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Effect of storage capacity on CO₂ pipeline optimisation

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Abstract

This paper shows the effects of storage capacity on the selection of least cost CO₂ transport infrastructure design where there are two candidate injection sites (sinks) and a static supply of CO₂ (source). We investigate the least cost pipeline configuration under different combinations of CO₂ flow rates, pipeline lengths and storage capacities. A frequency distribution of least cost design shows that the capacity of the smaller sink is one of the main drivers for pipeline design. The insights gained from this study can also be applied in large-scale CO₂ pipeline networks optimisation.

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Keywords: Pipeline design; sink capacity; injectivity

Nomenclature

\begin{align*}
C_i & \quad \text{Capacity for sink } i, \text{ Gt} \\
F & \quad \text{CO₂ flow rate, Mtpa} \\
I_i & \quad \text{Injectivity for sink } i, \text{ Mtpa/well} \\
L_i & \quad \text{Distance between the source and sink } i, \text{ km} \\
T & \quad \text{Time required to fill the small sink using maximum flow rate, years}
\end{align*}

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1. Introduction

Understanding the effect of the uncertainties associated with CO₂ injection on CCS economics is a challenging problem. Although storage accounts for a relatively small part of the total CCS costs [1], the capacity and injectivity of potential storage reservoirs may affect the economics and design of CO₂ capture and transport systems. This is of particular importance when optimising CCS networks because of the timing effects produced by introducing new sources and/or sinks into the transport infrastructure. The storage capacity, injection site location and reservoir properties can all affect the design of CO₂ pipelines, as well as capture and transport costs. For example, if an injection site does not have enough capacity to store the total amount of CO₂ from a capture project, decision makers would need to consider whether to use a larger capacity site, or use the site with small capacity and later switch to a larger capacity site.

Two methodologies have been proposed in the literature for dealing with the effects of storage uncertainties and reservoir properties in the CCS source-sink matching problem. The first approach considers the effect of reservoir properties on transport infrastructure using linear programming models and explores the effect of sink uncertainties using stochastic simulations [2]. This methodology is not applicable to every CCS scenario because the pipeline optimisation model does not take into account re-compression along the pipeline, which would be necessary for longer transport distances. This approach would be acceptable for areas where emission sources and injection locations are relatively close together (such as in the U.S., where the average distance between a source and a potential sink is less than 150 km [3]). However, it may not be applicable for cases such as Australia or Europe, where distances between large emitters and potential sinks can be up to 1,500 km. For long transport distances, recompression is needed and long pipeline distances makes optimal sink selection even more important.

The second approach applies Pinch Analysis for CCS source-sink matching [4]. Using this method, sources and sinks with different capacities and injectivities are connected in a similar way to a heat exchange network for heat sources and cooling fluids. However, this approach assumes that sources and sinks are in the same location. This can significantly under-estimate the cost of the CCS project, as the costs of building and operating the pipeline are ignored. Therefore, pinch analysis offers little insights into optimal CO₂ pipeline network design.

This paper explores least cost pipeline design selection within a set of potential options for a CCS scenario consisting of a static source and two sinks with different properties. The effects of the sink locations and properties on the optimal pipeline design are analysed.

2. Scenarios and assumptions

2.1. Scenarios

The CO₂ transport and injection costs are evaluated for a simple generic CCS chain where there are two candidate injection sites (sinks) and a static supply of CO₂ (source) as indicated in Fig. 1. Two scenarios are considered, each involving one source and two sinks –

- Scenario 1: Both sinks have the same injectivity, but one has a larger capacity and is located further away from the source than the smaller capacity sink;
- Scenario 2: Both sinks are at the same distance from the source with one sink having higher injectivity but lower capacity than the other.
For each of the two scenarios, we consider three design options, as shown in Fig. 2 –
- Option 1 – Using the large sink only (Large Only)
- Option 2 – Using both sinks together (BOTH)
- Option 3 – Using the small sink first and shifting to the large one later (SHIFT).

It may be possible to list other options, such as partially using the smaller sink before the switch, or constructing a pipeline connecting the sinks. However, for simplicity, it is assumed that the relative location and properties of the sinks are such that any other options would result in sub-optimal designs. For example, it can be assumed that the distance between the two sinks is larger than the distance of either sink to the source, or that the topography impedes constructing a pipeline linking the two sinks. Therefore, further options are not considered in this paper.

2.2. Assumptions

The range of input values investigated in this paper are summarised in Table 1. The typical pipeline length used ranges from 150 to 750 km, which covers most of the possible cases for CCS pipeline construction [5]. For example, in North America a large percentage of CO₂ sources and potential sinks are within 150 km [3]. The upper bound for transport distance is applicable to many potential CCS scenarios, particularly in Australia [1]. The nominal pipeline diameters considered range from 100 to 1,500 mm (4–60 in), which are common sizes in the oil and gas pipeline industry.
Table 1. Summary of input variable ranges used in the two scenarios.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1 Equal distance to sinks</th>
<th>Scenario 2 Equal injectivity in sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ flow rate</td>
<td>( F = 24 ) to 36 Mtpa</td>
<td></td>
</tr>
<tr>
<td>Sink capacity</td>
<td>( C_2 &gt;&gt; C_1 ); ( C_1 = 0.25 ) to 0.5 Gt</td>
<td></td>
</tr>
<tr>
<td>Pipeline length</td>
<td>( L_1 = L_2 ); ( L_1 = 150 ) to 750 km</td>
<td>( L_1 &lt; L_2 ); ( L_2/L_1 = 2 ) to 3</td>
</tr>
<tr>
<td>Injectivity</td>
<td>( I_2 = 0.25 ) Mtpa; ( I_1 = 0.5 ) Mtpa</td>
<td>( I_2 = I_1 = 0.5 ) Mtpa</td>
</tr>
</tbody>
</table>

Several typical CO₂ flow rates are selected for this paper, ranging from 24 Mtpa to 36 Mtpa. This range is indicative of the flow rate in a trunk line receiving CO₂ flow from multiple CO₂ sources [1]. In addition, the costs of the CO₂ capture operation are not considered in this paper. This is because capture operations can be optimised separately from pipeline design [1]. The number of wells used for each storage site is calculated by the flow rate divided by the injectivity of the sink. Other assumptions include –

- The distance between the two sinks is larger than the distance of either sink to the source, such that it is not economically attractive to construct a pipeline between the sinks.
- The life time of the project is 25 years.
- The smaller sink does not have enough capacity to store the total amount of CO₂ captured and transported over the life time of the project.

The techno-economic calculations are based on the Integrated Carbon Capture and Storage Economics Model (ICCSEM), developed by UNSW Australia for the CO2CRC. ICCSEM has been thoroughly validated and benchmarked, and has been found to be in good agreement with other published studies [6]. Further details about the assumptions used in this model are available elsewhere [7].

3. Cost drivers and distribution of the optimal design

3.1. Cost drivers

Fig. 3. Cost trends for the three design options under scenario 2, for the case with \( F = 30 \) Mtpa, \( C_1 = 0.5 \) Gt, \( C_2 = \infty \), \( L_1 = 150 \) km and \( L_2 = 300 \).
For each combination of input variables within each case, the minimum levelised transport and storage cost is obtained for the three design options using ICCSEM. The design with lowest cost out of the three options is then identified. Fig. 3 shows the cost trends for the different design options, for a specific case under scenario 2. Other cases under the two scenarios follow the same cost trends. The cost of the “Large Only” option is constant because the capacity of the small sink does not affect the design of this option. In contrast, the costs for the “BOTH” and “SHIFT” options decrease as the capacity of the small sink increases. In addition, the rate of decrease of the cost of the “BOTH” option appears to decline when the time required to fill the small sink is more than 12 years. This is because the economies of scale in pipeline costs reach a limit if the flow rate transported to both sinks is equal.

Fig. 3 also shows that around point T1, the “Large Only” design option should be used because it has the lowest cost. Around point T2 the “BOTH” design option results in the lowest cost, whereas around point T3 the “SHIFT” option is cheapest. Fig. 4 shows the cost breakdown for the lowest cost design options at points T1, T2 and T3. It can be seen from Fig. 4 that the “BOTH” option (at time T2) has the highest compression costs, as two pipelines are in operation and so two sets of compressors are required throughout the project. Whereas, the “SHIFT” option (at time T3) has the highest injection costs because this option requires the largest number of wells to be drilled.

3.2. Frequency distribution of optimal designs

By calculating the optimal costs of all the cases under the two scenarios in Table 1, the probability of each individual design option being the lowest cost option can be estimated. Fig. 5 depicts these results as a probability distribution for each design option against the time required to fill the small sink using the maximum flow rate (T). For both scenarios (described in Table 1), the time to fill the smaller sink drives the optimal injection strategy. More specifically –

- If the small sink cannot hold at least 6 years of total captured emissions, it should not be used. This is because the extra cost of developing a second, smaller storage site cannot be economically justified because of its low storage capacity.

- The “BOTH” design option has a higher chance of being used if the small sink can hold between 10 and 18 years of total captured emissions. The reasons for this are different for the two scenarios considered.
Scenario 1, with equal distance to each sink, developing both sites in parallel means the total injection cost is lower as the small sink has better properties. Whereas in Scenario 2, with equal injectivity, building one long pipeline with a large diameter costs more than building two smaller diameter pipelines – one of which is shorter than the other.

- The small sink will always be used if its capacity is equivalent to more than 14 years’ worth of total captured emissions. Further, the “SHIFT” option becomes increasingly attractive because of the effect of discounting on the cost of developing the pipelines and wells for the larger site.

Fig. 5. Effect of small sink size on the probability that each of the design options has the lowest cost for both the equal distance and equal injectivity scenarios.

4. Conclusions

In this paper, the lowest cost pipeline configuration and injection site selection strategy was investigated under different combinations of CO₂ flow rates, pipeline lengths and storage capacities. The economics of three possible transport and storage options are discussed for each case, including (a) using only a larger sink, (b) using two sinks concurrently throughout the project life cycle, and (c) initially using a smaller sink that is closer and then switching to a larger sink at a later stage. The preliminary results indicate that, under some circumstances, there are benefits for using a sink with less capacity than the project requires. For example, shifting injection from a small sink to a large sink is attractive if the small sink has enough capacity to store more than 15 years’ worth of total emissions. However, the large sink should be used alone if the small sink can only store the total captured CO₂ flow rate for less than 6 years. The insights gained from this study can be used in multiple-source multiple-sink network optimisation.

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