Investigating the variation in CO$_2$ sequestration supply curves

The MIT Faculty has made this article openly available. Please share how this access benefits you. Your story matters.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>As Published</td>
<td><a href="http://dx.doi.org/10.1016/j.egypro.2011.02.184">http://dx.doi.org/10.1016/j.egypro.2011.02.184</a></td>
</tr>
<tr>
<td>Publisher</td>
<td>Elsevier</td>
</tr>
<tr>
<td>Version</td>
<td>Final published version</td>
</tr>
<tr>
<td>Accessed</td>
<td>Sat Dec 29 14:22:44 EST 2018</td>
</tr>
<tr>
<td>Citable Link</td>
<td><a href="http://hdl.handle.net/1721.1/95841">http://hdl.handle.net/1721.1/95841</a></td>
</tr>
<tr>
<td>Terms of Use</td>
<td>Creative Commons Attribution</td>
</tr>
<tr>
<td>Detailed Terms</td>
<td><a href="http://creativecommons.org/licenses/by-nc-nd/3.0/">http://creativecommons.org/licenses/by-nc-nd/3.0/</a></td>
</tr>
</tbody>
</table>
Investigating the variation in CO$_2$ sequestration supply curves

Antonio C. Baclig$^{a1}$, Ernst A. van Nierop$^a$, Charles M. Brankman$^a$, Robert W. Selover$^a$, Kurt Z. House$^{a,b}$

$^a$C12 Energy, 2054 University Avenue Suite 400, Berkeley, CA 94704, USA
$^b$Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Abstract

CCS projects that can bring together all pieces of the system—capture, transport, and storage—at the lowest cost will likely be the first to become operational. We have modeled the cost per tonne of CO$_2$ of a geologic sequestration system that stores CO$_2$ in saline aquifers in the United States. The model includes aspects of capture, transport, storage, and finance, and we present the sensitivity of the model to various source- and sink-specific parameters. From our cost model we developed CO$_2$ sequestration supply curves for CO$_2$ sources within 100 miles of nine identified CO$_2$ sinks in the Illinois Basin. The supply curves present the amount of CO$_2$ that can be sequestered under current economic and technical conditions at a given CO$_2$ price, and can and should be used by policy makers and commercial organizations to determine the most economical combinations of sources and sinks for CCS on national, regional, and local levels.

1. Introduction

Climate change is happening. According to the Intergovernmental Panel on Climate Change’s 2007 Synthesis Report, limiting a global average temperature increase to 2.0-2.4°C will require CO$_2$ emissions reductions of 50-85% of year 2000 levels by 2050 [1]. Much work has been performed on the most cost-effective ways of reducing CO$_2$ emissions, with geologic sequestration of CO$_2$ emerging as a cost-competitive tool for deep emissions cuts [2]. A successful CO$_2$ geologic sequestration project, however, will require bringing together all pieces of the system—capture, transport, and storage. This coordinated infrastructure must operate at a cost that is less than or comparable to other carbon mitigation options for CCS to make sense.
CO₂ supply curves can be constructed to depict how much CO₂ can be sequestered at or below a given CO₂ price. Such a supply curve including more than 2,000 stationary CO₂ sources across the United States and Canada showed that the majority of CO₂ emissions from those sources can be transported and stored for less than $15/tCO₂ [3]. An example supply curve (Figure 1) containing projects for possible CCS projects that we have modeled from across the United States shows an order of magnitude variation in CO₂ sequestration costs per tonne of CO₂. Supply curves such as these, which visually display the amount of CO₂ that can be sequestered under current economic and technical conditions at a given CO₂ price, are important decision-making tools for policy makers and commercial organizations. A complete picture of the technical CCS potential in the United States would be given by a supply curve of viable projects that includes all costs of the systems, from capture to transport and storage. However, such a national or regional supply curve hides the variation in CO₂ supply curves on local levels [4], and therefore limits information about the areas in which CCS would be most economical.

We have modeled the cost per tonne of CO₂ of a system for geologic sequestration in saline aquifers in the United States, including capture (e.g., source-type specific capture costs), transport (e.g., pipeline and right-of-way costs), storage (e.g., characterization costs, well costs, and monitoring costs), and finance (e.g., weighted average cost of capital). We examine the sensitivity of the cost model to various parameters. From our cost model, we have developed CO₂ sequestration supply curves for sources close to various sequestration targets. Here we present supply curves for nine sequestration targets identified in the Illinois Basin, an area that has high geologic sequestration potential, a large number of coal-fired power plants, and significant CCS development activity. The variation in these supply curves indicates that the locations and properties of CO₂ sources and sinks will create a large variation in local costs of abating CO₂ emissions.

2. Cost Model

Our cost model is based on technical reports and proprietary cost estimates. For the capture costs, our model assumes that a coal power plant employs current-generation amine scrubbing with steam for the stripper taken from the steam cycle, and therefore an energy cost determined by the plant’s generation cost. We use a scaling factor to estimate the cost of the capture unit at different levels of CO₂ flow. For each power plant modeled, a capture unit was assumed to be sized for 90% capture of the entire power plant’s CO₂ production. The model does not treat
capture from natural gas-fired power plants or other industrial facilities with low-concentration CO2 streams (e.g. cement plants, iron and steel smelters) because coal plants, as the largest emitters of CO2, were considered to be the most likely near-term users of CO2 capture systems. Costs for the CO2 avoided from coal power plants were calculated based on a comparison of the carbon intensity of the coal plant before and after the installation of CO2 capture. For industrial facilities that emit near-pure streams of CO2 (e.g. ethanol plants, natural gas processing plants, and refineries), the capture system only includes a dehydrator. For all sources, CO2 compression to 120 bar for pipeline transport is assumed. Pipeline costs were taken from the “conservative” estimate developed by McCollum and Ogden [5] and depend on the CO2 flow-rate in the pipeline. Costs for geologic characterization, injection, monitoring, and bonding were taken from the U.S. EPA [6]. For financing, all models here assume a 30-year debt and project lifetime, and a weighted-average cost of capital (WACC) of 12%.

3. Selection of CO2 Sources and Sinks in the Illinois Basin

We modeled CCS costs for nine CO2 sinks and 63 CO2 sources in the Illinois Basin. The Illinois Basin contains a regionally extensive layer of Mt. Simon Sandstone that has been the focus of intensive studies for use in geologic CO2 sequestration [7]. From a comprehensive listing and description of over 450 structures that were identified in Illinois [8] and data from the Illinois Oil and Gas Resources [9], we compiled parameters on the aerial extent, structural closure, and depth of the Mt. Simon, the carbon storage reservoir of interest for these nine targets. Only sequestration in deep saline aquifers (specifically, the Mt. Simon sandstone) was considered because estimates of the CO2 capacity in saline aquifers typically greatly exceeds that in other types of reservoirs such as EOR fields (for example, a Illinois State Geological Survey (ISGS) study found that saline reservoirs accounted for 88% of the estimated capacity [10]). Structural closure was assumed to be necessary to confine the CO2 both vertically and horizontally to a well defined region. The sink-specific aerial extent, reservoir depth, and reservoir thickness (taken as the thickness of closure) of each sink were input in the cost model. Due to lack of location-specific information on reservoir properties, the permeability at all sinks was assumed to be 25 mD.
Forty-four existing coal-fired power plants, 16 ethanol plants, and three refineries were identified within 100 miles of these nine sequestration targets. The CO₂ emissions for each source were calculated based on standard carbon content of coal [11], CO₂ produced from fermentation to produce ethanol [12], and any hydrogen production from refineries, which was assumed to require a steam methane reformer and thus emit a pure stream of CO₂. For all sinks, only the sources within 100 miles of that sink were modeled.

4. Results and Discussion

Figure 3 shows supply curves for the nine CO₂ sinks. Although the supply curves show the same characteristic shapes, the variation between them will likely be significant for the development of CCS projects in Illinois. For example, over 50 Mt/yr can be made available at sink 6 for less than $60/tCO₂; however, an order of magnitude less, ~5 Mt/yr can be made available for less than that amount at sink 7. On the other hand, because of the proximity of ethanol plants, more than double the CO₂ flow is available at sink 7 for $25/tCO₂ (~2 Mt/yr) as at sink 6 (<1 Mt/yr). Not only the amount of CO₂ that can be sequestered at a given price, but also the number of CO₂ sources that can sequester at that price should be taken into account, because some sources may have high CO₂ emissions but for some reason be unsuitable for CCS, thereby skewing the CCS potential for a CO₂ sink. For example, although sink 9 has the potential for 20 MtCO₂/yr of storage for less than $55/tCO₂, the majority of that comes from one large source; if that source does not implement CCS or sequesters at another sink, the cost of CO₂ at sink 9 will increase by at least $10/tCO₂. By contrast, sinks 1, 2, and 4 have three large CO₂ sources that can sequester for less than $60/tCO₂. The CO₂ quantities, prices, and number of sources should be considered when determining a location’s CCS potential.

On each supply curve is an estimate for the average yearly capacity of the CO₂ sink assuming a 30 year lifetime. Due to limited information on the spatial variability of the porosity of the Mt. Simon the capacities of each sink were estimated by multiplying the areal extent by half of the thickness and assuming a 10% porosity in each case. The capacity variation in sinks again affects their CCS development potential. Sink 7 only has enough capacity for the near-pure streams of CO₂ that would cost less than $25/tCO₂, whereas sink 6 would have sufficient estimated capacity for a GW-scale coal power plant. Comparing the combined 30 year average yearly capacity of the CO₂ sinks (24 Mt/yr) to the combined emissions rates of the CO₂ sources (204 Mt/yr) suggests that many more sinks will be needed if all of these sources were to continue to operate in a CO₂-constrained world. A similar study performed by the ISGS for the entire Illinois Basin found sinks with a combined 30 year average yearly capacity of 157 Mt/yr, and 283 Mt/yr of emissions from the region [10]. Studies such as these indicate that, at least in the Illinios Basin, geological CO₂ sequestration can facilitate a large reduction in emissions, but cannot account for all of the emissions from the regional CO₂ sources.

---

2 Note that two of the three refineries did not produce hydrogen according to the National Petrochemical and Refiners Association’s 2009 “United States Refining and Storage Capacity Report,” and thus were not modeled; all the CO₂ from those facilities was assumed to be emitted at low concentrations and therefore to be expensive to capture.
Figure 3 Supply curves for the nine CO₂ sinks, the boxed number in the top-left corner of each plot referring to the number of the sink in Figure 3. Red dotted lines indicate estimated capacities for each sink averaged over 30 years. On top are the supply curves for up to 50 Mt/yr of CO₂ supply. On bottom are supply curves for near-pure CO₂ stream sources (ethanol plants and refineries).
5. Sensitivity of the Cost Model

To determine the factors that most affect the variation in CCS prices, we studied the sensitivity of the cost model to various parameters. Figure 4 shows the sensitivity of the overall cost per tonne of CO₂ avoided for a coal power plant and a pure stream emitter (base cases) to 10% changes in the studied parameters. For coal power plants, the parameters investigated for sensitivity were the net capacity of the plant, the efficiency without CCS, the assumed availability (capacity factor), the variable cost of production (including fuel and variable operating and maintenance), the pipeline distance, the contingency added for the capture unit, the WACC, the capital cost of the absorber, and the capital cost of the stripper. No sink-specific parameters were included in the sensitivities investigated for coal power plants because they did not make a significant difference in overall cost, the costs being dominated by the capture system. The comparison of sensitivities shows that, given the same distribution in all parameters, the WACC and the availability of a power plant (which directly affects how much CO₂ is captured and avoided) will make the largest difference in system costs, suggesting that the ability...
of utilities to secure favorable financing and power purchase mechanisms should be top priorities in a CCS project. For near-pure CO2 stream emitters, which typically have lower CCS system costs but emit less CO2 than coal power plants, the parameters investigated for sensitivity were the capital cost of the compressor, the depth of the reservoir, the size of the CO2 stream, the pipeline distance, the WACC, and the surface area of the sequestration target. The largest difference in system costs again came from the flowrate of CO2 and the WACC. Notably, a change in the distance of the sink, which changes the pipeline cost, is a much larger driver of costs for the small, pure stream emitters than for coal power plants with larger volumes of CO2.

6. Conclusion

The implication of these variations in supply curves for United States and global CCS policy is that some CO2 storage reservoirs, due to proximity to CO2 sources, and geological characteristics such as capacity and depth, will be more economical than others to be developed. Policies designed to incentivize the characterization and development of CO2 sinks should consider the supply curves for those sinks, examining the CO2 quantities, prices, and number of sources that can sequester at a given price.

7. References