Carbon Storage Newsletter

DECEMBER 2014

WHAT'S INSIDE?

HIGHLIGHTS

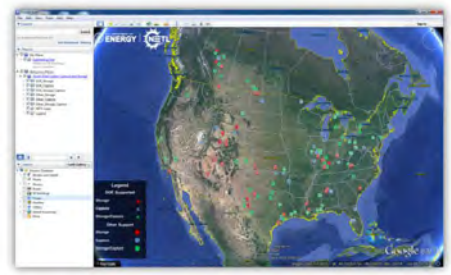
"NETL Collaborations Advance Carbon Management Strategies."

The Carbon Capture Simulation Initiative (CCSI) and the National Risk Assessment Partnership (NRAP) are using predictive computational modeling to help the U.S. Department of Energy (DOE) meet its goal of having carbon capture and storage (CCS) technologies ready for demonstration in the 2020 to 2025 timeframe. Meeting this goal requires the development of new approaches to reduce the 20 to 30 years typically required for commercial deployment of new technology concepts. Led by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), the two collaborative efforts use computational modeling, which involves developing mathematical equations and computer code to simulate the real-life behavior of engineered and natural systems. The use of these models allows for more efficient, timely, and cost-effective technology development and deployment. . For more information, visit DOE's national lab webpage. From *NETL News Release* on August 27, 2014.

ANNOUNCEMENTS

5th Version of NETL's CCS Database Now Available.

NETL's CCS Database includes active, proposed, and terminated CCS projects worldwide. The information is sourced from publically available information to provide the public with information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. As of November 2014, the database contained 274 CCS projects worldwide. The 274 projects include 69 capture, 60 storage, and 145 for capture and storage in more than 30 countries across 6 continents. While several of the projects are still in the planning and development stage, 128 are actively capturing and injecting carbon dioxide (CO_2). NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.



BSCSP Kevin Dome Carbon Storage Project Blog Available.

The Big Sky Carbon Sequestration Partnership (BSCSP) has created a "News from the Kevin Dome" blog on the BSCSP website as a means to regularly update the public about work being done on the Kevin Dome Carbon Storage Project. BSCSP expects to post updates on a weekly basis and as developments occur in the field.

Announcements (Continued)

Call for Papers: 2015 CCUS Conference: Abstracts Now Being Accepted.

The Call for Papers for the 14th Annual Conference on Carbon Capture, Utilization, and Storage has been released, and abstracts are being accepted through January 23, 2015. The theme of this year's conference, scheduled for April 28 through May 1, 2015, in Pittsburgh, Pennsylvania, USA, is "Advancing CO_2 Emission Reduction Systems to Achieve Global Reduction Goals, Meet Electricity Needs, and Utilize Domestic Resources."

White House Announces Launch of New Initiative.

The White House Office of Science & Technology Policy (OSTP) is launching a new Climate Education and Literacy Initiative to help connect American students and citizens with information about climate change. Following a call for information in October, more than 150 activities, projects, and ideas were submitted from more than 30 states. The submissions included approaches being implemented in K-12 classrooms, on college and university campuses, and in zoos, parks, aquariums, and museums to educate and engage the public.

RGGI Releases Q3 2014 Secondary Market Report.

Potomac Economics, the independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) market, continues to find no evidence of anti-competitive conduct in the RGGI CO_2 allowance secondary market. The report found that the average transfer price of RGGI's CO_2 allowances in the CO_2 Allowance Tracking System (COATS) during the third quarter of 2014 was $4.87, approximately 8 percent higher than in the second quarter of 2014 and 61 percent higher than the third quarter of 2013. According to the report, the clearing price of $4.88 in Auction 25 (held on September 3, 2014) is consistent with secondary market prices leading up to the auction.

Carbon Storage in the News

"Magellan Announces Potential Acquisition of CO_2 Source and Poplar Pilot Update."

Magellan Petroleum Corporation announced the acquisition of an option to purchase either the Farnham Dome (a CO_2 reservoir located in Carbon County, Utah, USA) or the un-contracted CO_2 at a fixed price. Magellan officials also updated the status of the CO_2 injection into the Charles formation at the Poplar CO_2-enhanced oil recovery (EOR) project in Montana, USA. After beginning injection in August 2014, the downhole pressure remained stable and above the minimum pressure necessary for CO_2-oil miscibility. It is expected that the expanding CO_2 front should aid in the recovery of additional oil. Magellan opened the four pilot producer wells in October 2014 and projects to see increased oil production. Magellan Petroleum Corporation is an oil and gas exploration and production company focused on the development of a CO_2-EOR program at Poplar Dome and the exploration of hydrocarbon resources in the Weald Basin, onshore United Kingdom. From *CNNMoney* on December 3, 2014.

"Shell Cansolv Starts Testing at TCM."

Shell Cansolv has initiated testing of its CO_2 capture process using exhaust gas from the combined heat and power (CHP) plant at the CO_2 Technology Centre Mongstad's (TCM) amine test facility in Norway. This phase will study the technology and validate the readiness for deployment at industrial-scale projects. TCM is an advanced facility for testing and improving CO_2 capture. The center is comprised of two CO_2 capture plants, each with a capacity to capture approximately 80,000 tons of CO_2 from the nearby refinery or 20,000 tons from a gas-fired power plant. In addition, the center has available space and infrastructure for future testing. From *Technology Centre Mongstad Press Release* on November 25, 2014.

Science

"Research Confirms How Global Warming Links to Carbon Emissions."

A team of researchers from the universities of Southampton, Bristol, and Liverpool have developed a theoretical equation to establish a link between CO_2 emissions and potential climate change. The results of the theoretical equation, which reveals the relationship between CO_2 and the ocean system, show that every million-million metric tons of CO_2 emitted could potentially warm the climate by one degree Celsius. In addition, the results, which are published in the journal "Nature Geoscience," also claim that surface warming is related to the total amount of CO_2 emissions from fossil fuels, with little change over time as ocean carbon and changes in heat uptake nearly cancel out. From *Science Daily* on December 1, 2014.

"Warmest Oceans Ever Recorded."

According to analysis of ocean temperature datasets, this past summer resulted in the highest global mean sea surface temperatures ever recorded, surpassing the temperatures recorded during the then record-breaking 1998 El Niño year. A researcher from the International Research Center at the University of Hawaii at Manoa found that, due to quick-rising sea-surface temperatures in the extratropical North Pacific, westerly winds pushed warm water that was usually stored in the western Pacific along

Science (Continued)

the equator to the eastern Pacific. As the warm water spread across the North American Pacific coast, heat that had been contained in the Western tropical Pacific for nearly a decade was released into the atmosphere. From *Science Daily* on November 14, 2015.

"Carbon Dioxide Warming Effects Felt Just a Decade After Being Emitted."

According to Carnegie Institute of Science researchers, a single CO_2 emission could have its maximum warming effects on the Earth in as little as 10 years, while the potential warming can persist for more than a century. The researchers' study also claims that it is possible the benefits from emission reductions, such as the avoidance of weather events like droughts, heatwaves, and flooding, will be felt by current and future generations. The study says that potential climate impacts, such as a rise in sea level and melting ice sheets, will have a longer time outlook. Published in IOP Publishing's journal "Environmental Research Letters," the study combined information taken from a group of climate models used in the latest Intergovernmental Panel on Climate Change (IPCC) assessment, finding that that median time between a single CO_2 emission and maximum warming was 10.1 years. From *Science Daily* on December 3, 2014.

Policy

"U.S.-China Joint Announcement on Climate Change."

The United States of America and the People's Republic of China announced bilateral cooperation on climate change and will collaborate with other countries to adopt a protocol, another legal instrument, or an agreed outcome at the United Nations (UN) Climate Conference in Paris, France, in 2015. Under the agreement, the United States would cut its 2005 level of carbon emissions by 26 to 28 percent before the year 2025. China would peak its carbon emissions by 2030 and will also aim to increase the share of non-fossil fuels in primary energy consumption to approximately 20 percent by 2030. Both sides intend to work toward higher targets over time. The United States and China believe that technological innovation is essential for reducing the cost of current mitigation technologies. Energy technology cooperation between the two nations is shown from past efforts, such as establishing the U.S.-China Climate Change Working Group (CCWG), agreeing to work together towards the global phase down of hydrofluorocarbons (HFCs), creating the U.S.-China Clean Energy Research Center (CERC), and agreeing on a joint peer review of inefficient fossil fuel subsidies under the G-20. Finally, the United States and China announced additional measures to strengthen and expand their cooperation by using the existing entities such as the CCWG, the CERC, and the U.S.-China Strategic and Economic Dialogue. The measures include expanding joint clean energy research and development (R&D); advancing major carbon capture, utilization, and storage demonstrations; enhancing cooperation on HFCs; launching a climate-smart/low-carbon cities initiative; promoting trade in green goods; and demonstrating clean energy. From *White House Press Release* on November 11, 2014.

Policy

"UK, Canada Sign Joint Research Agreement for Carbon Capture and Storage."

The United Kingdom (UK) Department of Energy and Climate Change (DECC) and Department of Natural Resources of Canada (NRCan) signed an agreement to collaborate on CCS research, innovation, and knowledge sharing. The UK and Canada will: (1) build on existing R&D partnerships between the research centers; (2) develop joint research projects, reciprocal visits, and access to testing; and (3) pursue joint CCS-themed academic programs. Among other knowledge sharing objectives, the countries will share experience in CCS regulation. More information on the agreement is available via the "Joint Statement from the Department of Natural Resources of Canada and the Department of Energy and Climate Change of the United Kingdom concerning Carbon Capture and Storage." From *Energy Business Review* on November 19, 2014.

"EPA Finalizes Greenhouse Gas Permit for Carbon Capture Facility."

The U.S. Environmental Protection Agency (EPA) issued a final GHG Prevention of Significant Deterioration (PSD) construction permit to Nuevo Midstream, LLC, to build three gas-processing plants in Orla, Texas. The facility is expected to "help increase processing of natural gas in Texas and New Mexico," according to EPA officials. The project, which is the first GHG PSD construction permit in Texas for CO_2 capture and storage, will involve the expansion of three cryogenic plants and two 1,000-gpm amine plants, in addition to selling GHGs for EOR operations. For more information on GHG permits in Texas, click here. From *U.S. EPA News Release* on November 25, 2014.

"The prospects for coal-fired power plants with carbon capture and storage: A UK perspective."

The following is the Abstract of this article: "CCS facilities coupled to coal-fired power plants provide a climate change mitigation strategy that potentially permits the continued use of fossil fuels whilst reducing the CO_2 emissions. Potential design routes for the capture, transport and storage of CO_2 from United Kingdom (UK) power plants are examined. Energy and carbon analyses were performed on coal-fired power stations with and without CCS. Both currently available and novel CCS technologies are evaluated. Due to lower operating efficiencies, the CCS plants showed a longer energy payback period and a lower energy gain ratio than conventional plant. Cost estimates are reported in the context of recent UK industry-led attempts to determine opportunities for cost reductions across the whole CCS chain, alongside international [endeavors] to devise common CCS cost estimation methods. These cost figures should be viewed as 'indicative' or suggestive. They are nevertheless helpful to various CCS stakeholder groups [such as those in industry, policy makers (civil servants and the staff of various government agencies), and civil society and environmental 'non-governmental organisations' (NGOs)] in order to enable them to assess the role of this technology in national energy strategies and its impact on local communities." **Geoffrey P. Hammond and Jack Spargo**, *Energy Conversion and Management*. (Subscription may be required.)

GEOLOGY

"Constraints on the magnitude and rate of CO_2 dissolution at Bravo Dome natural gas field."

The following is the Abstract of this article: "The injection of CO_2 captured at large point sources into deep saline [formations] can significantly reduce anthropogenic CO_2 emissions from fossil fuels. Dissolution of the injected CO_2 into the formation brine is a trapping mechanism that helps to ensure the long-term security of geological CO_2 storage. [The authors] use thermochronology to estimate the timing of CO_2 emplacement at Bravo Dome, a large natural CO_2 field at a depth of 700 m in New Mexico. Together with estimates of the total mass loss from the field [the authors] present, to [their] knowledge, the first constraints on the magnitude, mechanisms, and rates of CO_2 dissolution on millennial timescales. Apatite (U-Th)/He thermochronology records heating of the Bravo Dome reservoir due to the emplacement of hot volcanic gases 1.2–1.5 Ma. The CO_2 accumulation is therefore significantly older than previous estimates of 10 ka, which demonstrates that safe long-term geological CO_2 storage is possible. Integrating geophysical and geochemical data, [the authors] estimate that 1.3 Gt CO_2 are currently stored at Bravo Dome, but that only 22 [percent] of the emplaced CO_2 has dissolved into the brine over 1.2 My. Roughly 40 [percent] of the dissolution occurred during the emplacement. The CO_2 dissolved after emplacement exceeds the amount expected from diffusion and provides field evidence for convective dissolution with a rate of 0.1 g/(m^2y). The similarity between Bravo Dome and major US saline [formations] suggests that significant amounts of CO_2 are likely to dissolve during injection at US storage sites, but that convective dissolution is unlikely to trap all injected CO_2 on the 10-ky timescale typically considered for storage projects." **Kiran J. Sathaye, Marc A. Hesse, Martin Cassidy, and Daniel F. Stockli**, *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required.)

"Reactive and Pore Structure Changes in Carbon Dioxide Sequestration."

The following is the Abstract of this article: "The importance of reactions involving CO_2, brine and rock formations into which CO_2 is injected for CO_2 [storage] in saline [formations] is understood. However, the pore-level changes that occur due to these reactions under flow conditions and their impact on the ultimate fate of CO_2 in the repository have not received the same level of attention due to the perceived slowness of the carbonation reactions. In this paper [the authors] examine these reactive changes and their impact on the pore structure in sandstones and limestones at realistic [formation] pressure and temperatures, and under reactive flow conditions. The changes observed at the pore-level by direct porosity and micro-computer tomography measurements were complemented by the measurements of time-dependent effluent concentrations of target cations. It is observed that iron chemistry plays an important role in the dissolution and precipitation reactions in Berea sandstone. Illite dissolution leads to a peak in iron concentration in effluent brines. Higher level of dissolution and porosity increase is observed near the inlet of the core. In limestones, consistent dissolution is observed throughout the experiment. Wormholes are also generated for experiments with a larger total flow rates. Results show that reactive changes can cause significant pore-level changes over a short injection span during CO_2 [storage] in saline [formations] with profound implications on injectivity and possibly major mechanical changes." **Hyukmin Kweon, Christian Payne, and Milind D. Deo**, *Ind. Eng. Chem. Res*. (Subscription may be required.)

"Influence of Porous Texture and Surface Chemistry on the CO_2 Adsorption Capacity of Porous Carbons: Acidic and Basic Site Interactions."

The following is the Abstract of this article: "Doped porous carbons exhibiting highly developed porosity and rich surface chemistry have been prepared and subsequently applied to clarify the influence of both factors on [CO_2] capture. Nanocasting was selected as synthetic route, in which a polyaramide precursor (3-aminobenzoic acid) was thermally polymerized inside the porosity of an SBA-15 template in the presence of different H_3PO_4 concentrations. The surface chemistry and the porous texture of the carbons could be easily modulated by varying the H_3PO_4 concentration and carbonization temperature. Porous texture was found to be the determinant factor on [CO_2] adsorption at 0°C, while surface chemistry played an important role at higher adsorption temperatures. [The authors] proved that nitrogen functionalities acted as basic sites and oxygen and phosphorus groups as acidic ones toward adsorption of CO_2 molecules. Among the nitrogen functional groups, pyrrolic groups exhibited the highest influence, while the positive effect of pyridinic and quaternary functionalities was smaller. Finally, some of these N-doped carbons exhibit CO_2 heats of adsorption higher than 42 kJ/mol, which make them excellent candidates for CO_2 capture." **Ángela Sánchez-Sánchez, Fabián Suárez-García, Amelia Martínez-Alonso, and Juan M. D. Tascón**, *ACS Appl. Mater. Interfaces*. (Subscription may be required.)

"Influence of Maximum Pressure on the Path of CO_2 Desorption Isotherm on Coal."

The following is the Abstract of this article: "Coal seams with a high CO_2 content may have outburst risk, and degasification of CO_2 has to be conducted before these coal seams can be safely extracted. For [geo-storage] of CO_2 in unmineable coal seams, injected CO_2 may desorb with the reduction of CO_2 pressure. Desorption of CO_2 dominates these processes, while adsorption isotherms are widely used assuming that the adsorption–desorption process is fully reversible. To understand the difference between CO_2 adsorption and desorption isotherms, i.e., sorption hysteresis, as well as the dependence of CO_2 sorption hysteresis on maximum pressure, four cycles of CO_2 adsorption–desorption experiments are conducted continuously with increasing maximum pressure (1, 2, 3, and 4 MPa). The difference of CO_2 emission volume between adsorption and desorption isotherms is compared, and a significant deviation (0.059 and 0.032 mol/g) has been observed. The adsorption isotherms show a good repeatability, indicating that the gas holding capacity does not change during a long-term contact with CO_2. However, a distinct difference between the desorption isotherms is observed. The path of desorption isotherm depends upon the maximum pressure, and higher maximum pressures can reduce the proneness of CO_2 desorption in the pressure range of this study (0–4 MPa). [The authors] suggest that desorption isotherms should be used to predict the CO_2 emission volume and long-term storage stability, and the maximum pressure of the laboratory sorption test should be decided

GEOLOGY (CONTINUED)

according to the in situ coal seam pressure." **Gongda Wang, Ting Ren, Kai Wang, and Yaqin Wu**, *Energy Fuels*. (Subscription may be required.)

"Intrinsic Kinetics of Platy Hydrated Magnesium Silicate (Talc) for Geological CO_2 Sequestration: Determination of Activation Barrier."

The following is the Abstract of this article: "Hydrated magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$), commonly known as talc, is a direct carbonation agent. In this study, [the authors] investigated the utility of the carbonation reaction for CO_2 adsorption. To gain insight into talc carbonation, [the authors] performed CO_2 temperature-programmed-desorption and dynamic flow system experiments. Structural modifications proved that CO_2 adsorption occurred on the surface of the talc adsorbents to form carbonates. [The authors] achieved stable carbonation activities of talc by varying the temperature. In addition, the reaction kinetic model of talc carbonation based on the changes of CO_2 concentration was developed. From the observation that the activation energy of talc-based carbonation using the Arrhenius equation is 51.4 ± 4.8 kJ/mol, it is inferred that the chemical reaction is a rate-determining step for talc sequestration, based on relatively high activation energy." **Soonchul Kwon, Min Cho, and Seung Geol Lee**, *Ind. Eng. Chem. Res*. (Subscription may be required.)

TECHNOLOGY

"Experimental and Computational Study of CO_2 Storage and Sequestration with Aqueous 2-Amino-2-hydroxymethyl-1, 3-propanediol (TRIS) Solutions."

The following is the Abstract of this article: "Experimental solubility data of CO_2 in (5 and 10) mass% TRIS aqueous solutions were measured at (318.15 and 333.15) K and up to 10 MPa. The solubility data were well correlated with the modified Kent-Eisenberg model. The reaction mechanism, reaction energies, and equilibrium constants for the formation of bicarbonate and carbamate from CO_2, H_2O, and TRIS were studied using the quantum-chemical approach COSMO-RS (conductor-like screening model for real solvents) at the BP/TZVP level. The bicarbonate and carbamate formations were confirmed by using Fourier transform infrared (FTIR) spectroscopy. The results demonstrate that the formation of the bicarbonate anion is the main product formed by the direct reaction of CO_2 with water and TRIS, and reveal that the carbamate anion was formed by a proton transfer from TRIS−CO_2 zwitterion to TRIS. Density functional theory (DFT) calculations with transition-state optimization and intrinsic reaction coordinate (IRC) in water using IEF-PCM solvation model at the B3LYP/6-311++G(d,p) levels of theory were employed to support the reaction pathway for the bicarbonate and carbamate formations. The conversion of the absorption product to stable carbonate ($CaCO_3$) was also investigated experimentally by adding various Ca^{2+} sources, $CaCl_2$•$2H_2O$ aqueous solution, and artificial sea water." **Rama Oktavian, Mohamed Taha, and Ming-Jer Lee**, *J. Phys. Chem. A*. (Subscription may be required.)

"Field Demonstration of CO_2 Leakage Detection in Potable Aquifers with a Pulselike CO_2-Release Test."

The following is the Abstract of this article: "This study presents two field pulselike CO_2-release tests to demonstrate CO_2 [release] detection in a shallow [formation] by monitoring groundwater pH, alkalinity, and dissolved inorganic carbon (DIC) using the periodic groundwater sampling method and a fiber-optic CO_2 sensor for real-time in situ monitoring of dissolved CO_2 in groundwater. Measurements of groundwater pH, alkalinity, DIC, and dissolved CO_2 clearly deviated from their background values, showing responses to CO_2 [release]. Dissolved CO_2 observed in the tests was highly sensitive in comparison to groundwater pH, DIC, and alkalinity. Comparison of the pulselike CO_2-release tests to other field tests suggests that pulselike CO_2-release tests can provide reliable assessment of geochemical parameters indicative of CO_2 [release]. Measurements by the fiber-optic CO_2 sensor, showing obvious [release] signals, demonstrated the potential of real-time in situ monitoring of dissolved CO_2 for [release] detection at a geologic carbon [storage] (GCS) site. Results of a two-dimensional reactive transport model reproduced the geochemical measurements and confirmed that the decrease in groundwater pH and the increases in DIC and dissolved CO_2 observed in the pulselike CO_2-release tests were caused by dissolution of CO_2 whereas alkalinity was likely affected by carbonate dissolution." **Changbing Yang, Susan D. Hovorka, Jesus Delgado-Alonso, Patrick J. Mickler, Ramón H. Treviño, and Straun Phillips**, *Environ. Sci. Technol*. (Subscription may be required.)

"Field based stable isotope analysis of CO_2 by mid-infrared laser spectroscopy for CCS monitoring."

The following is the Abstract of this article: "A newly developed isotope ratio laser spectrometer for CO_2 analyses has been tested during a tracer experiment at the Ketzin pilot site (northern Germany) for CO_2 storage. For the experiment, 500 t of CO_2 from a natural CO_2 reservoir was injected in supercritical state into the reservoir. The carbon stable isotope value (δ13C) of injected CO_2 was significantly different from background values. In order to observe the breakthrough of the isotope tracer continuously, the new instruments were connected to a stainless steel riser tube that was installed in an observation well. The laser instrument is based on tunable laser direct absorption in the mid-infrared. The instrument recorded a continuous 10-day carbon stable isotope data set with 30 minutes resolution directly [onsite] in a field-based laboratory container during a tracer experiment. To test the instruments performance and accuracy the monitoring campaign was accompanied by daily CO_2 sampling for laboratory analyses with isotope ratio mass spectrometry (IRMS). The carbon stable isotope ratios measured by conventional IRMS technique and by the new mid-infrared laser spectrometer agree remarkably well within analytical precision. This proves the capability of the new mid-infrared direct absorption technique to measure high precision and accurate real-time stable isotope data directly in the field. The laser spectroscopy data revealed for the first time a prior to this experiment unknown, intensive dynamic with fast changing δ13C values. The arrival pattern of the tracer suggest that the observed fluctuations were probably caused by migration along separate and distinct preferential flow paths between injection well and observation well. The short-term variances as observed in this study might have been missed during previous works that applied laboratory based IRMS analysis. The new

Technology (Continued)

technique could contribute to a better tracing of the migration of the underground CO_2 plume and help to ensure the long-term integrity of the reservoir." **Robert van Geldern, Martin E Nowak, Martin Zimmer, Alexandra Szizybalski, Anssi Myrttinen, Johannes A. C. Barth, and Hans-Jürg Jost**, *Anal. Chem*. (Subscription may be required.)

Terrestrial

"Threshold Dynamics in Soil Carbon Storage for Bioenergy Crops."

The following is the Abstract of this article: "Because of increasing demands for bioenergy, a considerable amount of land in the midwestern United States could be devoted to the cultivation of second-generation bioenergy crops, such as switchgrass and miscanthus. The foliar carbon/nitrogen ratio (C/N) in these bioenergy crops at harvest is significantly higher than the ratios in replaced crops, such as corn or soybean. [The authors] show that there is a critical soil organic matter C/N ratio, where microbial biomass can be impaired as microorganisms become dependent upon net immobilization. The simulation results show that there is a threshold effect in the amount of aboveground litter input in the soil after harvest that will reach a critical organic matter C/N ratio in the soil, triggering a reduction of the soil microbial population, with significant consequences in other microbe-related processes, such as decomposition and mineralization. These thresholds are approximately 25 and 15 [percent] of aboveground biomass for switchgrass and miscanthus, respectively. These results suggest that values above these thresholds could result in a significant reduction of decomposition and mineralization, which, in turn, would enhance the [storage] of atmospheric [CO_2] in the topsoil and reduce inorganic nitrogen losses when compared to a corn–corn–soybean rotation." **Dong K. Woo, Juan C. Quijano, Praveen Kumar, Sayo Chaoka, and Carl J. Bernacchi**, *Environ. Sci. Technol*. (Subscription may be required.)

Trading

"California Says Carbon Permits Sell Out at Auction with Quebec."

Officials from the California Air Resources Board (CARB) said that firms spent approximately $407 million in the latest quarterly auction of CO_2 emissions permits. The auction, held on November 25, was the first conducted that included participation from the Canadian province of Quebec. All of the nearly 34 million allowances available were sold. The auctions are part of California's cap-and-trade program, which seeks to limit CO_2 emissions as part of the state's initiative to address climate change. The California cap-and-trade program and Québec cap-and-trade system officially linked in January 2014. This enabled mutual acceptance of compliance instruments issued by each jurisdiction and the jurisdictions to hold joint auctions of GHG allowances. Quebec is the first entity to join the program. Each CO_2 emissions permit gives a firm the right to emit one ton of CO_2. More information on the auction is available via the CARB press release. From *Sacramento Bee* on December 3, 2014.

"CO_2 Allowances Sold for $5.21 in 26th RGGI Auction."

The states participating in RGGI announced that 18,198,685 CO_2 allowances were sold at their 26th auction at a clearing price of $5.21. All allowances offered for sale were sold, generating more than $94 million for reinvestment in energy efficiency and renewable energy initiatives, direct bill assistance, and GHG abatement programs. The cumulative proceeds from all RGGI CO_2 allowance auctions currently total $1.9 billion dollars; more information is available via the Market Monitor Report for Auction 26. RGGI's second control period began on January 1, 2012, and ends on December 31, 2014. Regulated power plants in the participating states will be required to demonstrate compliance for the second control period on March 2, 2015. The 2014 RGGI cap is 91 million short tons; the RGGI cap then declines 2.5 percent each year from 2015 to 2020. From *RGGI News Release* on December 5, 2014.

"Futures trading with information asymmetry and OTC predominance: Another look at the volume/volatility relations in the European carbon markets."

The following is the Abstract of this article: "This paper constitutes the first exercise of [analyzing] the European carbon market efficiency from a double perspective combining both nature of execution venues (screen vs. OTC trading) and their volatility/liquidity relations. Using a bivariate asymmetric GJR-GARCH model, [the authors] first document that OTC (exchange traded) trading volume shows consistent bi-(uni) directional Granger causality to [the authors'] volatility estimates, consistent with greater responsiveness of the OTC (exchange traded) market to changes in market-wide (idiosyncratic) risks. Second, [the authors] report significant contemporaneous and lagged positive causality of OTC derivatives volume on spot/futures volatility confirming that the Sequential Information Arrival Hypothesis (SIAH) applies. Third, [the authors] find that the one-way causality from OTC to futures volumes is mainly driven by heterogeneous investor beliefs: trading volume provides an indication on how (private) information is dispersed and held at different levels rather than proxying information signal itself. After rejecting execution venues' substitutability, [the authors] advocate for systematic clearing and netting of OTC positions through a unique clearing house and reporting rules to identify speculation in line with Mifid (Art. 59) proposals." **Yves Rannou and Pascal Barneto**, *Energy Economics*. (Subscription may be required.)

Recent Publications

"Use of Science-Based Prediction to Characterize Reservoir Behavior as a Function of Injection Characteristics, Geological Variables, and Time."

The following is from the Executive Summary of this NRAP document: "This report summarizes a detailed study designed to generate a baseline understanding of how pressure plumes and CO_2 plumes behave in CO_2 storage reservoirs as a function of storage-site properties, injection conditions, and time. The goal of the study was to provide quantitative insight into how operational and geologic factors can impact risk at storage sites both during injection and post injection. The study focused on reservoir performance. Thus, this study does not explore risk directly; calculation of risk requires coupling reservoir behavior to other features and processes at the storage site (such as flow along legacy wells). Nevertheless, the focus on reservoir behavior provides critical insight into how the storage system is expected to evolve relative to risk. Specifically, the evolution of differential pressure and CO_2 plumes in the reservoir are central to two categories of potential impacts of concern: fluid release from the reservoir (which could pose a risk to groundwater resources), and slippage along a critically stressed fault (which could produce a felt seismic event). Hence, this aspect of reservoir behavior is central to assessment of risk at a storage site. Future work will utilize the National Risk Assessment Partnership's (NRAP) integrated assessment models (IAMs) to link reservoir behavior with direct technical risk metrics, such as [release] of CO_2 back to the atmosphere or the nature of potential groundwater impacts. [The authors] identified several simple metrics that facilitate the quantification of reservoir behavior for different injection conditions (e.g., rates or durations) and for various reservoir properties. These metrics were applied to results from detailed simulations of >2,300 different scenarios. The resulting analysis helps to elucidate the expected risk-related behavior for scenarios ranging from small pilot tests to large-scale storage operations, demonstrating how this behavior varies over both space and time. Hence, this analysis can help to inform consideration of questions such as: How large of an area might be impacted for a given size of injection? How much of a pressure increase might a reservoir experience for a given size of injection? How will sites evolve post injection for a given size of injection?" For more information on NRAP, please see the "Highlights" section of this newsletter.

"Scaling the CO_2 storage industry: A study and a tool."

The following is from the Executive Summary of this document: "CCS is a critical technology in reducing CO_2 emissions from energy and industry. The Intergovernmental Panel on Climate Change (IPCC) estimates that the cost of the necessary emissions reductions would more than double without CCS. A failure to deploy CCS would thus be a failure to avoid a warming world. The availability of CO_2 storage is the linchpin of CCS deployment. A lack of storage capacity could render CO_2 capture futile, and in the worst case could discourage investments in CCS projects. A CO_2 storage industry that can match the scale of the oil and gas sector will therefore be necessary to enable the necessary scale of CCS deployment. This report takes a look at the practicalities of developing CO_2 storage in Europe and answers three key questions: (1) What is the rate at which CO_2 storage needs to be developed for CCS to be deployed and climate goals met? (2) Is the nascent CO_2 storage industry capable of scaling up quickly? (3) What are the requirements of a CO_2 storage industry? Bellona has built a simple yet robust model to answer these questions and give insight into the broad lines of the future scale of CO_2 storage activities. It examines storage scenarios for onshore and offshore storage in saline [formations], depleted oil and gas fields, and for EOR. The model uses storage data and the anticipated CO_2 captured each year to measure the necessary CO_2 storage capacity to be deployed throughout Europe…"

Legislative Activity

"Sens. Whitehouse and Schatz Introduce Carbon Free Legislation."

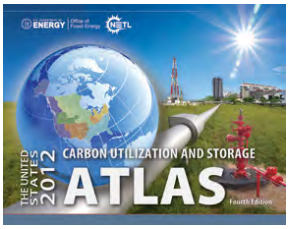
U.S. Senator Sheldon Whitehouse introduced legislation that would potentially reduce CO_2 emissions while generating revenue over 10 years, which would be credited to the American Opportunity Fund for uses such tax cuts, economic assistance to low-income families and those in areas with high energy costs, and climate mitigation and adaption. Cosponsored by U.S. Senator Brian Schatz, the "American Opportunity Carbon Free Act" would require emitters to pay a fee for every ton of CO_2 emitted. The fee would start at $42 per ton in 2015 and increase annually. Working with EPA, the U.S. Department of Treasury would assess and collect the fee, which would be assessed on all coal, oil, and natural gas produced in or imported to the United States. From *U.S. Senator Sheldon Whitehouse Press Release* on November 19, 2014.

About DOE's Carbon Storage Program

The Carbon Storage Program is implemented by the U.S. Department of Energy's Office of Fossil Energy and managed by the National Energy Technology Laboratory. The program is developing technologies to capture, separate, and store CO_2 in order to reduce greenhouse gas emissions without adversely influencing energy use or hindering economic growth. NETL envisions having a technology portfolio of safe, cost-effective, carbon dioxide capture, transport, and storage technologies that will be available for commercial deployment.

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 U.S. Department of Energy's 2012 United States Carbon Utilization and Storage Atlas (Atlas IV) shows that the United States has at least 2,400 billion metric tons of potential carbon dioxide storage resource in saline formations, oil and gas reservoirs, and unmineable coal. Data from Atlas IV is available via the National Carbon Sequestration Database and Geographic Information System (NATCARB), which is a geographic information system-based tool developed to provide a view of carbon capture and storage potential.

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more are available via the Carbon Storage Reference Shelf.

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

There are several ways to join the conversation and connect with NETL's Carbon Storage Program:

NETL RSS Feed

NETL on Facebook

NETL on Twitter

NETL on LinkedIn

NETL on YouTube

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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