Office of Fossil Energy

Carbon Sequestration Newsletter

June 2012

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Introduction

This Newsletter is created by the National Energy Technology Laboratory and represents a summary of carbon sequestration news covering the past month. Readers are referred to the actual article(s) for complete information. It is produced by the National Energy Technology Laboratory to provide information on recent activities and publications related to carbon sequestration. It covers domestic, international, public sector, and private sector news.

Highlights

***Fossil Energy Techline,* "New DOE 'Best Practices' Manual Features Top Strategies for Carbon Storage Wells."**

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) released its latest best practices manual (BPM), titled, "Carbon Storage Systems and Well Management Activities." The BPM covers the planning, permitting, design, drilling, implementation, and decommissioning of carbon dioxide (CO_2) storage wells. The manual builds on lessons learned through NETL research; the experiences of the Regional Carbon Sequestration Partnerships' (RCSPs) carbon capture, utilization, and storage (CCUS) field tests; and the acquired knowledge of industries that have been actively drilling wells for more than 100 years. In addition, the BPM provides an overview of the well-management activities associated with CCUS projects, beginning with pre-injection planning and continuing through post-injection operations; it provides a roadmap and resource for lessons learned about well-management issues and what project planners and operators can expect as a project progresses. The manual discusses the types of experts needed for a successful CCUS project team and informs the general public about the approach that project developers undertake to ensure human and environmental safety as they design, drill, maintain, and close these wells. (**See Recent Publications section for the Executive Summary and a link to the "Carbon Storage Systems and Well Management Activities" BPM.**) The BPM is available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-Carbon-Storage-Systems-and-Well-Mgt.pdf. June 7, 2012, http://www.fossil.energy.gov/news/techlines/2012/12025-NETL_Issues_Best_Practices_Manual.html.

***Fossil Energy Techline,* "NETL Publications Earn National Communications Awards."**

NETL, the research laboratory for DOE's Office of Fossil Energy (FE), received two National Association of Government Communicators (NAGC) 2012 first-place awards for superior government communications for the Carbon Sequestration Atlas of the United States and Canada (Atlas III) and netlognews. The annual Blue Pencil & Gold Screen Awards recognize communications pieces produced by government agencies that are particularly high quality and effective. Atlas III received top honors in the Technical or Statistical Report category. The atlas updates U.S. and Canadian geologic CO_2 storage potential and provides information on the activities of DOE's RCSPs. NETL developed the atlas in collaboration with the RCSPs and the National Carbon Sequestration Database and Geographical Information System (NATCARB) team. Two versions of Atlas III – an interactive viewer and a print version – are available for viewing and downloading from NETL's website. The NAGC Blue Pencil & Gold Screen Awards program is an international competition that recognizes superior government communications products and those who produce them. Atlas III can

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Highlights (Continued)

be viewed at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/2010atlasIII.pdf. More information on NATCARB is available at: http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html. June 8, 2012, http://www.fossil.energy.gov/news/techlines/2012/12026-NETL_Publications_Earn_National_Aw.html.

***NETL News Release*, "Energy Department Announces New Mapping Initiative to Advance North American Carbon Storage Efforts."**

DOE, with partners from Canada and Mexico, released the North American Carbon Storage Atlas (NACSA), the first-ever atlas mapping the potential CO_2 storage resource in North America last month. According to NACSA, North America contains at least 500 years of geologic storage resource for CO_2 emissions that result from either industrial sources or power plants. In addition to estimating storage resource for North American oil and gas fields, unmineable coal, and saline formations, NACSA also documents the location of approximately 2,250 large stationary CO_2 sources, which, along with documenting the locations of storage potential of various geological sites, helps quantify the benefits and opportunities for potential CCUS projects. Created through the North American Carbon Atlas Partnership (NACAP) and developed by DOE, Natural Resources Canada (NRCan), and the Mexican Ministry of Energy, NACSA also includes work from DOE's RCSPs, whose 400 organizations provide input to NETL's NATCARB database. To view the atlas, go to: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/NACSA2012.pdf. For more information on NACAP, visit: http://www.nacsap.org/. The NACSA Interactive Viewer is available at: http://gis.netl.doe.gov/NACAP/. May 2, 2012, http://www.netl.doe.gov/publications/press/2012/120502_energy_department_announces.html.

Sequestration in the News

***Natural Resources Canada News Release*, "Government of Canada Invests in Carbon Capture and Storage Technology,"** and ***Carbon Capture Journal*, "Canada's Husky Energy Launches CCS and EOR Project."**

The government of Canada announced an investment in Husky Energy's enhanced oil recovery (EOR) and carbon capture and storage (CCS) project in Lloydminster, Saskatchewan. The investment will help support the project's goal to develop new knowledge and methods for EOR while reducing greenhouse gas (GHG) emissions. Husky Energy's facility began operating in mid-March and converts approximately 250 tonnes of CO_2 produced daily by its ethanol plant into a high-pressure liquid, which is transported to oil fields for EOR. Husky Energy is one of eight companies to receive funding from the ecoENERGY Technology Initiative, which has provided a total of approximately $150 million for industry-led initiatives to advance CCS technologies. May 17, 2012, http://www.nrcan.gc.ca/media-room/news-release/2012/61/6227, and May 20, 2012, http://www.carboncapturejournal.com/displaynews.php?NewsID=949&PHPSESSID=hlevpjmfhqg35gfjc2h9n14st0.

Sequestration in the News (Continued)

***NewsOK.com*, "Carbon Dioxide Spurs Devon's Oil Production in Wyoming."**

Devon Energy Corporation is using CO_2 to produce approximately 5,700 barrels of oil per day through EOR at its Beaver Creek operation in central Wyoming. The CO_2 used for EOR is piped from an Exxon Mobil Corporation field approximately 100 miles away. Officials believe the oil field, which has been producing oil since 1954 and includes around 18 production wells and injection wells, could produce as much as 12 million barrels of oil; to date, it has yielded approximately 3.5 million barrels. Devon Energy is currently studying the geology and reservoir properties of other fields where EOR could be applied. Wyoming lawmakers have allocated funding to help address right-of-way issues with the Bureau of Land Management (BLM) as part of an effort to support pipeline development to boost EOR operations. May 11, 2012, http://newsok.com/carbon-dioxide-spurs-devons-oil-production-in-wyoming/article/3674340?custom_click=pod_headline_energy-news.

***Reuters*, "Scotland Opens Research [Center] for CO_2 Oil Recovery."**

Scotland's University of Edinburgh opened a research center to study the use of EOR, which experts believe has the potential to release 3 billion barrels of oil in the North Sea. Funded by the Scottish government, Scottish Enterprise, and the CCS developer 2CO, the center will conduct research under the umbrella of Scottish Carbon Capture and Storage, which is a collaboration between the University of Edinburgh, Heriot-Watt University, and the British Geological Survey. May 23, 2012, http://www.reuters.com/article/2012/05/23/us-britain-eor-centre-idUSBRE84M0RP20120523.

***Bloomberg*, "Abu Dhabi May Inject CO_2 in Offshore Fields to Boost Output.**

Abu Dhabi National Oil Company (ADNOC) may start injecting CO_2 into its offshore fields for EOR, according to an official from the company's Abu Dhabi Marine Operating Co. unit. ADNOC is exploring methods to reduce the oil industry's use of the 5 billion cubic feet of gas produced daily in the United Arab Emirates. ADNOC is also working with Abu Dhabi's renewable energy company Masdar to capture carbon. ADNOC is planning to boost output to 3.5 million barrels a day by 2017, up from approximately 2.8 million barrels currently. ADNOC's onshore unit, Abu Dhabi Co. for Onshore Oil Operations, has completed a pilot project to inject 1.2 million cubic feet of CO_2 a day into the Rumaitha field and is now planning four to five pilot projects for 2013 and 2014, according to an official. June 6, 2012, http://www.rggi.org/docs/PR060412_Compliance.pdf.

Announcements

2012 NETL CO_2 Capture Technology Meeting.

NETL's 2012 CO_2 Capture Technology Meeting will be held at the Sheraton Station Square Hotel in Pittsburgh, Pennsylvania, on July 9-12, 2012. This year's meeting will provide a public forum to present CO_2 capture technology development status and accomplishments made under NETL's Innovations for Existing Plants (IEP), Carbon Storage, and Demonstration Programs, as well as highlight DOE's Advanced Research Projects Agency-Energy (ARPA-E) CO_2 capture portfolio. In addition to covering post-, oxy-, and pre-combustion technologies, the meeting will also cover solvent, membrane, chemical looping, and compression technologies. To learn more, go to: http://netldev.netl.doe.gov/events/2012-co2-capture.

2012 NETL Carbon Storage R&D Project Review Meeting.

The DOE Carbon Storage R&D Project Review Meeting will be held at the Sheraton Station Square Hotel in Pittsburgh, Pennsylvania, on August 21-23, 2012. More than 120 DOE-sponsored projects will be presented, covering DOE's carbon storage infrastructure and Core R&D projects. In addition, DOE's RCSP Initiative and the American Recovery and Reinvestment Act (ARRA) Site Characterization projects will be featured. Presentations will focus on regulatory issues, government-industry collaborations, and large-scale international storage efforts. An interactive reception/poster session will also be held to highlight related work being performed by ARRA-supported Regional Carbon Sequestration Training Centers, DOE National Laboratories, RCSP subcontractors, and other organizations directly participating in geologic carbon storage and characterization projects in the United States and internationally. Poster submissions are being accepted through July 6, 2012, at: http://netldev.netl.doe.gov/File%20Library/Events/2012/Carbon%20Storage%20RD%20Project%20Review%20Meeting/Poster-Abstract-Sub-Form_CS.pdf. More information is available at: http://netldev.netl.doe.gov/events/carbon-storage-project-review.

NETL Paper Released: NEMS-CCUS: A Model and Framework for Comprehensive Assessment of CCUS and Infrastructure.

This paper presents a recent application of the NETL-funded NEMS-CCUS (National Energy Modeling System) Model that enables the simulation of CO_2 pipelines and pipeline networks across the 48 contiguous states. The model was used to assess the role of CO_2 capture, utilization, and storage in both carbon tax and clean energy standard (CES) cases. The paper is available at: http://www.netl.doe.gov/energy-analyses/pubs/CMTC150377.pdf.

Announcements (Continued)

NETL Report Released: ***A Benefits Analysis of the Existing Plants Emissions and Capture (EPEC) Program.***
This paper presents an analysis of NETL's EPEC Program. The overall goal of NETL's EPEC Program is to develop CCUS technologies that limit the increase in the cost of electricity generation to 35 percent of that generated by an equivalent greenfield plant without CCUS. The analysis was made using NETL's Carbon Transport and Storage (CTS) model integrated into the NEMS. The report is available at: http://www.netl.doe.gov/energy-analyses/pubs/EPECBenefitsAnalysisReport.pdf.

DOE's Assistant Secretary for Fossil Energy Discusses CCUS.
Charles McConnell, DOE's Assistant Secretary for Fossil Energy, discussed CCUS in an online interview with Platts TV. To view a video of the interview, visit: http://www.plattsenergyweektv.com/video/default.aspx?bctid=1648563473001.

Science

***AG Professional*, "Rising CO_2 Levels Impact Rice Gene Flow."**

Research conducted by the U.S. Department of Agriculture (USDA) shows that rising levels of atmospheric CO_2 facilitate the flow of genes from wild or weedy rice plants to domesticated rice varieties, resulting in domesticated plants taking on characteristics that could affect future rice production. Researchers documented how atmospheric CO_2 concentrations affected growth by conducting a two-year combination growth chamber and field study and observing the exchange of genetic material between the two plant types. Twenty-four-hour CO_2 concentrations in the chambers were set at 300, 400, and 600 parts per million (ppm), and were then approximated to the atmospheric CO_2 values present during the end of the 19th century, the current value, and projected values for the end of the 21st century, respectively. A genetic analysis of the two rice varieties' hybrid seed offspring was then conducted. The results indicated that the transfer of wild genetic material to the domesticated rice line resulted in the production of seed with weedy characteristics that would affect domesticated rice production. May 24, 2012, http://www.agprofessional.com/news/Links-between-weedy-domesticated-rice-to-rising-CO2-levels-153570545.html.

***GlobalPost*, "Climate Change Threatens Baby Sea Turtles, Study Says."**

According to a study conducted by Drexel University, leatherback baby sea turtles are at risk of being baked inside their nests due to potential climate change. Researchers studied six nesting seasons (2004 to 2010) in which leatherback mothers planted their eggs in holes in the sand, with the babies hatching approximately two months later. By analyzing the hatched and spoiled eggs, the researchers found that the turtles had the highest mortality rate during seasons governed by El Niño, which are hot and dry. Using the region's model of potential climate change, which shows increased temperatures and conditions relative to El Niño, it was concluded that the turtles could be affected. May 24, 2012, http://www.globalpost.com/dispatch/news/science/120524/climate-change-threatens-baby-sea-turtles-study-says.

***New York Times*, "Butterfly Species Expands Range With Climate Change."**

A study conducted by University of York researchers showed that a warming climate has led to brown argus butterflies spreading into England approximately 50 miles northward over the past 20 years to allow for its caterpillars to feed of the countryside's wild geranium plant population. The researchers determined the shift in the butterflies' range was due to potential climate change by studying data on their locations and populations over four decades. Uncommon in England in the 1980s, the brown argus has also seen an increase in population. The butterflies' typical diet is the rock rose, abundant in the south of England, but the caterpillars have since developed a taste for geraniums as the summer temperatures have increased, leading them to expand their range northward. May 24, 2012, http://www.nytimes.com/2012/05/29/science/butterfly-species-expands-range-with-climate-change.html?_r=4.

Policy

***Environmental Expert*, "Protocol for Community-Scale GHG Emissions Launched."**

The C40 Cities Climate Leadership group and the International Council for Local Environmental Initiatives (ICLEI) have launched a "community protocol" to measure GHG emissions at the community level in an effort to establish a single standard for measuring emissions from cities. The protocol will replace previously published standards, such as the International Local Government GHG Emissions Analysis Protocol and the International Standard for Determining GHG Emissions for Cities. The protocol was developed in collaboration with the World Resources Institute and the Joint Work Programme of Cities Alliance. A draft edition of the protocol was released for public comment in March 2012, with more than 30 organizations providing comments. The global partners will next pilot the community protocol in selected cities around the world, based on expressions of interest. Results and feedback will be reflected in the first edition of the full

Policy (Continued)

community protocol, which is expected to be published in late 2012. To view the draft protocol, visit: http://www.ghgprotocol.org/files/ghgp/GPC_PilotVersion_1.0_May2012_20120514.pdf. May 15, 2012. http://www.environmental-expert.com/news/protocol-for-community-scale-ghg-emissions-launched-294649.

Geology

"*In Situ* Molecular Spectroscopic Evidence for CO_2 Intercalation into Montmorillonite in Supercritical Carbon Dioxide."

The following is the Abstract of this article: "The interaction of anhydrous supercritical CO_2 ($scCO_2$) with both kaolinite and 1W (i.e., close to but less than one layer of hydration) calcium-saturated montmorillonite was investigated under conditions relevant to geologic carbon [storage] (50°C and 90 bar). The CO_2 molecular environment was probed in situ using a combination of three novel high-pressure techniques: X-ray diffraction, magic angle spinning nuclear magnetic resonance spectroscopy, and attenuated total reflection infrared spectroscopy. [The authors] report the first direct evidence that the expansion of montmorillonite under $scCO_2$ conditions is due to CO_2 migration into the interlayer. Intercalated CO_2 molecules are rotationally constrained and do not appear to react with waters to form bicarbonate or carbonic acid. In contrast, CO_2 does not intercalate into kaolinite. The findings show that predicting the seal integrity of caprock will have complex dependence on clay mineralogy and hydration state." **John S. Loring, Herbert T. Schaef, Romulus V.F. Turcu, Christopher J. Thompson, Quin R.S. Miller, Paul F. Martin, Jianzhi Hu, David W. Hoyt, Odeta Qafoku, Eugene S. Ilton, Andrew R. Felmy, and Kevin M. Rosso**, *Langmuir*, Available online April 25, 2012, doi:10.1021/la301136w, http://pubs.acs.org/doi/abs/10.1021/la301136w. (Subscription required.)

"Direct Nanoscale Observations of CO_2 [Storage] during Brucite [$Mg(OH)_2$] Dissolution."

The following is the Abstract of this article: "The dissolution and carbonation of brucite on (001) cleavage surfaces was investigated in a series of in situ and ex situ atomic force microscopy (AFM) experiments at varying pH (2–12), temperature (23–40°C), aqueous $NaHCO_3$ concentration (10^{-5}–1 M), and PCO_2 (0–1 atm). Dissolution rates increased with decreasing pH and increasing $NaHCO_3$ concentration. Simultaneously with dissolution of brucite, the growth of a Mg–carbonate phase (probably dypingite) was directly observed. In $NaHCO_3$ solutions (pH 7.2–9.3,), precipitation of Mg–carbonates was limited. Enhanced precipitation was, however, observed in acidified $NaHCO_3$ solutions (pH 5, DIC ≈ 25.5 mM) and in solutions that were equilibrated under a CO_2 atmosphere (pH 4, DIC ≈ 25.2 mM). Nucleation predominantly occurred in areas of high dissolution such as deep step edges suggesting that the carbonation reaction is locally diffusion-transport controlled. More extensive particle growth was also observed after ex situ experiments lasting for several hours. This AFM study contributes to an improved understanding of the mechanism of aqueous brucite carbonation at low temperature and pressure conditions and has implications for carbonation reactions in general." **J. Hövelmann, C.V. Putnis, E. Ruiz-Agudo, and H. Austrheim**, *Environ. Sci. Technol.*, Available online April 13, 2012, doi:10.1021/es300403n, http://pubs.acs.org/doi/abs/10.1021/es300403n. (Subscription required.)

"Stable carbon isotope techniques to quantify CO_2 trapping under pre-equilibrium conditions and elevated pressures and temperatures."

The following is the Abstract of this article: "Flow-through experiments in the laboratory were conducted to monitor the fate of CO_2 using stable carbon isotopes ($\delta^{13}C$) techniques in dynamic, pre-equilibrium conditions. Such conditions are typical, for instance in CCS, in the initial stages of CO_2 injection, near injection well regions of the reservoir. For this purpose, a reactive percolation bench (ICARE 4) was used, injecting a CO_2-saturated brine at supercritical conditions (pCO_2 = 84 bar, T = 60°C) through quartzitic limestone at an average flow rate of 2 x 10^{-9} m^3 s^{-1}. Calcium (Ca^{2+}) and dissolved inorganic carbon (DIC) concentration data and pH were used to aid analytical interpretations. During CO_2 injection, $\delta^{13}C_{DIC}$ values decreased from about -11‰ to those of the injected CO_2 (-29.3‰), indicating CO_2 sourced carbon dominance over a carbonate sourced one in the system. Simultaneously DIC and Ca^{2+} concentrations increased from 1 mmol L^{-1} to a maximum of 71 mmol L^{-1} and 31 mmol L^{-1}, respectively. Isotope and mass balances were used to quantify the amount of DIC originating from either the injected CO_2 or carbonates. At the end of the experiments, between 71 and 98 [percent] of the total DIC originated from CO_2 dissolution, the remaining amount is attributed to carbonate dissolution. Furthermore, the total amount of injected C_{CO2} trapped as DIC ranged between 9 and 17 [percent] and between 83 and 91 [percent] was in free phase. The state of carbonate equilibrium of the host fluid, under the high pressure-temperature conditions after CO_2 injection was identified, verifying pre-equilibrium conditions. Results confirm observations made in reported field data. This [emphasizes] that the combination of CO_2 monitoring, the development of a thorough understanding of carbonate equilibrium, as well as the quantification of CO_2-trapping, is essential for a solid assessment of reservoir performance and safety considerations during CO_2 injection. These are equally important for understanding water-rock-CO_2 dynamics in natural subsurface environments." **A. Myrttinen, E. Jeandel, O. Ukelis, V. Becker, R. van Geldern, P. Blum, and J.A.C. Barth**, *Chemical Geology*, Available online May 19, 2012, doi:10.1016/j.chemgeo.2012.05.008, http://www.sciencedirect.com/science/article/pii/S0009254112002276?v=s5. (Subscription may be required.)

"Measurement of accessible reactive surface area in a sandstone, with application to CO_2 mineralization."

The following is the Abstract of this article: "A new characterization approach is employed in this study that enables the measurement of the surface area of each reactive mineral located within the connected pore network of a sandstone from a carbon [storage] pilot site in Cranfield, Mississippi. The mineral distribution is measured in 2D by chemical mapping using Energy Dispersive X-ray Spectroscopy-Scanning Electron Microscopy (SEM-EDX) coupled with an image segmentation technique. The pore structure is mapped at high resolution using a pixel contrast thresholding technique applied to 2D Backscattered Electron Microscopy (BSE-SEM) images. After merging the mineral

Geology (Continued)

distribution and porosity maps, the accessibilities of each mineral present in the rock sample are quantified. These quantifications require characterizing in advance the connected pore network in the merged maps, which is done considering the permeability of chlorite measured at the nano-scale in three dimensions by Focus Ion Beam-Scanning Electron Microscopy (FIB-SEM). The accessible surface area of each reactive mineral is finally determined by multiplying the fraction of each reactive mineral next to the connected pore network, measured in 2D, with the surface area of the connected pore network in the rock, which is measured in 3D from X-ray based micro tomography (μ-CT) images and subsequently refined with a correction factor that accounts for the missing pore connectivity. This is necessary since μ-CT voxel resolution (880 nm) is lower than the pixel resolution achieved with BSE-SEM (330 nm). The accessible surface areas of the reactive minerals present in the sandstone rock can be used to accurately scale the rate constants for quantitative prediction and ultimately control of CO_2 injection in the subsurface at the Cranfield pilot site." **Gautier Landrot, Jonathan B. Ajo-Franklin, Li Yang, Stefano Cabrini, and Carl I. Steefel**, *Chemical Geology*, Available online May 23, 2012, doi:10.1016/j.chemgeo.2012.05.010, http://www.sciencedirect.com/science/article/pii/S000925411200229X?v=s5. (Subscription may be required.)

Technology

"Molecular modeling of carbon dioxide transport and storage in porous carbon-based materials."

The following is the Abstract of this article: "To fundamentally study the molecular processes in porous carbon-based systems relevant to transport and storage of [CO_2], non-equilibrium molecular dynamics simulations have been carried out with an external driving force imposed on a carbon-based 3-D pore network. The purpose of this study is to investigate the transport properties of pure [CO_2], methane and nitrogen as well as binary mixtures nitrogen and [CO_2] and also methane and [CO_2] through modeled 3-D carbon-based systems representative of porous carbon-based materials. The 3-D pore network has been generated atomistically using the Voronoi tessellation method of a structure containing approximately 125,000 atoms. Simulations have been carried out to determine the effect of the pore structure, exposure to an external potential and composition mixture on phenomena such as fluid distribution in the system and permeability for broad ranges of conditions. The results indicate that the morphological characteristics and energetic effects play a dominant role in the flow and transport properties of fluids. As expected among these factors, the porosity of the structure strongly affect the permeability. In addition, [the authors'] simulation results indicate that the permeability is zero below a critical porosity of about 0.2 due to the low connectivity in the pore network." **Mahnaz Firouzi and Jennifer Wilcox**, *Microporous and Mesoporous Materials*, Available online March 7, 2012, doi:10.1016/j.micromeso.2012.02.045, http://www.sciencedirect.com/science/article/pii/S1387181112001382. (Subscription may be required.)

"The outlook for improved carbon capture technology."

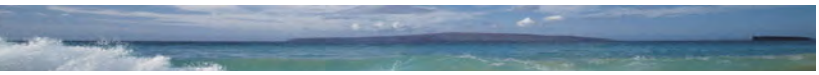
The following is the Abstract of this article: "CCS is widely seen as a critical technology for reducing atmospheric emissions of CO_2 from power plants and other large industrial facilities, which are major sources of [GHG] emissions linked to global climate change. However, the high cost and energy requirements of current CO_2 capture processes are major barriers to their use. This paper assesses the outlook for improved, lower-cost technologies for each of the three major approaches to CO_2 capture, namely, post-combustion, pre-combustion and oxy-combustion capture. The advantages and limitations of each of method are discussed, along with the current status of projects and processes at various stages in the development cycle. [The authors] then review a variety of 'roadmaps' developed by governmental and private-sector organizations to project the commercial roll-out and deployment of advanced capture technologies. For perspective, [the authors] also review recent experience with R&D programs to develop lower-cost technologies for [sulfur dioxide (SO_2) and nitrogen oxide (NO_X)] capture at coal-fired power plants. For perspective on projected cost reductions for CO_2 capture [the authors] further review past experience in cost trends for SO_2 and NO_X capture systems. The key insight for improved carbon capture technology is that achieving significant cost reductions will require not only a vigorous and sustained level of R&D, but also a substantial level of commercial deployment, which, in turn, requires a significant market for CO_2 capture technologies. At present such a market does not yet exist. While various incentive programs can accelerate the development and deployment of improved CO_2 capture systems, government actions that significantly limit CO_2 emissions to the atmosphere ultimately are needed to realize substantial and sustained reductions in the future cost of CO_2 capture." **Edward S. Rubin, Hari Mantripragada, Aaron Marks, Peter Versteeg, and John Kitchin**, *Progress in Energy and Combustion Science*, Available online May 11, 2012, doi:10.1016/j.pecs.2012.03.003, http://www.sciencedirect.com/science/article/pii/S0360128512000184. (Subscription may be required.)

"A parametric study of the transport of CO_2 in the near-surface."

The following is the Abstract of this article: "Previous simulations of the behavior of a CO_2 plume from a discrete line source near the ground surface have generally assumed that the water-table, soil layering, and land surface were all horizontal. As might be expected, these conditions produce plumes with a high degree of symmetry. The three dimensional TOUGH2 simulations reported here begin to consider several complications: degree of soil heterogeneity, presence of a capillary barrier, water table depth, CO_2 [release] rate, sloping topography, and regional groundwater flow (sloping water-table). The results show that the ground surface CO_2 flux distribution can be significantly different due to variation in the aforementioned factors, e.g. presence of a capillary barrier. The plume affected by these factors can assume an irregular shape characterized by multiple pathways to the surface. These pathways make the detection of a CO_2 [release] by soil gas or surface flux measurements conditionally possible at tens of meters away from the initial [release] location. Such phenomena should be considered when designing CO_2 detection network design." **Egemen Ogretim, Everett Mulkeen, Donald D. Gray, and Grant S. Bromhal**, *International Journal of Greenhouse*

Technology (Continued)

Gas Control, Available online May 15, 2012, doi:10.1016/j ijggc.2012.04.007, http://www.sciencedirect.com/science/article/pii/S1750583612000953. (Subscription may be required.)



Terrestrial

"Grassland carbon [storage] and emissions following cultivation in a mixed crop rotation."

The following is the Abstract of this article: "Grasslands are potential carbon [formations] to reduce unprecedented increase in atmospheric CO_2. Effect of age ([one to four]-year-old) and management (slurry, grazing multispecies mixture) of a grass phase mixed crop rotation on carbon [storage] and emissions upon cultivation was compared with 17-year-old grassland and a pea field as reference. Aboveground and root biomass were determined and soils were incubated to study CO_2 emissions after soil disturbance. Aboveground biomass was highest in [one]-year-old grassland with slurry application and lowest in [four]-year-old grassland without slurry application. Root biomass was highest in [four]-year-old grassland, but all [one to four]-year-old grasslands were in between the pea field (0.81 ± 0.094 g kg^{-1} soil) and the 17-year-old grassland (3.17 ± 0.22 g kg^{-1} soil). Grazed grasslands had significantly higher root biomass than cut grasslands. There was no significant difference in the CO_2 emissions within [one to four]-year-old grasslands. Only the 17-year-old grassland showed markedly higher CO_2 emissions (4.9 ± 1.1 g CO_2 kg^{-1} soil). Differences in aboveground and root biomass did not affect CO_2 emissions, and slurry application did not either. The substantial increase in root biomass with age but indifference in CO_2 emissions across the age and management in temporary grasslands, thus, indicates potential for long-term [storage] of soil C." **Bharat Sharma Acharya, Jim Rasmussen, and Jørgen Eriksen**, *Agriculture*, Ecosystems & Environment, Available online March 26, 2012, doi:10.1016/j.agee.2012.03.001, http://www.sciencedirect.com/science/article/pii/S0167880912000849. (Subscription may be required.)

Trading

***RGGI News Release*, "97 [Percent] of RGGI Units Meet First Compliance Period Obligations."**

According to the Regional Greenhouse Gas Initiative's (RGGI) first three-year Compliance Summary Report, 206 of the 211 power plants subject to the requirements met program compliance obligations. The program's first three-year control period began on January 1, 2009, and concluded on December 31, 2011. The average annual CO_2 emissions for the three-year period were 126 million short tons, a 23 percent reduction when compared to the preceding three-year period from 2006 to 2008. Three-year average electricity consumption across the participating states declined 2.4 percent during the same periods, according to the U.S. Energy Information Administration (EIA). Carbon dioxide emissions were collectively reduced to 33 percent below the annual cap of 188 million short tons. The number of allowances held in each compliance entity's RGGI CO_2 Allowance Tracking System (RGGI COATS) account is matched with actual emissions and submitted to the respective state to evaluate compliance. The Compliance Summary Report is available in RGGI COATS at: https://rggi-coats.org/eats/rggi/index.cfm?fuseaction=reportsv2.compliance_summary_rpt&clearfuseattribs=true. More information about the RGGI states' electricity generation and emissions trends is available as part of the comprehensive 2012 program review report, available at: http://www.rggi.org/docs/Retrospective_Analysis_Draft_White_Paper.pdf. June 6, 2012, http://www.rggi.org/docs/PR060412_Compliance.pdf.

***California Air Resources Board News Release*, "Air Resources Board Announces Release of Draft Regulations for Cap-and-Trade Linkage with Québec."**

The California Air Resources Board (CARB) released proposed regulations linking its cap-and-trade program to Québec's, forming a joint carbon market to reduce GHG emissions. The proposed regulations provide guidelines to ensure that carbon allowances from Québec and California are interchangeable at auction and can be used in one another's programs for compliance purposes; provide joint, enforceable standards for development and use of CO_2 offsets; and establish a framework for investment in clean energy technology, businesses, and jobs. California adopted its cap-and-trade program in October 2010 with plans to link to other programs, and over the past five years has been working with several states and Canadian provinces within the Western Climate Initiative (WCI) on approaches to linking their emission trading. Québec is the first to be proposed for linkage as its program has similar reduction and reporting rules as California's. The first linked auction between California and Québec is scheduled for November 14, 2012. To view the proposed regulation, visit: http://www.arb.ca.gov/regact/2012/capandtrade12/capandtrade12.htm. May 9, 2012, http://www.arb.ca.gov/newsrel/newsrelease.php?id=300.

"An assessment of greenhouse gas emissions-weighted clean energy standards."

The following is the Abstract of this article: "This paper quantifies the relative cost-savings of utilizing a [GHG] emissions-weighted Clean Energy Standard (CES) in comparison to a Renewable Portfolio Standard (RPS). Using a bottom-up electricity sector model for Hawaii, this paper demonstrates that a policy that gives 'clean energy' credit to electricity technologies based on their cardinal ranking of lifecycle GHG emissions, normalizing the highest-emitting unit to zero credit, can reduce the costs of emissions abatement by up to 90 [percent] in comparison to a typical RPS. A GHG emissions-weighted CES provides incentive to not only pursue renewable sources of electricity, but also promotes fuel-switching among fossil fuels and improved generation efficiencies at fossil-fired units. CES is found to be particularly cost-effective when projected fossil fuel prices are relatively low." **Makena Coffman, James P. Griffin, and Paul Bernstein**, *Energy Policy*, Available online March 3, 2012, doi:10.1016/j.enpol.2012.01.068, http://www.sciencedirect.com/science/article/pii/S0301421512000961. (Subscription may be required.)

Recent Publications

"Carbon Storage Systems and Well Management Activities."

The following is from the Executive Summary of this document: "The purpose of the DOE Carbon Storage Program is to demonstrate that CO_2 can be economically, successfully, and securely stored permanently in a manner that is compliant with the best engineering and geological practices; Federal, state, and local regulations; and in the best interests of local and regional stakeholders. In a typical CCS project, CO_2 is captured at an anthropogenic source, transported to a suitable location, and injected into deep geologic formations for permanent storage in saline and hydrocarbon bearing formations. Wells are a critical component of any CCS project; they will be drilled and completed for multiple purposes, including: exploring the suitability of geologic formations; injecting CO_2; monitoring the behavior and location of injected CO_2; and, in the case of CO_2 utilization through enhanced oil recovery, producing hydrocarbons from the injection zone. The purpose of this report is to share lessons learned regarding site-specific management activities for carbon storage well systems. This manual builds on the experiences of the [RCSPs] and acquired knowledge from the petroleum industry and other private industries that have been actively drilling wells for more than 100 years. Specifically, this manual focuses on management activities related to the planning, permitting, design, drilling, implementation, and decommissioning of wells for geologic storage projects. A key lesson and common theme reiterated throughout the seven DOE [BPMs] is that each project site is unique. This means that each CCS project needs to be designed to address specific site characteristics, and should involve an integrated team of experts from multiple technical (e.g., scientific and engineering) and nontechnical (e.g., legal, economic, communications) disciplines. Additionally, works during the characterization, siting, and implementation phases of projects are iterative; the results from previously completed tasks are analyzed and used to make decisions going forward. This means that as data comes in, the conceptual model of the site is revised and updated to allow better future decisions." The complete NETL BPM is available for download at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-Carbon-Storage-Systems-and-Well-Mgt.pdf.

"Induced Seismicity Potential in Energy Technologies (2012)."

The following is a brief background on this National Academy of Sciences Report: "In the past several years, some energy technologies that inject or extract fluid from the Earth, such as oil and gas development and geothermal energy development, have been found or suspected to cause seismic events, drawing heightened public attention. Although only a very small fraction of injection and extraction activities among the hundreds of thousands of energy development sites in the United States have induced seismicity at levels noticeable to the public, understanding the potential for inducing felt seismic events and for limiting their occurrence and impacts is desirable for state and federal agencies, industry, and the public at large. To better understand, limit, and respond to induced seismic events, work is needed to build robust prediction models, to assess potential hazards, and to help relevant agencies coordinate to address them." The complete version is available for download at: http://dels.nas.edu/Report/Induced-Seismicity-Potential-Energy-Technologies/13355.

"North American Carbon Storage Atlas."

The following is the Foreword of this document: "NRCan, the Mexican Ministry of Energy (SENER), and U.S. DOE are proud to release NACSA, which was produced under the leadership of NACAP. Production of this Atlas is the result of cooperation and coordination among carbon storage experts from local, state, provincial, and Federal government agencies, as well as industry and academia. This Atlas provides a coordinated overview of CCS potential across Canada, Mexico, and the United States. The primary purpose of the Atlas is to show the location of large stationary CO_2 emission sources and the locations and storage potential of various geological storage sites. This Atlas is a first attempt at providing a high-level overview of the potential for large-scale carbon storage in North America." The Atlas is available for download at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/NACSA2012.pdf. .

"Carbon Dioxide Enhanced Oil Recovery: A Critical Domestic Energy, Economic, and Environmental Opportunity."

The following is from the Introduction of this document: ñCO_2-EOR offers a safe and commercially proven method of domestic oil production that can help the United States simultaneously address three urgent national priorities: [1] Increasing [the Nation's] energy security by reducing dependence on foreign oil, often imported from unstable and hostile regimes; [2] Supporting job creation, increasing tax revenue, and reducing [the Nation's] trade deficit by keeping dollars now spent on oil imports [in the United States] and at work in the U.S. economy; and [3] Protecting the environment by capturing and storing CO_2 from industrial facilities and power plants, while getting more American crude from areas already developed for oil and gas production. A largely unheralded example of American ingenuity, CO_2-EOR was pioneered in West Texas in 1972 as a way to sustain oil production in otherwise declining oil fields. It works by injecting CO_2 obtained from natural or man-made sources into existing oil fields to free up additional crude oil trapped in rock formations. In this way, CO_2-EOR can significantly extend the lifespan and revitalize production of mature oil fields in the United States. Today, over 3,900 miles of pipelines in the United States annually transport approximately 65 million tons of CO_2 that the oil industry purchases for use in EOR, producing 281,000 barrels of domestic oil per day, or six percent of U.S. crude oil production." The report is available at: http://www.pewclimate.org/docUploads/EOR-Report.pdf.

Legislative Activity

***Officer of Governor Matt Mead News Release*, "Governor Looks to Support CO_2 Pipeline Network."**

Wyoming governor Matt Mead has opened discussions about a proposed statewide network of CO_2 pipeline corridors within Federal land boundaries that would protect open spaces and minimize environmental impacts. As a result of pre-approved corridors, permitting time would be shortened, allowing for EOR. Under current plans, pipeline corridors on Federal land are determined separately by the nine individual Wyoming BLM offices. Any proposal between Governor Mead and BLM would be reviewed and open to public comment, possibly becoming a Record of Decision to update each Resource Management Plan of the various Wyoming BLM offices. May 1, 2012, http://governor.wy.gov/media/pressReleases/Pages/GovernorLookstoSupportCO2.aspx.

***Oroville Mercury-Register*, "Oroville City Council Approves Plan to Reduce Greenhouse Gas Emissions."**

Using a grant from the Strategic Growth Council, Oroville City Council (California) will develop a Climate Control Plan to comply with California legislation to reduce GHG emissions. The goal of Sustainable Community Planning Grants is to develop plans to reduce GHG emissions in compliance with Assembly Bill 32 and Senate Bill 375 for Sustainable Communities and Climate Protection. To view AB 32, go to: http://www.arb.ca.gov/cc/ab32/ab32.htm. To view SB 375, visit: http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_0351-0400/sb_375_bill_20080930_chaptered.pdf. May 16, 2012, http://www.orovillemr.com/news/ci_20634563/oroville-city-council-approves-plan-reduce-greenhouse-gas.

Events

July 3, 2012, **CMI Academic Symposium 2012**, *The University of Melbourne, Melbourne, Australia*. This one-day Carbon Market Institute (CMI) symposium will focus on education and training in response to the needs of Australian industry in moving to a new low-carbon economy. Participants will interact with carbon market industry leaders and academic providers to cover topics such as realizing the benefits of carbon pricing and clean energy legislation. The program and registration form are available for download at: http://www.carbonmarketinstitute.org/events/cmi-academic-symposium-2012/.

July 8-12, 2012, **Global Conference on Global Warming 2012**, *Istanbul Technical University, Istanbul, Turkey*. The primary themes of this conference focus on potential climate change in multiple disciplines, such as engineering, science, ecology, education, economics, management, political sciences, and information technology. The topical areas include, but are not limited to: carbon storage, carbon tax, modeling and simulations, and global policies. The complete list of topical areas is available at: http://www.gcgw.org/gcgw12/index.php?conference=gcgw&schedConf=gcgw12&page=schedConf&op=overview.

July 12-13, 2012, **4th International Conference on Climate Change: Impact and Responses**, *The University of Washington, Washington, USA*. This conference will address a range of themes relating to potential climate change, such as natural and human causes; ecosystem and human impacts; and technological, social, ethical, and political responses. The conference program will consist of a mix of plenary and parallel sessions. More information is available at: http://on-climate.com/conference-2012/.

July 23-25, 2012, **Carbon Capture and Storage: Science, Technology, and Policy**, *MIT, Cambridge, Massachusetts, USA*. This short course covers the science, technology, and policy aspects of CCS, focusing on the role of CCS in the climate change mitigation portfolio; the technical approaches to CO_2 capture; the science behind geologic storage, site selection, and risk evaluation; and the role of policy in establishing a market and business opportunities for CCS. For more information, visit the course website at: http://web.mit.edu/professional/short-programs/courses/carbon_capture_storage.html.

September 4-6, 2012, **Carbon Capture & Storage: A Field-Based Masterclass**, *Springfield County Hotel, Stoborough, Wareham, Dorset, UK*. This three-day course follows the path of CO_2 from extraction from rocks in the subsurface, through its use, to the capture and safe storage back into the rocks. The training experience will combine classroom sessions, case studies, and field visits. For more information, download the course flyer at: http://www.ccstlm.com/content_189_.

Events (Continued)

October 17-18, 2012, **ImechE Carbon Capture and Storage – Ready, Steady, Go!**, *Institution of Mechanical Engineers, London, UK*. The Institution of Mechanical Engineers' (ImechE) 6th international conference aims to prepare companies for commercial-scale CCS technologies by covering, among other topics, the latest in European Union (EU) and UK government CCS decisions, funding for CCS research and project development, CCS business development and investment opportunities, and legal and regulatory issues surrounding the development market. To download the brochure, visit the seminar's website at: http://events.imeche.org/EventView.aspx?EventID=1442.

November 5-9, 2012, **CLIMATE 2012**. This online climate conference will focus on the latest scientific findings on the social, economic, and political aspects of potential climate change. New projects and innovative initiatives in both industrialized and developing countries by universities, scientific institutions, government bodies, non-governmental organizations (NGOs), and other stakeholders will be covered. For more information, visit the conference website at: http://www.climate2012.de/.

November 18-22, 2012, **International Conference on Greenhouse Gas Technologies 11 (GHGT-11)**, *Kyoto International Conference Center, Japan*. This will be the second visit to Kyoto by the GHGT conference series, with more than 1,600 delegates expected to attend. A formal agenda has not yet been developed; however, registration is now open at: http://www.ghgt.info/index.php/Content-GHGT11/ghgt-11-conference-registration.html. Visit: http://www.ghgt.info/index.php/Content-GHGT11/ghgt-11-overview.html for more details.

For subscription details...

Please visit http://listserv.netl.doe.gov/mailman/listinfo/sequestration, enter your email address, and create a password. This will enable you to receive a pdf version of the Carbon Sequestration Newsletter at no cost.
To view an archive with past issues of the newsletter, see: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/subscribe.html.

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