



**OTC 19710**

## **CO<sub>2</sub> Sequestration in the Offshore Environment: Challenges, Opportunities and Solutions**

Joseph M. Reilly, ExxonMobil Upstream Research

Copyright 2008, Offshore Technology Conference

This paper was prepared for presentation at the 2008 Offshore Technology Conference held in Houston, Texas, U.S.A., 5–8 May 2008.

This paper was selected for presentation by an OTC program committee following review of information contained in an abstract submitted by the author(s). Contents of the paper have not been reviewed by the Offshore Technology Conference and are subject to correction by the author(s). The material does not necessarily reflect any position of the Offshore Technology Conference, its officers, or members. Electronic reproduction, distribution, or storage of any part of this paper without the written consent of the Offshore Technology Conference is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of OTC copyright.

CO<sub>2</sub> sequestration is an extremely important global issue facing both the energy industry and the public at large. Research in this area is in its early phases, with significant challenges in geoscience, engineering and policy.

This manuscript is intended as an introduction to the OTC.08 panel discussion scheduled for Tuesday 6<sup>th</sup> May 2:30pm-4:00pm. The OTC.08 program also includes a complimentary technical session entitled “CO<sub>2</sub> Challenge: Monitoring, Minimization, Removal Technology and Detection” which is scheduled for Tuesday 6<sup>th</sup> May 9:00am – noon.

The members of the OTC.08 panel session represent a selection of the premier research efforts in this area from the United States, Australia and Europe:

Dr. Sally Benson, Stanford GCEP  
Dr. Kevin Dodds, CSIRO, CO<sub>2</sub>CRC  
Dr. Heleen Groeneweg, ECN Policy Studies, CO<sub>2</sub>ReMoVe  
Dr. Daniel Schrag, Harvard University Center for the Environment  
M. Nafi Toksoz, MIT

The discussion will focus on CO<sub>2</sub> sequestration activities which will impact the offshore environment; including geotechnical research, storage options, monitoring, verification, utilization for enhanced recovery and regulatory framework.

Following are the detailed biographies and introductory comments from our distinguished panel.

### **Sally M. Benson**

Sally M. Benson was appointed GCEP Executive Director in March 2007. An internationally-recognized scientist with extensive management experience, Benson is responsible for guiding the development of GCEP's diverse research portfolio. A Professor (Research) in the Department of Energy Resources Engineering in the School of Earth Sciences, Benson has been a member of Stanford's faculty since 2007.

Prior to joining GCEP, Benson was a staff scientist in the Earth Sciences Division at Lawrence Berkeley National Laboratory (LBNL). In 2004, she completed a four-year term as Deputy Director of Operations at the lab. Benson also served as Division Director for Earth Sciences and Associate Laboratory Director for Energy Sciences at LBNL.

A ground water hydrologist and reservoir engineer, Benson has conducted research to address a range of issues related to energy and the environment. Her research interests include geologic storage of CO<sub>2</sub> in deep underground formations, technologies and energy systems for a low-carbon future, influence of climate change on critical habitats, biogeochemistry of selenium, and geotechnical instrumentation for subsurface characterization and monitoring. She is an internationally recognized expert on geological storage of carbon dioxide storage in geological formations and was a coordinating lead author for the IPCC Special Report on Carbon Dioxide Capture and Storage.

Benson graduated from Barnard College at Columbia University in 1977 with a bachelor's degree in geology. She completed

her graduate education in 1988 at the University of California, Berkeley, after receiving master's and doctoral degrees, both in materials science and mineral engineering.

The author or co-author of over 160 scientific publications, Benson is a member of the American Geophysical Union, the Society of Petroleum Engineers, the American Association for the Advancement of Science, and the American Chemical Society.

### ***Challenges, Issues and Opportunities for Monitoring Storage of CO<sub>2</sub> in Offshore Geological Formations***

A great deal of progress has been in demonstrating techniques for monitoring on-shore geological storage of CO<sub>2</sub>. Methods are available for monitoring all of the geological units from the storage reservoir up to the ground surface. Direct methods are even available for measuring CO<sub>2</sub> fluxes from the ground surface into the atmosphere. Achieving this same level of monitoring coverage may be more challenging in offshore environments—due to the high cost of drilling wells, high cost of offshore logging and monitoring services, and the limited demonstration of technology for directly measuring CO<sub>2</sub> fluxes from the sea floor. On the other hand, seismic imaging at Sleipner has been very effective for monitoring CO<sub>2</sub> migration in the Utsira Formation. Additionally, a recent study by Brewer et al. (2006) demonstrated that acoustic imaging of the water column could provide 3-dimensional images of a rising plume of CO<sub>2</sub>. Other innovations drawn from the marine sciences may provide a wealth of monitoring options that have yet to be tested. Nevertheless, questions remain about the degree of quantification possible and threshold detection levels—and whether these are sufficiently sensitive to provide confidence that an offshore storage project is not leaking. Potential biological impacts from leaking CO<sub>2</sub> raise additional concerns that must be addressed.

The issues raise several questions. What kind and extent of monitoring is needed for off-shore storage projects? Are there technologies available from the marine sciences that could be adapted for monitoring offshore storage projects? Are the technologies available today sufficient? If not, what else is needed? What could be done to gain confidence that monitoring systems are adequate? One way to address these issues is to develop an offshore leak detection verification facility, where monitoring technologies could be demonstrated and tested. Controlled releases of CO<sub>2</sub> from the seafloor or sub-seafloor could be used to quantitatively test, improve and verify the performance of a variety of monitoring approaches. Biological impacts could also be evaluated during and after these controlled releases. An analogous experiment was conducted in an on-shore environment with great success (Spangler and Dobeck, 2007). If the scientific community could join together in a coordinated effort to test, improve and verify offshore monitoring—this would make big strides towards building the confidence needed for large-scale CCS projects in offshore environments.

Peter G. Brewer, Baixin Chen, Robert Warzinski, Arthur Baggeroer, Edward T. Peltzer, Rachel M. Dunk, and Peter Walz, 2006. Three-dimensional acoustic monitoring and modeling of a deep-sea CO<sub>2</sub> droplet cloud. *GEOPHYSICAL RESEARCH LETTERS*, VOL. 33, L23607, doi:10.1029/2006GL027181, 2006

Spangler and Dobeck (2007): A Controlled Field Pilot for Testing Near Surface CO<sub>2</sub> Detection Techniques and Transport Models *Eos Trans. AGU*, 88(52), Fall Meet. Suppl., Abstract U42A-02.

### **Kevin Dodds**

Kevin Dodds has recently joined BP Alternative Energy in the role of Lead, Geological Integrity and Monitoring Technology for the rapidly developing CCS team within BP. Kevin spent nine years in Perth in the Australian national research organization CSIRO, running a pore pressure research program and more recently was engaged with the Cooperative Research Centre for Greenhouse Gases (CO2CRC) Otway Basin Pilot demonstration project. In this respect he developed the monitoring and verification program from atmosphere to reservoir for that project. Prior to this Kevin spent 20 years with Schlumberger in various technical and marketing leadership positions around the world. Kevin who is Australian has been past President of the ASEG, Pacific Regional Coordinator for SEG and Chairman of the Australian Geoscience Council. He now lives and works in Houston.

### ***CO<sub>2</sub> Sequestration in the Offshore Environment: Challenges, Opportunities and Solutions***

The application of CO<sub>2</sub> sequestration to the offshore environment brings the opportunity to develop practical applications to the monitoring of the storage process in an offshore context. Many of the issues of establishing storage performance and safety are the same as for land, however their implementation will in many instances be under different regulatory jurisdictions than onshore, and require marine technology solutions to establish storage integrity and assurance. The first large-scale storage process at Sleipner has not been followed by other offshore projects, although several have been in early stages of development such as BP Miller, Gippsland in Australia and Chevron Gorgon which have provided insights into political as well as technical challenges.

## Heleen Groenenberg

Heleen Groenenberg is a scientific researcher at ECN Policy Studies, where her principal occupation centers on CO<sub>2</sub> capture and storage. Working in pioneering projects supporting the development of new EU legislation for CCS, she has a first class overview of the difficulties and challenges related to the regulation of CCS, regarding both the management of risks involved, and the design of adequate policy incentives to realize large-scale deployment of CCS. Dr. Groenenberg earned her graduate degree in Soil, Water and Atmosphere at Wageningen University, and finished her dissertation on post-Kyoto commitments for the industrialized and developing world at Utrecht University in 2002. She joined ECN after working as a post-doc Global Change and Energy at the European Commission's Joint Research Center in Seville.

### ***Expertise relevant to the panel theme: CO<sub>2</sub> Sequestration in the Offshore Environment: Challenges, Opportunities and Solutions***

Expertise relevant to the panel discussion is based on the Draft Contribution to Future Guidelines for Licensing of CO<sub>2</sub> storage in Saline Reservoirs and Depleted Hydrocarbon Reservoirs, produced in the CO<sub>2</sub>ReMoVe project. CO<sub>2</sub>ReMoVe is a consortium of industrial, research and service organizations with experience in CO<sub>2</sub> geological storage. So far, Europe has invested large research efforts in CO<sub>2</sub> geological storage monitoring in several storage types, gaining experience with industrial-scale projects (Sleipner, Weyburn), and other "subsurface laboratories" (Ketzin, K12B, Kanioy). Two new industrial-scale geological storage projects (In Salah and Snohvit) now provide the opportunity to build on this work. The CO<sub>2</sub>ReMoVe consortium proposes a range of monitoring techniques, applied over an integrated portfolio of storage sites, and will develop:

- 1) Methods for base-line site evaluation
- 2) New tools to monitor storage and possible well and surface leakage
- 3) New tools to predict and model long term storage behavior and risks
- 4) A rigorous risk assessment methodology for a variety of sites and time-scales
- 5) Guidelines for best practice for the industry, policy makers and regulators

So far, the work in the CO<sub>2</sub>ReMoVe project has run in parallel with the development of an EU Directive for the geological storage of CO<sub>2</sub>, which regulates the risks of CO<sub>2</sub> storages. In particular, a thorough site selection and characterization is emphasized in both documents. Apart from this risk regulation further work will be undertaken to establish accounting rules for CO<sub>2</sub> emissions seeping from CCS operations in the EU Emissions Trading Scheme. In addition, the role of impurities in the CO<sub>2</sub> stream needs to be addressed in greater detail.

## Daniel Schrag

Daniel Schrag is Professor of Earth and Planetary Sciences at Harvard University and the Director of the Harvard University Center for the Environment. Schrag studies climate and climate change over the broadest range of Earth history. He is currently working on technological approaches to mitigating the effects of human-induced climate change. In particular, he has pioneered the possibility of injection of liquid CO<sub>2</sub> below the ocean floor as a method for carbon storage for heavily-populated coastal regions of the U.S. and other countries.

### ***Permanent Storage of CO<sub>2</sub> in deep-sea sediments***

Through a variety of modeling and laboratory efforts, we have examined the feasibility of injection of CO<sub>2</sub> into deep-sea sediments as a permanent storage facility. Our calculations show that once injected, the higher density of the liquid CO<sub>2</sub> at appropriate pressures and temperatures, as well as the potential to form CO<sub>2</sub> hydrates that will impede the migration of CO<sub>2</sub> upward towards the sea floor, makes this approach essentially a leak-proof method for CO<sub>2</sub> storage. Although this method is not appropriate for all point sources of CO<sub>2</sub>, especially those far from the coast, the enormous capacity and low leakage potential make this an excellent option as part of a national carbon sequestration portfolio.

## M. Nafi Toksöz

M. Nafi Toksöz is Robert R. Shrock Professor of Geophysics, Founder of the Earth Resources Laboratory and its Director from 1982 to 1998, and Director of the George R. Wallace, Jr. Geophysical Observatory at the Massachusetts Institute of Technology. He received his geophysical engineering degree at Colorado School of Mines and his M.S. and Ph.D. degrees, in geophysics, at the California Institute of Technology. He has been a faculty member in the Department of Earth, Atmospheric, and Planetary Sciences, M.I.T., since 1965.

Prof. Toksöz has made major scientific contributions in many areas of geophysics, including seismic exploration, plate

tectonics, planetary interiors, earthquake seismology, and imaging. He is the 2006 recipient of the Harry Fielding Reid Medal of the Seismological Society of America. He has received the scientific achievement medals from NASA, his alma mater, the Colorado School of Mines, and other institutions. In November 1999, SEG honored M. N. Toksöz with Honorary Membership. He is a member of the American Geophysical Union, Seismological Society of America, Society of Exploration Geophysicists, Geological Society of America, AAPG, and AAAS.

Prof. Toksöz is the author or co-author of more than 300 technical papers in geophysics, including many articles on geophysics and seismology. He has edited books and served on editorial boards of scientific journals. M. N. Toksöz has and continues to serve on scientific advisory and review committees for U.S. government agencies, universities, international organizations, and industry. His academic activities include teaching, leading several research projects, and advising a number of graduate students.

### ***Science and Engineering Requirements for Geologic CO<sub>2</sub> Sequestration***

CO<sub>2</sub> sequestration in geological formations requires proper site selection, effective monitoring, and remediation options should a CO<sub>2</sub> release occur. Much information about subsurface reservoirs has been obtained from oil and gas fields, natural CO<sub>2</sub> reservoirs, and subsurface storage facilities for natural gas and other fluids. The knowledge from these geologic storage examples is extremely valuable. However, they need to be complemented with additional information, specific to CO<sub>2</sub> properties, to ensure the selection and monitoring of a safe storage site. Some areas for additional studies are:

1. Geochemical and Petrophysical Studies of the CO<sub>2</sub>-Fluid-Rock System.
2. Geomechanical Aspects of Injections
3. Basin-Scale Modeling of CO<sub>2</sub> Distribution.
4. Isotropic Tagging of Injected CO<sub>2</sub>.
5. Geobiology.

In the discussion I will concentrate on the reservoir monitoring aspects of CO<sub>2</sub> sequestration. Public acceptance of the sequestration in geologic formation depends strongly on an effective monitoring system that determines the distribution and the fate of the injected CO<sub>2</sub>. Geophysical methods will play a key role in the monitoring. Developing sensitive and cost-effective methods for long-term monitoring is an important part of sequestration.