Gate-to-Gate Life Cycle Analysis Model of Saline Aquifer Sequestration

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Agenda

Technology Description

Unit Processes

Model Structure

Key Parameters

Gate-to-Gate Results

Sensitivities

Technology Description: Saline Aquifer Sequestration of Carbon Dioxide

- Saline aquifers are geological formations saturated with brine water
- In United States (U.S.) saline aquifers have broader geographical distribution than oil and gas reservoirs and have potential for large-capacity, long-term carbon dioxide (CO_2) storage
- CO_2 storage capacity of saline aquifers in U.S. has been estimated from 2.1 to 20 trillion tonnes of CO_2 (NETL, 2012)
- This analysis includes following processes:
  - Site Preparation
  - Well Construction
  - Sequestration Operations
  - Site Monitoring
  - Brine Management
  - Well Closure
  - Land Use

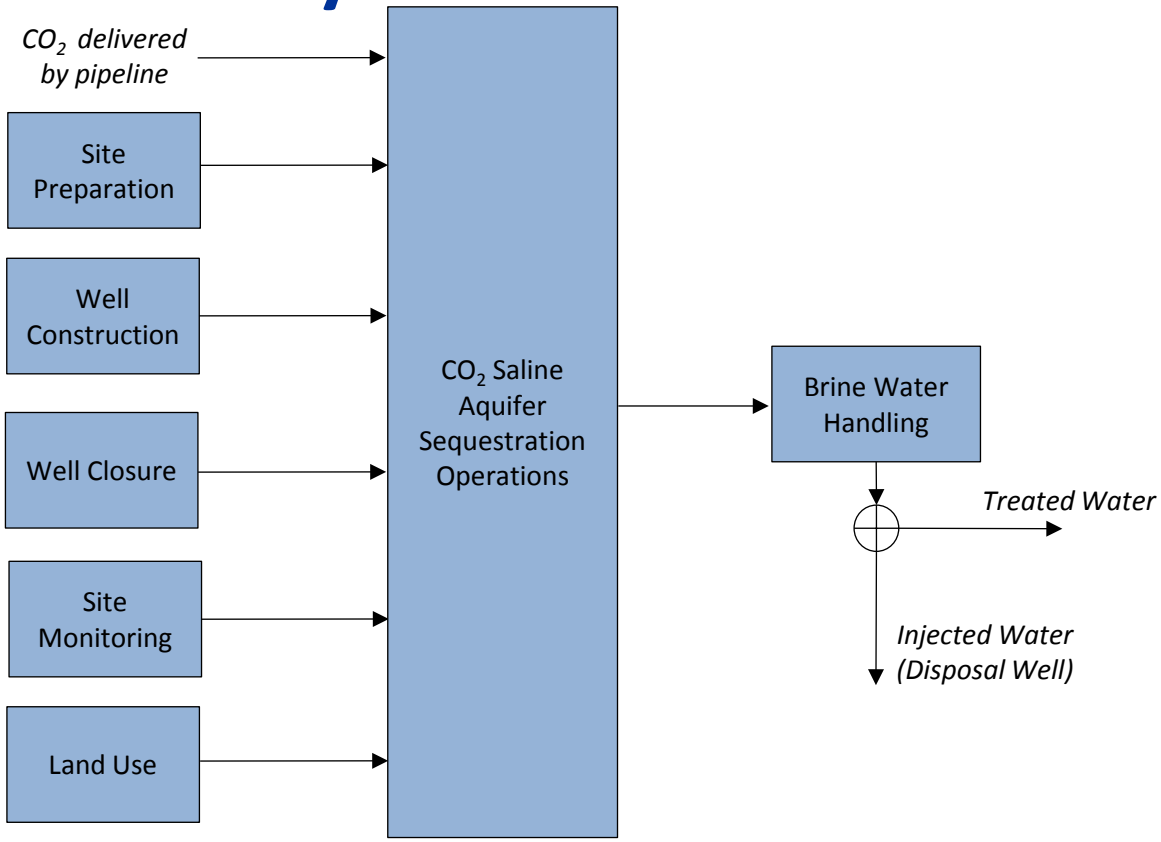
Unit Processes

- **Site Preparation**
  - Preparation of saline aquifer site requires a seismic survey conducted by vibroseis trucks
  - Vibroseis trucks consume diesel for transport and equipment operation
  - Typical site survey takes seven, 12-hour days (CSLC, 2012).
- **Well Construction**
  - Construction and installation of wells includes drilling of well bore, followed by installation of well casing
  - Well casing provides strength to well bore and prevents contamination of groundwater
  - Eight different well types of varying depths are required for CO_2 sequestration in a saline aquifer
  - NETL saline aquifer storage cost model (internal, unpublished model) has representative list of possible storage formations in U.S.
- **Sequestration Operations**
  - Operation of CO_2 injection site uses electricity to pressurize and inject incoming CO_2 into an underground formation
  - Electricity requirements of injection site are function of injection pressure and number of injection wells
  - In addition to fugitive CO_2 emissions from injection pump, this analysis also models leakage of CO_2 from underground formation
  - Brine water production from saline aquifer is one method to control pressure in underground formation, but it is not always required (ANL, 2011)

Unit Processes

- **Site Monitoring**
  - This analysis accounts for construction of monitoring wells and seismic testing during site operations
  - Other types of monitoring activities are a negligible contribution to environmental burdens of saline aquifer site
- **Brine Management**
  - Management of brine at saline aquifer site consumes electricity, used by water treatment processes and/or injection pumps
  - Two water treatment technologies are used in this analysis: reverse osmosis and vapor compression distillation
  - Instead of treating produced brine water at surface, reinjection into suitable underground formation near production site is possible (ANL, 2011)
- **Well Closure**
  - Purpose for plugging wells prior to abandonment is to ensure that abandoned wells do not allow injected fluids or natural brines to pass into underground sources of drinking water (USDW) (EPA, 1994)
  - This analysis uses EPA guidance for Class II wells, defined as wells that inject fluids that are brought to surface in connection with conventional oil or natural gas production

Life Cycle Model Structure



- Only input to saline aquifer model is CO_2 delivered by pipeline, and only output is treated water exiting brine water treatment process
- Brine water injected in a disposal well does not exit system boundaries, but brine water that has gone through treatment is product of saline aquifer system
- Total land use for saline aquifer sequestration site modeled in this analysis was 497,800 m^2. GHG emissions due to direct land use are based on land use profiles for five states in Permian Basin (Colorado, New Mexico, Oklahoma, Texas, and Wyoming). No agricultural land is converted, so there is no indirect land use.

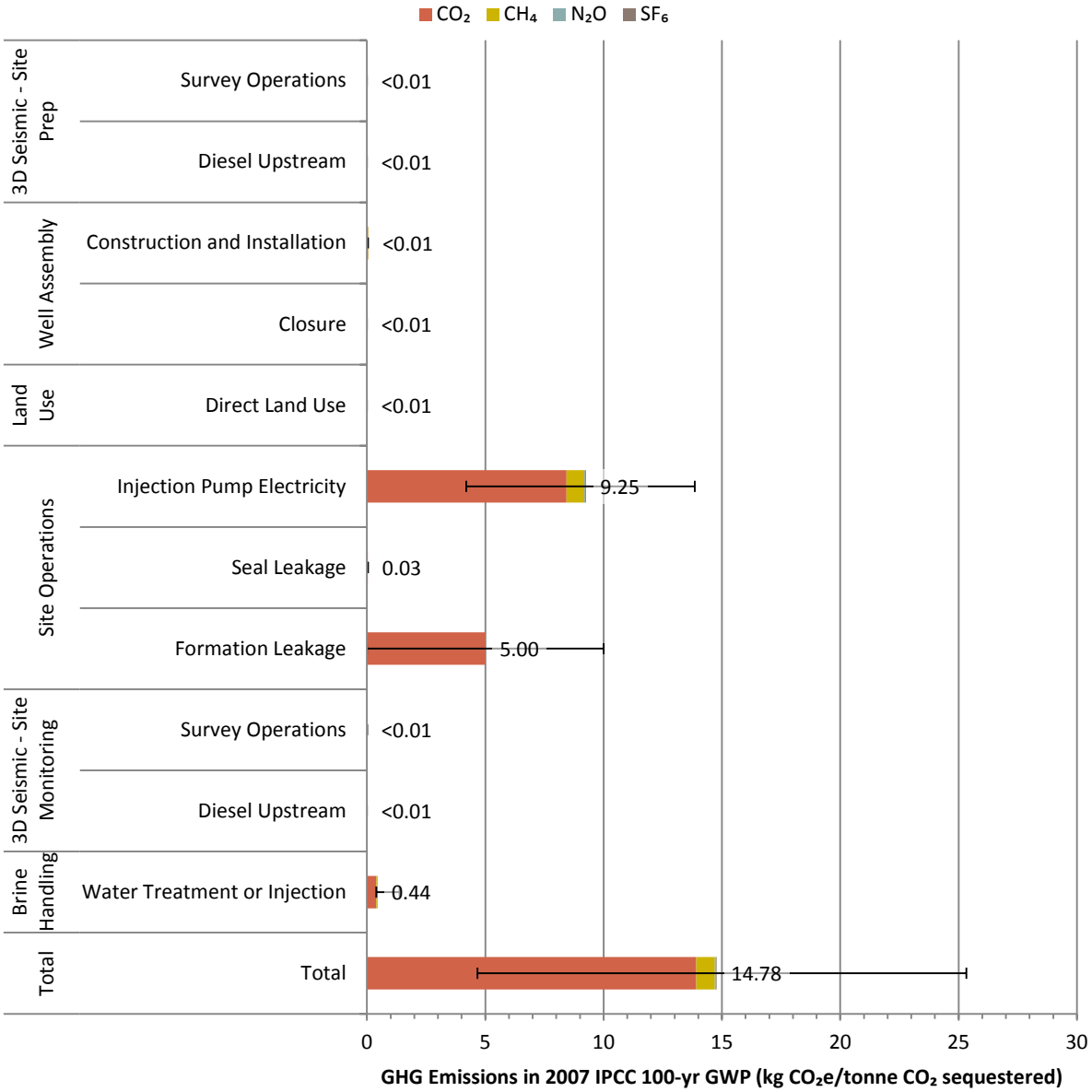
Model Parameters

Parameter Name	Low	Expected	High	Units	Description
Site Preparation/Monitoring					
Seismic truck fuel efficiency	N/A	1.08E-02	N/A	km/liter	Vibroseis truck (diesel engine) seismic survey average fuel consumption
Number of trucks	N/A	4	N/A	dimensionless	Number of vibroseis trucks needed for seismic survey
Survey Area	N/A	2.89E+01	N/A	square miles	Surface area of CO_2 plume in formation
Well Construction/Closure					
Above-seal Monitoring Well	N/A	2.36E+03	N/A	m	Well depth
Groundwater Monitoring Well	N/A	1.52E+02	N/A	m	Well depth
Injection Well	N/A	2.52E+03	N/A	m	Well depth
In-Reservoir Monitoring Well	N/A	2.42E+03	N/A	m	Well depth
Stratographic Test Well	N/A	2.62E+03	N/A	m	Well depth
Vadose Zone Monitoring Well	N/A	1.22E+01	N/A	m	Well depth
Water Disposal Well	N/A	2.52E+03	N/A	m	Well depth
Water Production Well	N/A	2.52E+03	N/A	m	Well depth
CO_2 Injection Operations					
Brine Production	1.3	1.4	1.5	kg/kg	Amount of brine produced from saline aquifer per kg of CO_2 injected
CO_2 Mass Flow	N/A	1.00E+04	N/A	tonne/day	Flow rate of CO_2 through compressor
Formation Leakage	0.0%	0.5%	1.0%	%	Percentage of sequestered CO_2 that leaks from saline aquifer over 100 years
Injection Pump Seal Leakage Factor	N/A	6.36E+01	N/A	kg/MW-day	Emission factor for CO_2 released to air from injection pump
Injection Pump Power	2.47E-04	5.33E-04	7.70E-04	MW/tonne CO_2/day	Pumping power requirements per unit injected per day
Injection Wells	N/A	2	N/A	wells	Number of injection wells for formation
Injection pressure	2,090	3,780	5,180	psia	Hydrostatic Pressure at Midpoint of Saline Aquifer Formation
Injection Years	N/A	100	N/A	years	Number of years of CO_2 injection into saline aquifer sequestration site

Model Parameters

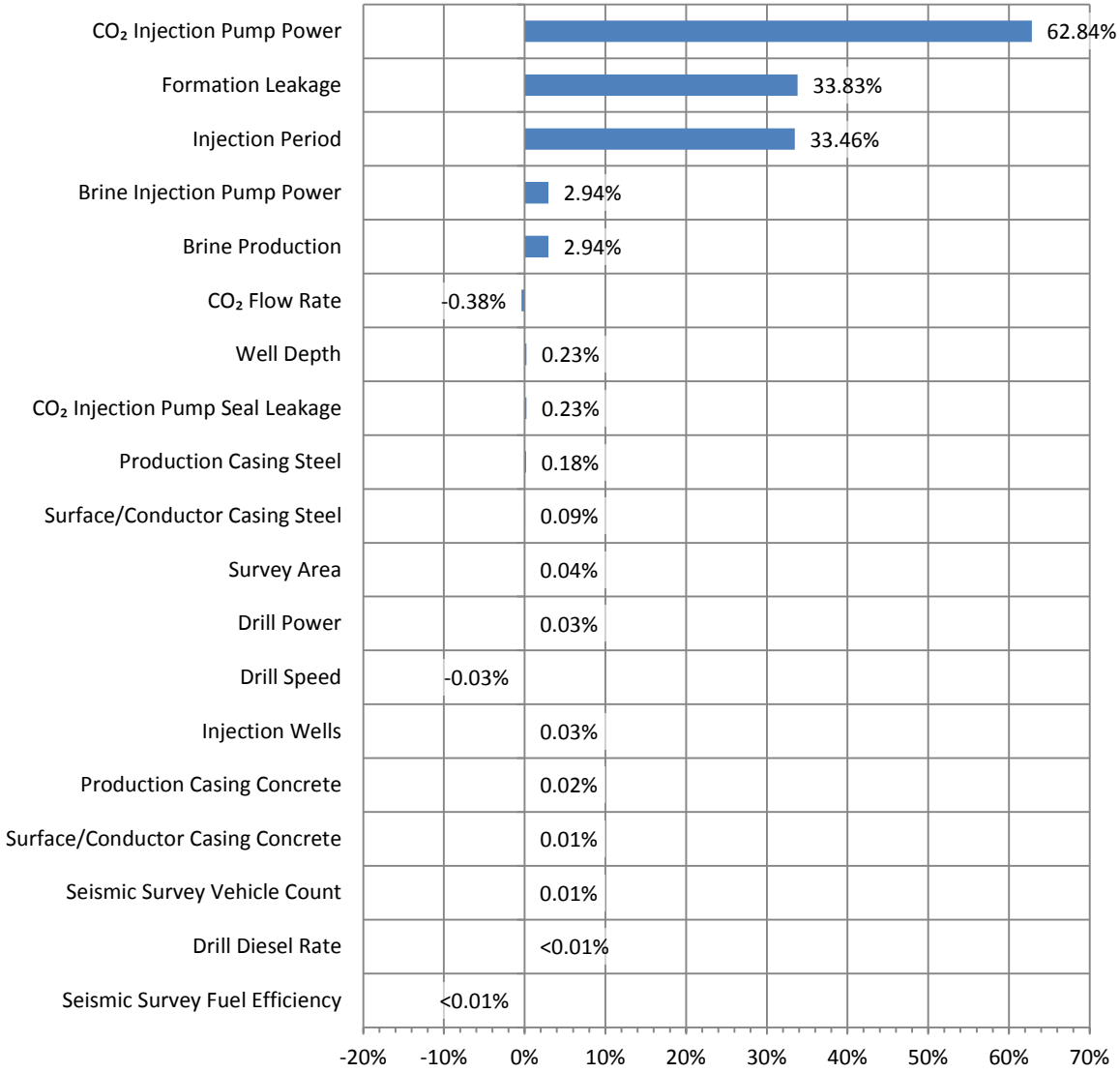
Parameter Name	Low	Expected	High	Units	Description
Brine Handling					
Brine Total Dissolved Solids	4.00E+04	4.00E+04	6.00E+04	mg/L	Total dissolved solids content in brine that is produced
Distillation Power	N/A	N/A	1.41E-03	kWh/kg	Power requirements for distillation treatment per kg of brine influent
Brine Injection Pump Power	4.30E-04	4.30E-04	4.30E-04	kWh/kg	Power requirements for water injection pump per kg of water injected
Reverse Osmosis Power	7.16E-04	N/A	N/A	kWh/kg	Power requirements for reverse osmosis treatment per kg of brine influent
Treatment Scenario	1	0	1	dimensionless	0 = reinjection; 1 = on-site treatment
Electricity Grid	**U.S. Mix**	**ERCOT Mix**	**GTSC**		
Coal	45.87%	33.03%	0.00%	%	Percentage of U.S. power from coal
Geothermal	0.38%	0.00%	0.00%	%	Percentage of U.S. power from geothermal
Gas Turbine Simple Cycle (GTSC)	0.00%	0.00%	100.00%	%	Percentage of U.S. power from natural gas simple cycle turbine
Hydro	7.30%	0.16%	0.00%	%	Percentage of U.S. power from hydropower
Natural Gas	22.65%	47.90%	0.00%	%	Percentage of U.S. power from natural gas
Nuclear	20.43%	12.31%	0.00%	%	Percentage of U.S. power from nuclear
Petroleum	0.95%	1.05%	0.00%	%	Percentage of U.S. power from petroleum
Solar	0.03%	0.00%	0.00%	%	Percentage of U.S. power from solar
Wind	2.39%	5.54%	0.00%	%	Percentage of U.S. power from wind

Gate-to-Gate GHG Results



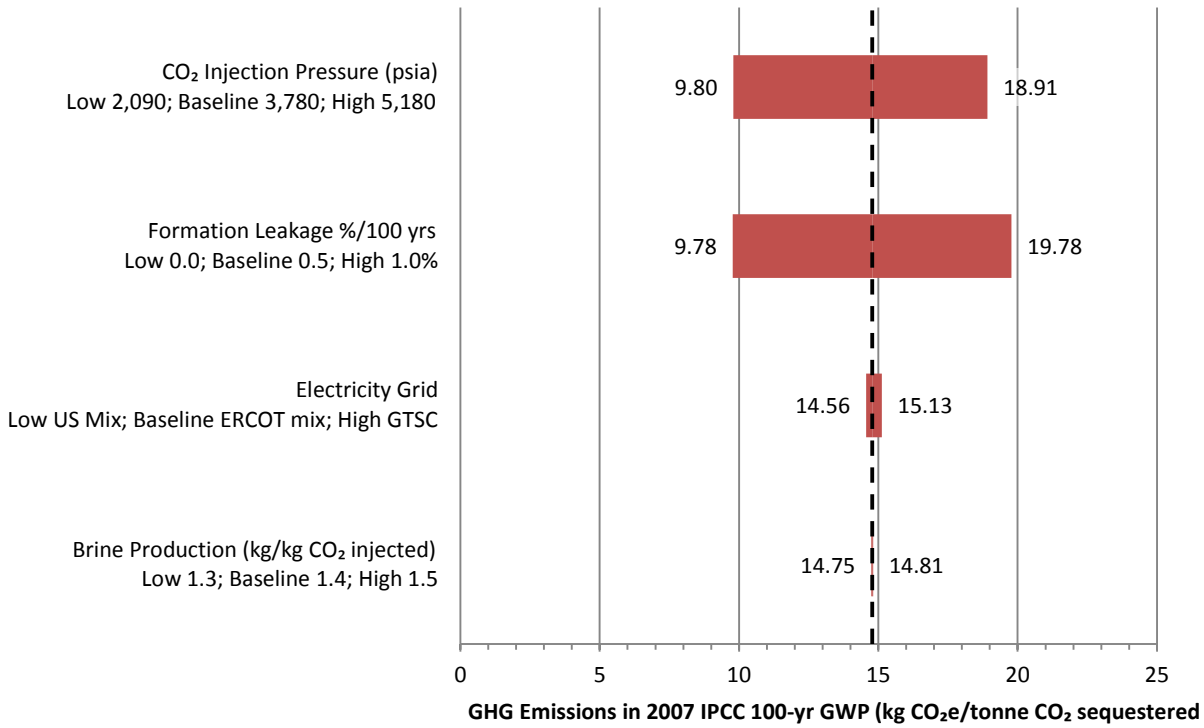
- Emissions associated with electricity for CO_2 injection pump compose 62.6 percent of gate-to-gate GHG emissions
- Next highest contributor is leakage of sequestered CO_2 from formation (33.8 percent)
- Lower bound of uncertainty bars for formation leakage is zero, representing a scenario with no leakage from formation
- Uncertainty in CO_2 injection pump electricity requirement is based on power demand for pump to achieve required injection pressure (function of geology)
- Added uncertainty for pumping GHG emissions is due to source of electricity to power pump (U.S. grid mix, ERCOT mix, GTSC)

Sensitivity of GHG Emissions to Parameter Changes



- Based on gate-to-gate boundaries, a 100 percent increase in CO_2 injection pump power consumption causes an 62.8 percent increase in total GHG emissions
- A 100 percent increase in leakage rate of CO_2 from formation causes a 33.8 percent increase in gate-to-gate GHG emissions
- GHG emissions are not sensitive to changes in parameters related to well construction and closure, site preparation, and site monitoring
- Two of four most sensitive parameters are linked to electric power demands for a process – GHG emissions are driven by composition of electricity grid

Sensitivity of GHG Emissions to Parameter Uncertainty



- This figure presents sensitivity results based on the uncertainty in the parameter values as shown on slides 7 and 8.
- In this system, the majority of uncertainty is driven by required injection pressure and formation leakage, with a smaller amount of uncertainty added based on the composition of the electricity grid and the brine production rate from the aquifer.

Recommendations and Conclusions

- Above results are only from gate to gate, so they should be used with care
- These new unit processes will allow further LCA modeling of CCUS scenarios
- Differences in gate-to-gate GHG emissions are driven by electricity requirements for injection pumping, which is driven by aquifer geology
- Composition of electricity grid directly affects emissions associated with saline aquifer sequestration operations

References

ANL. (2011). Management of Water Extracted from Carbon Sequestration Projects. (ANL/EVS/R-11/1). Chicago, Illinois: Argonne National Laboratory Retrieved July 25, 2012, from http://www.ipd.anl.gov/anlpubs/2011/03/69386.pdf

CSLC. (2012). Central Coastal California Seismic Imaging Project. Retrieved July 31, 2012, from http://www.slc.ca.gov/Division_Pages/DEPM/DEPM_Programs_and_Reports/CCCSIP/CCCSIP.html

CSM. (2009). An Integrated Framework for Treatment and Management of Produced Water - Technical Assessment of Produced Water Treatment Technologies. Golden, Colorado: Colorado School of Mines.

EPA. (1994). Plugging and Abandoning Injection Wells. Retrieved September 11, 2012, from http://www.epa.gov/r5water/uic/r5guid/r5_04.htm

EPA. (2010). Geologic CO_2 Sequestration Technology and Cost Analysis (EPA 816-R10-008). Washington, DC: Environmental Protection Agency Retrieved July 6, 2012, from http://water.epa.gov/type/groundwater/uic/class6/upload/geologicco2sequestrationtechnologyandcostanalysisnov2010.pdf

EPA. (n.d.). Geologic Sequestration Class VI Wells. Environmental Protection Agency Retrieved September 11, 2012, from http://water.epa.gov/type/groundwater/uic/class6/gsclass6wells.cfm

McCollum, D. L., & Ogden, J. M. (2006). Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity. (UCD-ITS-RR-06-14). Davis, California: Institute of Transportation Studies, University of California Davis Retrieved September 10, 2012, from http://pubs.its.ucdavis.edu/publication_detail.php?id=1047

NETL. (2012). Carbon Sequestration Atlas of the United States and Canada Fourth Edition. National Energy Technology Laboratory Retrieved January 31, 2013, from http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIV/

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