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CO_2 Storage and Sink Enhancements: Developing Comparable Economics

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ABSTRACT

This paper reports on a project that compared the economics of major technologies and practices under development for CO_2 storage and sink enhancement, including options for storing captured CO_2, such as active oil reservoirs, depleted oil and gas reservoirs, deep aquifers, coal beds, and oceans, as well as the enhancement of biological sinks such as forests and croplands. For the geologic and ocean storage options, CO_2 capture costs from another project were added to the costs of CO_2 storage estimated in this project to provide combined costs of CO_2 capture and storage. Combined costs of CO_2 capture and storage were compared with CO_2 sink enhancement costs on a life-cycle greenhouse gas (GHG) avoided basis. The CO_2 storage and sink enhancement options compared in this project differ greatly in the timing and permanence of CO_2 sequestration. In addressing the timing and permanence issue, a 100-year planning horizon was assumed and the net present value of both costs and revenues was considered. The methods for comparing the economics of diverse CO_2 storage and sink enhancement options are overviewed and representative base-case costs of storage and sink enhancement options are compared.

INTRODUCTION

In order to plan for potential CO_2 mitigation mandates, utilities need better cost information on CO_2 mitigation options, especially storage and sink enhancement options that involve non-utility operations. One of the major difficulties in evaluating CO_2 storage and sink enhancement options is obtaining consistent, transparent, accurate, and comparable economics. This paper reports on a project that compares the economics of major technologies and practices under development for CO_2 storage and sink enhancement, including options for storing captured CO_2, such as active oil reservoirs, depleted oil and gas reservoirs, deep aquifers, coal beds, and oceans, as well as the enhancement of biological sinks such as forests and croplands.

CO_2 CAPTURE AND STORAGE

Methodology

Capture costs were obtained from a DOE/EPRI [1] project that evaluated several CO_2 capture technologies. Integrated gasification combined cycle (IGCC) cases were used as the basis for the capture component of this project. Costs of CO_2 capture were based on differences between reference and capture IGCC plants. Revenue requirement (RR) methodology which is applicable to regulated utilities was used by DOE/EPRI [1] to estimate costs of CO_2 capture. Revenue requirement methodology was also used in this project to estimate CO_2 storage costs so that capture and storage costs could be combined on an equal basis. Storage options were sized to accommodate the CO_2 captured (2.158 Gg CO_2/year) from the IGCC CO_2 capture plant noted above, 404 MW (net), operating at 80 percent capacity factor; 90 percent of the CO_2 produced was captured.

Revenue Requirement Methodology

In the DOE/EPRI [1] project, a levelized RR ($/yr) was calculated for each year of the 20-year book life of the plant as follows:

$$\begin{aligned}\text{Levelized RR} &= \text{Levelized Carrying Charge (LCC)} + \text{Expenses} \\ &= \text{Levelized annual cost of electricity} \qquad (1)\end{aligned}$$

where LCC = Total Plant Cost (or TPC) x Levelized Carrying Charge Factor (or LCCF), and Expenses include O&M and fuel costs. The TPC includes process facilities capital, general facilities capital, engineering and home office overhead, project and process contingencies, and miscellaneous expenses generally included under owners costs. Assumptions in the DOE/EPRI [1] project resulted in a LCCF of 0.15 and an after-tax discount rate of 6.09%. In calculating the costs of storing captured CO_2, the RR methodology for CO_2 capture was generalized to accommodate options for enhanced revenues from CO_2 storage such as enhanced oil recovery (EOR) and enhanced coal bed methane recovery (ECBMR):

$$\begin{aligned}\text{Levelized RR} &= \text{LCC} + \text{O\&M costs} - \text{Enhanced revenues} \\ &= \text{Levelized annual net cost of storing } CO_2 \qquad (2)\end{aligned}$$

GHG Bases for Calculating Costs

Costs ($/Mg C equivalent) were estimated on CO_2 captured, CO_2 avoided, and life-cycle (LC) GHG avoided bases. The LC GHG avoided basis included all significant GHG avoided from cradle to grave, but did not include externalities (i.e., damage assessments). Carbon dioxide avoided and LC GHG avoided via CO_2 capture were estimated based on the difference in CO_2 and LC GHG emissions from reference and capture plants. Carbon dioxide and LC GHG emissions were also estimated for each of the CO_2 storage options evaluated, and CO_2 and LC GHG emissions avoided were estimated for CO_2 capture and storage combined. Combined costs of CO_2 capture and storage were compared with costs of sink enhancement options, forestry and cropland, on a LC GHG avoided basis.

Accounting for Timing Differences: CO_2 Storage vs. Sink Enhancement

The timing and permanence of GHG abatement and the timing of costs differ greatly between CO_2 capture/storage options and CO_2 sink enhancement options. In addressing the timing and permanence issue, a 100-year planning horizon was assumed and CO_2 removals and emissions/leaks were treated as separate events. The idea is that when one removes a ton of CO_2, one receives the current price of CO_2. When a ton of CO_2 is released, the owner of this CO_2 must then purchase a credit from elsewhere at the current price. This approach assumes that CO_2 prices will be set as a result of government policy either through market mechanisms (e.g., a cap and trade system) or in the form of a tax (e.g., a carbon tax). With these assumptions, the cost of CO_2 storage and sink enhancement ($/Mg C equivalent) was calculated as a breakeven C price ($/Mg C equivalent). A breakeven C price was calculated for each CO_2 storage and sink enhancement scenario by setting the sum of discounted C revenues (C price times the amount of C removed) equal to the sum of discounted C storage or sink enhancement costs for the 100-year planning horizon and solving for a breakeven C price.

Base Case Assumptions
Base cases for the geologic storage options assumed a pipeline CO_2 transportation distance of 100 km from the power plant to the storage operation and a well depth of 1220 m for all geologic options except enhanced coalbed methane recovery in which case a well depth of 610 m was assumed. In calculating enhanced oil and gas revenues, wellhead oil and gas prices of $15 per bbl and $2.00 per MBtu, respectively, were assumed. The ocean pipeline and ocean tanker options assumed a pipeline CO_2 transportation distance of 100 km from the power plant to the ocean shore and a pipeline or tanker CO_2 transportation distance of 100 km from the shore to the ocean injection point. An injection depth of 2000 m was assumed for both ocean options. The ocean options were designed on a scale to accommodate CO_2 from three base-case IGCC power plants.

Results

GHG Bases for Calculating Costs
The IGCC capture plant captured 2.158 Gg (million tonnes) CO_2 per year. Compared with the IGCC reference plant, the IGCC capture plant avoided 1.824 Gg direct CO_2 emissions per year, and avoided 1.807 Gg LC GHG CO_2 equivalents per year. Carbon dioxide and LC GHG emissions from the CO_2 storage operations were relatively small (not presented) and were subtracted from CO_2 avoided during capture and LC GHG emissions avoided during capture, respectively, to get CO_2 avoided via capture and storage combined and LC GHG emissions avoided via capture and storage combined.

Costs
Carbon dioxide capture costs were $54/Mg C eq. CO_2 captured, $63/Mg C eq. CO_2 avoided via capture, and $64/Mg C eq. LC GHG avoided via capture. Carbon dioxide capture + net storage costs are presented in Table 1 for base cases on C equivalent stored, C equivalent CO_2 avoided via capture and storage, and C equivalent LC GHG avoided via capture and storage bases. These costs were calculated on an NPV basis for years 1-100. Costs are very similar on CO_2 and LC GHG avoided bases and are significantly higher on these two bases than on the stored basis. The two lowest-cost storage processes are enhanced oil recovery and enhanced coalbed methane recovery, both of which provide enhanced revenues that partially offset costs of CO_2 storage.

TABLE 1

CO_2 CAPTURE + NET STORAGE COSTS FOR BASE CASES

Storage Process	$/Mg C eq. CO_2 stored	$/Mg C eq. CO_2 avoided	$/Mg C eq. LC GHG avoided
Depleted Gas Reservoir	72	85	86
Depleted Oil Reservoir	68	80	81
Deep Saline Aquifer	65	77	77
Enhanced Oil Recovery	12	15	15
Enhanced Coalbed Methane Recovery	34	41	41
Ocean Pipeline	74	86	89
Ocean Tanker	118	141	143

FOREST MANAGEMENT

Case Studies

Additional C can be sequestered in forests by establishing new plantations, restoring existing forests, or by avoiding deforestation.

Cases studies representing a wide range of management types, trees, and geographic locations were included (Table 2).

TABLE 2

FORESTRY CASE STUDIES

Type of Management	Type of Trees	Country/region
Plantation	Loblolly pine	USA (South)
Plantation	Douglas Fir	USA (Pacific NW)
Plantation	Spanish Cedar	Mexico
Restoration	Pine-oak	Mexico
Restoration	Miombo	Southern Africa
Agro-forestry	Mango-Tamarind	India (South)
Avoidance of deforestation	Various	Mexico

Costs

Base-case costs ($/Mg C eq.) are presented in Figure 1 on an aboveground basis (aboveground C/costs) and a life-cycle GHG avoided basis with product revenues (aboveground C + below ground C + product C + non-CO_2 GHG C eq./net costs after product revenues). These two accounting bases bracket the costs ($/Mg C eq.) for each of the cases. Costs are on an NPV basis, 100-year planning horizon. The Mango-Tamarind costs are relatively high on an aboveground basis because costs for the ago-forestry system are high and no credit is taken for the relatively high value agricultural products. The Mango-Tamarind costs are relatively low on the aboveground C + below ground C + product C + non-CO_2 GHG C eq. basis because credit is taken for both more C and products that more than offset costs.

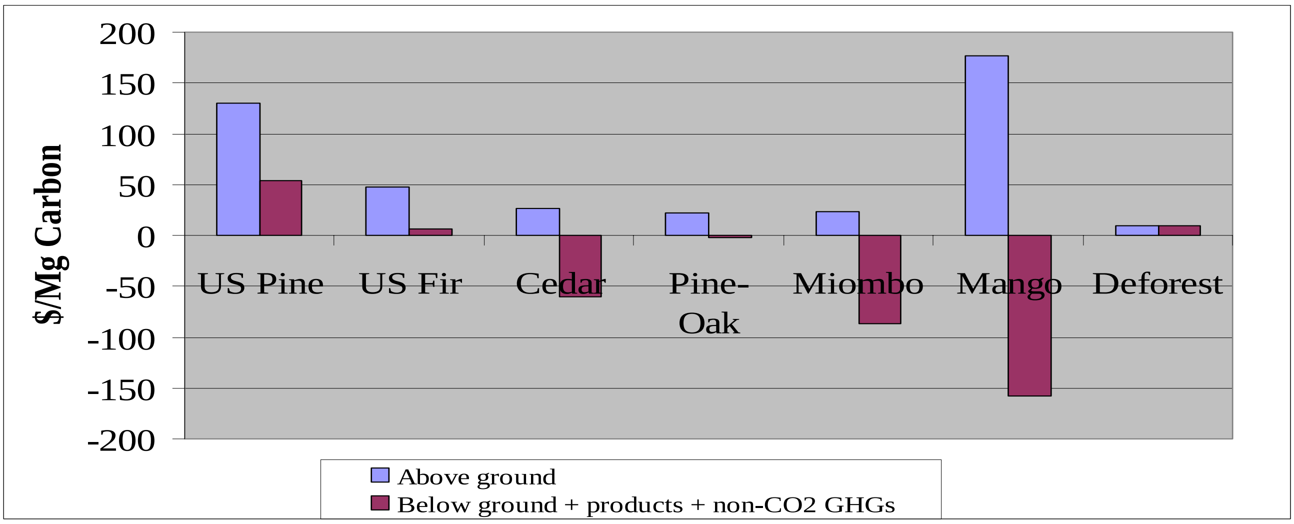

Figure 1. Base-case costs for forestry cases

CROPLAND VIA REDUCING TILLAGE

Reducing tillage on cropland slows the rate of organic matter decomposition and increases soil organic matter levels until a new equilibrium level is attained (typically about 20 to 30 years after shifting from intensive tillage to no tillage). Carbon is sequestered in the added soil organic matter. Reducing tillage reduces equipment and fuel use, increases herbicide use, and can affect the amount of nitrogen fertilizer required and N_2O emissions from the soil. Costs to a utility are an adoption incentive to get farmers to switch from intensive tillage to no-tillage, transaction costs for aggregating and brokering GHG credits, and monitoring costs for assuring that contractual obligations are fulfilled.

Case Studies

Case studies for converting from intensive-tillage to no-tillage agriculture were conducted for the following United States agricultural regions and cropping systems:

- Central Corn Belt (corn/soybean rotation* and continuous corn*)
- Central Great Plains (grain sorghum/soybean rotation and continuous grain sorghum)
- Western Great Plains (wheat/fallow* and wheat fallow to wheat/sorghum/fallow)
- Mississippi Corridor (corn/soybean rotation and continuous cotton*)

These cases represent the range of costs for CO_2 sink enhancement expected due to converting from intensive-tillage to no-tillage on U.S. cropland. Costs ($/Mg C equivalent life-cycle GHG avoided) are a function of the adoption incentive a utility would have to pay farmers to get them to switch from intensive tillage to no tillage system, transaction costs, monitoring costs, and changes in C sequestered in soil organic matter, N_2O emissions from soil, and GHG emissions from crop production inputs. Cases noted with an asterisk represent the range of costs expected from converting from intensive tillage to no tillage on U.S. cropland.

Costs

Base-case costs are presented in Table 3 for cases that represent the range of base-case costs expected from converting from intensive tillage to no tillage on U.S. cropland. These results are presented for cases in which an annual adoption incentive is paid for 5, 10, 15, or 20 years. These costs are based on the assumption that, due to soil quality and crop yield benefits that develop over time, a farmer would continue the no-till practice after the adoption incentive stops.

TABLE 3

BASE-CASE COSTS OF CO_2 SINK ENHANCEMENT—INTENSIVE TILL TO NO TILL

	Corn/soybean	Continuous corn	Wheat/fallow	Continuous cotton
Incentive period, years	Cost (NPV basis, 100-year planning horizon) $/Mg C equivalent life-cycle avoided			
5	30	30	37	54
10	48	51	58	88
15	62	66	73	113
20	72	77	85	132

CONCLUSIONS

For CO_2 storage options, costs are very similar on a CO_2 avoided basis and a LC GHG avoided basis and costs on both of these bases are significantly higher than on a CO_2 stored basis.

Base-case cost ranges on a life-cycle GHG avoided basis are as follows:

- CO_2 capture + net storage costs ($15 to 145/Mg C equivalent avoided)
- Forest management
  --Aboveground basis ($10 to 175/Mg C equivalent avoided)
  --Aboveground + below ground + products basis ($-160 to 55/Mg C equivalent avoided)
- Cropland via reducing tillage
  --Mid-range, 10-year adoption incentive period ($50 to 90/Mg C equivalent avoided)

These base-case cost ranges are non site specific, mid-range estimates to be used as a general indication of costs for CO_2 storage and sink enhancement options. Costs of capturing and storing CO_2 will vary from the base-case estimates in this paper depending on the capture technology used, distance between the capture plant and storage operation, and characteristics of the storage reservoir. Costs of improved forest management for the types of cases presented will vary with forest productivity, land and labor costs inherent in a location, and other local factors. Costs of reducing tillage on US cropland will also vary with local factors. Sensitivities to key variables were included in the final report.

Avoidance of deforestation and enhanced oil recovery are the least cost options in situations where they are practical.

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