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A TOOL TO FACILITATE MODELING AND PILOT PROJECTS FOR SEQUESTRATION OF CARBON DIOXIDE IN SALINE FORMATIONS

Keywords: greenhouse gasses, capture and storage

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ABSTRACT

Saline water-bearing formations that extend beneath much of the continental United States are attractive candidates for disposal of CO_2 produced during power generation or by other industrial processes. We have quantified the characteristics of saline formations that assure that gas can be efficiently injected into the selected subsurface unit and that it will remain sequestered for suitably long time periods. A GIS data base of these geologic attributes of 21 saline formations is available to support data analysis and comparison with CO_2 source locations. Attributes include depth, permeability, formation thickness, net sand thickness, percent shale, sand-body continuity, top seal thickness, continuity of top seal, hydrocarbon production from interval, fluid residence time, flow direction, CO_2 solubility in brine (P, T and salinity), rock mineralogy, water chemistry, and porosity. Variations in formation properties should be considered in order to match a surface greenhouse gas emissions reduction operation with a suitable subsurface disposal site.

INTRODUCTION

For CO_2 sequestration to be a successful component in U.S. emission-reduction strategies requires a favorable intersection of a number of variables such as the market for electricity, fuel source, power and industrial plant design and operation, a suitable geologic host for sequestration, and a suitable pipeline or right-of-way from the plant to the injection site. The concept of CO_2 sequestration in saline water-bearing formations (saline "aquifers") isolated at depths below potable aquifers became of widespread interest several years ago (Bergman and Winter, 1995) and continues to evolve. Saline formations are attractive because large volumes of prospective sink underlie many parts of the United States. Significant barriers remain, however, including high costs and potential citizen concerns about the safety and effectiveness of this process. Our contribution to the U.S. effort to reduce greenhouse gas emission via underground sequestration is a data base of formations that may have potential for sequestering CO_2. This data base can be used to (1) match CO_2 sources with prospective sinks, (2) conduct preliminary feasibility analysis, and (3) build various types of economic and process models. Our goal is to provide low-cost but realistic data that can support the search for viable options for CO_2 sequestration.

The scope of our investigations is saline water-bearing formations outside of oil and gas fields. We are accepting the concept of hydrodynamic trapping (Hitchon, 1996), in which the CO_2 is isolated from the atmosphere and potable water supplies by very long (>1,000 yr) travel times between the injection site and these environments. A structural trap for the CO_2 is not required. We are also focusing on onshore sites near large or closely spaced commercial power plants and other industrial centers with point-source emissions of CO_2. This definition allows exploration for large volumes of saline formations that may be optimal injection sites near sources where sequestration could be undertaken at minimal cost.

METHODS

In the feasibility phase of our project, we (1) mapped the 1996 carbon emissions of power plants to identify basins where sinks would be useful, (2) collected informal information on the areal distribution of industrial CO_2 sources, (3) identified 16 parameters that describe the properties of reservoirs and seals in potential sinks, and (4) tested the feasibility of collecting these data in saline formations.

During Phase II of our project, we compiled regional scale information and quantitatively mapped the 16 parameters for at least one target saline formation in 21 basins. This data compilation is based entirely on literature review, employing regional summaries, water-supply papers, state survey and U.S. Geological Survey maps and publications, oil and gas resource assessments, waste injection literature, and unpublished data sources including theses and contract reports. We used recent stratigraphic overviews to identify at least one potential saline

aquifer in areas with CO_2 sources. Then we conducted a literature search using GeoRef (http://georef.cos.com/) and other online resources and consulted local experts to locate, acquire, and compile the required information. We ranked the quality of data for each parameter as follows: (1) detailed data digitized from the cited source, (2) generalized or schematic data from the cited source, (3) detailed data interpreted during this project, (4) sparse or descriptive data interpreted during this project, and (5) little or no data, values based on analog data.

Raw data showing the spatial distribution of each parameter was digitized. In most basins, the raw data consisted of one or more paper maps, which were scanned and georeferenced using Cartesian projection and latitude-longitude as calibration points, digitized using NDS Mapper software, attributed, and imported into ESRI ArcView GIS (geographic information system). One source of error in the data base lies in unknown projection and imprecise registration of the source maps. A few data sets were obtained in digital format (for example, from N. Gupta Battelle Memorial Institute, USGS online sources, and an unpublished oil field data base compiled by M. Holtz, Bureau of Economic Geology).

Data were then manipulated in GIS and spreadsheet software to standardize highly variable raw data. Once in ArcView the maps were reprojected in meters and in Albers Equal Area projection, and the spreadsheet data were standardized into common units. Variability in original data is the major source of error in the data set; however, standardization is necessary for interbasinal comparisons, and we think that the precision is adequate for the intended purpose of supporting the search for CO_2 sequestration options. Site-specific follow-up studies will be required at any potential sequestration prospect to confirm relationships observed at a regional scale.

We did not attempt a comprehensive survey of potential saline formations. Saline formations were selected using the following informal criteria: (1) the formation has geographic and geologic potential to serve as a sink for areas of point-source CO_2 emissions, (2) sufficient data were located to map some of the parameters, and (3) inclusion of the formation contributes a geologically diverse set of potential sinks to be used for modeling experiments.

RESULTS

During the feasibility phase of evaluation of parameters that describe the properties of reservoirs and seals in potential sinks, we decided that the state of the science was too immature to determine which variables are critical. We therefore decided to compile diverse data. Variables were selected either because other workers have used them for models or basin assessment (for example Hendriks and Blok, 1995; Holloway and van der Straaten, 1995; Koide and others, 1995; Hitchon, 1996; van der Meer, 1996; Weir and others, 1996; Gupta and others 1998) or because they are commonly used in reservoir evaluation or for underground waste disposal site evaluation. These diverse data sets will then facilitate further evaluation and modeling.

Six parameters were selected primarily to describe injectivity. Injectivity controls how fast CO_2 can be injected into the saline formation without excessive pressure buildup. Depth is a primary constraint on the density of the injected CO_2. At typical temperature and pressure 800 m approximates the critical point, below which CO_2 requires less volume, which improves injectivity. Permeability and formation thickness are the rock variables that determine the flow rate from a well. Net sand (net high permeability strata) describes the thickness of the strata that accept fluid and are used for capacity assessment. Percent shale and sand-body continuity are indexes to the internal heterogeneity of the injection unit; they are needed to model the behavior of the CO_2 after it is injected.

Ten parameters were collected primarily to assess how effective the unit would be at trapping the CO_2. Under most conditions, CO_2 at critical point will be buoyant in brine. The top seal is defined as the low-permeability unit above the prospective injection unit that will limit leakage of the injected CO_2 upward into potable water and the atmosphere. The thickness of the top seal as well as its continuity can be used to calculate the rate of escape of CO_2 to assure that trapping will be effective. Production of oil or gas from the interval can provide a pathway for more rapid release of CO_2 to the atmosphere; pragmatically it raises issues of mineral rights. Injection of CO_2 in producing intervals can be beneficial to production, maintaining pressure and helping to mobilize oil. Use or reuse of hydrocarbon reservoirs for CO_2 sequestration has been considered in a number of studies, such as Holtz and others (1999), and is therefore not the focus of our study. Because we are using a hydrodynamic trapping assumption, fluid residence time

and flow direction are important in assessing effectiveness of lateral trapping in the formation and identifying potential short lateral paths for leakage to fresh water or the atmosphere. Temperature, pressure, and salinity are major variables in calculating CO_2 solubility in brine. Mineral trapping, in which CO_2 reacts with minerals in the rock, can also provide a very long term trapping mechanism (Hitchon, 1996); therefore, we compiled rock mineralogy and brine chemistry to permit assessment of the role of this process. Porosity is a simple variable for assessing the total volume of storage in the saline formation.

We identified 21 candidate formations in onshore U.S. basins, including Los Angeles, Powder River, Sevier, Mojave, South Carolina, Alabama, North Carolina , Appalachian, Illinois, Texas Gulf Coast, East Texas, Florida, Black Warrior, Denver, Williston, Michigan, San Juan, Palo Duro, and Anadarko. Data sets of 16 parameters for the target saline formation in each basin have been compiled and digitized. In many basins, several potential prospects were identified. We selected one or two formations to characterize in this study and note the potential for additional resource in overlying and underlying formations.

DISCUSSION

When we proposed this study, we thought that saline formations were generally poorly known because they are unused. We expected to have to interpolate information from oil and gas producing areas and aquifers. However, during the feasibly phase as well as the assessment phase, we found that data describing saline formations at a regional scale are moderately abundant. Data are derived from regional studies integrating areas productive for resources as well as assessment of saline formations themselves for potential for deep well injection of waste or saline water resources. In many places more detail can be extracted from sources such as well records and regulatory information from various types of injection, including waste and gas storage.

Capacity for CO_2 sequestration in different basins is highly variable. Primary causes of variability are formation thickness and permeability. For example, much larger volumes of CO_2 could be injected into thousands of feet of high-permeability sand typical of the Tertiary of the Gulf Coast than in the few hundred feet of older and less permeable basal Cambrian sandstones of the Midwest. In addition, quality of seals varies greatly, from thick, ductile mudstones to brittle and potentially highly fractured carbonate rocks. Many areas contain layered seal and permeable strata that may have the potential for greater protectiveness than a single thick seal. However, feasibility of implementing a sequestration project may not require optimal geologic conditions; other variables may bring a lower capacity sink into use.

We did not attempt a comprehensive survey of potential saline formations; therefore, our study is not intended as a refinement of the total volume assessment of Bergman and Winter (1995) or as a tool for evaluating all the sequestration options at a given site. It is, however, suitable for meeting our goal to provide realistic data that can support the search for viable options for CO_2 sequestration. In addition, our study provides a template for additional data compilation to create a detailed national assessment of capacity. This flexible data base can be used for construction of other scenarios, for example, combination of CO_2 utilization and geologic sequestration.

The data base is available to researchers in ArcView format from the Bureau of Economic Geology (contact us at http://www.beg.utexas.edu/).

CONCLUSIONS

Variations in formation properties should be considered in order to match a surface greenhouse gas emissions reduction operation with a suitable subsurface disposal site. In this environment, where cost is a critical limiting factor, matching CO_2 capture processes with an optimal subsurface site for sequestration can be essential. This data base provides a vehicle for assessing the interaction between surface variables such as the nature of the source and type of capture and infrastructure and subsurface geologic variables.

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