Projecting the scale of the pipeline network for CO2-EOR and its implications for CCS infrastructure development

Matthew Tanner

Office of Petroleum, Gas, & Biofuels Analysis

U.S. Energy Information Administration

October 25, 2010

This paper is released to encourage discussion and critical comment. The analysis and conclusions expressed here are those of the author and not necessarily those of the U.S. Energy Information Administration.

Abstract

CO_2-EOR is the practice of injecting CO_2 into mature oil fields for the purposes of increasing oil recovery. A growing pipeline network is used to transport CO_2 from natural and anthropogenic sources to CO_2-EOR injection points. This paper estimates the scale and location of future infrastructure requirements for CO_2-EOR consistent with crude oil prices that rise to $125 per barrel by 2035 (2008 dollars). These estimates are derived by using the National Energy Modeling System (NEMS). In addition, the links between CO_2 transportation infrastructure for CO_2-EOR and CO_2 transportation for CCS assuming a carbon price are discussed. Despite sufficient scale, there is little overlap between the projected regional CO_2-EOR infrastructure required for CO_2-EOR and the most likely requirements for CO_2 transportation for carbon capture and sequestration (CCS). This preliminary result suggests there exists limited potential for CO_2-EOR infrastructure to be adapted for use in CCS.

Introduction

CO_2-EOR is the process by which CO_2 is injected into mature oil fields in order to increase oil recovery. Currently 50 million tons CO_2 per year is used for CO_2-EOR of which 90% is obtained from natural reservoirs [5]. The CO_2 is transported from sources to oil fields around the U.S. and in Canada by several long-distance pipelines shown in Figure 1. The existing CO_2 pipeline infrastructure includes both the large long-distance pipelines and smaller distribution pipelines that transport CO_2 to specific CO_2-EOR wells. Furthermore, in the next few years, Denbury Resources plans to extend their western pipeline from Jackson Dome in Alabama to reach CO_2-EOR fields in the Gulf Coast. Overall, the amount of CO_2 transported by pipelines in the country is expected to keep increasing in the short-term due to relatively high oil prices. Over the long-term, assuming high oil prices are sustained, oil producers will continue to be willing to pay for CO_2 which will provide incentives for industrial sources to capture and sell their CO_2 with a corresponding increase in the construction of transportation infrastructure. Potentially, with sufficiently high carbon prices, this infrastructure could be adapted for transport and sequestration of CO_2 for non-EOR purposes, lowering the initial cost of CCS for later adopters.

In 2008, 5.8 billion metric tons of CO_2 were emitted in the U.S. of which 1.9 billion were from coal-fired power plants [5]. The potential for CCS to play an important role in reducing greenhouse gas emissions is largely determined by the extent to which it can be economically adopted for power generation. For example, EIA's basic analysis of the American Power Act of 2010 projects nearly 500 million tons per year of CO_2 are captured and sequestered by 2035 [6]. The 50 million metric tons per year already transported and used for

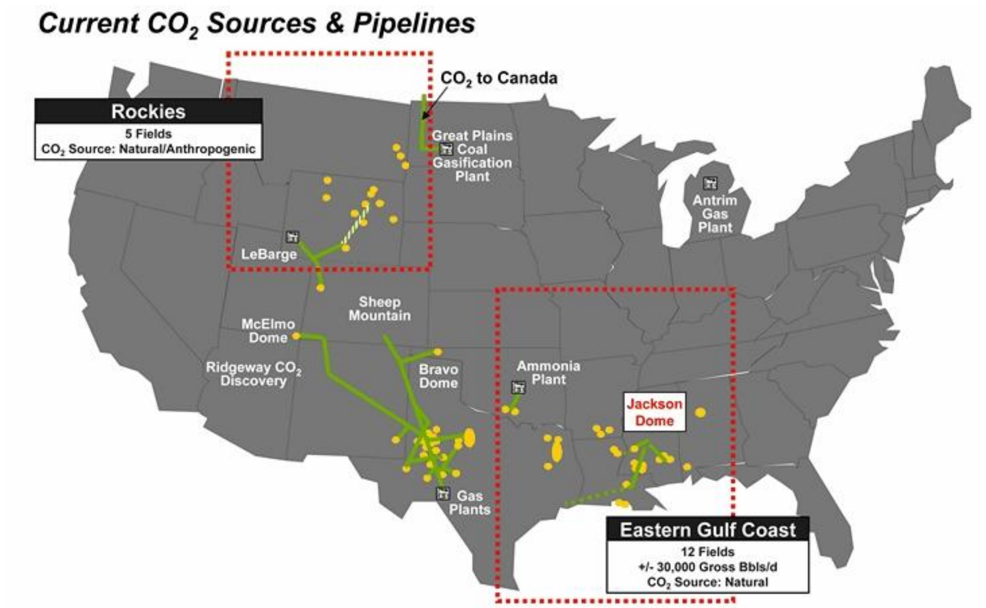

Figure 1: Existing CO_2-EOR pipelines: sources and routes [9]

CO_2-EOR is already 10% of this total and is expected to keep rising. The question of whether CO_2-EOR infrastructure could be adapted for CCS is not one of scale but instead of location and whether the CO_2-EOR pipelines would have excess capacity at the time that CCS were to become economically feasible.

This paper considers the CO_2 transportation and distribution network implied by CO_2-EOR production modeling in NEMS. The early CO_2-EOR opportunities on the Gulf Coast and Midcontinent are in decline by the end of the projection period leaving significant infrastructure that could potentially be used for CCS assuming a carbon price sufficient for emitters to adopt CCS. This paper discusses the limiting factors that are likely to prevent this CO_2-EOR infrastructure from playing a role in early construction of transportation pipelines for CCS. Specifically, the majority of CO_2-EOR infrastructure is suboptimally located for adapting it for CCS.

Background

Whether or not available CO_2-EOR infrastructure can lower implementation costs for early adopters of CCS depends on whether the current model of long-distance trunklines connecting multiple sources is the form a CCS pipeline network would take. Early research has identified widespread geologic formation with potential for permanent carbon sequestration. Assuming it is economically feasible to inject commercial quantities of CO_2 into all of them, 95% of large U.S. CO_2 sources are within 50 miles of a storage reservoir.

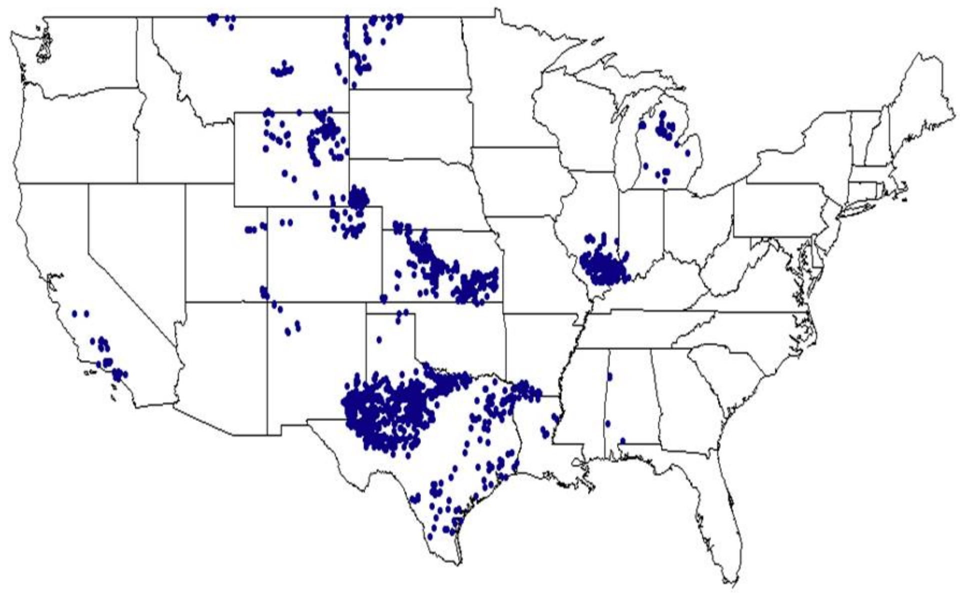

Figure 2: CO_2-EOR fields considered in OGSM

In this situation, the likely CO_2 pipeline network consists of dedicated lines from each source to a nearby site [3] and the presence of CO_2-EOR pipelines have little impact. However, if some geologic formations have much lower sequestration costs than others, then significant cost savings may result from a pipeline system with trunklines transporting CO_2 from multiple sources to low-cost sequestration sites [1, 2]. In this case, as CO_2-EOR fields are depleted, existing trunk pipelines and distribution networks could be adapted for use in CCS. The value of adapting CO_2-EOR pipelines depends on the location of the trunk pipelines and distribution networks in relation to attractive sequestration sites as well as the timing of the depletion of CO_2-EOR fields.

In fact, recent research into the cost of CO_2 sequestration in saline aquifers suggests that there is wide variance in the cost to sequester CO_2 in different geologic formations [4, 8]. Furthermore, two of the saline aquifers with the most sequestration potential are the Frio saline aquifer on the Gulf Coast and the Mt.Simon saline aquifer in Illinois and Michigan. This increases the likelihood of trunk pipelines for CCS transporting CO_2 from sources to the best sequestration sites. Since, both these formations overlap geographically with potential sites for CO_2-EOR as shown in Figure 2, any infrastructure developed there for CO_2-EOR injection wells is well-situated for adaptation to CCS. The scale and future availability of such infrastructure is the primary open question.

EOR modeling in NEMS

The Oil and Gas Supply Module (OGSM) in NEMS is a regional model of U.S. oil and gas production [7]. The model includes representations of oil and gas fields and production technology. Hence, CO_2-EOR is only one of multiple technologies that can be selected by the model based on relative profitability. Figure 3 shows the OGSM lower 48 production regions which can be matched to Figure 2 which shows the location of fields in which CO_2-EOR can be used.

Figure 3: OGSM regional breakdown

Inputs to OGSM include assumptions on the characteristics of existing and undiscovered fields including the quantity of petroleum that can be produced using different technologies. OGSM ranks eligible fields by their expected net present value for all possible drilling technologies. Fields with positive net present values are selected in rank order of value subject to regional drilling, capital, and other constraints. The net present value of CO_2-EOR fields includes the cost of purchasing CO_2 from the lowest cost available CO_2 source, considering that the regional quantities of CO_2 available is limited. Oil production and CO_2 use in an individual field are functions of the exogenous parameters on that field.

Available CO_2 for EOR in OGSM is modeled regionally by considering a variety of potential source categories and costs to obtain CO_2 from those sources. CO_2 is available from both natural and anthropogenic sources with anthropogenic sources disaggregated into different industries. In the absence of a price on carbon, it is assumed that oil producers must bear the entire capital and operating cost of capture and compression to obtain CO_2 at the plant gate from a given industry including a return on investment. The CO_2 must then be transported by the oil producers to an CO_2-EOR field. Further assumptions are made on the maximum amount of CO_2 from each industry that could actually be captured for CO_2-EOR. Finally, CO_2 can be recycled within a field so more CO_2 reducing the quantity that must be purchased from sources each model year. Appendix A.1 gives the amounts and costs of available CO_2 at a national level, see the OGSM documentation for detailed regional CO_2 availability and cost [7].

In the value of CO_2-EOR for a specific field, the lowest cost source of CO_2 is determined. CO_2 can be obtained either within the field's region for a transportation cost of $7.20 or CO_2 can be purchased in a different region and transported by an inter-regional pipeline. This inter-regional transport is allowed after 2016 with transportation costs rising as transportation distance increases. Appendix A.2 gives detailed inter-regional transport assumptions from OGSM. The actual CO_2-EOR pipeline network in OGSM is modeled with aggregated pipeline capacity between regions rather than as specific discrete pipelines. Since transportation rates are constant as a function of quantity, the transportation rates may not be reasonable if only small amounts of CO_2 are being moved.

For this analysis, NEMS was run using preliminary assumptions for AEO2011. The primary sensitivity was on the oil price path as that is one of the primary drivers of CO_2-EOR production and CO_2 use. Figure 4 shows the world oil price paths in the reference, low, and high price cases.

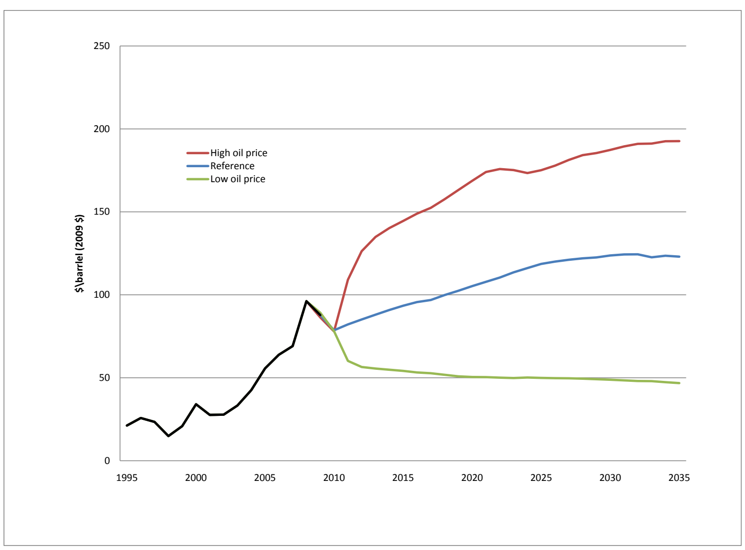

Figure 4: Oil price cases

OGSM CO_2-EOR results

This section provides a summary of the findings. While the specific results are subject to change as the numerous cases for AEO2011 are finalized, the broader qualitative results are likely to remain relavant.

Reference

OGSM results show that in the reference case, CO_2-EOR activity substantially increases over the projection period. In 2009, approximately 50 million tons of CO_2 were purchased to produce approximately 400,000 barrels of oil. Of this, Kinder Morgan's Cortez pipeline transports approximately 20 million metric tons CO_2 from the Rocky Mountain region to the Southwest region. The remainder of the CO_2 is transported shorter distances within OGSM regions.

The reference case projection results by region in 2015, 2025, and 2035 are shown in Table 1. The table gives oil production in thousand barrels per day, CO_2 purchases, and inter-regional CO_2 transport in million metric tons per year. National CO_2 purchases are expected to rise to 145 million tons per year by 2025 with 35 million tons transported inter-regionally. Of this CO_2, nearly 80 millions tons per year comes from anthropogenic sources. The production of oil from CO_2-EOR is 1.1 million barrels per day. After that, CO_2 purchases and oil production decline as fields are depleted, potentially leaving underutilized CO_2 transport infrastructure.

	CO_2-EOR in 2015			CO_2-EOR in 2025			CO_2-EOR in 2035		
	oil prod. MB/day	purch. MMtons	trans. MMtons	oil prod. MB/day	purch. MMtons	trans. MMtons	oil prod. MB/day	purch. MMtons	trans. MMtons
East Coast	5.2	0.8	0.0	17.1	4.2	0.0	8.2	4.2	0.0
Gulf Coast	81.4	14.6	0.0	137.0	19.6	0.0	92.7	9.7	0.0
Midcon	45.2	5.4	0.0	250.1	21.0	11.1	175.1	27.7	3.2
Southwest	388.6	69.7	19.5	534.8	74.3	24.2	498.7	74.2	25.9
Rocky Mtns	71.2	8.1	0.0	122.1	13.2	0.0	85.4	10.0	0.0
West Coast	8.6	0.8	0.0	38.1	4.8	0.0	27.6	3.9	0.0
Total	**600.2**	**80.0**	**19.5**	**1099.1**	**144.8**	**35.3**	**887.7**	**129.7**	**29.1**

Table 1: Reference case results

Extensive infrastructure is required for the CO_2-EOR activity shown in Table 1. The Southwest region has the most CO_2-EOR with almost 75 million tons CO_2 purchased in 2035. This quantity of CO_2 injected into fields requires sufficient distribution capacity to move CO_2 from large pipelines to injection wells. The Midcontinent, Gulf Coast, and Midcontinent regions also require large quantities of CO_2 for EOR and require distribution capacity to move it through to injection wells. The pipeline infrastructure implied by these results can also include large, but relatively short, intra-regional lines that do not show up in the inter-regional transportation column.

The projection also shows significant changes in pattern of inter-regional transport of CO_2. Much of the incremental CO_2 captured for CO_2-EOR in this case comes from anthropogenic sources. A high proportion of the relatively low cost CO_2 available nationwide is in the Gulf Coast. This means that the much of the change in CO_2 transport quantities is due to CO_2 being moved from the Gulf Coast to CO_2-EOR fields in the Southwest and Midcontinent regions. The quantity of CO_2 transported to the Southwest region increases from 20 million to 26 million tons, while a further 11 million tons is transported to the Midcontinent region. The likely form of this infrastructure is one or two trunklines connecting the sources in the Gulf Coast to the CO_2-EOR fields further west.

Sensitivities

Table 2 shows the results in the high oil price sensitivity case. With a higher oil price, many more CO_2-EOR fields are economic at the assumed CO_2 prices. Cumulative CO_2 purchases and oil production are higher, while inter-regional transport is actually lower. The reason for this somewhat counter-intuitive result is that limits in the supply of CO_2 begin to have an effect in some of the regions, meaning that some CO_2-EOR fields are not developed due to resource constraints. Regionally, CO_2-EOR activity in the Gulf Coast is much higher in this case and much of the CO_2 that was being transported out of the region in the reference is now used within the region and is no longer available to the Midcontinent. Thus, a shortage of sufficiently cheap CO_2 causes CO_2-EOR production in the Midcontinent to fall significantly. However, the Southwest region consumes a larger share of available CO_2 so the size of the inter-regional pipeline out of the Gulf Coast is not significantly smaller. There is great uncertainty in the order in which CO_2-EOR fields would actually be developed and it is important to note that the CO_2 allocation model does not inter-temporally optimize distribution. Higher CO_2-EOR activity means that CO_2 distribution networks required would be increased in size.

	CO_2-EOR in 2015			CO_2-EOR in 2025			CO_2-EOR in 2035		
	oil prod. MB/day	purch. MMtons	trans. MMtons	oil prod MB/day	purch. MMtons	trans. MMtons	oil prod. MB/day	purch. MMtons	trans. MMtons
East Coast	5.2	0.9	0.0	17.9	3.2	0.0	9.6	1.5	0.0
Gulf Coast	83.9	13.5	0.0	191.1	32.3	0.0	108.9	16.4	0.0
Midcon	45.1	5.2	0.0	209.5	32.4	0.0	158.8	35.1	0.0
Southwest	395.0	53.5	19.5	531.4	77.9	27.8	434.7	73.9	25.6
Rocky Mtns	71.3	8.9	0.0	135.8	20.5	1.4	87.6	11.6	0.0
West Coast	8.6	0.8	0.0	43.9	7.3	2.3	23.1	4.3	0.0
Total	**609.0**	**82.8**	**19.5**	**1129.5**	**173.7**	**31.6**	**822.7**	**142.8**	**25.6**

Table 2: High oil price case results

Table 3 shows the results from the low oil price case. In this case, oil prices fall from their current level and do not rise over the long-term. In this case, CO_2-EOR production does increase through 2025 but not as drastically as it does in cases with higher oil prices. CO_2 purchases are down meaning that the implied construction of CO_2-EOR infrastructure is much smaller. Inter-regional pipelines do not grow beyond what already exists.

	CO_2-EOR in 2015			CO_2-EOR in 2025			CO_2-EOR in 2035		
	oil prod. MB/day	purch. MMtons	trans. MMtons	oil prod MB/day	purch. MMtons	trans. MMtons	oil prod. MB/day	purch. MMtons	trans. MMtons
East Coast	2.6	0.5	0.0	2.1	0.7	0.0	1.5	0.4	0.0
Gulf Coast	76.4	11.2	0.0	126.5	15.8	0.0	93.9	12.5	0.0
Midcon	48.5	6.3	0.9	184.3	19.0	5.0	89.5	12.5	0.0
Southwest	353.1	45.0	19.5	382.1	45.4	14.3	298.5	35.8	11.7
Rocky Mtns	64.7	7.3	0.0	112.8	14.1	3.6	77.2	12.2	2.2
West Coast	8.6	0.7	0.0	22.0	1.4	0.0	34.2	4.3	0.0
Total	**553.8**	**71.0**	**20.4**	**829.9**	**96.4**	**22.9**	**594.6**	**76.7**	**13.9**

Table 3: Low oil price case results

Discussion

The results of this analysis show that under the reference case world oil price path, CO_2-EOR activity in the U.S. would increase significantly over the projection period peaking around 2025. As the amount of CO_2 purchases for injection into CO_2-EOR fields increases to over 150 million tons per year, substantial pipeline infrastructure transporting CO_2 from sources through trunk and distribution lines to injection wells would need to be constructed. Inter-regional pipeline construction between the Gulf Coast and CO_2-EOR fields in the Southwest and Midcontinent regions are projected to be required. CO_2 purchases and CO_2-EOR activity declines in the later stages of the projection period, implying that much of this infrastructure would be underutilized.

Assuming a carbon price makes CCS economically viable, there does not seem to be much overlap in the pipeline infrastructure that would be required for CCS and the CO_2-EOR pipelines projected by NEMS. Either the inter-regional pipelines, the pipeline right-of-ways, or the distribution networks could potentially be adapted for use in CCS but there are several reasons why the economic rationale for this could be limited. In the reference case, main large-diameter CO_2 pipelines are expected to connect the CO_2-EOR fields in the Southwest and Midcontinent with natural CO_2 sources in the Rocky Mountains and with anthropogenic CO_2 sources in the Gulf Coast region. Coal-fired power plants mitigating carbon with CCS are likely to be located in the East Coast and Gulf Coast OGSM regions. Furthermore, as mentioned previously, the most attractive saline aquifers for sequestration are in the East Coast and Gulf Coast OGSM regions. It would be unlikely to be cost-effective to transport CO_2 first to the Gulf Coast and then use the CO_2-EOR pipelines to connect them to the depleted oil and gas fields that are co-located with CO_2-EOR fields.

The presence of CO_2 distribution networks may have a somewhat greater role in the development of CCS infrastructure. Large-scale sequestration in formations such as the saline aquifers on the Gulf Coast are likely to require many injection wells. For example, the Frio Formation in the Gulf Coast that underlies CO_2-EOR fields which are in decline by the end of the projection period. This means that much of the infrastructure constructed to distribute 20 million tons CO_2 per year to CO_2-EOR injection would be available for adaptation to CCS. The same is possible for the Mt. Simon formation under CO_2-EOR fields on the East Coast. However, the potential for distribution lines to effect CCS infrastructure development is limited by the relatively small-scale of the projected CO_2-EOR activity in these two regions. A single 2 GW coal power plant emits over 10 million tons CO_2 per year and so the CO_2-EOR distribution infrastructure would be overwhelmed quickly. Much more distribution infrastructure would be present in the Southwest and Midcontinent regions but these regions are further from CO_2 sources and the depleted oil and gas fields there are not as attractive for sequestration. Savings in distribution infrastructure costs are unlikely to be sufficient to overcome this.

Adding further to pessimism regarding the significance of CO_2-EOR infrastructure to the development of CCS infrastructure are the results from the sensitivity cases on world oil price. The reference case price path is a persistently higher price than has existed before and would provide large incentive for the development of capital intensive projects such as CO_2-EOR infrastructure. The world oil price is likely to have high volatility, raising the economic hurdles to the use of CO_2-EOR on mature oil fields, reducing the extent of CO_2-EOR infrastructure. Also limiting infrastructure investment for CO_2-EOR could be the potential stranding of pipeline assets if peak CO_2 demand is not sustained for a sufficiently long period.

Despite this, CO_2-EOR and CCS are still linked. Even without a carbon price, CO_2-EOR can provide early incentives for carbon capture, potentially speeding the development of the technologies. A rising carbon price would lower the cost of CO_2 for oil producers. As was shown in the high oil price case, the availability of cheap, capturable CO_2 can be a limiting factor in CO_2-EOR . It is plausible that alternative sources of CO_2, made economic by a carbon price could could give oil producers incentives to subsidize the construction of pipeline infrastructure that could be used for transporting CO_2 to both CO_2-EOR fields and to non-EOR sequestration sites.

References

[1] Bielicki, J. M. (2008). Returns to scale in carbon capture and storage infrastructure and deployment. Discussion paper from Energy Technology Innovation Policy at Harvard Kennedy School.

[2] Chandel, M., L. Pratson, and E. Williams (2010). Potential economies of scale in CO_2 transport through use of a trunk pipeline. *Energy Conversion and Management 51*, 2825–2834.

[3] Dooley, J., R. Dahowski, and C. Davidson (2009). Comparing existing pipeline networks with the potential scale of future u.s. CO_2 pipeline networks. *Energy Procedia 1*, 1595–1602.

[4] Eccles, J. K., L. Pratson, R. G. Newell, and R. B. Jackson (2009). Physical and economic potential of geological CO_2 storage in saline aquifers. *Environmental Science Technology 43*, 1962–1969.

[5] EIA (2010a). EIA website. retrieved from `www.eia.doe.gov`.

[6] EIA (2010b). Energy market and economic impacts of the american power act of 2010. Report #: SR-OIAF/2010-01 retrieved from `www.eia.doe.gov`.

[7] EIA (2010c). OGSM documentation. retrieved from `www.eia.gov`.

[8] McCoy, S. T. and E. S. Rubin (2009). Variability and uncertainty in the cost of saline formation storage. *Energy Procedia 1*, 4151–4158.

[9] Resources, D. (2010). Denbury website. retrieved from `http://www.denbury.com/`.

A Appendix

A.1 Available CO_2 assumptions

Source	MMtons CO_2	Cost/ton	First availability
Natural CO_2	58.05	$18.0 + 0.008 * oilprice$	immediately
Natural gas processing	10.84	27.36	immediately
Hydrogen	16.74	27.66	2013
Ethanol	18.39	32.94	2013
Ammonia	4.54	30.60	2011
Cement	13.53	70.02	2016
Power plants	∞	100.00	2021
Planned capture	as built	27.00	as built
XTL plants	as built	27.18	as built

A.2 CO_2 transportation assumptions

	Northeast	Gulf Coast	Midcon	Southwest	Rocky Mtns	West Coast	N. Great Plains
East Coast	$7.20	$14.40	$14.40	$28.80	$28.80	$43.20	$21.60
Gulf Coast	$14.40	$7.20	$14.40	$14.40	$28.80	$36.00	$28.80
Midcon	$14.40	$14.40	$7.20	$14.40	$14.40	$28.80	$14.40
Southwest	$28.80	$14.40	$14.40	$7.20	$14.40	$28.80	$28.80
Rocky Mtns	$28.80	$28.80	$14.40	$14.40	$7.20	$14.40	$14.40
West Coast	$43.20	$36.00	$28.80	$28.80	$14.40	$7.20	$21.60
N. Great Plains	$21.60	$28.80	$14.40	$28.80	$14.40	$21.60	$7.20