NETL the ENERGY lab

Carbon Storage Newsletter

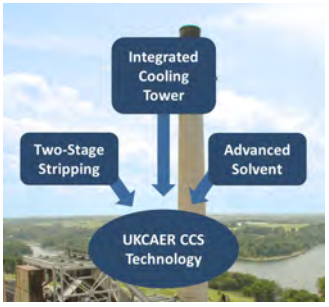
August 2014

What's Inside?

Highlights

"Projects Selected for Safe and Permanent Geologic Storage of Carbon Dioxide."

The U.S. Department of Energy (DOE) selected 13 projects to develop technologies, methodologies, and characterization tools to improve the ability to predict geologic carbon dioxide (CO_2) storage capacity, understand geomechanical processes, and enhance geologic storage safety. The projects will be managed by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) and were awarded in two areas of interest: "Geomechanical Research" and "Fractured Reservoir and Seal Behavior." The Geomechanical Research area project performers include the University of Wyoming, Clemson University, University of Texas at Austin, Northern Illinois University, Battelle Memorial Institute, Pennsylvania State University, Sandia Technologies, Montana State University, and the Colorado School of Mines. The Fractured Reservoir and Seal Behavior area project performers include Princeton University, the Colorado School of Mines, Washington University, and University of Texas at Austin. Project details are available via the link. The total value of the projects is approximately $17.6 million over three years, with $13.8 million of DOE funding and $3.8 million of non-Federal cost sharing. Carbon capture and storage (CCS) research is focused on developing technologies to capture industrially generated CO_2 and safely and permanently storing it in underground geologic formations to reduce the amount of CO_2 being released into the atmosphere. From *NETL News Release* on August 6, 2014.



"Construction Begins on DOE-Sponsored Carbon Capture Project at Kentucky Power Plant."

Construction has initiated on a DOE-funded carbon capture pilot project at Kentucky Utilities' E.W. Brown Generating Station near Harrodsburg, Kentucky, USA. The unit will test a novel system from the University of Kentucky Center for Applied Energy Research (UKCAER) at slipstream scale that captures CO_2 from the flue gas of an operating coal-fired power plant. The 2-megawatt thermal system will be the first megawatt-scale carbon capture pilot unit in Kentucky. The project will be managed by NETL; DOE is contributing $14.5 million for the five-year project. For more information about the UKCAER project, visit NETL's project webpage. From *NETL News Release* on July 21, 2014.

"World's Largest Post-Combustion Carbon Capture Project Begins in Construction."

In partnership with NRG Energy Inc. and JX Nippon, DOE announced the beginning of construction on the Petra Nova Project, a commercial-scale, post-combustion carbon capture retrofit project. Once completed, the project is expected to capture approximately 1.4 million metric tons of CO_2 annually from an existing coal-fired power plant in Texas, USA; the captured CO_2 will then be used for enhanced oil recovery (EOR) at a depleted oil field approximately 80 miles away. The 240-megawatt project is expected to capture 90 percent of the CO_2 using a process previously deployed in a DOE-sponsored pilot-scale test in Alabama that successfully captured more than 150,000 metric tons of CO_2 annually from a coal power plant. From *NETL News Release* on July 16, 2014.

HIGHLIGHTS (CONTINUED)

"Energy Department Project Captures and Stores more than One Million Metric Tons of CO_2."

In partnership with Air Products and Chemicals, Inc., DOE announced that more than 1 million metric tons of CO_2 have been captured at a hydrogen production facility in Port Arthur, Texas, USA. The project captures more than 90 percent of the CO_2 from the product stream of two commercial-scale steam methane reformers using vacuum swing adsorption. In addition to geologic storage, the captured CO_2 will be used for EOR at the depleted West Hastings Field in southeast Texas. By using EOR, West Hastings could yield as much oil as it would from traditional production activities; it is estimated that the West Hastings Field could produce in the range of 60 to 90 million additional barrels of oil using CO_2 injection. Air Products' vacuum swing adsorption project, supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program, is one of several ICCS projects advancing and deploying CCS technologies. From *U.S. Department of Energy Press Release* on June 26, 2014.

ANNOUNCEMENTS

DOE-Sponsored Project Shows Potential for Carbon Storage in Wyoming.

A DOE-sponsored study revealed that the Wyoming Rock Springs Uplift (a geologic feature in southwestern Wyoming) could potentially store 14 to 17 billion metric tons of CO_2. The Rock Springs Uplift was found to have ideal geologic characteristics for carbon storage and proximity to large, anthropogenic CO_2 emission sources. The Wyoming Rock Springs Uplift storage potential is equal to 250 to 300 years' worth of CO_2 emissions produced by Wyoming's coal-fired power plants and other large regional anthropogenic CO_2 sources at current emission levels.

DOE Reaches Agreement to Test Carbon Capture and Gasification Technologies.

DOE signed a cooperative agreement with Southern Company to evaluate advanced carbon capture and gasification technologies at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama, USA. Under the NETL-managed agreement, Southern Company will test pre- and post-combustion carbon-capture technologies, materials, and processes that support advanced fossil-fuel conversion systems, primarily coal gasification.

12th International Conference on Greenhouse Gas Control Technologies.

GHGT-12 will be held on October 5-9, 2014, in Austin, Texas, USA. This will be the first visit by the conference series to Austin and more than 1,600 participants are expected to attend. The event will be hosted by the University of Texas at Austin and the IEA Greenhouse Gas R&D Programme (IEAGHG). Details regarding the Technical Program, abstracts, and poster sessions are now available.

BSCSP Kevin Dome Carbon Storage Project Blog Available.

The Big Sky Carbon Sequestration Project (BSCSP) has created a "News from the Kevin Dome" blog on the BSCSP website as an effort 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.

Save the Date: MGSC Conference.

The Midwest Geological Sequestration Consortium (MGSC) will hold their annual conference at the I Hotel and Conference Center in Champaign, Illinois, USA, on November 6, 2014. More details will be available in the future.

PCOR Partnership Annual Membership Meeting.

The Plain CO_2 Reduction (PCOR) Partnership Annual Membership Meeting is scheduled for September 16-17, 2014, at the Embassy Suites Denver – Downtown/Convention Center in Denver, Colorado, USA. The meeting will highlight recent program accomplishments, storage strategies and technologies, regulatory developments, and carbon storage infrastructure. Registration, hotel information, and an agenda are available via the link.

Carbon Storage in the News

"PSE Launches gCCS – World's First Full-Chain Modelling Software for CCS."

Process Systems Enterprise (PSE) launched its gCCS modelling software designed for full CCS chains from power generation through CO_2 capture, compression, and transport to injection. The gCCS systems modeling environment, which will be used in PSE's gPROMS advanced process modelling platform, employs models to predict how the CCS chain's components will interact under different scenarios. According to PSE, the Peterhead CCS Project will use the software to investigate the flexibility of the operation of the capture process when integrated within the full system. From *PSE Press Release* on July 9, 2014.

"National Grid Awards CCS Pipeline Contract," and **"Study to Examine North Sea Carbon Dioxide Transport/Storage Needs."**

National Grid Carbon Ltd (NGC) selected Genesis to conduct a front-end engineering and design (FEED) study for a pipeline that will transport CO_2 from the Drax Power Station in Humberside, United Kingdom (U.K.), to a storage site in the North Sea. The pipeline infrastructure will have the capacity to transport up to 18.7 million tons of CO_2 per year. The White Rose CCS Project requires approximately 2.2 million tons of CO_2 per year. Genesis will perform risk evaluation and cost estimates, along with the engineering and design of the transportation and storage system. NGC will provide the transportation and storage elements for the CCS project in collaboration with Capture Power Ltd. The CO_2 will be injected approximately 0.6 miles beneath the North Sea seafloor for storage. From Energy Live News on August 1, 2014, and from *Offshore Magazine* on July 4, 2014.

"Pilot Carbon Capture Project to Begin this Year."

After signing a collaboration agreement in June 2014 for their pilot project to go online in April 2015, Neumann Systems Group (NSG) and CO_2 Solutions have agreed to begin operations by October 2014. The pilot facility, which is expected to capture approximately 10 tons of CO_2 per day, will use a system that combines NSG's NeuStream compact absorber and stripper systems with CO_2 Solutions' enzyme-based technology to strip CO_2 from flu gas. The pilot facility is located in Colorado Springs, Colorado, USA. From *Wyoming Business Report* on July 17, 2014.

Science

"Climate Change May Reduce Corn, Wheat Crop Yields."

According to a new study, rising temperatures may increase the odds of slower corn and wheat yields. The study, published in *Environmental Research Letters*, claims that there is as much as a 10 percent chance that the rate of corn yields, and a 5 percent probability for wheat, will slow as a result of potential climate change. When scientists removed potential climate change from the equation that predicted the crop yield growth, the chance of slower growth falls to approximately 1 in 200. According to estimates, a rise in global temperatures of approximately 1.8 degrees Fahrenheit would slow the rate of corn growth by seven percent and wheat by approximately six percent. From *Bloomberg* on July 25, 2014.

"Alaska Frogs Reach Record Lows in Extreme Temperature Survival."

A recent paper from the University of Alaska Fairbanks demonstrates that freeze tolerance in Alaska wood frogs is greater than previously thought. In subarctic interior Alaska, wood frogs overwinter in the ground, creating hibernacula, where temperatures can remain below freezing for more than six months with a minimum temperature of -4 degrees Fahrenheit. Researchers tracked the wood frogs in their natural hibernacula to study how cold and for how long a period they could survive in their natural habitat. Researchers discovered that when outside their natural environment, wood frogs accumulate higher concentrations of glucose in their tissues. By packing their cells with glucose, frogs are able to stabilize their cells and reduce the drying out of cells that the ice creates. From *ScienceDaily* on July 22, 2014.

Policy

"Japan, Mexico Sign Carbon Trade Deal."

Japan and Mexico signed an agreement under the Joint Crediting Mechanism (JCM) program that allows for Japanese companies to earn carbon credits by investing in technologies, products, systems, services, and infrastructure to cut greenhouse gas (GHG) emissions in Mexico. The program will to help Japan meet a domestic GHG emission target of three percent above 1990 emissions by 2020. Mexico has several projects registered under the United Nations' (U.N.) Clean Development Mechanism (CDM), which allows for investment in emission reduction projects to earn credits to offset emissions. Mexico has pledged to reduce GHG emissions by 30 percent from the level forecast in 2010 by 2020. Participants in the JCM will not be able to use projects registered under other international emission reduction schemes. Japan has also partnered with Costa Rica, Ethiopia, Indonesia, Kenya, Mongolia, and Vietnam under the JCM. From *Reuters* on July 28, 2014.

"California and Mexico Sign Pact to Fight Climate Change."

California's Governor and Mexican environmental officials signed a memorandum of understanding (MOU) to reduce GHG emissions. The MOU calls for the development of carbon pricing systems and the alignment of the systems in the future. California operates a carbon cap-and-trade system that sets a limit on carbon emissions and requires businesses to either reduce emissions or purchase credits to meet the target. California plans to link its carbon cap-and-trade market with a similar effort in Quebec (Canada) and expand the system to encourage price stability and the program's environmental impact. In 2013, California signed similar agreements with British Columbia (Canada), Oregon (United States), and Washington (United States). California

Policy (Continued)

also has an agreement with China's National Development and Reform Commission to share carbon trading and related information. From *Reuters* on July 28, 2014.

"A risk-based framework for measurement, monitoring and verification of the Quest CCS Project, Alberta, Canada."

The following is the Abstract of this article: "The Quest Carbon Capture and Storage Project will make an early contribution to reducing CO_2 emissions generated by upgrading bitumen from the Alberta oil sands by injecting up to 1.08 million tonnes of CO_2 per year for 25 years into a deep saline [formation] located north-east of Edmonton, Alberta. Regulatory approvals and societal acceptance for this project are contingent on gaining and maintaining confidence in the safety and long-term security of the storage site. Site selection, [characterization] and engineering designs are the prime means of ensuring CO_2 storage risks are as low as reasonably practicable. As a further precaution, a comprehensive [program] of Measurement, Monitoring and Verification (MMV) will evaluate storage performance. The purpose of MMV is to monitor conformance and containment. Conformance monitoring is designed to track the build-up of pressure and CO_2 inside the storage complex to demonstrate the long-term security of storage. Containment monitoring is designed to demonstrate containment and, if necessary, to trigger timely control measures to mitigate any unexpected [release] pathways and to protect the environment. To achieve this, the MMV [program] is designed according to a systematic site-specific risk assessment, diversified to avoid dependence on single technologies and will be adapted through time according to observed performance." **Stephen Bourne, Syrie Crouch, and Mauri Smith**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Framework for the analysis of the low-carbon scenario 2020 to achieve the national carbon Emissions reduction target: Focused on educational facilities."

The following is the Abstract of this article: "Since the increase in GHG emissions has increased the global warming potential, an international agreement on carbon emissions reduction target (CERT) has been formulated in Kyoto Protocol (1997). This study aimed to develop a framework for the analysis of the low-carbon scenario 2020 to achieve the national CERT. To verify the feasibility of the proposed framework, educational facilities were used for a case study. This study was conducted in six steps: (i) selection of the target school; (ii) establishment of the reference model for the target school; (iii) energy consumption pattern analysis by target school; (iv) establishment of the energy retrofit model for the target school; (v) economic and environmental assessment through the life cycle cost and life cycle CO_2 analysis; and (vi) establishment of the low-carbon scenario in 2020 to achieve the national CERT. This study can help facility managers or policymakers establish the optimal retrofit strategy within the limited budget from a short-term perspective and the low-carbon scenario 2020 to achieve the national CERT from the long-term perspective. The proposed framework could be also applied to any other building type or country in the global environment." **Choongwan Koo, Hyunjoong, and Taehoon Hong**, *Energy Policy*. (Subscription may be required.)

Geology

"Interaction between CO_2-rich sulfate solutions and carbonate reservoir rocks from atmospheric to supercritical CO_2 conditions: Experiments and modeling."

The following is the Abstract of this article: "A test site for CO_2 geological storage is situated in Hontomín (Burgos, northern Spain) with a reservoir rock that is mainly composed of limestone. During and after CO_2 injection, the resulting CO_2-rich acid brine gives rise to the dissolution of carbonate minerals (calcite and dolomite) and gypsum (or anhydrite at depth) may precipitate since the reservoir brine contains sulfate. Experiments using columns filled with crushed limestone or dolostone were conducted under different P–pCO_2 conditions (atmospheric: 1–$10^{-3.5}$ bar; subcritical: 10–10 bar; and supercritical: 150–34 bar), T (25, 40 and 60°C) and input solution compositions (gypsum-undersaturated and gypsum-equilibrated solutions). [The authors] evaluated the effect of these parameters on the coupled reactions of calcite/dolomite dissolution and gypsum/anhydrite precipitation. The CrunchFlow and PhreeqC (v.3) numerical codes were used to perform reactive transport simulations of the experiments. Within the range of P–pCO_2 and T of this study only gypsum precipitation took place (no anhydrite was detected) and this only occurred when the injected solution was equilibrated with gypsum. Under the P–pCO_2–T conditions, the volume of precipitated gypsum was smaller than the volume of dissolved carbonate minerals, yielding an increase in porosity ($\Delta\phi$ up to ≈ 4 [percent]). A decrease in T favored limestone dissolution regardless of pCO_2 owing to increasing undersaturation with decreasing temperature. However, gypsum precipitation was favored at high T and under atmospheric pCO_2 conditions but not at high T and under 10 bar of pCO2 conditions. The increase in limestone dissolution with pCO_2 was directly attributed to pH, which was more acidic at higher pCO_2. Limestone dissolution induced late gypsum precipitation (long induction time) in contrast to dolostone dissolution, which promoted rapid gypsum precipitation. Moreover, owing to the slow kinetics of dolomite dissolution with respect to that of calcite, both the volume of dissolved mineral and the increase in porosity were larger in the limestone experiments than in the dolostone ones under all pCO_2 conditions (10−3.5 and 10 bar). By increasing pCO_2, carbonate dissolution occurred along the column whereas it was localized in the very inlet under atmospheric conditions. This was due to the buffer capacity of the carbonic acid, which maintains pH at around 5 and keeps the solution undersaturated with respect to calcite and dolomite along the column. 1D reactive transport simulations reproduced the experimental data (carbonate dissolution and gypsum precipitation for different P–pCO_2–T conditions). Drawing on reaction rate laws in the literature, [the authors] used the reactive surface area to fit the models to the experimental data. The values of the reactive surface area were much smaller than those calculated from the geometric areas." **Maria Garcia-Rios, Jordi Cama, Linda Luquot, and Josep M. Soler**, *Chemical Geology*. (Subscription may be required.)

"Core flooding experiments of CO_2 enhanced coalbed methane recovery."

The following is the Abstract of this article: "This paper presents the results of CO_2 enhanced coal bed methane (ECBM) core floods on intact coal core

GEOLOGY (CONTINUED)

from the Bowen Basin and the Hunter Valley, Australia, at pore pressures of 4 MPa and 10 MPa. The core floods involved flooding with CO_2 to displace methane from the core and then reversing the flood by injecting methane to displace the CO_2 from the previous flood. An important parameter for ECBM is the displacement or sweep efficiency which was estimated directly from the mass balance over the core flood. Displacement efficiencies obtained through CO_2 injection were excellent with more than 99 [percent] of the CH_4 recovered during the core floods. The reverse experiments in which CH_4 was injected to displace CO_2 were notably less effective with an average of 95 [percent] displacement obtained for the Bowen Basin core sample and only 71 [percent] displacement obtained for the Hunter Valley core sample by the end of the experiment. History matching was performed with the reservoir simulator SIMED II which used a hydrostatic permeability model, the extended Langmuir model, and a bi-disperse diffusion model. In general, good history matches were obtained between simulated and observed flow rates, mass balances, and breakthrough times demonstrating that the model could accurately represent the ECBM process. It was found that the triple porosity gas diffusion model provided an improved agreement to observations over the unipore model. Connell–Lu–Pan's hydrostatic permeability model was used in the history matching which differentiates between bulk and pore sorption strain. During the CO_2 flooding experiments a change in permeability was observed as CO_2 displaced CH_4 in the core. As the stress conditions were constant, this was the result of the sorption strain impacting on the porosity and thus permeability. However, for the reverse core flood in which CH_4 was injected to displace CO_2, no permeability changes were observed, implying that pore and bulk strain were the same and thus cancelled out." **R. Sander, L.D. Connell, Z. Pan, M. Camilleri, D. Heryanto, N. Lupton**, *International Journal of Coal Geology*. (Subscription may be required.)

"Fluid-rock interaction in CO_2-saturated, granite-hosted geothermal systems: Implications for natural and engineered systems from geochemical experiments and models."

The following is the Abstract of this article: "Hydrothermal experiments were conducted and geochemical models constructed to evaluate the geochemical and mineralogical response of fractured granite and granite + epidote in contact with thermal water, with and without supercritical CO_2, at 250°C and 25–45 MPa. Illite ± smectite ± zeolite(?) precipitate as secondary minerals at the expense of K-feldspar, oligoclase, and epidote. Illite precipitates in experiments reacting granite and granite + epidote with water; metastable smectite forms in the experiments injected with supercritical CO_2. Waters are supersaturated with respect to quartz and saturated with respect to chalcedony in CO_2-charged experiments, but neither mineral formed. Carbonate formation is predicted for experiments injected with supercritical CO_2, but carbonate only formed during cooling and degassing of the granite + epidote + CO_2 experiment. Experimental results provide insight into the buffering capacity of granites as well as the drivers of clay formation. Metastable smectite in the experiments is attributed to high water–rock ratios, high silica activities, and high CO_2 and magnesium–iron concentrations. Smectite precipitation in supercritical CO_2-bearing geothermal systems may affect reservoir permeability. Silicate formation may create or thicken caps within or on the edges of geothermal reservoirs. Carbonate formation, as desired for carbon [storage] projects coinciding with geothermal systems, may require extended periods of time; cooling and degassing of CO_2-saturated waters leads to carbonate precipitation, potentially plugging near-surface production pathways." **Caroline Lo Ré, John P. Kaszuba, Joseph N. Moore, and Brian J. McPherson,** *Geochimica et Cosmochimica Acta*. (Subscription may be required.)

TECHNOLOGY

"Fully coupled wellbore-reservoir modeling of geothermal heat extraction using CO_2 as the working fluid."

The following is the Abstract of this article: "[The authors] consider using CO_2 as an alternative to water as a working fluid to produce geothermal electricity through the application of a coupled reservoir, wellbore, and surface power-plant model. [The authors'] approach has relaxed some of the simplifying assumptions others have made in previous work, through the application of a subsurface reservoir model fully coupled with a detailed wellbore simulator. [The authors] also include a simplified representation of CO_2 turbomachinery for a surface plant optimized for direct use of supercritical CO_2. The wellbore model includes heat transfer between the fluid in the well and the surrounding formation, in addition to frictional, inertial, and gravitational forces. [The authors'] results show that thermophysical operating conditions and the amount of power production are greatly influenced by wellbore flow processes and by wellbore/caprock heat transfer. [The authors] investigate competing effects that control development of a thermosiphon, which enables production of geothermal electricity without the need for a continuously operating external pump." **Lehua Pan, Barry Freifeld, Christine Doughty, Steven Zakem, Ming Sheu, Bruce Cutright, and Tracy Terrall**, *Geothermics*. (Subscription may be required.)

"Multi-scale experimental study of carbonated water injection: An effective process for mobilization and recovery of trapped oil."

The following is the Abstract of this article: "Steady flow of a disconnected gas phase (bubbles) is realized in porous media during carbonated water injection (CWI) under conditions that promote continuous exsolution of the dissolved gas. Using microfluidic pore networks etched on glass as well as a miniature core-flooding setup integrated with micro computed tomography (CT) imaging apparatus, [the authors] demonstrate capillary interactions of the flowing gas bubbles with a previously trapped oil phase (three-phase ganglion dynamics), which lead to mobilization of oil ganglia and remarkably high oil recovery. When three-phase ganglion dynamics are induced by carbonated water injection in low-permeability Berea sandstone core samples containing waterflood residual oil, more than 34 [percent] and 40 [percent] of the original oil in place additional recoveries are achieved in macro- and micro-scale flow tests, respectively, while a significant amount of CO_2 is permanently [stored] in the pore space as capillary-trapped and dissolved gas. It is observed that when oil globules come into contact with CO_2, they form thick spreading layers between brine and gas and are carried by moving gas clusters. The oil layers stay stable until the gas clusters leave the medium. Individual oil and gas blobs captured during micro-CT imaging are statistically analyzed to further

Technology (Continued)

examine underlying pore-level displacement physics of the process." **A.H. Alizadeh, M. Khishvand, M.A. Ioannidis, and M. Piri**, *Fuel*. (Subscription may be required.)

"Multi-branched horizontal wells for coalbed methane production: Field performance and well structure analysis."

The following is the Abstract of this article: "Horizontal wells, such as multi-lateral and multi-branched horizontal wells (MBHWs) have been effectively used in the development of coalbed methane (CBM) fields, especially for coal beds with very low permeability and low compressive strength, in which the performance of conventional fracture-stimulated vertical wells is ineffective. In this study, the performance of MBHWs in the Liulin block of the Ordos Basin in central North China is analyzed and compared to that of hydraulically fractured vertical wells. The field pilot data show that the gas production rate of most fractured vertical wells decreased rapidly after a short period of time, far below expectation, while the performance of MBHWs is satisfactory and relatively stable during [three] years of production. A numerical simulation model was established based on the coal reservoir characteristics. The productivities of different well types are predicted and compared to the field data. The poor performance of the fractured vertical wells is thought to be caused by the early closure of the fractures and proppant embedded in the coal matrix or by a poor proppant delivery inside the fractures. The high and stable productivity of the MBHWs is attributed to their large drainage volume and to the stability of the wellbores. Simulation results show that the parameters of a MBHW, such as the branch angle, length, and spacing, can be optimized to maximize its productivity. Though the drilling cost of a MBHW is relatively high in comparison to vertical wells, its high and stable productivity can compensate for the drilling cost. Therefore, MBHWs are thought to be more appropriate than vertical wells for the successful exploitation of the CBM resource potential in the Liulin Block and surrounding area." **Jianhua Ren, Liang Zhang, Shaoran Ren, Jingde Lin, Shangzhi Meng, Guangjun Ren, and Thomas Gentzis,** *International Journal of Coal Geology*. (Subscription may be required.)

TerreStrail

"Calculating carbon mass balance from unsaturated soil columns treated with $CaSO_4$-minerals: Test of soil carbon sequestration."

The following is the Abstract of this article: "Renewed interest in managing C balance in soils is motivated by increasing atmospheric concentrations of CO_2 and consequent climate change. Here, experiments were conducted in soil columns to determine C mass balances with and without addition of $CaSO_4$-minerals (anhydrite and gypsum), which were hypothesized to promote soil organic carbon (SOC) retention and soil inorganic carbon (SIC) precipitation as calcite under slightly alkaline conditions. Changes in C contents in three phases (gas, liquid and solid) were measured in unsaturated soil columns tested for one year and comprehensive C mass balances were determined. The tested soil columns had no C inputs, and only C utilization by microbial activity and C transformations were assumed in the C chemistry. The measurements showed that changes in C inventories occurred through two processes, SOC loss and SIC gain. However, the measured SOC losses in the treated columns were lower than their corresponding control columns, indicating that the amendments promoted SOC retention. The SOC losses resulted mostly from microbial respiration and loss of CO_2 to the atmosphere rather than from chemical leaching. Microbial oxidation of SOC appears to have been suppressed by increased Ca^{2+} and SO_4^{2-} from dissolution of $CaSO_4$ minerals. For the conditions tested, SIC accumulation per m^2 soil area under CaSO4-treatment ranged from 130 to 260 g C m^{-1} infiltrated water (20–120 g C m^{-1} infiltrated water as net C benefit). These results demonstrate the potential for increasing C [storage] in slightly alkaline soils via $CaSO_4$-treatment." **Young-Soo Han and Tetsu K. Tokunaga**, *Chemosphere*. (Subscription may be required.)

Trading

"Washington State Outlines Plans for Carbon Trading."

According to a memorandum released by Washington State's Governor, the state is considering plans for a cap-and-trade system. The memorandum suggests the possibility of the state linking with the Western Climate Initiative (WCI) trading scheme, which also includes California and the Canadian provinces of British Columbia, Ontario, Quebec, and Manitoba. The state's current climate legislation looks to achieve 1990 GHG emission levels by 2020, with a 25 percent reduction on 1990 levels by 2035. In addition, the state has also established a green employment initiative that aims for jobs in the low-carbon sector to increase from 8,400 in 2004 to 25,000 in 2020. From *RTCC.org* on July 29, 2014.

"Case study on initial allocation of Shanghai carbon emission trading based on Shapley value

The following is the Abstract of this article: "Carbon emission trading is an effective measure to reduce GHG emissions worldwide. China has publicized plans to initiate the demonstration of carbon emission trading in seven regions as of 2013. Initial allocation is fundamental, but it proposes difficulty in the mechanism design of the carbon emission trading system. Benchmark, grandfathering and the Shapley value have been employed to simulate a specific case, which consists of the initial allocation of carbon emission allowances of three power plants in Shanghai, China. The results of the Shapley value are regarded as a theoretical equitable reference. The results of benchmark are similar to those of the Shapley value. However, it is apparent that the allocation regarding grandfathering is inequitable. Considering other factors, [the authors] proposed the following: At the introduction of experimental stage, free allocation pertaining to grandfathering can be adopted; meanwhile, benchmark should be prepared and adopted at the appropriate time. Furthermore, a portion of the initial allowances can be reserved for auction, and this portion for auction will escalate to the extent of 100 [percent] upon entering the formal stage. In addition, the tiered price mechanism and the subsidy policy are also suggested." **Zhenliang Liao, Xiaolong, and Jiaorong Shi**, *Journal of Cleaner Production.* (Subscription may be required.)

Trading (Continued)

"Does EU emissions trading bite? An event study."

The following is the Abstract of this article: "The aim of this paper is to examine whether shareholders consider the EU Emissions Trading Scheme (EU ETS) as value-relevant for the participating firms. An analysis is conducted of the share prices changes as caused by the first publication of compliance data in April, 2006, which disclosed an over-allocation of emission allowances. Through an event study, it is shown that share prices actually increased as a result of the allowance price drop when firms have a lower carbon-intensity of production and larger allowance holdings. There was no significant value impact from firms' allowance trade activity or from the pass-through of carbon-related production costs (carbon [release]). The conclusion is that the EU ETS does 'bite'. The main impact on the share prices of firms arises from their carbon-intensity of production. The EU ETS is thus valued as a restriction on [emissions]." **Thijs Jong, Oscar Couwenberg, and Edwin Woerdman**, *Energy Policy.* (Subscription may be required.)

Recent Publications

"Second-Generation Reduced-Order Model for Calculation of Groundwater Impacts as a Function pH, Total Dissolved Solids, and Trace Metal Concentrations."

The following is a summary of this NETL-published document completed as part of the National Risk Assessment Partnership (NRAP): "NRAP is developing a science-based toolset for the quantitative analysis of the potential risks associated with changes in groundwater chemistry from CO_2 injection. In order to address uncertainty probabilistically, NRAP is developing efficient, reduced-order models (ROMs) as part of its approach. These ROMs are built from detailed, physics-based process models to provide confidence in the predictions over a range of conditions. The ROMs are designed to reproduce accurately the predictions from the computationally intensive process models at a fraction of the computational time, thereby allowing the utilization of Monte Carlo methods to probe variability in key parameters. This report presents the development of ROMs designed to predict the evolution of several groundwater metrics over time in response to leakage of CO_2 and/or brine. The ROMs are based on simulations from continuum-scale reactive transport simulations in which the inherent uncertainties in the groundwater system were propagated throughout the predictive process. Lawrence Livermore National Laboratory's (LLNL) focus was on the assessing the magnitude of the trace element source term found in CO_2-rich brines, the impact of leakage from multiple wells, and aquifer heterogeneity. Potentially variable parameters that were considered include aquifer heterogeneity, permeability, porosity, regional groundwater flow, CO_2, total dissolved solids (TDS), and trace metal leakage rates over time. Aquifer heterogeneity was characterized from the proportions of geologic units identified from lithologic well logs from the High Plains Aquifer to derive spatial correlation lengths; variation in CO_2 and brine flux was derived from first-generation reservoir and wellbore models; and TDS and trace metal concentrations were based on reported storage reservoir compositions. The overall fidelity of the ROMs was very good with linear correlations greater than 0.9 when directly compared with simulated results."

"NSealR—A Brief User's Guide."

The following is from the Executive Summary of this NETL-published document completed as part of NRAP: "This report provides a guide to the use of the NSealR computer code. The NSealR code is being developed as part of the effort to quantify the risk of geologic storage of CO_2. NSealR is constructed as a stand-alone code to describe the flow or leakage of CO_2 through the low permeability rock formation (or seal) overlying the storage reservoir into which CO_2 is injected. Eventually, the NSealR is intended to be integrated into the CO_2-PENS system as a separate module, and therefore, NSealR incorporates CO_2-PENS assumptions, parameters, formats and definitions as appropriate for consistency. At present, CO_2-PENS does not incorporate a seal horizon, but includes a possible description of this aspect in code documentation. NSealR is intended to address this gap and adds functionality such as allowing spatially variable flow properties and by adding complexity relative to flow through the seal. For example, to emulate CO_2-PENS flexibility, NSealR allows a number of ways to describe the seal horizon, to correspond to the user's current understanding of the barrier. The NSealR code provides for the simulation of CO_2 flow through the seal barrier horizon, a rock formation that is assumed to be a thin, 1 relatively impermeable, fractured rock unit, initially saturated with a saline groundwater. A two-phase, relative permeability approach and Darcy's law are used for one-dimension (1-D) flow computations of CO_2 through the horizon in the vertical direction. The code is written using GoldSim's simulation software platform and is structured using seven upper-level containers (or subroutines) for code logic. The logic proceeds from two containers for seal property and simulation input, followed by logic to establish the analysis basis of permeability and seal horizon thickness and fluid properties, which in turn serves as the basis for the computation container and a final container for output control."

"Carbon Capture & Sequestration Market – Global Trends & Forecasts to 2019."

The following is the Summary of this document: "[CCS] witnessed high growth in recent years due to increasing climatic concerns, environmental concerns, and regulatory norms imposed by local governments, which speed up the market. The various technologies in different regions helped [CCS] the companies in this market to create a niche market by capturing of carbon and their storage.

Recent Publications (Continued)

The key services include capture, transport, and storage activities for safe [CCS] of the excessive carbon present in the atmosphere. The CCS market is estimated to reach about $6.8 billion by 2019, signifying a firm growth rate of over 27.18 [percent] from 2013 to 2019. Currently, strict environmental regulations force operators to implement cost efficient carbon capturing practices and transportation that need to be addressed and corresponded to safe storage policies. The ongoing and upcoming developments in capture and storage activities are high opportunity areas for the [CCS] market. Geographically, the market has been studied for different regions such as the Americas, Europe, Asia-Pacific, and Middle East-Africa. The value of the market is analyzed in detail for all major countries…The study represents the trend of growth strategies adopted by the service provider companies of various types. The major strategies are identified: [1] Industrial expansion; [2] Contract agreements; [3] Merger and acquisitions; [4] Others. Key companies [CCS] market are Shell Cansolv (Canada), Siemens (Germany), Hitachi (Japan), Schlumberger (U.S.), Honeywell's UOP (U.S.) and Mitsubishi Heavy Industries (Japan). The leading companies in the [CCS] market focus on the growth of their industrial expansions with the key objective of serving power and gas companies. Thus, from 2010 to 2014, the contract agreements lead the growth strategies, accounting for around a share of 46 [percent]."

"CO_2 EOR Market - Permian Basin Industry Analysis, Size, Share, Growth, Trends and Forecast 2013 - 2019."

The following is a description of this document: "The CO_2 EOR market report by Transparency Market Research provides an in-depth analysis of the Permian Basin CO_2 EOR industry. The report provides comprehensive analysis of the CO_2 EOR fields, operators and their production capacities and also provides the forecasts and estimates for the Permian Basin CO_2 supply market by volume. The report also analyses the demand and supply characteristics of the market by providing a detailed forecast and an analysis of volume and revenue for the period 2013 to 2019. Out of all the three major methods of EOR, namely, thermal, gas/CO_2, and chemical, CO_2 EOR technology has proven the most viable and commercially profitable in the U.S. The Permian Basin region based in West Texas has seen high development and expansion of the CO_2 EOR market as huge opportunities exist there. Capacity addition, as well as exploration of new projects, is taking place in the Permian Basin and creating a demand for highly pure and low cost CO_2. Traditionally, the CO_2 was sourced from natural CO_2 reservoirs; however, the trend is expected to change in the near future with the emergence of new industrial CCS projects…"

Legislative Activity

"Carbon Capture and Sequestration."

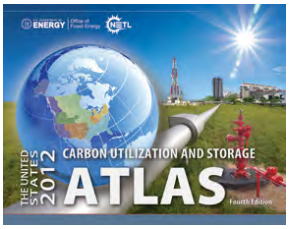
The following is the Abstract of this article: "This chapter examines U.S. laws applicable to CCS and identifies reforms that will be necessary for CCS to operate as a viable GHG emissions control strategy domestically. In the United States, few, if any, new coal-fired power plants are some have been designed to facilitate economical retrofitting. In September 2013, the U.S. Environmental Protection Agency (EPA) issued a proposed rule to limit GHG emissions from use of CCS at some new plants. [EPA was directed] to propose a rule by 2014 to limit GHG emissions from existing plants. U.S. policy on CCS is potentially critical to its adoption as an emissions control strategy in other countries, as well. Adoption of CCS by high GHG-emitting countries such as China and India may require effective demonstration of both the capture technology and sequestration at commercial scale in the United States. China has taken steps towards developing CCS technology, but more widespread adoption of CCS globally may be facilitated or accelerated by its development at commercial scale in the United States." **Wendy B. Jacobs**, *Chapter 17, in Global Climate Change and U.S. Law.* (Subscription may be required.)

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:

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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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