Tuesday May 1, 2012
Poster # 272

The Eleventh Annual Carbon Capture, Utilization & Sequestration Conference
Pittsburgh, PA

SAND2012-3380C

Building a National Carbon Dioxide Storage Supply Curve: A Systems Approach Incorporating Geologic Uncertainty

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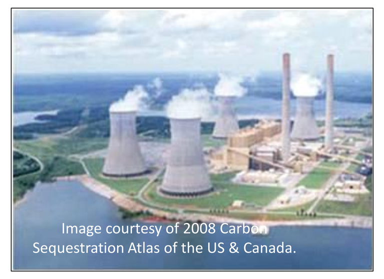
I. Background

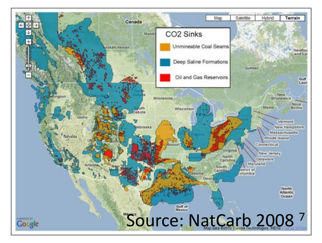
A. Carbon Dioxide Capture (CC) at Power Plants



Fossil fuel-based power plants represented ~40% of all atmospheric carbon dioxide (CO_2) emissions from the United States in 2008 [1], and thus are an important target for any large scale effort to reduce atmospheric CO_2 emissions. Currently, the best available technologies to mitigate these CO_2 emissions include post combustion scrubbing using an aqueous monoethanolamine chemical process (any plant type), or a more efficient pre-combustion "Selexol" process available only to integrated gas combined cycle (IGCC) plants.

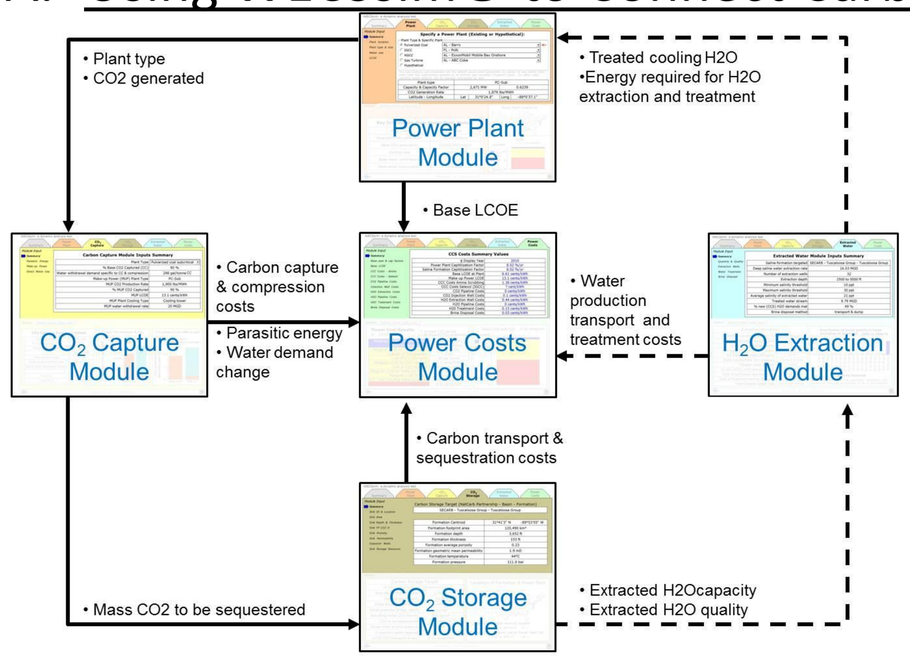
B. Carbon Dioxide Storage (CS) in Geologic Formations

To reduce increases in atmospheric CO_2 concentrations, CO_2 would need to be captured and stored, likely in geologic formations. Depleted oil and gas reservoirs, un-mineable coal seams, and deep (>2500 feet) saline formations are being explored as targets for large scale geologic storage of CO_2. Of these, deep saline formations may represent the largest potential sink. The 2008 NATCARB Database[2] produced by the National Energy Technology Laboratory (NETL) is a national scale effort to map and quantify potential storage resources.



II. WECSsim©
(The Water Energy & Carbon Sequestration Simulation Model)

A. Using WECSsim© to Connect Carbon Dioxide Sources & Sinks

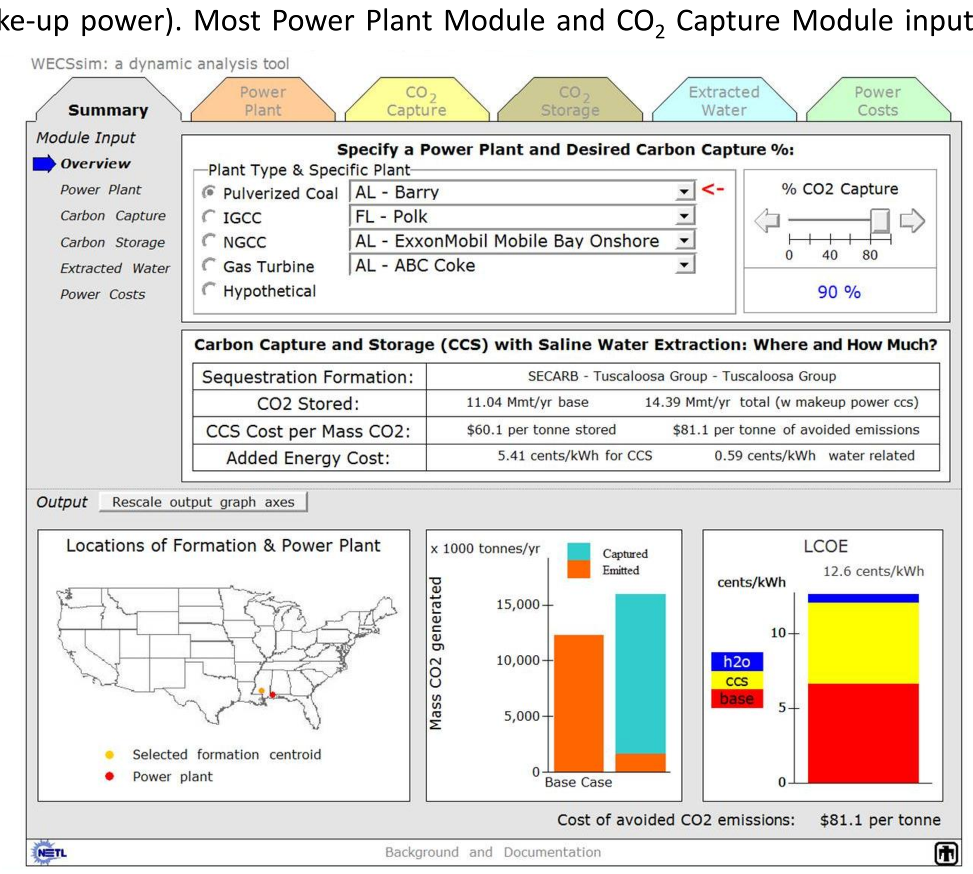


Sandia National Laboratories has developed the Water Energy and Carbon Sequestration simulation (**WECSsim©**) model to evaluate the costs and CO_2 amounts that would be associated with large scale CO_2 capture from any coal or gas fired power plant in the United States and permanent storage in the most economically viable deep saline formations. WECSsim evaluates the costs associated with removing saline water from the storage formation for pressure management.

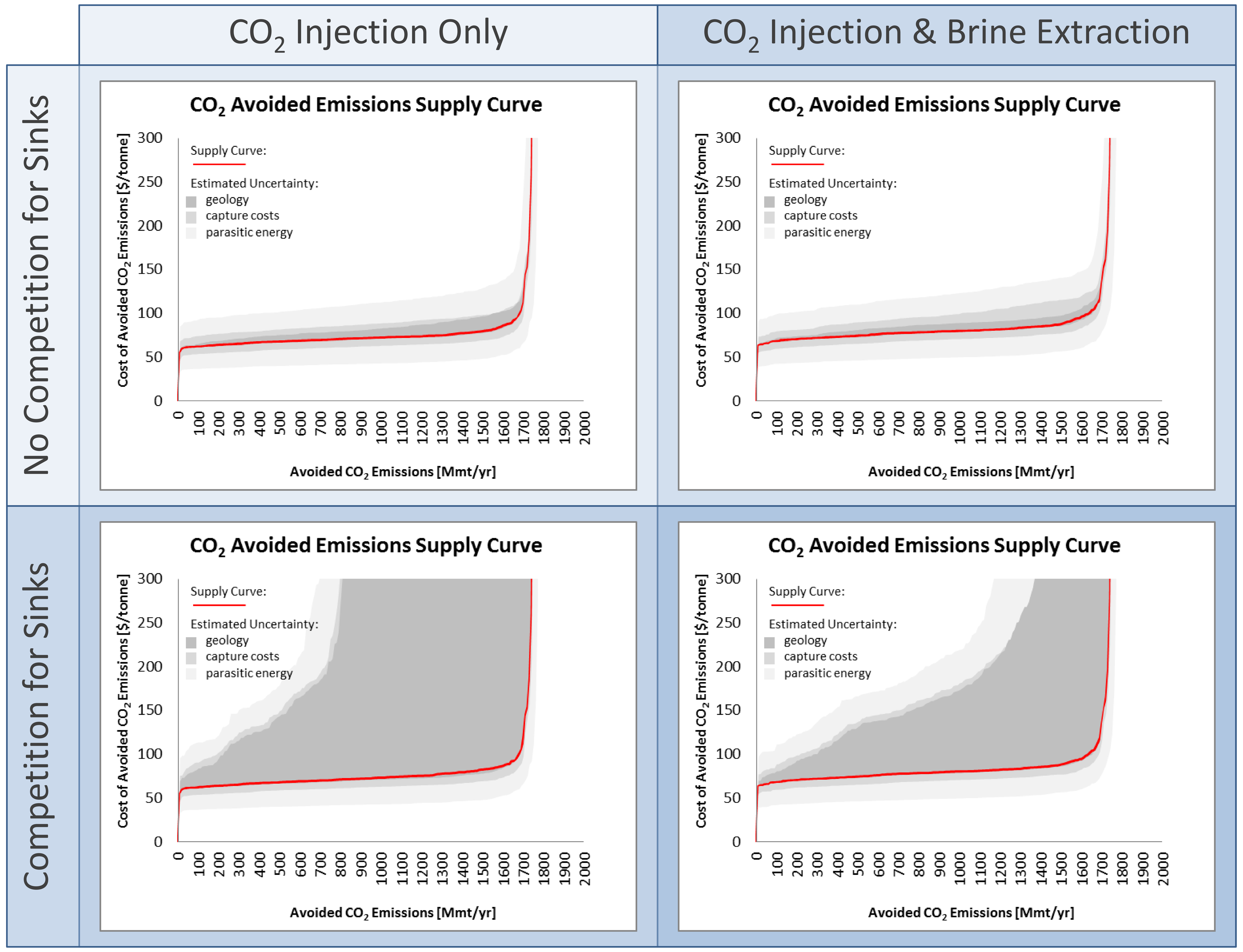
WECSsim modules include a power plant module, a CO_2 capture module, a CO_2 sequestration module, an extracted water module, and a power costs module.

B. WECSsim© Input and Output

WECSsim model inputs include power plant information, level of carbon capture desired, and type of power plant used to make-up for parasitic losses (make-up power). Most Power Plant Module and CO_2 Capture Module inputs have default values which change based on the power plant type and cooling technology utilized. With output from the CO_2 Capture Module, WECSsim queries the 2008 NATCARB Database (see section I.B. above) database to find the best available (least cost) target sequestration formation. This formation is used to populate default inputs to the CO_2 Storage Module and the Extracted Water Module. WECSsim then uses default or user specified inputs to all five modules to calculate energy, water, and economic costs associated with the selected carbon capture and sequestration scenario. WECSsim can be used to evaluate a single hypothetical plant of model user specification, a single existing power plant, or the entire existing U.S. fleet of coal and gas fired power plants (eGRID2007 [3] database).

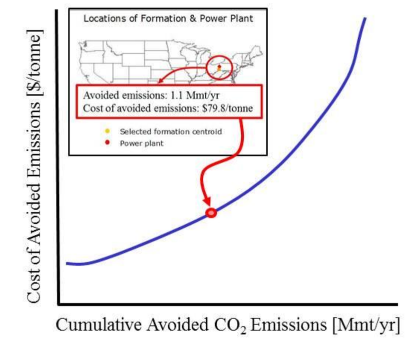


III. Carbon Dioxide Avoided Emissions Supply Curves

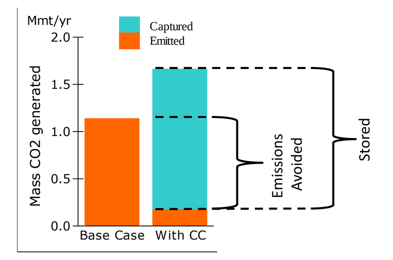


A. Supply Curves

For each power plant in each CO_2 capture and storage (CCS) scenario, WECSsim calculates the total mass of CO_2 to be stored, chooses a least cost storage formation, and calculates the unit cost of carbon storage and the unit cost of avoided emissions (see figure at right). These cost-mass CO_2 pairs are then sorted by ascending costs for all power plants and the mass of CO_2 values are summed to obtain cumulative values. Sorted costs versus cumulative mass supply curves are shown at left.



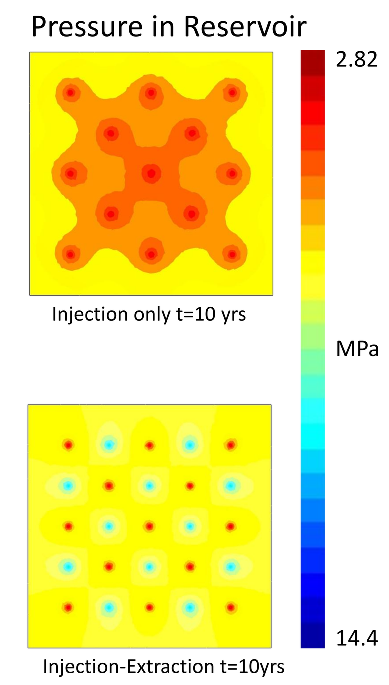
B. Stored versus Not Emitted



If (as would be expected) the energy requirements for CO_2 capture and storage are met with carbon based energy resources, the amount of CO_2 stored is greater than the avoided emissions. This result is visualized in the figure at left. Total costs are the same, and thus avoided emissions are more expensive per unit CO_2 than is storage.

C. Methods: Brine Extraction

Extraction of brine from the target storage formation may be an important strategy to manage pressure buildup in the reservoir, and make more efficient use of pore space[4,5]. Brine extraction scenarios shown here are for a volume of brine equal to the volume of CO_2 stored. Extraction wells are interspersed with injection wells in an "inverted five-spot" pattern. Extraction is stopped when breakthrough occurs. Extracted brine is between 10 and 30 parts per thousand total dissolved solids, and is treated and used above ground. As seen in the supply curves at left, brine extraction adds costs, but reduces the risk of overestimating geologic sink size and quality. This result depends on improved storage efficiency associated with combined injection-extraction reservoir management. Current work to more fully quantify this effect in TOUGH2-ECO2N[6] (figures at right) is ongoing and additional work will quantify the role of spatial heterogeneity on this reservoir management strategy.



D. Methods: Competition for Sinks

First order analysis of source to sink pairings for CCS evaluates each least cost pairing independently of other sources. This leads to the overly optimistic supply curves in the top row of the matrix above. In a more realistic scenario, source operators will obtain rights to storage volume in a given sink, and that portion of the formation will no longer be available for storage of CO_2 by any other operator. The order in which sources implement CCS and gain rights to the sinks is beyond the scope of this analysis, but initial analysis using an arbitrary power plant order resulted in the supply curves in the bottom row of the matrix above. Competition for sinks changes the economics very little if our current estimates of geologic resource size and quality are reasonable (red lines), however, if current estimates are overly optimistic however (darker grey area), competition for sinks becomes very important and could substantially reduce the economic efficacy of CCS to avoid emissions of CO_2.

E. Methods: Uncertainty

Previous analysis[7] has shown that CO_2 capture costs are dominant in a CCS cost breakdown, but that estimates of geologic parameters can create substantial cost variability. Here we expand this result by varying capture costs and parasitic energy losses by +- 40%, and the geologic parameters of formation porosity and permeability by +- 100%. The grey shading in the supply curves above were generated by applying these changes to each parameter individually and thus represent only a first order approximation of uncertainty. Ongoing work will incorporate a more rigorous Monte Carlo approach with statistical distributions of the input parameters of interest to refine these estimates.

IV. Conclusions and References

F. Conclusions

The two supply curves developed without competition for geologic storage sinks (top row of supply curve matrix) represent an estimate of potential costs to implement CCS at any single power plant in the U.S. before any substantial CCS effort is underway nationally. These no-competition supply curves show little sensitivity to changes in geologic quality or brine extraction. This is because CCS, if considered only one source at a time, is not constrained by current estimates of geologic quality and quantity. (For these runs, the distance between source and sink is not restricted by WECSsim). The bottom supply curves thus represent a more realistic analysis of what costs might look like if large scale CCS were implemented in the U.S. With many large sources competing for geologic pore space, the sinks are more limited. In the default case (red lines), the available storage resource is sufficient that brine extraction is not necessary from a reservoir management perspective. However, if current estimates of geologic quality are overly optimistic with respect to porosity and permeability, the reduced availability of high quality sinks drives up costs substantially. Under this scenario, brine extraction is a very important tool in managing the available CO_2 sinks. Thus, for large scale CCS, active reservoir management using brine extraction should be considered not just in areas of water scarcity[8], but in all sinks, as a hedge against overestimates of the overall geologic resource.

G. References

1. National Energy Technology Laboratory (NETL), 2007b, *Carbon Dioxide Capture from Existing Coal-Fired Power Plants*. DOE/NETL-401-110907. (Final Report (Original Issue Date, December 2006)), Revision Date, November 2007
2. NATCARB, 2008, *Carbon Sequestration Atlas of the United States and Canada – 2nd Edition,* National Energy Technology Laboratory http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/index.html accessed 12/3/2010 and http://geoportal.kgs.ku.edu/natcarb/atlas08/gsinks.cfm accessed 12/3/2010
3. Tidwell, V.C., P.H. Kobos, L. Malczynski, G. Klise and W. Hart, *Decision Support for Integrated Water-Energy Planning*, SAND Report SAND2009-6521, Sandia National Laboratories, Albuquerque, NM, 2009.
4. Kobos, P.H., Cappelle, M.A., Krumhansl, J.L., Dewers, T.A., McNeamar, A. and D.J. Borns, 2011, *Combining power plant water needs and carbon dioxide storage using saline formations: Implications for carbon dioxide and water management policies*, International Journal of Greenhouse Gas Control, 5, 899-910.
5. Buscheck, T.A., Sun, Y., Chen, M., Hao, Y., Wolery, T.J., Bourcier, W.L., Court, B., Celia, M.A., Friedmann, S.J., and Aines, R.D., 2012, *Active CO2 reservoir management for carbon storage: Analysis of operational strategies to relieve pressure buildup and improve injectivity*, International Journal of Greenhouse Gas Control, v. 6, p. 230-245
6. Pruess, K., 2005, ECO2N: a TOUGH2 fluid property module for mixtures of water, NaCl, and CO2, Lawrence Berkeley National Laboratory, LBNL-57952, p. 66.
7. Heath, J.E., Kobos, P.H., Roach, J.D., Dewers, T.A. and S.A. McKenna, 2012, *Geologic Heterogeneity and Economic Uncertainty of Subsurface Carbon Dioxide Storage,* SPE Economics & Management Journal, January 32-41.
8. Roach, J.D., Kobos, P., Klise, G.T., Krumhansl, J.L. and A. McNemar, *New Demands, New Supplies: A National Look at the Water Balance of Carbon Dioxide Capture and Sequestration*, American Geophysical Union, Poster SAND2010-8624C, December 13 – 16, 2010, San Francisco, CA.

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