CO2 capture and storage (CCS) selected papers – Technical annotated bibliography

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CO_2 Capture and Storage (CCS) Selected Papers- Technical Annotated Bibliography

General Overview

Preston, C., Monea, M., Jazrawi, W., Brown, K., Whittaker, S., White, D., Law, D., Chalaturnyk, R., Rostron, B. (2005) IEA GHG Weyburn CO_2 Monitoring and Storage Project, *Fuel Processing Technology*, 86, 1547-1568.
This paper presents a summary of the Weyburn field CO_2 injection project. Site characterization shows the Weyburn field is appropriate for long-term CO_2 storage. The authors demonstrate successful detection of CO_2 distribution using seismic surveys, and obtain results using geochemical sampling methods. Long-term risk assessment suggests that no CO_2 penetration occurred, no interruption to the EOR process, and minimal sealing impact.

van der Meer, B. (2005) Carbon Dioxide Storage in Natural Gas Reservoirs, Oil & Gas Science and Technology, 60(3), 527-536.
This paper discusses the potential for storing CO_2 in natural gas reservoirs. The authors discuss characteristics of hydrocarbon reservoirs for CO_2 sequestration, as well as material properties of CO_2 and reservoir fluids. They described the driving mechanisms of hydrocarbon reservoirs and their implications for CO_2 storage. The authors also illustrate the advantages and disadvantages of natural gas reservoirs compared to other CO_2 storage options. They ultimately assert that the volume of available gas reservoirs in the US is limited whereas the natural gas storage potential in the EU is quite high.

Wilson et al. (2004) IEA GHG Weyburn CO_2 Monitoring & Storage Project Summary Report 2000-2004, Petroleum Technology Research Center.
This book summarizes the Weyburn field CO_2 injection project. The book is organized into four main topics: (1) geological characterization, (2) prediction, monitoring, and verification of CO_2 movements, (3) storage capacity, distribution prediction, and economic limits, and (4) long-term risk assessment. The authors provide a detailed explanation of each topic, empirical data, and lessons learned from Weyburn.

Risk Assessment

Lindeberg, E. (2002), The Quality of a CO_2 Repository: What is the Sufficient Retention Time of CO_2 Stored Underground, *Proceedings of 6th International Conference on Greenhouse Gas Control Technologies*, 255-260.
This paper proposes tools for determining minimum retention time for CO_2 sequestration in underground storage. The author develops a climate model that relates climate change to leakage of CO_2 from underground storage. He then calculates the escape rate of CO_2 from the storage sites. From this calculation, he firmly concludes that the typical retention time for geologic storage should be at least 10,000 years to prevent CO_2 leakage from appreciably impacting the climate.

Numerical Modeling (Fluid Flow)

Andre, L., Audigane, P., Azaroual, M., and Menjoz, A. (2007) Numerical Modeling of Fluid-Rock Chemical Interactions at the Supercritical CO_2-Liquid Interface During CO_2 Injection into a Carbonate Reservoir, the Dogger Aquifer (Paris Basin, France), *Energy Conversion and Management*, 48, 1782-1797.
This paper describes numerical modeling of geochemical reactions for CO_2 injected into carbonate rock formations. The authors adopt an axis-symmetrical model, and used TOUGHREACT and SCALE2000. From the modeling results, they show the injection of CO_2 -saturated water increases porosity up to 90% due to dissolution of carbonate. They also demonstrate that injection of supercritical CO_2 only increases porosity 5-7%, and near-injector porosity actually decreases due to mineral precipitation. The vaporization of liquid water near the injected supercritical CO_2 causes brine and precipitation to form.

Ghomian, Y., Pope, G. A., and Sepehrnoori, K. (2008) Reservoir Simulation of CO_2 Sequestration Pilot in Frio Brine Formation, USA Gulf Coast, *Energy*, 33(7), 1055-1067.
This paper describes the simulation of CO_2 sequestration at the Frio Brine Formation near Houston, Texas. The authors provide a detailed summary of input data such as CO_2 solubility, CO_2 saturated brine density, and viscosity for numerical code (GEM). They show that predictions of CO_2 breakthrough time and CO_2 plume movement from the modeling match well with field measurements. They also demonstrate that, after ten years from the injection date, a significant part of the injected CO_2 will be stored in the form of trapped gas or dissolved aqueous phase in the brine. Only 2-5% of the injected CO_2 is in the form of free gas, so that the possibility of leakage through caprock is fairly low.

Jessen, K., Kovscek, A. R., and Orr Jr., F. M. (2005), Increasing CO_2 Storage in Oil Recovery, *Energy Conversion and Management*, 46, 293-311.
This paper focuses on numerical modeling of multiphase fluid flow from CO_2 injection in the enhanced oil recovery (EOR) process. The authors introduce a new modeling technique, called streamline simulation, and compare its results with those of traditional finite difference methods. They discuss methods of increasing CO_2 storage during EOR without decreasing oil production, and offer the following recommendations: (1) adjust injection gas composition to maximize CO_2 concentration, (2) design well completions to create injection profile to reduce the adverse effect of preferential flow through high permeability zones, (3) optimize water injection, (4) consider aquifer injection to store CO_2, and (5) consider reservoir re-pressurization after the end of the field's production life.

Kovscek, A. R., and Wang, Y. (2005), Geologic Storage of Carbon Dioxide and Enhanced Oil Recovery. I. Uncertainty Quantification Employing a Streamline Based Proxy for Reservoir Flow Simulation, *Energy Conversion and Management*, 46, 1920-1940.
This paper introduces the concept of, 'co-optimization,' simultaneously maximizing both economic oil recovery and the volumes of CO_2 emplaced in oil reservoirs. An important component of the work flow is the assessment of uncertainty in predictions of performance. To quantify uncertainty, streamline simulations were adopted as an alternative to exhaustive and time-consuming full physics flow simulations. The authors generate equi-probable reservoir models, considering uncertainties, and then run streamline simulations. They prove the streamline simulations are fast and useful for selecting a representative reservoir model subset.

Oldenburg, C. M. and Lewicki, J. L. (2006) On Leakage and Seepage of CO_2 from Geologic Storage Sites into Surface Water, *Environmental Geology*, 50, 691-705.
This paper evaluates the leakage and the seepage of CO_2 and CH_4 from geologic storage sites into surface water. The authors use analytical solutions to estimate the flow rate of CO_2 and CH_4. They found that: (1) the flow of gas in a secondary connected fluid phase within a primary liquid phase prevails over that in discrete bubbles in medium to fine-grained porous media, (2) the flow of gas in the form of discrete bubbles dominate over dispersion in surface water, and (3) as CO_2 migrates upward, ebullition will occur due to the decrease of solubility of gas into brine in lower pressure.

Pruess, K. and Garcia, J. (2002) Multiphase Flow Dynamics during CO_2 Disposal into Saline aquifers, *Environmental Geology*, 42, 691-705.
This paper models the injection of CO_2 into saline aquifers. The authors solve mass conservation equations for three components (water, salt, and CO_2), and the governing equations are solved using the finite difference method. Based on several explicit assumptions such as one-dimensional fluid flow, negligence of chemical reactions, and effects of mechanical stress, the authors show that (1) pressure response is sensitive to space discretization effects, whereas saturation response is much more robust, and (2) CO_2 loss from a storage unit through geologic discontinuities may be a self-enhancing process, suggesting that reliable containment of CO_2 will require multiple barriers.

Rutqvist, J., Birkholzer, J. T., and Tsang, C-F (2008) Coupled Reservoir-Geomechanical Analysis of the Potential for Tensile and Shear Failure Associated with CO_2 Injection in Multilayered Reservoir-Caprock Systems, *International Journal of Rock Mechanics and Mining Sciences*, 45(2), 132-143.
This paper evaluates the potential for tensile fracturing and shear-slip along pre-existing fractures associated with CO_2-injection in a multilayered geological system. The authors estimate pressure change in a reservoir due to CO_2 injection using the TOUGH2 reservoir simulator. From the pressure change, they calculate the stress change using the FLAC geomechanical simulator. Then, with the obtained stress change, they assess the potential for tensile fracturing and shear-slip. The main conclusions are: (1) the potential for shear failure is generally higher than the potential for tensile failure. Thus, at an injection site, shear failure along pre-existing fractures will probably occur earlier than tensile failure, (2) if upward migration of fluid pressure occurs in a multilayered CO_2-storage system, estimating the maximum sustainable injection pressure needs to consider the coupled fluid flow and upper-system geomechanical responses, where mechanical failure potential may be the highest, and (3) the orientation of the shear failure and propagation of the failure plane are highly dependent on the initial stress field. Therefore, it is important to estimate the 3-D in-situ stress field when designing the CO_2 injection process.

Geochemistry

Lagneau, V., Pipart, A., and Catalette, H. (2005) Reactive Transport Modeling of CO_2 Sequestration in Deep Saline Aquifers, *Oil & Gas Science and Technology*, 60(2), 231-247.
This paper presents numerical modeling of CO_2 sequestration in deep saline aquifers to evaluate the advantages and disadvantages of reactive transport modeling. The authors use two 2-D numerical codes to investigate the evolution of CO_2: Hytec to simulate geochemical modeling and R2D2 for the fluid-transport part. They chose two aquifers: the Dogger carbonated aquifer (Paris Basin), and the Bunter sandstone aquifer (North Sea). These aquifers were selected to describe CO_2 dissolution in the carbonated aquifer and carbonate mineral precipitation in the sandstone aquifer. In the carbonate aquifer, they show that transport is the key factor of the dispersion of dissolved CO_2 with a quick dissolution of supercritical CO_2 bubbles and transport of the injected CO_2 bubbles. They also demonstrated that, in the sandstone aquifer, the reactivity of the dissolved CO_2 with the host rock minerals controls the evolution of CO_2 in the reservoir. While it seems that reactive transport codes can simulate CO_2 sequestration process, the authors point out that detailed aquifer information, improved CO_2 phase change description, and reactivity of the supercritical CO_2 with host rock minerals are needed for better sequestration modeling.

Monitoring

Hovorka et al. (2006) Measuring Permanence of CO_2 Storage in Saline Formations: the Frio Experiment, *Environmental Geosciences*, 13(2), 105-121
This paper presents a summary of the Frio Brine field CO_2 injection project. The authors provide comprehensive descriptions of site characterization and monitoring techniques. They show post-injection measurements, including time-lapse vertical seismic profiling, cross-well seismic topography, and saturation logs. These measurements suggest that CO_2 is retained permanently in the reservoir, and dissolution into the brine in the reservoirs is rapid and volumetrically significant. They also demonstrate that the results of numerical modeling using TOUGH2 and field measurements match well. However, tool resolution and complex characteristics of reservoirs have lead to prediction uncertainties.

Comprehensive Guide

Intergovernmental Panel on Climate Change (2005), Special Report on Carbon Dioxide Capture and Storage, 1-431.
This report fully catalogues the sources, capture mechanisms, transportation, and storage options for CO_2. It discusses the costs, economics, politics, and regulatory framework of CO_2 sequestration. The report also places Carbon Capture and Storage (CCS) in the context of other climate change mitigation options. The report compiles all major CCS literature and field work, enumerating major CCS breakthroughs, barriers, and gaps in knowledge. It provides a technical summary and a summary for policy makers approved by governments represented in the IPCC.

General Overview

Bentham, M. and Kirby, G. (2005) CO_2 Storage in Saline Aquifers, *Oil & Gas Science and Technology*, 60(2), 559-567.
This paper describes storage options and risk factors for CO_2 storage in saline aquifers. The authors describe the geology of saline aquifers and provide estimates of storage capacity and capture costs for several European Union countries. They also discuss lessons learned from the Sleipner site in the North Sea, currently the only commercial-scale saline aquifer CO_2 storage facility in the world. A global appraisal of prospective saline aquifer CO_2 storage sites is given at a regional-level as well.

Hovorka, Susan D. (2007), Introduction to Geologic Sequestration of CO_2, PowerPoint Presentation, 1-20.
This presentation briefly outlines key concepts related to the capture and geologic storage of CO_2. Specifically, the author gives brief descriptions of recent safety and volumetric adequacy assessments. System maturity is also considered, and determined to be ready for commercial-scale programs as a part of a greenhouse gas emissions reduction portfolio.

Technology Guide

Carbon Capture and Storage: Technological and Regulatory Considerations (2008), National Association of Regulatory Utility Commissioners, 1-16.
This paper provides a comprehensive overview of Carbon Capture and Storage (CCS) technology and associated regulations. Specifically, the NARUC identifies CO_2 capture methods, storage sites, current research, permits/regulations, and risks. Cost recovery and financial risks are also separately described for each CCS method given. The NARUC ultimately conclude the benefits of CCS significantly outweigh its plausible harms.

Carbon Sequestration Technology Roadmap and Program Plan (2007), U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, 1-48.
This paper discusses current NETL Sequestration Program research contributing to commercially viable sequestration systems. The paper is organized into three primary sections: Program Overview, Challenges, and Technology Development Efforts (TDE). TDE focuses on Core R&D and Regional Partnerships. The stated goal of the NETL Sequestration Program is to develop, by 2012, fossil fuel conversion systems that offer 90 percent CO_2 capture, with 99 percent storage permanence, at less than a 10 percent increase in the cost of energy services.

Risk Assessment

Kovscek, A. R. (2002) Screening Criteria for CO_2 Storage in Oil Reservoirs, *Petroleum Science and Technology*, 20(7), 841-866.
This paper evaluates site-selection screening criteria for CO_2 storage and Enhanced Oil Recovery (EOR) in oil reservoirs. The author accepts or rejects proposed criteria based on what, if any, contribution they make towards understanding the geophysical and surface facility aspects of reservoir engineering. Final suggested criteria include: initial saturation, porosity, permeability, pore pressure gradient, seal existence, oil chemistry, and surface facility properties.

Lewicki, J. L., J. Birkholzer, and Chin-Fu Tsang (2007) Natural and Industrial Analogues for Leakage of CO_2 from Storage Reservoirs: Identification of Features, Events, and Processes and Lessons Learned, *Environmental Geology*, 52, 457-467.
This paper presents a list of various natural and anthropogenic analogues for CO_2 leakage. The authors provide detailed information on these analogues for CO_2 leakage such as leakage types and triggering mechanisms. The authors also evaluate concerns regarding potential hazardous effects of CO_2 leakage on human health and ground water chemistry. They conclude that, in most cases, such health risks are negligible and ground water remains potable despite slight changes in acidity.

Geochemistry

Li, Z., Dong, M., Li, S. , and Huang, S. (2006) CO_2 Sequestration in Depleted Oil and Gas Reservoirs-Caprock Characterization and Storage Capacity, *Energy Conversion and Management*, 47, 1372-1382.
In this paper, the authors explain the important relationship between CO_2 injection pressure and critical caprock sealing pressure. They calculate storage capacity for a given void reservoir, and demonstrate the effects of (1) marginal increases in pressure past critical levels and (2) extracting residual reservoir water. Suggested methods of characterizing gas flow through caprock are also given. The authors conclude that, although depleted oil and gas reservoirs are the most attractive geological media for CO_2 storage, their total capacity is limited. Therefore, it is crucial to fully utilize the capacity of a given reservoir, thereby maximizing the value of the depleted oil and gas reservoirs in reducing CO_2 emissions.

Monitoring

Winthaegen, P., Arts, R., and Schroot, B. (2005) Monitoring Subsurface CO_2 storage, Oil & Gas Science and Technology, 60(3), 573-582.
This paper provides an overview of available monitoring techniques for CO_2 storage. The authors suggest that injected CO_2 should be separate from other CO_2 sources and characterized by some means such as isotopic analysis. In addition to describing traditional ground monitoring techniques for CO_2 injection, the authors also assess the benefits and limitations of satellite and airborne monitoring methods.