CSN CARBON STORAGE NEWSLETTER

APRIL 2016

This newsletter is compiled by the National Energy Technology Laboratory to provide information on recent activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news in the following areas:

CARBON STORAGE PROGRAM DOCUMENTS and REFERENCE MATERIALS

HIGHLIGHTS

"U.S. Department of Energy Announces Funding Opportunities for Subsurface Technology and Engineering Crosscut Initiative."

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) announced a collaborative funding opportunity that will focus on advanced research projects aimed at the deployment and validation of carbon storage monitoring, verification, and accounting technologies in an operational field environment. The Funding Opportunity Announcement (FOA), titled "*Development of Technologies for Sensing, Analyzing, and Utilizing Novel Subsurface Signals in Support of the Subsurface Technology and Engineering (SubTER) Crosscut Initiative*," will also focus on the identification and validation of new technologies that characterize and image critical subsurface features. The FOA is sponsored through the Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office (GTO) and the Office of Fossil Energy's (FE) *Carbon Storage Program*. The closing date for applications is May 5, 2016. From *Energy.gov* on March 10, 2016.

ANNOUNCEMENTS

Research Experience in Carbon Storage Accepting Applications.

RECS Research Experience in Carbon Sequestration www.recsco2.org

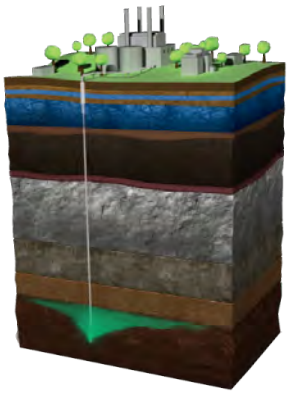
The Research Experience in Carbon Sequestration (RECS) Program, a DOE/FE initiative, is accepting applications from graduate students and early career professionals for RECS 2016, scheduled for June 12-20, 2016, in Birmingham, Alabama, USA. RECS 2016 will offer hands-on experience in areas related to carbon capture, utilization, and storage. The deadline to apply is May 13, 2016. For more information, visit the *RECS website*.

Tools to Monitor Carbon Storage Released.

Simulation tools developed by the DOE-led National Risk Assessment Partnership (NRAP) are under review by members of industry, regulatory agencies, universities, and other organizations, such as the *Regional Carbon Sequestration Partnerships (RCSPs)*. The successful deployment of the tools will enable users to predict the safety and permanence of carbon storage systems. Following review, the NRAP project team will implement improvements based on the feedback, with the final tool release expected in late 2016. For more information on NRAP and the new tool set, visit the *NRAP website*.

U.S. to Lead International Carbon Capture Test Network.

The International Test Center Network (ITCN), a global consortium of facilities conducting research and development (R&D) on carbon capture technologies, will be led by the United States (represented by FE). The ITCN was formed by the DOE-sponsored *National Carbon Capture Center (NCCC)* and Norway's *Technology Centre Mongstad (TCM)* to facilitate knowledge transfer from carbon capture test facilities around the world.



Global CCS Institute Releases Global Storage Portfolio.

The Global CCS Institute published a new report summarizing regional storage resource assessments. Designed as a regularly updated reference containing the latest assessment of geological storage in regions around the world, the *Global Storage Portfolio* summarizes storage resource potential of nations that have published regional assessments. A summary of the portfolio is available in the Recent Publications section of this newsletter.

Western Australia Project Releases Well Data.

The South West Hub Carbon Capture and Storage (CCS) project released new well data to aid research in the feasibility of storing carbon dioxide (CO_2) in underground formations. More information is available via the Government of Western Australia's Department of Mines and Petroleum (DMP) *website*.

CARBON STORAGE in the NEWS

"15,000 Metric Tons of CO_2 Stored at Otway."

CO2CRC and its Australian and international research partners injected 15,000 metric tons of CO_2 at the Otway research facility in Nirranda of South Western Victoria. Researchers remotely monitored the injected CO_2 by using fiber-optic cables and a high-resolution buried receiver fitted with automated communications facilities. The tested equipment provides options to reduce the surface monitoring activities required to verify the CO_2 plume movement. From *Carbon Capture Journal* on April 8, 2016.

"[NET Power Breaks Ground on Demonstration Plant]."

NET Power, LLC, announced it has broken ground on a demonstration plant in La Porte, Texas, USA. The power plant will demonstrate NET Power's Allam Cycle technology, a natural gas power system that uses CO_2 to drive a combustion turbine and produces pipeline-quality CO_2 that can be stored or used in industrial processes, such as enhanced oil recovery (EOR). Commissioning of the plant is expected to begin in late 2016 and be completed in 2017. From *NET Power* on March 9, 2016.

"Tomakomai CCS Project [Now Online]."

The Global CCS Institute announced a fully integrated CCS project came online in southwest Hokkaido, Japan. Carbon dioxide from a hydrogen production unit in an oil refinery will be captured and purified before compression and subsequent injection into offshore geological formations. From *Global CCS Institute Media Release* on March 18, 2016.

"[$15 Million Invested to Enhance Carbon Capture Technology]."

A CO_2 Solutions enzyme-enabled carbon capture technology was studied at a demonstration project at Valleyfield in Québec, with the results validated through a third-party engineering firm. Québec, Canada, plans to reduce its greenhouse gas (GHG) emissions by 20 percent below 1990 levels by 2020, and 37.5 percent below the same level by 2030. From *CO_2 Solutions Release* on March 18, 2016.

SCIENCE

"Trees Deal With [Potential Climate Change] Better Than Expected."

According to a new study, forests may release less atmospheric CO_2 during hotter temperatures than previously thought. While scientists originally hypothesized that plants would release more CO_2 into the atmosphere as global temperatures rose, new data showed that plants are able to adapt their respiration to increases in temperature over long periods. Researchers tested how respiration rates of 10 different species of trees were affected by temperature increases over a period of three to five years in two separate conditions: ambient and warmer. The results, published in the journal "Nature," showed trees that were acclimated to the warmer temperatures increased their CO_2 release by a smaller amount than those only exposed to a short-term temperature increase of the same magnitude. The Abstract of the study, titled "Boreal and temperate trees show strong acclimation of respiration to warming," is available below. From *The New York Times* on March 16, 2016.

"Boreal and temperate trees show strong acclimation of respiration to warming."

The following is the Abstract of this article: "Plant respiration results in an annual flux of CO_2 to the atmosphere that is six times as large as that due to the emissions from fossil fuel burning, so changes in either will impact future climate. As plant respiration responds positively to temperature, a warming world may result in additional respiratory CO_2 release, and hence further atmospheric warming. Plant respiration can acclimate to altered temperatures, however, weakening the positive feedback of plant respiration to rising global air temperature, but a lack of evidence on long-term (weeks to years) acclimation to climate warming in field settings currently hinders realistic predictions of respiratory release of CO_2 under future climatic conditions. Here [the authors] demonstrate strong acclimation of leaf respiration to both experimental warming and seasonal temperature variation for juveniles of [10] North American tree species growing for several years in forest conditions. Plants grown and measured at 3.4°C above ambient temperature increased leaf respiration by an average of 5 [percent] compared to plants grown and measured at ambient temperature; without acclimation, these increases would have been 23 [percent]. Thus, acclimation eliminated 80 [percent] of the expected increase in leaf respiration of non-acclimated plants. Acclimation of leaf respiration per degree temperature change was similar for experimental warming and seasonal temperature variation. Moreover, the observed increase in leaf respiration per degree increase in temperature was less than half as large as the average reported for previous studies, which were conducted largely over shorter time scales in laboratory settings. If such dampening effects of leaf thermal acclimation occur generally, the increase in respiration rates of terrestrial plants in response to climate warming may be less than predicted, and thus may not raise atmospheric CO_2 concentrations as much as anticipated." **Peter B. Reich, Kerrie M. Sendall, Artur Stefanski, Xiaorong Wei, Roy L. Rich, and Rebecca A. Montgomery**, *Nature*. (Subscription may be required.)

"Development of environmental impact monitoring protocol for offshore carbon capture and storage (CCS): A biological perspective."

The following is the Abstract of this article: "Offshore geologic storage of CO_2, known as offshore CCS, has been under active investigation as a safe, effective mitigation option for reducing CO_2 levels from anthropogenic fossil fuel burning and climate change. Along with increasing trends in implementation plans and related logistics on offshore CCS, thorough risk assessment (i.e. environmental impact monitoring) needs to be conducted to evaluate potential risks, such as CO_2 gas [release] at injection sites. Gas [releases] from offshore CCS may affect the physiology of marine organisms and disrupt certain ecosystem functions, thereby posing an environmental risk. Here, [the authors] synthesize current knowledge on environmental impact monitoring of offshore CCS with an emphasis on biological aspects and provide suggestions for better practice. Based on [the authors'] critical review of preexisting literatures, this paper: (1) discusses key variables sensitive to or indicative of gas [release] by summarizing physico-chemical and ecological variables measured from previous monitoring cruises on offshore CCS; (2) lists ecosystem and organism responses to a similar environmental condition to CO_2 [release] and associated impacts, such as ocean acidification and hypercapnia, to predict how they serve as responsive indicators of short- and long-term gas exposure, and (3) discusses the designs of the artificial gas release experiments in fields and the best model simulation to produce realistic [release] scenarios in marine ecosystems. Based on [the authors'] analysis, [the authors] suggest that proper incorporation of biological aspects will provide successful and robust long-term monitoring strategies with earlier detection of gas [release], thus reducing the risks associated with offshore CCS." **Hyewon Kim, Yong Hoon Kim, Seong-Gil Kang, and Young-Gyu Park**, *Environmental Impact Assessment Review*. (Subscription may be required.)

POLICY

"Malaysia Committed In Reducing CO_2 Emissions…"

Malaysia will reduce its CO_2 emission intensity by 40 percent, government officials announced. To date, the country has reduced their emissions by 33 percent. According to the ***Eleventh Malaysian Plan***, the Malaysian government has set aside funding to develop and implement technologies. From *Malaysian Digest* on March 20, 2016.

"A commentary on the [U.S.] policies for efficient large scale renewable energy storage systems: Focus on carbon storage cycles."

The following is the Abstract of this article: "The inevitable depletion of fossil resources and increasing atmospheric [GHG] concentrations demonstrate the need for renewable energy conversion technologies for a sustainable economy. Intermittencies and variability in availability of renewable energy sources are the challenges for uninterrupted energy supply, which can be overcome by large scale energy storage facilities. Pumped hydroelectric energy storage is an efficient but a very low energy density energy storage method that dominates the current energy storage market with ~96 [percent] share. [The authors] first present a recently developed potential solution for large scale efficient and dense energy storage: closed loop carbon storage cycles and a specific example dimethyl ether storage cycle. [The authors] then discuss the relevant [U.S.] energy storage regulations, policy initiatives, their status, and potential modifications that will contribute to the invention and implementation of novel energy storage systems." **Emre Gençer and Rakesh Agrawal**, *Energy Policy*. (Subscription may be required.)

"'Best practice' community dialogue: The promise of a small-scale deliberative engagement around the siting of a carbon dioxide capture and storage (CCS) facility."

The following is the Abstract of this article: "In New Zealand the Taranaki region has been identified as a likely place for [CO_2 storage] as a result of its oil and gas industry, potential storage reservoirs and skilled local workforce. As yet there are no plans to deploy the CCS technology in this particular region but this presented an opportunity for pro-active engagement with local stakeholders, including the urban community, farmers and landowners, local iwi (Māori), local and regional councils and the oil/gas industry. As an alternative to a standard consultation technique, a small-scale dialogue-based method was used, based on the principles of deliberative engagement. In this context, the emphasis was on developing an informed understanding of different viewpoints and solution-focused decision-making. This method of engagement was found to be cost-effective, revealed some unexpected viewpoints and identified some important precursors to risk perception in New Zealand. The empowerment of participants, assisted by independent scientists and the opportunity for facilitated dialogue, were key success factors. Moreover, the approach was valued by the wider community and perceived as a means to open up dialogue around other regional energy issues. In summary, small-scale deliberative engagement processes are a viable alternative or complement to standard community consultation techniques for engagement around the siting of CCS facilities." **Fiona J. Coyle**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Persuasiveness, importance and novelty of arguments about Carbon Capture and Storage."

The following is the Abstract of this article: "CCS is a promising technology for reducing carbon emissions, but the public is often reluctant to support it. To understand why public support is lacking, it is crucial to establish what citizens think about the arguments that are used by proponents and opponents of CCS. [The authors] determined the persuasiveness, importance and novelty of 32 arguments for and against CCS using a discrete choice experiment in which respondents made consecutive choices between pairs of pro or con arguments. [The authors] used latent class models to identify population segments with different preferences. The results show that citizens find arguments about climate protection, which is the primary goal of CCS, less persuasive than other arguments, such as normative arguments (for example 'a waste product such as CO_2 should be disposed of properly') or arguments about benefits of CCS for energy production and economic growth. This discrepancy complicates communication that aims to convince citizens of the benefits of CCS for climate protection." **Kevin P.F. Broecks, Sander van Egmond, Frank J. van Rijnsoever, Marlies Verlinde-van den Berg, and Marko P. Hekkert**, *Environmental Science & Policy*. (Subscription may be required.)

GEOLOGY

"Palaeogeographic mapping to understand the hydrocarbon and CO_2 storage potential of the post-rift Warnbro Group, offshore Vlaming Sub-basin, southern Perth Basin, Australia."

The following is from the Abstract of this article: "The Lower Cretaceous Gage Sandstone and South Perth Shale are a prospective reservoir-seal pair in the Warnbro Group, offshore Vlaming Sub-basin, Western Australia. Plays include post-breakup pinch-outs and [four]-way dip closures. A sequence stratigraphic analysis incorporating seismic interpretation, well log analysis and new biostratigraphic data characterised the reservoir-seal pair. Palaeogeographic mapping reveals multiple regressive-transgressive cycles which infilled the central palaeodepression on the Valanginian Unconformity. Within the deltaic South Perth Supersequence, the Gage Lowstand Fan (lithostratigraphically referred to as the Gage Sandstone) is a sand-rich submarine fan system and ranges from canyon-confined inner fan to basin-plain middle fan deposits. Major sediment contributions were from north–south-trending canyons adjacent to the Mandurah Terrace. Detailed seismic facies mapping and well log analysis of the Gage Lowstand Fan show that distal middle fan sand sheets and stacked channelised sands in the inner fan may provide an extensive reservoir of good to excellent quality. Seal quality varies greatly and may explain the lack of exploration success at some structural closures. A re-evaluation of the regional seal determined the extent of deepwater shale facies that provides an effective seal for the underlying submarine fans. 3D geological modelling confirms that the reservoir is suitable for hydrocarbon entrapment and CO_2 storage. Migration path analysis identified the presence of multiple structural and stratigraphic closures at the top of the reservoir. Previous petroleum systems modelling concluded that some source rock maturation probably post-dates deposition of the effective seal thereby allowing structural closures to be charged with hydrocarbons. Uncertainties potentially comprising hydrocarbon preservation and CO_2 storage include reactivation of large syn-rift faults that may breach top seal, the potential absence of base seal, effective seal thickness, and reservoir thickness and quality." **Megan E. Lech, Diane C. Jorgensen, Chris Southby, Liuqi Wang, Victor Nguyen, Irina Borissova, and David Lescinsky**, *Marine and Petroleum Geology*. (Subscription may be required.)

"Isothermal adsorption kinetics properties of carbon dioxide in crushed coal."

The following is the Abstract of this article: "Understanding the dynamic response of coal to [CO_2] sorption is crucial for optimizing [CO_2 storage] in unmineable coal seams and enhanced coalbed methane recovery. In order to explore the adsorption kinetics of [CO_2] in coal, 15 isothermal adsorption tests were conducted on bituminous and sub-bituminous coals at 50°C for increasing equilibrium pressures (up to 4 MPa). The pseudo-second order (PSO) model is introduced to approximate the [CO_2] sorption kinetics in coal, and the kinetics properties are then investigated via the PSO model. The linear relationship between (t/q) and (t) is validated and confirmed with a high correlation coefficient (>99 [percent]). The kinetics parameter, k_2, decreases with both increasing equilibrium sorption pressure and increasing pressure difference. The sorption equilibrium content, Qe, in each sorption stage depends on both

the final equilibrium pressure and the pressure difference. Based on the relationship between sorption content and time, the sorption content for different pressure ranges is predicted using different time intervals. The analysis indicates that the adsorption process for [CO_2] in coal is a combination of both bulk diffusion-controlled and surface interaction-controlled processes; the former dominates the initial stage while the latter controls the majority of the overall process." **Xu Tang, Nino Ripepi, and Ellen Gilliland**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"CO_2 Storage Potential of Basaltic Rocks Offshore Iceland."

The following is the Abstract of this article: "Injection of CO_2 into basaltic formations provides significant benefits including permanent storage by [mineralization] and large storage volume. The largest geological storage potential lies offshore and in the case of basalt, along the mid-oceanic ridges where CO_2 could be stored as carbonate minerals for thousands of years. Most of the bedrock, both on land and offshore Iceland consists of basalt that could theoretically be used for injection of CO_2, fully dissolved in water. The most feasible formations are the youngest formations located within the active rift zone. It is estimated that up to 7000 $GtCO_2$ could be stored offshore Iceland within the Exclusive Economic Zone. Site specific geological research and pilot studies are required for refining the concept and offshore pilot scale projects should be considered as the next steps in evolving the method." **Sandra Ó. Snæbjörnsdóttir and Sigurdur R. Gislason**, *Energy Procedia*. (Subscription may be required.)

TECHNOLOGY

"Integration of SNG plants with Carbon Capture and Storage Technologies modeling."

The following is the Abstract of this article: "Several power plant configurations have been recently studied as an alternative to conventional technologies in the field of energetic conversion of coal. The price of natural gas shows a volatile trend and when at its maximum promotes a renewed interest in technologies converting coal into synthetic natural gas (SNG). Moreover, in a low-carbon economy these processes include the capture of CO_2 in the base plant configuration. This paper analyzes the possible integration of SNG plants with [CCS] Technologies. The studied SNG facilities are based on commercial coal gasification and methanation technologies currently available worldwide. The major problem in optimizing the methanation reaction, one of the most important stages of the whole process, is to achieve an efficient removal of the reaction heat to avoid catalyst sintering and prevent carbon particle formation. For this reason, in this study two different process configurations were compared. In the first configuration (case A), the removal of CO_2 is operated before the methanation section and the reaction is carried out in a series of adiabatic fixed bed reactors with inter-cooling and product recycle. In the second configuration (case B) the dilution of the methanation feed with CO_2 and steam controls the heat of reaction, being CO_2 captured downstream the process. For both the plant configurations, performance is analyzed and the energy penalty caused by the introduction of CCS is evaluated. Particular attention is devoted to heat integration between different sections of the plant. Results show similar efficiency in both the cases and that more than 50 [percent] of the input energy can be converted to [SNG]. The CCS integration leads to a slight efficiency reduction of about [one] percentage point. The selected plant configurations were tested and performance evaluated and compared in the Aspen Plus v. 8 simulation environment." **Claudia Bassano, Paolo Deiana, Lorenza Pacetti, and Nicola Verdone**, *Fuel*. (Subscription may be required.)

"A model to calculate effects of atmospheric deposition on soil acidification, eutrophication and carbon [storage]."

The following is the Abstract of this article: "Triggered by the steep decline in sulphur deposition in Europe and North America over the last decades, research and emission reduction policies have shifted from acidification to the effects of nitrogen (N) deposition and climate change on plant species diversity and carbon (C) [storage] in soils and biomass. Consequently, soil-ecosystem models need to include detailed descriptions of C and N processes, and ideally provide output that link to plant species diversity models. [The authors] describe an extension of the Very Simple Dynamic (VSD) model, called VSD+, which includes an explicit description of C and N turnover. Model simulations for three forest stands, which differ in N deposition and soil C/N ratios, show that VSD+ can well predict both trends and absolute values of NO_3 and NH_4 concentrations in soil and stream waters, soil C/N ratios and pH, which makes VSD+ suitable for providing input for plant species diversity models." **Luc T.C. Bonten, Gert Jan Reinds, and Maximilian Posch**, *Environmental Modelling & Software*. (Subscription may be required.)

"An integrated site characterization-to-optimization study for commercial-scale carbon dioxide storage."

The following is the Abstract of this article: "Injection of supercritical carbon dioxide ($scCO_2$) into deep saline [formations] is considered a promising option to mitigate global climate change. At a storage site, the main objectives of [CO_2 storage] are to maximize the volume of $scCO_2$ injected and minimize the [release] risk, while effectively managing formation fluid pressure buildup and the brine displaced by $scCO_2$. An integrated characterization-to-optimization study is carried out for potential commercial-scale deep saline [formation CO_2] storage proposed in western Wyoming. A three-dimensional heterogeneous reservoir model is built for which petrophysical and fluid flow parameters are populated using field characterization data and state-of-the-art laboratory measurements. The measured $scCO_2$ relative permeability end point is low compared to previous measurements on similar sandstones, which poses a challenge for CO_2 flow, formation pressure control, and storage efficiency. By carefully selecting a set of optimal well locations, perforation intervals, and bottomhole pressure constraints that lead to maximum CO_2-in-place and minimal CO_2 breakthrough at the producers, an injection rate ranging from 10.8 to 15.1 Mt/year is achieved for a duration of 50 years. After $scCO_2$ injection ceases, up to 62 [percent] of the total injected $scCO_2$ can be immobilized as residual $scCO_2$ in 1000 years. Because of the low $scCO_2$ relative permeability end point, post-$scCO_2$-injection chase brine operation is not found to be an effective means of enhancing residual trapping. Instead, by modulating reservoir fluid pressure, boundary conditions of the reservoir exert a more significant impact on flow. Given the same well configuration and bottomhole pressure constraints, an open reservoir with lateral background flow allows 40 [percent] additional $scCO_2$ injection compared to a compartmentalized system without background flow. However, background flow leads to a lower trapping efficiency – after 1000 years post-$scCO_2$-injection, only 54 [percent] of the total injected $scCO_2$ is immobilized as residual $scCO_2$. This research suggests that a careful engineering design can contribute to significant CO_2 storage at commercial scales while enhancing storage security. Site-specific multi-phase flow data should be measured for such a design, since for the study site, chase-brine operation is not effective when $scCO_2$ relative permeability is low." **Shuiquan Li, Morteza Akbarabadi, Ye Zhang, and Mohammad Piri**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

TERRESTRIAL

"Carbon storage in a bamboo (Bambusa vulgaris) plantation in the degraded tropical forests: Implications for policy development."

The following is the Abstract of this article: "Tropical forests potentially contribute to global climate change mitigation through carbon [storage], hence a global carbon pool. In order to mitigate the global climate change impact, the Kyoto protocol developed the clean development mechanism (CDM) which supports carbon credits for plantation activities in developing countries. Unfortunately, none of the CDM forestry projects included bamboo as a carbon reservoir. Although bamboo is an integrating part of tropical forest ecosystems, it was overlooked in the initial negotiating process. The present study, therefore, investigated the carbon storage potential of a common bamboo species, *Bambusa vulgaris* at Lawachara forest reserve of Bangladesh. Results showed that five-year-old *B. vulgaris* stand stored in total 77.67 t C ha^{-1} of which 50.44 t C ha^{-1} were stored in the above ground biomass (culms, branches and leaves), 2.52 t C ha^{-1} in the below ground biomass and 24.71 t C ha^{-1} in the soils. This amount of carbon storage is much more promising than the carbon storage of many other tree species considered in the CDM projects. These findings demonstrate the potential of *B. vulgaris* to be considered in CDM projects as a plantation species and thereby mitigate climate change impact more efficiently." **Md. Shawkat Islam Sohel, Mohammed Alamgir, Sayma Akhter, and Mizanur Rahman**, *Land Use Policy*. (Subscription may be required.)

"Carbon storage and nutrient mobilization from soil minerals by deep roots and rhizospheres."

The following is the Abstract of this article: "Roots mobilize nutrients via deep soil penetration and rhizosphere processes inducing weathering of primary minerals. These processes contribute to C transfer to soils and to tree nutrition. Assessments of these characteristics and processes of root systems are important for understanding long-term supplies of nutrient elements essential for forest growth and resilience. Research and techniques have significantly advanced since Olof Tamm's 1934 'base mineral index' for Swedish forest soils, and the basic nutrient budget estimates for whole-tree harvesting systems of the 1970s. Recent research in areas that include some of the world's most productive and intensively managed forests, including Brazil and the USA, has shown that root systems are often several meters in depth, and often extend deeper than soil is sampled. Large amounts of carbon are also sometimes stored at depth. Other recent studies on potential release of nutrients due to chemical weathering indicate the importance of root access to deep soil layers. Nutrient release profiles clearly indicate depletion in the top layers and a much higher potential in B and C horizons. Reviewing potential sustainability of nutrient supplies for biomass harvesting and other intensive forest management systems will advance understanding of these important ecosystem properties, processes and services relevant for management." **Ingeborg Callesen, Robert Harrison, Inge Stupak, Jeff Hatten, Karsten Raulund-Rasmussen, James Boyle, Nicholas Clarke, and Darlene Zabowski**, *Forest Ecology and Management*. (Subscription may be required.)

TRADING

"[Results of 31st RGGI Auction Announced]."

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of the 31st auction of CO_2 allowances. A total of 14,838,732 CO_2 allowances were sold at a clearing price of $5.25. None of the 10 million cost containment reserve (CCR) allowances, a fixed additional supply of allowances that are only available for sale if CO_2 allowance prices exceed certain price levels, were sold. The auction generated $77.9 million for reinvestment in strategic programs; to date, cumulative proceeds from all RGGI auctions exceeds $2.4 billion. More information is available in the ***Market Monitor Report for Auction 31***. In addition, the RGGI states also released the Auction Notice and application materials for their 32nd auction to be held June 1, 2016, in which 15,089,652 CO_2 allowances will be offered for sale at a reserve price of $2.10. The notice and materials provide potential auction participants with the information needed to submit a Qualification Application indicating their intent to bid. More information on CO_2 Allowance Auction 32 is available on the ***RGGI website***. From *RGGI News Release* on March 11, 2016.

"Role of carbon swap trading and energy prices in price correlations and volatilities between carbon markets."

The following is the Abstract of this article: "The present paper theoretically and empirically examines the role of carbon swap trading and energy prices in volatilities and price correlations between the [European Union (EU)] and Kyoto Protocol emissions trading schemes. A supply and demand based correlation model between [EU allowance (EUA)] and [secondary certified emissions reduction (sCER)] price returns is proposed in detail using inverse Box–Cox type marginal abatement cost (MAC) curves and simple emission reduction volume processes. The model includes financial players' EUA–sCER swap transaction in boom periods of carbon prices using the logit model for EUA and EUA–sCER swap volume correlations, and stronger energy price impacts on EUA prices than sCER prices using a mean-reverting lognormal process for energy prices. The empirical studies using EUA and sCER prices estimate the model parameters, resulting in a positive EUA volume impact on EUA–sCER swap transactions and a positive energy price impact on EUA prices. It is shown that high EUA–sCER price correlations during high EUA price periods stemmed from EUA–sCER swap transactions, whereas high EUA–sCER price correlations during the period of financial turmoil with low EUA prices came from the drop in energy prices. [The authors] also show that the leverage effects often observed in security markets exist in both the EUA and sCER markets according to the price–volatility relation." **Takashi Kanamura**, *Energy Economics*. (Subscription may be required.)

LEGISLATIVE ACTIVITY

"[Maryland Governor Signs Bills to Reduce GHG Emissions]."

The Governor of Maryland signed an environmental bill that reauthorizes and sets new targets for the Greenhouse Gas Reduction Act, which was originally passed in 2009 and required Maryland to reduce GHG emissions to 25 percent below 2006 levels by 2020. The new target aims for a GHG emissions reduction to 40 percent below 2006 levels by 2030. More information is available via the ***Governor's press release***. From *The Washington Post* on April 4, 2016.

RECENT PUBLICATIONS

"NETL's ARRA Site Characterization Initiative: Accomplishments."

The following is from the Executive Summary of this NETL document: "NETL's Storage Program received approximately $100 million from the American Recovery and Reinvestment Act of 2009 (ARRA). These funds were distributed among nine projects with a focus on characterizing high-priority formations that have potential for future commercial-scale geologic CO_2 storage. The formations studied are representative of different depositional environments and geologic settings that have significant potential for carbon storage. The projects targeted not only the development of individual sites for carbon storage, but also the regional characterization of distinct high-potential geologic formations. Characterizing these formations provides greater insight into the capabilities of similar geologic formations across the United States to safely and permanently store CO_2. Knowledge gained from these efforts may be applied to similar settings with potential for carbon storage and, thus, contribute valuable information for future commercial-scale carbon storage projects within the study areas. In addition, baseline subsurface conditions must be characterized and subsurface response to injection of large quantities of CO_2 must be assessed as part of the U.S. Environmental Protection Agency's (EPA) Underground Injection Control (UIC) Class VI regulatory framework. Class VI permits are required prior to any CO_2 injection in the United States that is part of a carbon storage project. These characterization data contribute to the development of best practices for safe, long-term storage of CO_2."

"Parameter Sensitivity Analysis with the Seismicity Simulation Program RSQSim."

The following is the Abstract of this NRAP document (NRAP is an initiative within DOE/NETL): "Earthquake simulations performed using the program RSQSim as part of the NRAP probabilistic seismic risk analyses depend on several parameters that are subject to degrees of uncertainty. In the current study, the sensitivity of simulation outputs to uncertainty in key RSQSim input parameters was analyzed using the Lawrence Livermore National Laboratory (LLNL) code PSUADE (Computer Code of Problem Solving Environment for Uncertainty Analysis and Design Exploration). A total sensitivity analysis was first performed to rank the parameters in terms of sensitivity, and then a detailed individual sensitivity analyses of the top-ranked parameters was conducted. The metric used to assess sensitivity is the Gutenberg-Richter b-value."

"Induced Seismicity and Carbon Storage: Risk Assessment and Mitigation Strategies."

The following is the Abstract of this NRAP document (NRAP is an initiative within DOE/NETL): "Geologic carbon storage (GCS) is widely recognized as an important strategy to reduce atmospheric CO_2 emissions. Like all technologies, however, [storage] projects create a number of potential environmental and safety hazards that must be addressed. These include earthquakes—from microseismicity to large, damaging events—that can be triggered by altering pore-pressure conditions in the subsurface. To date, measured seismicity due to CO_2 injection has been limited to a few modest events, but the hazard exists and must be considered. There are important similarities between CO_2 injection and fluid injection from other applications that have induced significant events—e.g. geothermal systems, waste-fluid injection, hydrocarbon extraction, and others. There are also important distinctions among these technologies that should be considered in a discussion of seismic hazard. This report focuses on strategies for assessing and mitigating risk during each phase of a CO_2 storage project. Four key risks related to fault reactivation and induced seismicity were considered. Induced slip on faults could potentially lead to: (1) infrastructure damage, (2) a public nuisance, (3) brine-contaminated drinking water, and (4) CO_2-contaminated drinking water. These scenarios lead to different types of damage—to property, to drinking water quality, or to the public welfare. Given these four risks, this report focuses on strategies for assessing (and altering) their likelihoods of occurrence and the damage that may result…"

"Global storage portfolio: a global assessment of the geological CO_2 storage resource potential."

The following is a summary of this document: "The primary purpose of the Institute's Global Storage Portfolio is to collate and [summarize] published regional assessments of key nations. The Portfolio also [summarizes] key data on a nation's readiness to host a commercial, large-scale project. For this reason, only proven storage scenarios including deep saline formations (DSF), depleted/depleting oil and gas fields (DGOF) and enhanced oil recovery using CO_2 (CO_2-EOR) are considered. The analysis has found that: [1] Substantial storage resources are present in most key regions of the world. [2] Reliable methodologies to determine and classify regional storage resources are available and have been widely applied, although there is no formally [recognized] international standard. [3] The level of resource assessment undertaken and the availability of [characterization] data is highly variable across regions. [4] The level of detail a regional resource assessment has progressed as well as the policy, legal and regulatory frameworks are key criteria that can be used to gauge the readiness of any given nation to deploy a CCS project. The storage resources are grouped into five regions: [(1) Asia-Pacific (fourteen countries); (2) Americas (five countries); (3) Middle East (three countries); (4) Europe and Russia (EU plus three countries); and (5) Africa (four countries)]. The resulting portfolio will enable the reader to rapidly establish a snapshot of a country's storage resource and potential to deploy a large-scale project."

ABOUT DOE'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** advances the development and validation of technologies that enable safe, cost-effective, permanent geologic storage of CO_2. The Carbon Storage Program also supports the development of best practices for CCS that will benefit projects implementing CCS at a commercial scale, such as those being performed under NETL's Clean Coal Power Initiative and Industrial Carbon Capture and Storage Programs. The technologies being developed and the small- and large-scale injection projects conducted through this program will be used to benefit the existing and future fleet of fossil fuel power-generating facilities by developing tools to increase our understanding of the behavior of CO_2 in the subsurface and identifying the geologic reservoirs appropriate for CO_2 storage.

The *Carbon Storage Program Overview* webpage provides detailed information of the program's structure, as well as links to the webpages that summarize the program's key elements.

Carbon Storage Program Resources

The *National Energy Technology Laboratory's CCS Database* includes active, proposed, and terminated CCS projects worldwide. The information is taken from publically available sources to provide convenient access to information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more are available via the *Carbon Storage Program Publications webpage*.

Get answers to your carbon capture and storage questions at NETL's *Frequently Asked Questions webpage*.

ABOUT NETL'S CARBON STORAGE NEWSLETTER

Compiled by the National Energy Technology Laboratory, this newsletter is a monthly summary of public and private sector carbon storage news from around the world. The article titles are links to the full text for those who would like to read more.

National Energy Technology Laboratory

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