	3
HIN-HMS	549	4	6	9	9	10
HMS-HTX	281	2	3	5	5	6

Appendix C: Additional Charts

This appendix contains additional result charts than those presented in Section 4 for both regional dip and dome structures and both pipeline systems.

Exhibit C-1 Bubble charts depicting the relative CCS costs for electric power plant with 3.58 Mt/Yr capture rate in dedicated (top) and trunkline (bottom) systems (dome, all source locations)



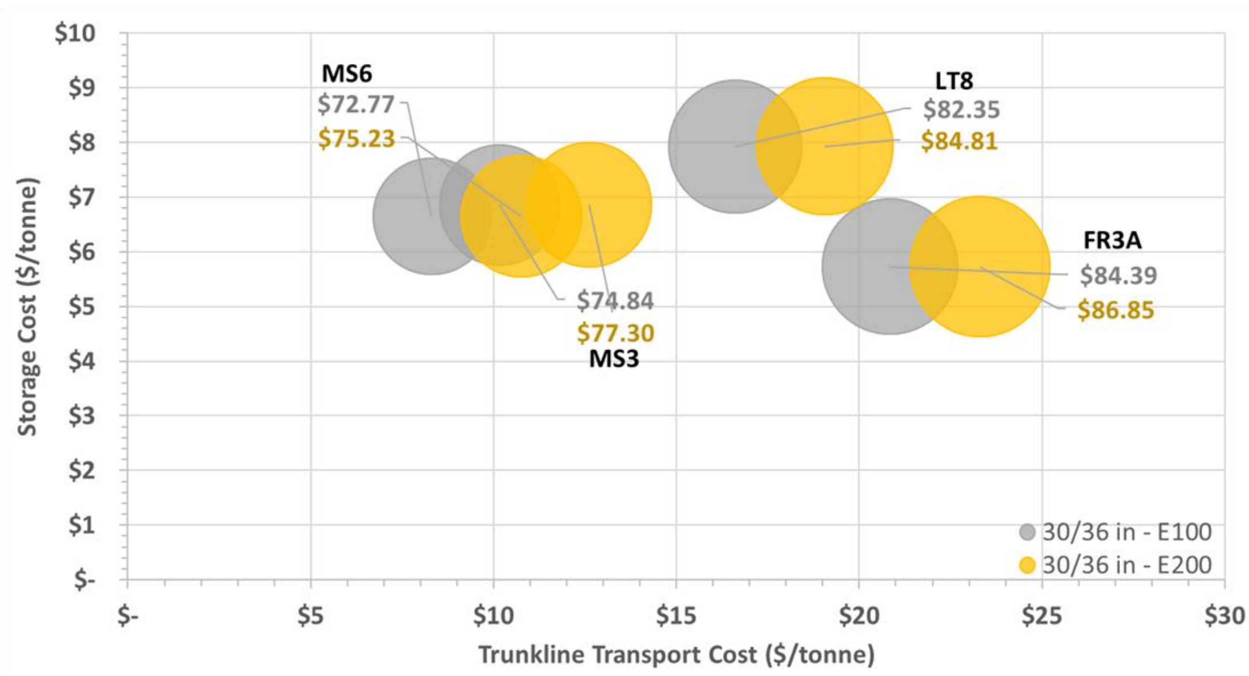
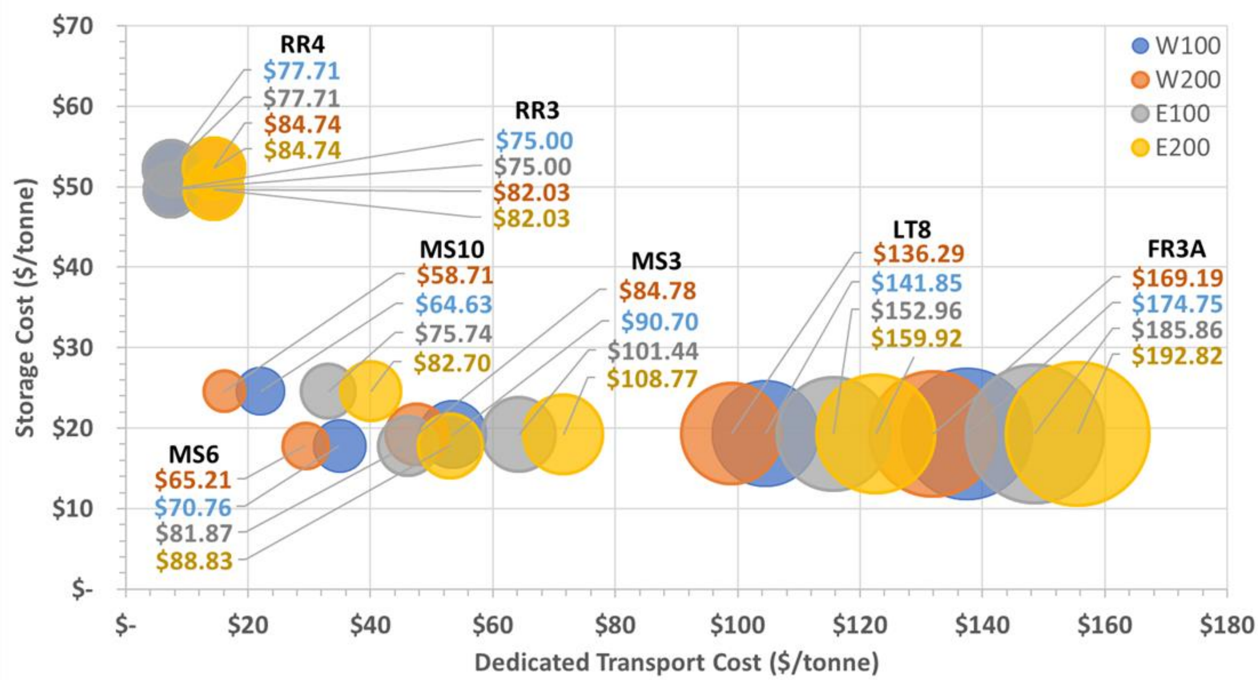


Exhibit C-2 Bubble charts depicting the relative CCS costs for NG processing plant with 0.65 Mt/Yr capture rate in dedicated (top) and trunkline (bottom) systems (dome, all source locations)



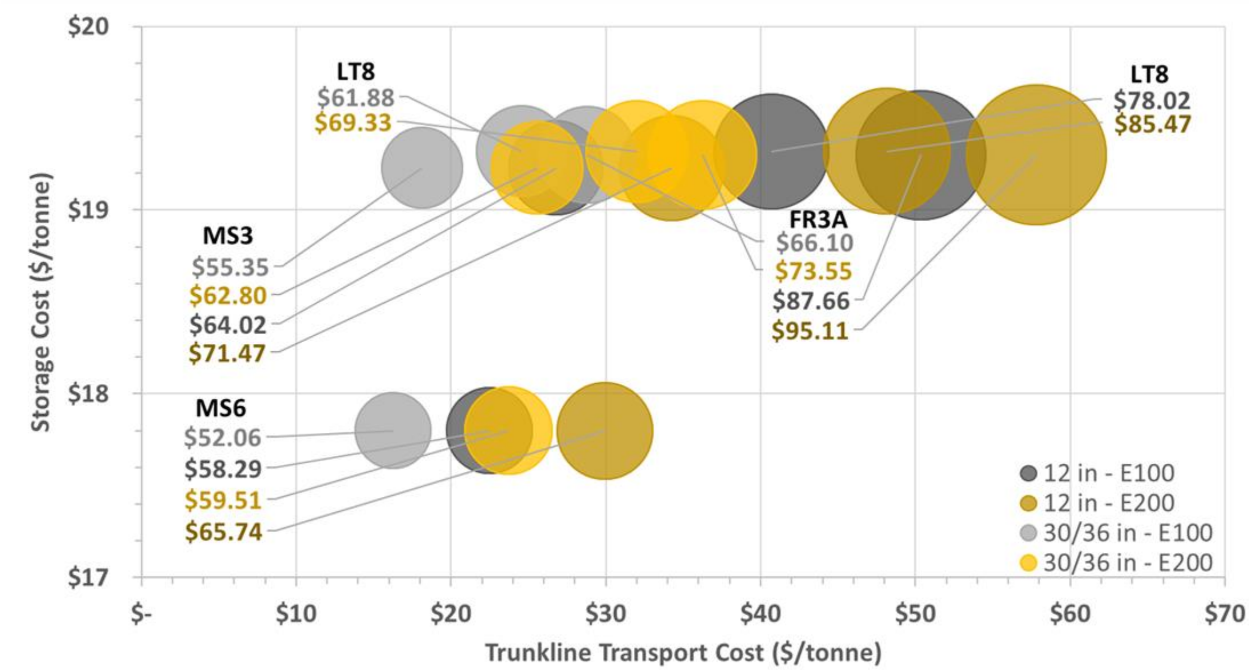


Exhibit C-3 Bar chart showing CCS costs for electric power plants and industrial plants by capture rate for dedicated system (dome, E200)

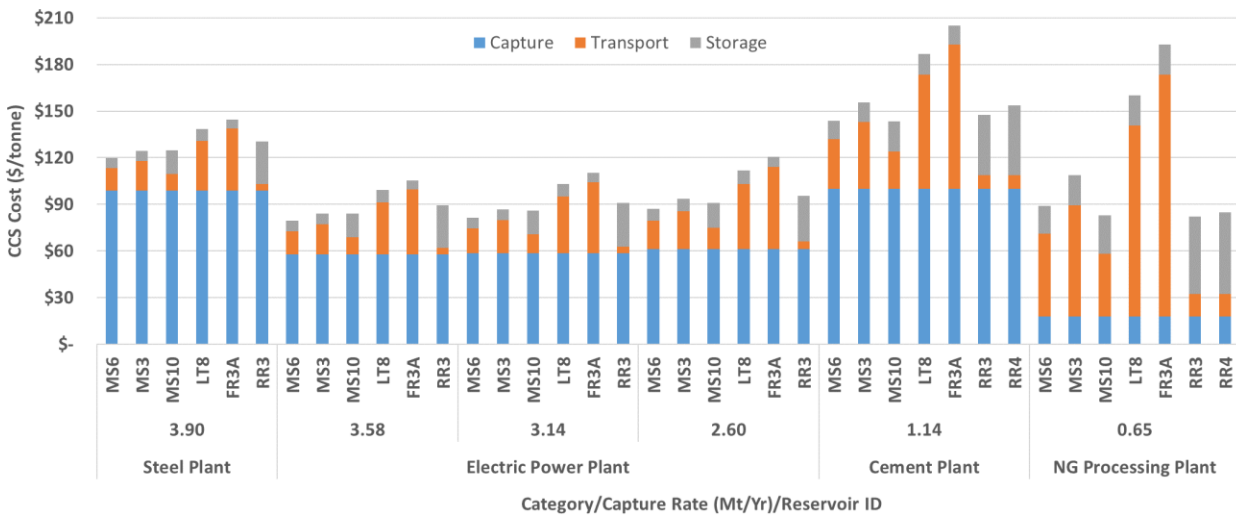


Exhibit C-4 Bar chart showing CCS costs for electric power plants and industrial plants by capture rate for trunkline system (dome, E200)

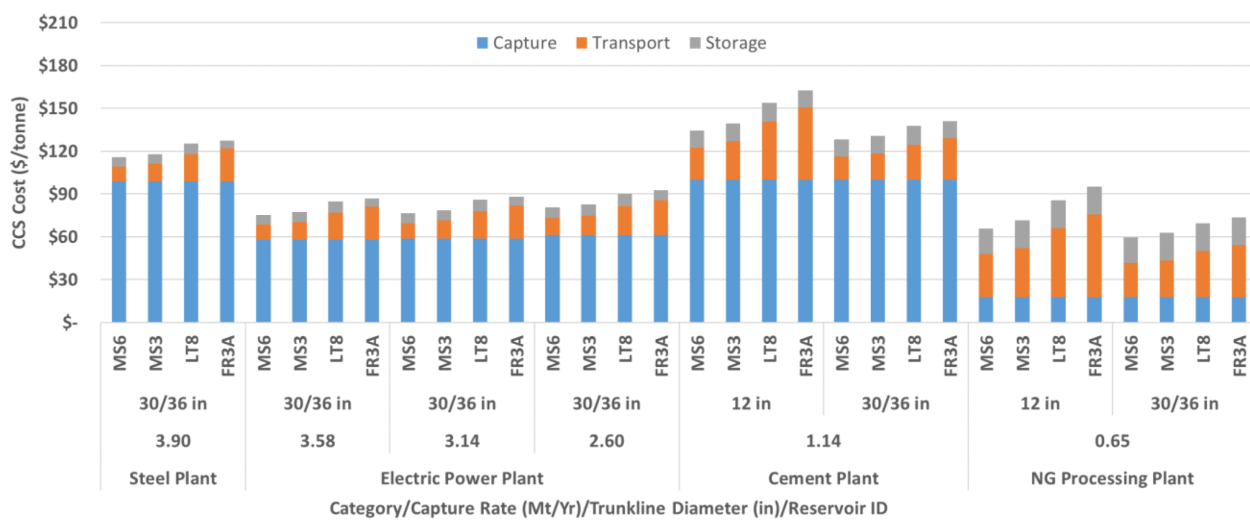


Exhibit C-5 Bar charts showing CCS costs for largest electric power plant and smallest industrial plant for dedicated (left) and trunkline (right) systems (regional dip and dome, E200)

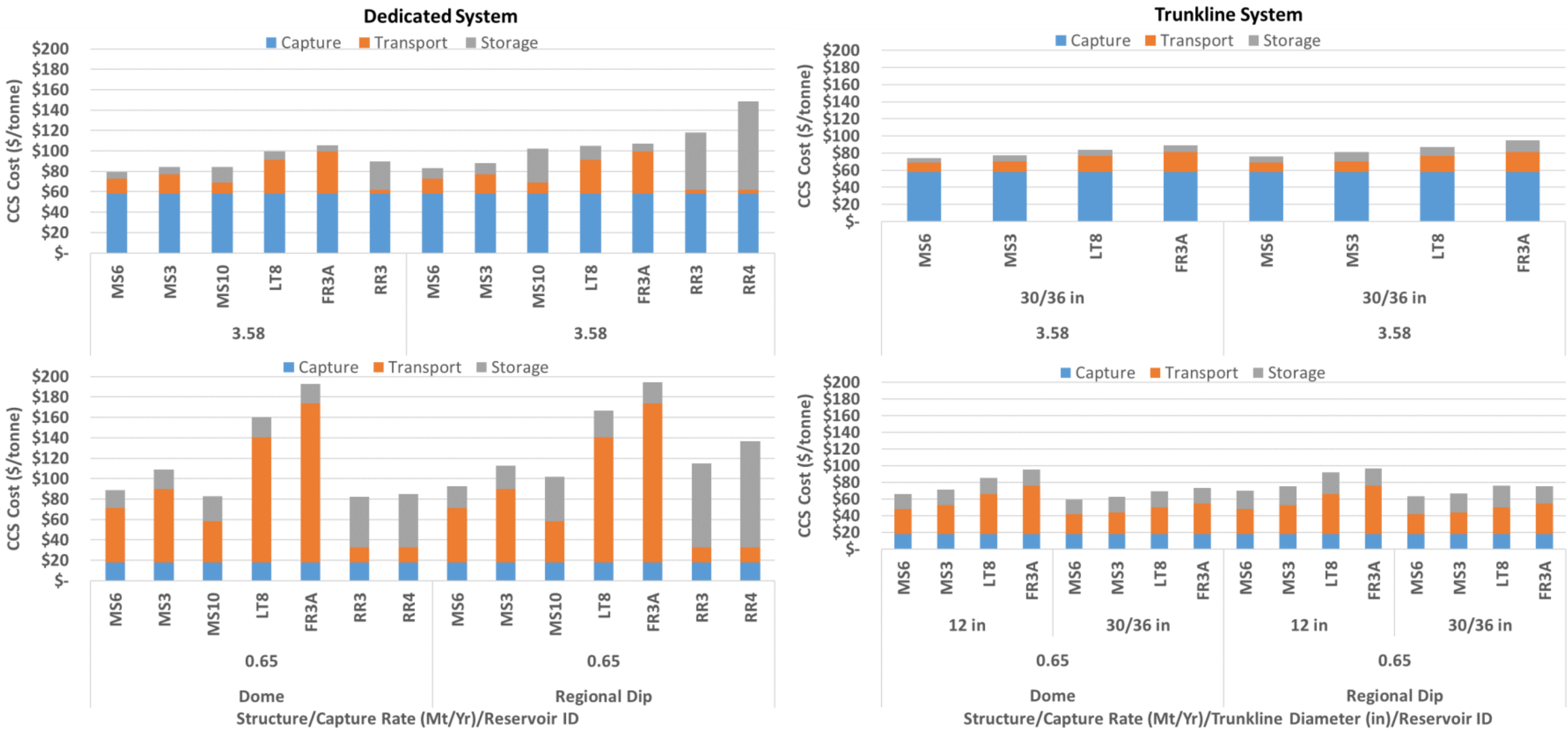
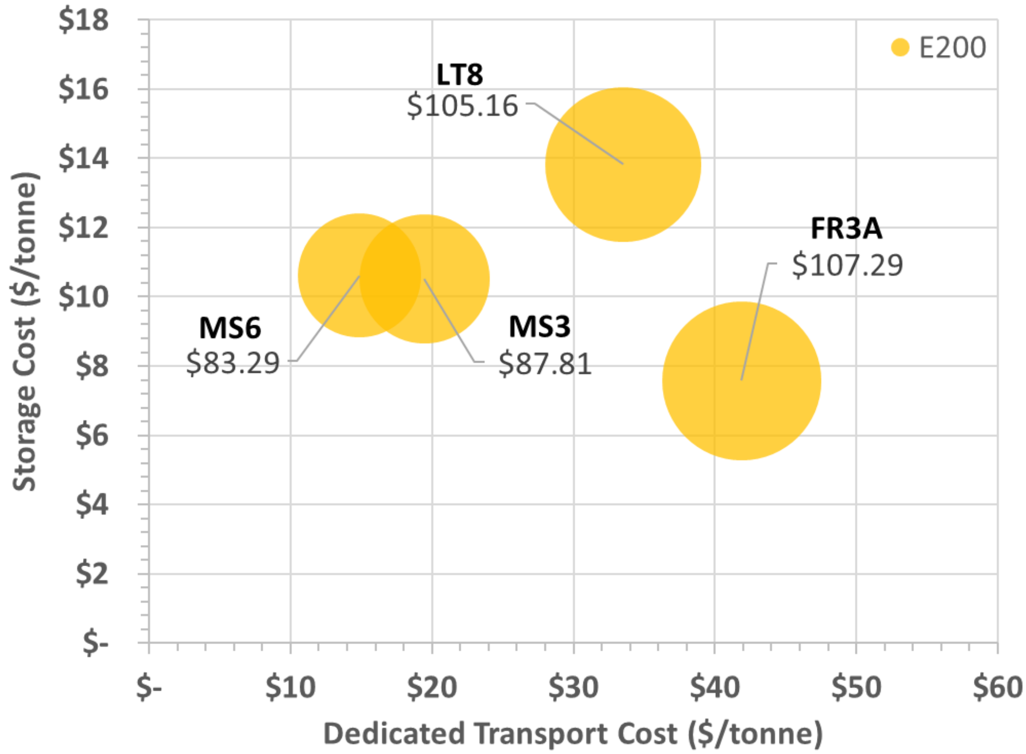


Exhibit C-6 Bubble charts depicting transport and storage costs comparisons between dedicated (top) and trunkline (bottom) systems for electric power plant with 3.58 Mt/Yr capture rate (regional dip, E200)



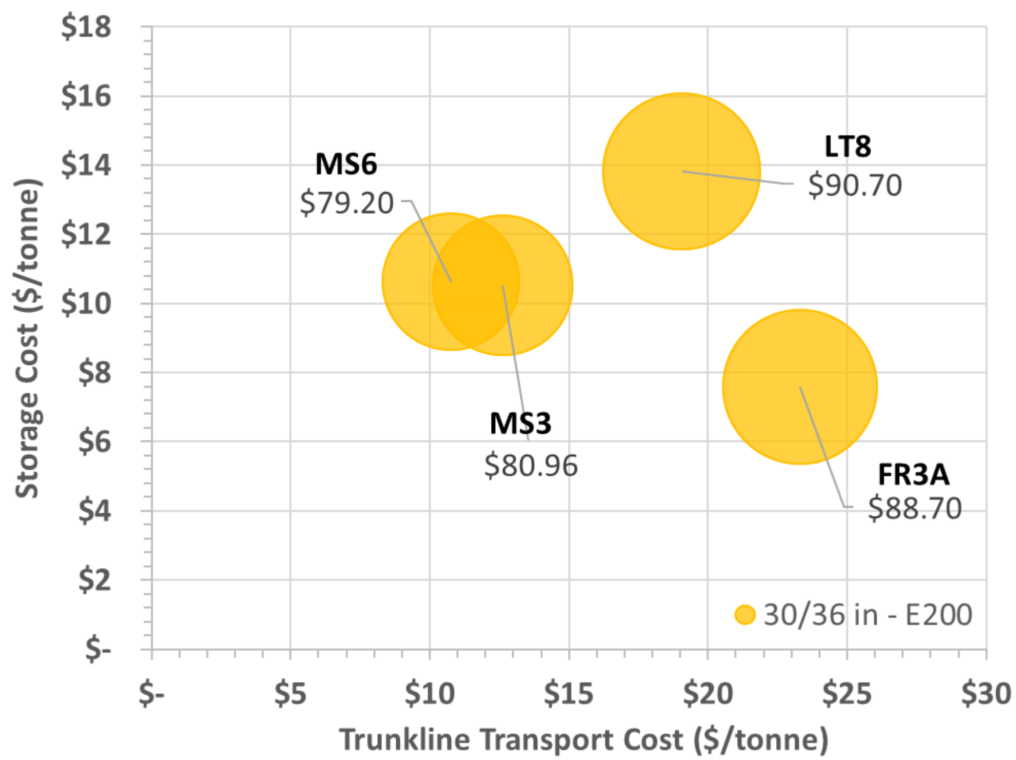
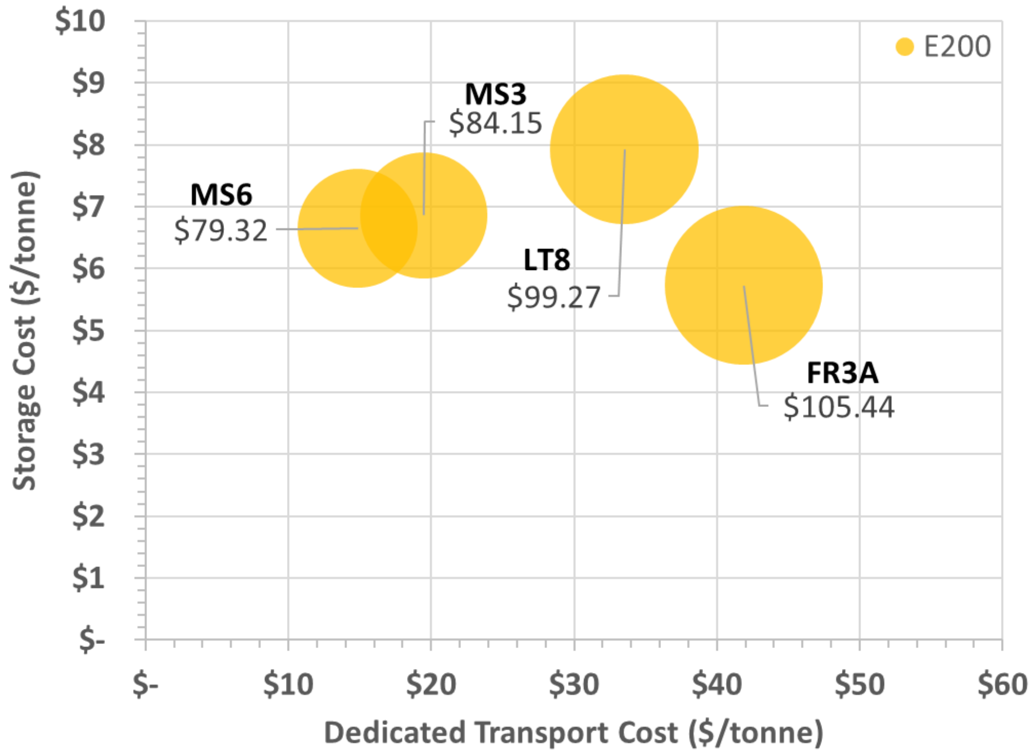


Exhibit C-7 Bubble charts depicting transport and storage costs comparisons between dedicated (top) and trunkline (bottom) systems for electric power plant with 3.58 Mt/Yr capture rate (dome, E200)



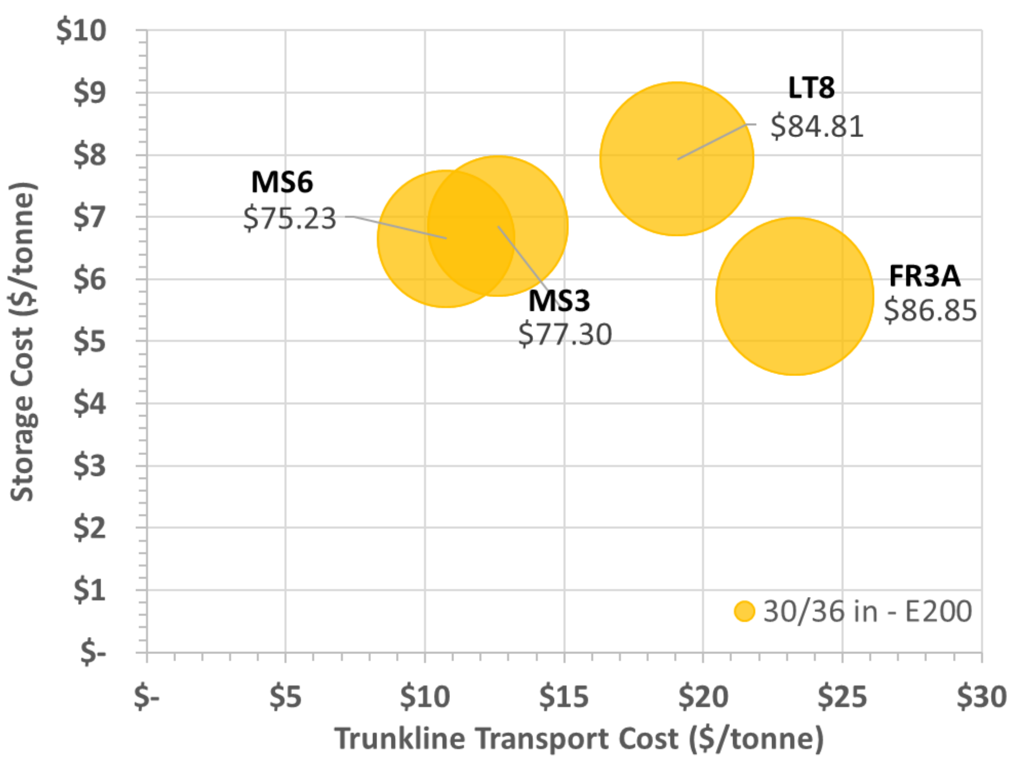
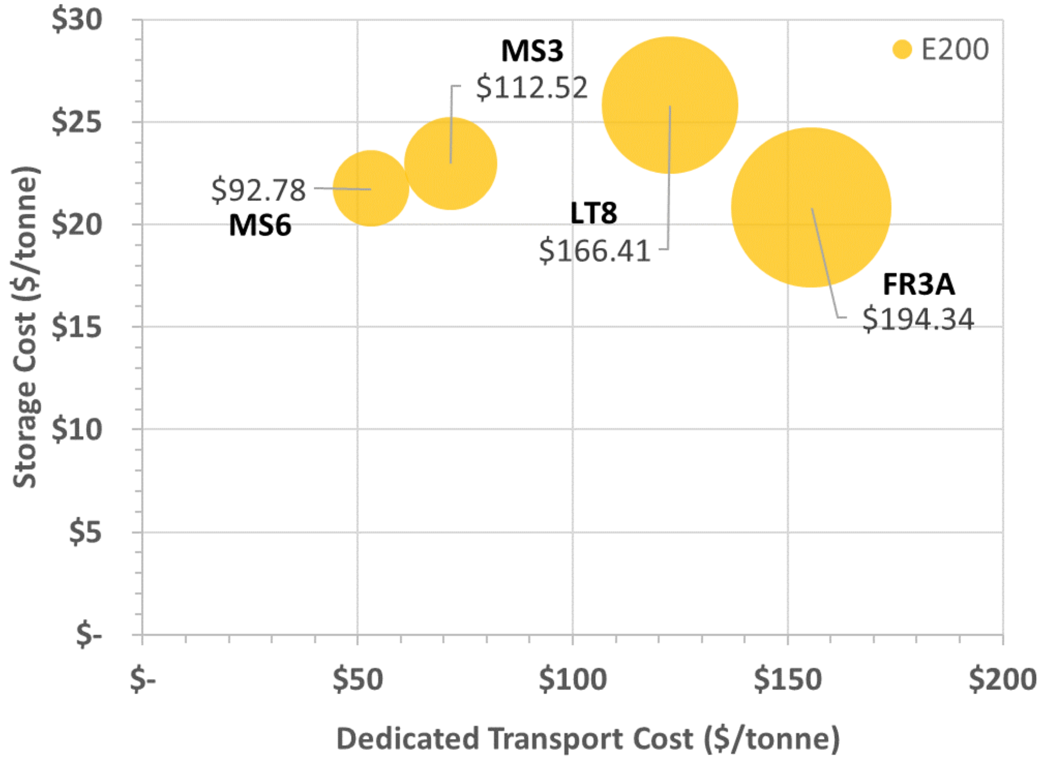


Exhibit C-8 Bubble charts depicting transport and storage costs comparisons between dedicated (top) and trunkline (bottom) systems for NG processing plant with 0.65 Mt/Yr capture rate (regional dip, E200)



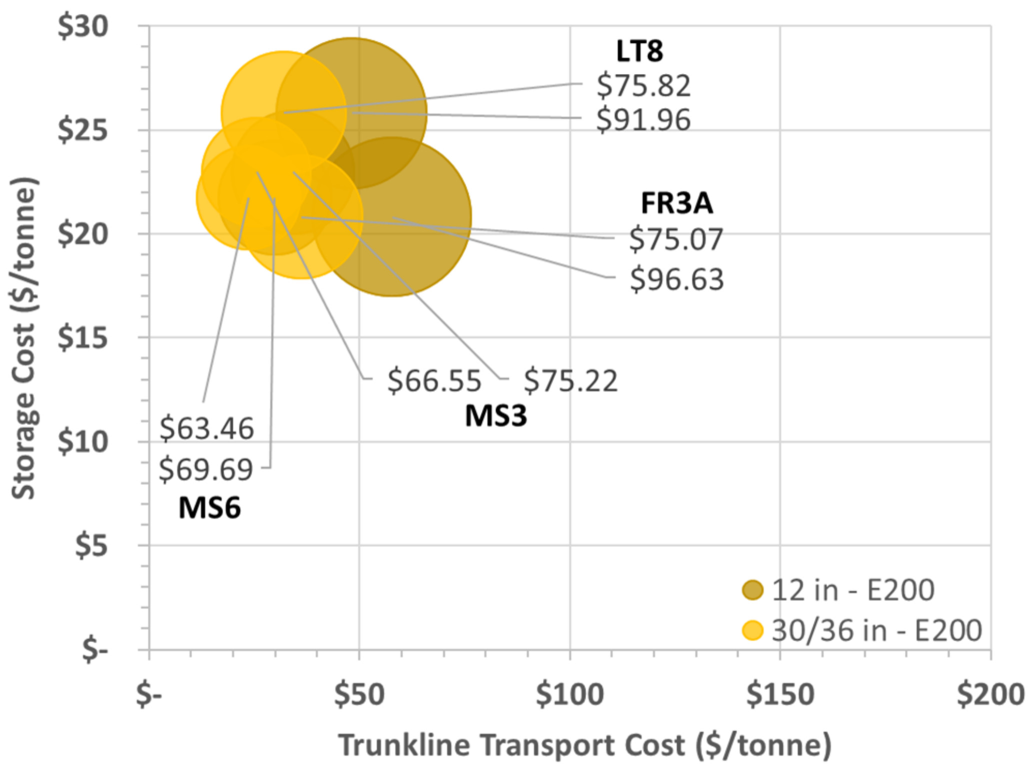
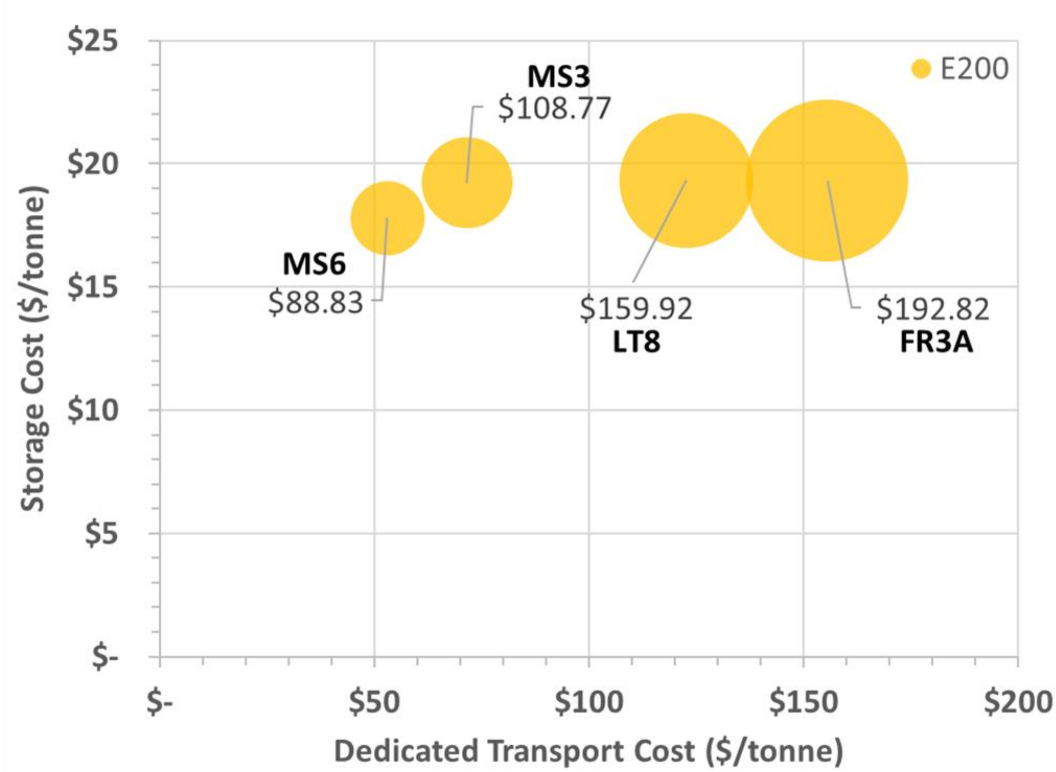


Exhibit C-9 Bubble charts depicting transport and storage costs comparisons between dedicated (top) and trunkline (bottom) systems for NG processing plant with 0.65 Mt/Yr capture rate (dome, E200)



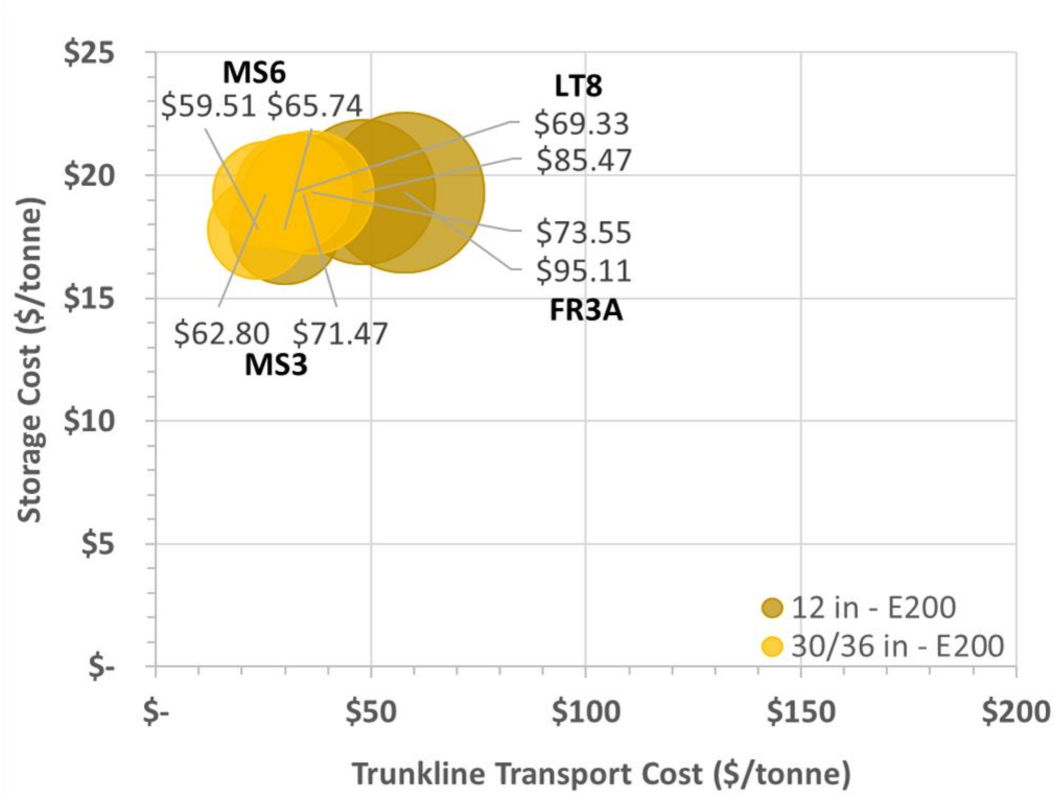
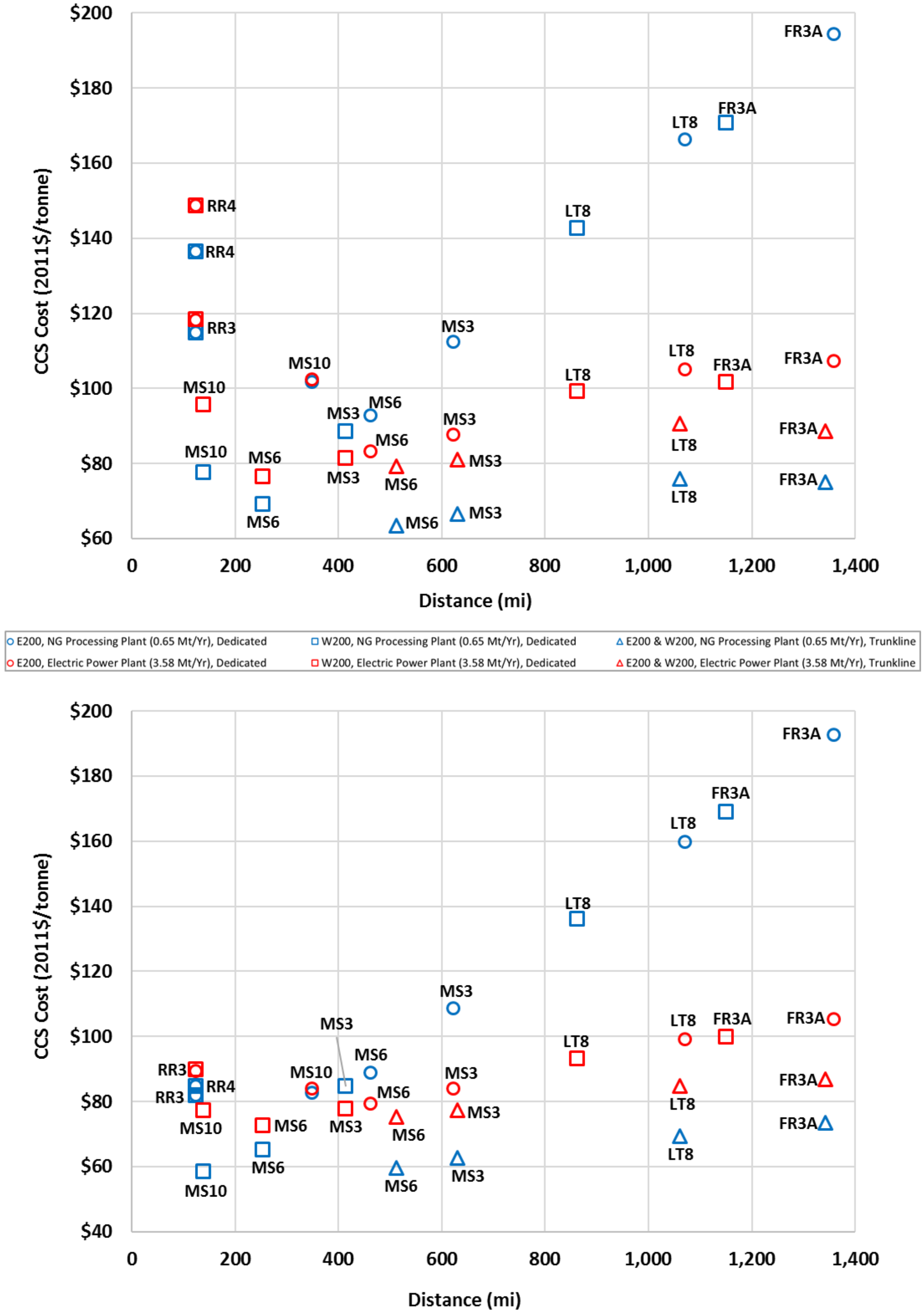
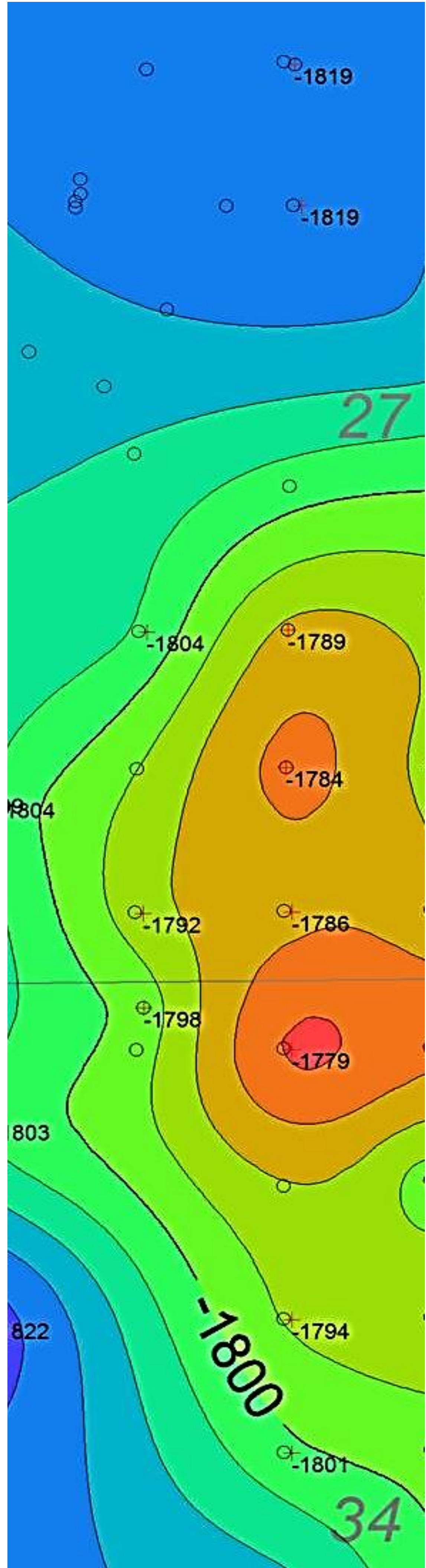


Exhibit C-10 Scatter plot depicting CCS cost vs. distance for NG processing plant (0.65 Mt//Yr) and electric power plant (3.58 Mt/Yr) for both pipeline systems (regional dip – top and dome – bottom, E200 and W200)





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