NETL the ENERGY lab

Carbon Storage Newsletter

April 2015

What's Inside?

Highlights

"NETL-Sponsored Study Confirms Vast Energy Resource in Residual Oil Zones."

National Energy Technology Laboratory (NETL)-sponsored researchers confirmed that carbon dioxide-enhanced oil recovery (CO_2-EOR) can extract oil from largely untapped areas called "residual oil zones" (ROZs). The researchers, led by the University of Texas-Permian Basin (UTPB), analyzed a geologic core taken during a pilot test from a well at the Goldsmith Landreth San Andres Unit in the Permian Basin, Ector County, Texas, USA. The results provide insight into the potential oil displacement efficiency of the CO_2-EOR process. The UTPB researchers are developing a state-of-the-art geologic model to compare past reservoir performance and current CO_2-EOR flood performance. The goal is to optimize the performance of an ROZ CO_2 flood and share the knowledge with other operators. ROZs are areas of relatively immobile oil that are found below the oil-water contact (the first observance of water) within an oil-bearing reservoir. In these zones, natural water flooding has swept away much of the original oil, leaving residual oil behind; recovery of this oil is not economic using primary or secondary oil recovery, requiring EOR techniques to produce the oil. From *NETL News Release* on February 24, 2015.

"Department of Energy, Shell Canada to Collaborate on CO_2 Storage."

The U.S. Department of Energy (DOE) and Shell Canada announced intentions to collaborate in field tests to validate advanced monitoring, verification, accounting (MVA), and assessment technologies for underground CO_2 storage at Shell's Quest carbon capture and storage (CCS) project in Alberta, Canada. The technologies under consideration would be tested alongside the state-of-the-art, comprehensive monitoring program that Shell has already put in place for the Quest project. The test results are expected to provide additional information that would benefit future large-scale CCS projects around the world. DOE is leveraging a Federal investment of approximately $3 million in existing and ongoing projects in their research and development (R&D) program by proposing roughly $500,000 for this collaborative effort. From *NETL News Release* on February 4, 2015.

Announcements

NETL Releases Updated Carbon Storage Website.

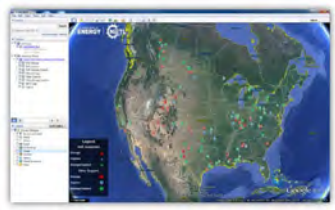
DOE's NETL released a new, user-friendly version of the Carbon Storage Program website. The site contains both introductory and in-depth information about the fundamentals of geologic carbon storage, supporting technologies, program developed publications and best practice manuals (BPMs), the status of the latest program-supported R&D activities, and more.

Technical Session on Engineering Geologic CO_2 Storage Systems.

The American Institute of Chemical Engineers' (AIChE) Annual Meeting, scheduled for November 8-13, 2015, in Salt Lake City, Utah, USA, will include a technical session, titled, "Engineering Geologic Carbon Dioxide Storage Systems."

Announcements (Continued)

Research presentations covering the science and technology of carbon storage, as well as field demonstrations of CO_2 injection, are encouraged. Conference details, abstract submission, and more information are available via the above link.



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

NETL'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. As of November 2014, the database contained 274 CCS projects worldwide, including 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 CO_2. NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.

MGSC Captures and Stores 1 Million Metric Tons of CO_2."

The Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of CO_2 and injected it into a saline formation. The CO_2 is captured from the Archer Daniels Midland Company ethanol-production facility in Decatur, Illinois, USA, and is compressed before transport by pipeline and subsequent injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying CCS technologies across the United States.

Conference Agenda Released.

The agenda has been released for the 14th Annual Carbon Capture, Utilization, and Storage Conference scheduled for April 28-May 1, 2015, at the Wyndham Grand Pittsburgh Downtown located in Pittsburgh, Pennsylvania, USA

RGGI States Initiate Bidding Process for Auction 28.

The Regional Greenhouse Gas Initiative (RGGI) states released the Auction Notice and application materials for their 28th quarterly CO_2 allowance auction, scheduled for June 3, 2015. The Auction Notice for CO_2 Allowance Auction 28 provides potential participants with the information needed to submit a Qualification Application and indicate their intent to bid. As indicated in the Auction Notice, the states will offer 15,507,571 CO_2 allowances for sale at a reserve price of $2.05.

Report on the Secondary Market for RGGI CO_2 Allowances: Fourth Quarter 2014.

Potomac Economics, the independent market monitor for RGGI, 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 during the fourth quarter of 2014 was $5.22, approximately 7 percent higher than in the prior quarter and 69 percent higher than the fourth quarter of 2013. Prices increased throughout the quarter, rising from approximately $4.95 at the start of October 2014 to a daily high of $5.32 in mid-December 2014.

Carbon Storage in the News

"Grangemouth CCS Project Gets State Funding."

The Caledonia Clean Energy Project, a new 570-megawatt CCS coal gasification power station in Grangemouth, Scotland, will receive $6.2 million in funding for industrial research and feasibility studies from the United Kingdom (UK) and Scottish governments. The power station will emit 90 percent less CO_2 than a coal-fired plant without CCS and 75 percent less than a comparable gas-fired plant without CCS. The project's research and feasibility studies are expected to be completed over the next 18 months. According to the UK Department of Energy and Climate Change (DECC), the findings will increase understanding of how to develop and deploy CCS at commercial scale. The facility marks the third major project to receive UK government backing, joining the White Rose 426-MW oxyfuel coal-fired CCS plant at Drax and the Peterhead project in Aberdeenshire. From *The Chemical Engineer* on March 30, 2015.

"Interactive Maps of Potential CO_2 Storage Sites."

The Norwegian Petroleum Directorate (NPD) produced two interactive versions of an atlas of potential CO_2 storage sites in the sea along the Norwegian coast. One version, integrated with NPD's ordinary "fact map," provides access to more information than the printed version, enabling users to compare storage data with available information from active and terminated wells on the Norwegian shelf.

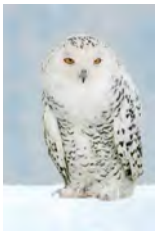
Carbon Storage in the News (Continued)

The second interactive version, called the "CO_2 StoryMap," presents the storage possibilities for a broader audience. Since 2011, NPD has published three atlases for the southern part of the North Sea, as well as the Norwegian Sea and Barents Sea, plus a compilation atlas for all sea areas. The atlases can be found on the NPD website. From *Norwegian Petroleum Directorate News Release* on February 12, 2015.

"Magellan Concludes Poplar CO_2-EOR Pilot a Technical Success and Provides Update on Utah CO_2 Option."

Magellan Petroleum Corporation has concluded that the CO_2-EOR pilot project at Poplar has demonstrated a technically viable CO_2-EOR technique as a tertiary recovery method in the Charles formation at Poplar Dome. The injection of CO_2 into the single injector well at Poplar was initiated in August 2014, with the four producer wells opening for production in October; since then, oil production has increased in three of the four, with a current run-rate in the range of 50 to 75 barrels of oil per day. Magellan expects the rate to increase through the summer and that the fourth producer well will soon produce oil. From *Magellan Petroleum Press Release* on April 7, 2015.

Science



"97 [Percent] of Northwest Alaska Bird, Mammal Species Could Experience Habitat Change from Warming Climate."

The habitat of 195 of the 201 bird and mammal species (approximately 97 percent) in northwest Alaska's arctic and subarctic region could be affected by potential climate change, according to a study conducted by the U.S. Forest Service. The study projected the effects of climate-related changes on the habitats of 162 species of birds and 39 species of mammals within 403,000 acres of the arctic by relating recent and projected vegetation changes. The findings, which were published in the journal "Climatic Change," revealed that up to 52 percent of the 201 species would experience habitat expansion under the models, 45 percent would experience habitat contraction, and 3 percent would experience no change at all. In addition, researchers found that mammal species would experience habitat declines at a higher proportion than bird species. From *ScienceDaily* on April 3, 2015.

"Western Canada to Lose 70 Percent of Glaciers by 2100."

According to University of British Columbia Researchers, British Columbia and Alberta could lose 70 percent of their glacier ice by the end of the 21st century due to potential climate change. Using observational data, computer models, and climate simulations, researchers found that warming temperatures are affecting the glaciers in western Canada, in particular freshwater ecosystems, as summer glacier melt provides cool water to many of the region's headwaters. The more than 17,000 glaciers in British Columbia and Alberta contribute to energy production through hydroelectric power, contribute to the water supply, and are vital to mining and agriculture operations. From *ScienceDaily* on April 6, 2015.

Policy

"Mexico Unveils National Strategy for Paris Climate Talks."

Mexico's Foreign and Environment Ministries unveiled a national climate plan to begin reducing greenhouse gas (GHG) emissions by 2026, leading to a 22 percent reduction in GHGs below business-as-usual levels by 2030. According to the plan, GHGs would become independent of economic growth after 2026, leading to a 40 percent reduction in emissions intensity per unit of gross domestic product from 2013 to 2030. Mexico, which submitted its plan to the United Nations ahead of the December 2015 climate summit in Paris, France, and without financial support from developed countries, said it could potentially raise its 2030 GHG target to 36 percent under some scenarios and conditions. From *Reuters* on March 27, 2015.

"Carbon Emissions Abatement (CEA) allocation and compensation schemes based on DEA."

The following is the Abstract of this article: "As environment constraints on economic growth are strengthening, Carbon Emissions Abatement (CEA) allocation becomes a significant issue that draws academia's attention. In the literature, the Data Envelopment Analysis (DEA) technique has been applied to obtain CEA allocation with centralized models. Nevertheless, a centralized allocation plan suffers from an implementation difficulty in persuading decision-making units (DMUs) into an agreement. In this paper, [the authors] propose a new two-step method to mitigate this side effect. In the first step, [the authors] provide improved DEA-based centralized allocation models under the assumptions of constant returns-to-scale (CRS) and variable returns-to-scale (VRS) respectively and in the second step, two compensation schemes are developed for centralized allocation plans. An empirical application to the countries in Organization for Economic Co-operation and Development (OECD) is presented to elaborate the main idea." **Chenpeng Feng, Feng Chu, Jingjing Ding, Gongbing Bi, and Liang Liang**, *Omega*. (Subscription may be required.)

"Quantitative risk assessment in the early stages of a CO_2 geological storage project: implementation of a practical approach in an uncertain context."

The following is the Abstract of this article: "Methodologies for quantitative risk assessment regarding CO_2 storage operations are currently scarce, mostly because of the lack of experience in this field and the relatively significant degree of uncertainty regarding the subsurface intrinsic properties and the processes occurring after the injection starts. This paper presents a practical approach designed to perform a quantitative risk assessment in an uncertain context. [The authors'] approach is illustrated by a realistic case study (Paris Basin, France), conceived to be representative of the level of information available in the early stages of a project. It follows the risk assessment principles from the international standards (ISO 31000:2009), which are adapted to account for the specificities and challenges of subsurface operations.

Policy (Continued)

After the establishment of the context of the specific case study, the main risks are identified and [the authors] analyze two different risk scenarios: risk of brine [release] from an abandoned well and risk of subsurface use conflict. These scenarios were selected to give a comprehensive overview of different types of analysis in terms of available data, modeling tools and uncertainty management methodologies. The main benefit of this paper is to propose an approach, based on existing risk assessment standards, best practices, and analysis tools, which allows an objective quantitative risk analysis taking into account the uncertainties, and therefore enabling fully informed decision-making while evaluating risk acceptability." **Louis de Lary, Jean-Charles Manceau, Annick Loschetter, Jeremy Rohmer, Olivier Bouc, Isaline Gravaud, Christophe Chiaberge, Pierre Willaume, and Thierry Yalamas**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Expert involvement in science development: (re-)evaluation of an early screening tool for carbon storage site characterization."

The following is the Abstract of this article: "CCS science development takes place in a highly contested and politicized environment and cannot be seen isolated from the public debate on energy policies. Early expert and decision-maker involvement in CCS science development thus is necessary for assessing the accountability and reliability of scientific methods and decision-tools. Relying on a participatory Group Delphi exercise with 14 experts involved, [the authors] carried out early expert involvement in science development with the evaluation of the so-called gravitational number (Gr) approach – an early screening tool for carbon storage site characterization. The aim was to elicit expert evaluations and judgments on the Gr approach and feeding back these judgments to method developers. Experts hinted to several Gr constraints, specifications and recommendations that served the method developers for re-designing and re-evaluating the screening tool. The expert assessment indicate an overall good understanding of the Gr approach with all but two items (far) beyond the scale midpoint of 3.5 on a seven point Likert scale. Evaluating reservoir characterization criteria, experts ranked safety related criteria more important than capacity related criteria. In a final evaluation of the Gr method, experts agreed unanimously to a very high degree that the Gr number approach alone is not meaningful and a review of Gr results by earth scientist is necessary. Oversimplification, therefore, seems to be the overarching downside aspect of the method that leads to the conclusion not to use the Gr results as a sole basis for decision making on site selection." **D. Scheer, W. Konrad, H. Class, A. Kissinger, S. Knopf, V. Noack**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Geology

"Numerical simulation of porosity and permeability evolution of Mount Simon sandstone under geological carbon sequestration conditions."

The following is the Abstract of this article: "A numerical model was developed with the use of reactive transport code CrunchFlow to estimate porosity, permeability and mineral composition changes of Mount Simon sandstone under typical geological carbon [storage] conditions (P = 23.8 MPa and T = 85 °C). The model predicted a permeability decrease from 1.60 mD to 1.02 mD for the Mount Simon sandstone sample in a static batch reactor after 180 days of exposure to CO_2-saturated brine, which is consistent with measured permeability results. Model-predicted solution chemistry results were also consistent with laboratory-measured solution chemistry data. SiO_2 (am) was the primary mineral that causes permeability decrease, followed by kaolinite. Both SiO_2 (am) formation and kaolinite formation were attributed to the dissolution of quartz and feldspar. This study shows that the formation of SiO_2 (am) and kaolinite in the pore space of host rock is possible under typical CO_2 [storage] conditions. SiO_2 (am) and kaolinite precipitation at the CO_2 plume extent could reduce the permeability of host rock and improve lateral containment of free-phase CO_2, contributing to overall security of CO_2 storage." **Liwei Zhang, Yee Soong, Robert Dilmore, and Christina Lopano**, *Chemical Geology*. (Subscription may be required.)

"Fracture permeability and relative permeability of coal and their dependence on stress conditions."

The following is the Abstract of this article: "Determination of petrophysical properties of coal bed methane (CBM) reservoirs is essential in evaluating a potential prospect for commercial exploitation. In particular, permeability of coal and relative permeability of coal to gas and water directly impact the amount of hydrocarbons that can be ultimately recovered. Due to the complex and heterogeneous nature of coal seams, proper relative permeability relationships are needed to accurately describe the transport characteristics of coal for reservoir modeling and production forecasting. In this work, absolute and relative permeability of different coal samples were determined experimentally under steady-state flowing conditions. Multiphase flow tests were conducted using brine, helium and [CO_2] as the flowing phases under different magnitudes of confining and pore pressures. Results indicate that effective stress (confining pressure – average pore pressure) has a significant effect on both absolute and relative permeability of coal. With increases in effective stresses, the absolute permeability decreases. Effective permeability and relative permeability, as well as the cross over point and the width of the mobile two-phase region decrease as the effective stress increases. In addition, the mobile range of gas and water in the coal samples investigated corresponds with water saturations above 50 [percent], irrespective of the base absolute permeability of the sample. In brine–[CO_2] two-phase flow experiments, the effect of [CO_2] adsorption was observed as effective permeabilities decreased in comparison to the helium–brine permeabilities at the same flowing ratios. As a result, relative permeability characteristics of CBM systems were found to be insufficiently represented as sole functions of fluid saturation. Field scale simulations of primary recovery from CBM systems using variable, stress-dependent relative permeabilities, showed a significant decrease in cumulative gas recovered. A multi-dimensional correlation between relative permeability, fluid saturation and specific surface area of the cleat network is proposed as a continuation from this work in order to account for stress-related changes in cleat network connectivity." **Dennis Arun Alexisa, Zuleima T. Karpyn, Turgay Ertekin, and Dustin Crandall**, *Journal of Unconventional Oil and Gas Resources*. (Subscription may be required.)

Geology (Continued)

"Chemical effects of sulfur dioxide co-injection with carbon dioxide on the reservoir and caprock mineralogy and permeability in depleted gas fields."

The following is the Abstract of this article: "The most suitable candidates for subsurface storage of CO_2 are depleted gas fields. Their ability to retain CO_2 can however be influenced by the effect which impurities in the CO_2 stream (e.g., H_2S and SO_2) have on the mineralogy of reservoir and seal. In order to investigate the effects of SO_2 [the authors] carried out laboratory experiments on reservoir and cap rock core samples from gas fields in the northeast of the Netherlands. The rock samples were contained in reactor vessels for 30 days in contact with CO_2 and 100 ppm SO_2 under in-situ conditions (300 bar, 100°C). The vessels also contained brine with the same composition as in the actual reservoir. Furthermore equilibrium modeling was carried out using PHREEQC software in order to model the experiments on caprock samples. After the experiments the permeability of the reservoir samples had increased by a factor of 1.2–2.2 as a result of dissolution of primary reservoir minerals. Analysis of the associated brine samples before and after the experiments showed that concentrations of K, Si, and Al had increased, indicative of silicate mineral dissolution. In the caprock samples, composed of carbonate and anhydrite minerals, permeability changed by a factor of 0.79–23. The increase in permeability is proportional to the amount of carbonate in the caprock. With higher carbonate content in comparison with anhydrite the permeability increase is higher due to the additional carbonate dissolution. This dependency of permeability variations was verified by the modeling study. Hence, caprock with a higher anhydrite content in comparison with carbonate minerals has a lower risk of [release] after co-injection of 100 ppmv SO_2 with CO_2." **Panteha Bolourinejad and Rien Herber,** *Applied Geochemistry*. (Subscription may be required.)

Technology

"Multiphase Modeling of Geologic Carbon Sequestration in Saline Aquifers."

The following is the Abstract of this article: "Geologic carbon [storage] (GCS) is being considered as a climate change mitigation option in many future energy scenarios. Mathematical modeling is routinely used to predict subsurface CO_2 and resident brine migration for the design of injection operations, to demonstrate the permanence of CO_2 storage, and to show that other subsurface resources will not be degraded. Many processes impact the migration of CO_2 and brine, including multiphase flow dynamics, geochemistry, and geomechanics, along with the spatial distribution of parameters such as porosity and permeability. In this article, [the authors] review a set of multiphase modeling approaches with different levels of conceptual complexity that have been used to model GCS. Model complexity ranges from coupled multiprocess models to simplified vertical equilibrium (VE) models and macroscopic invasion percolation models. The goal of this article is to give a framework of conceptual model complexity, and to show the types of modeling approaches that have been used to address specific GCS questions. Application of the modeling approaches is shown using five ongoing or proposed CO_2 injection sites. For the selected sites, the majority of GCS models follow a simplified multiphase approach, especially for questions related to injection and local-scale heterogeneity. Coupled multiprocess models are only applied in one case where geomechanics have a strong impact on the flow. Owing to their computational efficiency, VE models tend to be applied at large scales. A macroscopic invasion percolation approach was used to predict the CO_2 migration at one site to examine details of CO_2 migration under the caprock." **Karl W. Bandilla, Michael A. Celia, Jens T. Birkholzer, Abdullah Cihan, and Evan C. Leister**, *Groundwater*. (Subscription may be required.)

"N_2+CO_2+NaCl brine interfacial tensions and contact angles on quartz at CO_2 storage site conditions in the Gippsland basin, Victoria/Australia."

The following is the Abstract of this article: "Carbon geo-[storage] (CGS) has been identified as an important method to reduce CO_2 emissions to the atmosphere thus mitigating global warming. In CGS, the CO_2 captured from large point source emitters is injected into hydrocarbon reservoirs for enhanced oil and gas recovery or into deep saline [formations] for storage. In this context the State of Victoria (southeast Australia) is reviewing the suitability of Victorian sedimentary basins as CO_2 [storage formations]. The main focus is on the Gippsland basin, which has been positively evaluated from a geological point of view. Now it is necessary to assess the storage capacity of the formation and thus the intimately related fluid–fluid–rock properties. [The authors] therefore conducted interfacial tension and contact angle measurements at the prevailing storage conditions (13 MPa, 333 K); as a result, [the authors] show that CO_2 has a relatively high water contact angle (θ=47°), while lower θ values were measured for N2 (θ=40.6°=47°) and for a 50 mol% CO_2+50 mol% N_2 mixture (θ=33.9°). Consequently all systems were weakly water-wet. This implies that residual and structural trapping capacities are reduced; however, both mechanisms should work adequately. Specifically, [the authors] predict that a CO_2 column height of ~698 m can be permanently immobilized beneath the caprock." **Ahmed Al-Yaseri, Mohammad Sarmadivaleh, Ali Saeedi, Maxim Lebedev, Ahmed Barifcani, and Stefan Iglauer**, *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

"Optimized Carbonation of Magnesium Silicate Mineral for CO_2 Storage."

The following is the Abstract of this article: "The global ambition of reducing the [CO_2] emission makes [storage] reactions attractive as an option of storing CO_2. One promising environmentally benign technology is based on forming thermodynamically stable carbonated minerals, with the drawback that these reactions usually have low conversion rates. In this work, the carbonation reaction of Mg rich olivine, Mg_2SiO_4, under supercritical conditions has been studied. The reaction produces $MgCO_3$ at elevated temperature and pressure, with the addition of $NaHCO_3$ and NaCl to improve the reaction rates. A [storage] rate of 70 [percent] was achieved within 2 h, using olivine particles of sub-10 μm, whereas 100 [percent] conversion was achieved in 4 h. This is one of the fastest complete conversions for this reaction reported to date. The CO_2 [storage] rate is found to be highly dependent on the applied temperature and pressure, as well as the addition of $NaHCO_3$. In contrast, adding NaCl was found to have limited effect on the reaction rate. The roles of $NaHCO_3$ and NaCl as catalysts are

Technology (Continued)

discussed and especially how their effect changes with increased olivine particle size. The products have been characterized by Rietveld refinement of powder X-ray diffraction, scanning electron microscopy (SEM), and energy-dispersive X-ray (EDX) spectroscopy revealing the formation of amorphous silica and micrometer-sized magnesium carbonate crystals." **Espen Eikeland, Anders Bank Blichfeld, Christoffer Tyrsted, Anca Jensen, and Bo Brummerstedt Iversen**, *ACS Appl. Mater. Interfaces*. (Subscription may be required.)

"Monitoring CO_2 sequestration into deep saline aquifer and associated salt intrusion using coupled multiphase flow modeling and time-lapse electrical resistivity tomography."

The following is the Abstract of this article: "Successful geological storage of CO_2 [requires] efficient monitoring of the migration of CO_2 plume during and after large-scale injection in order to verify the containment of the injected CO_2 within the target formation and to evaluate risk. Field studies have shown that surface and cross-borehole electrical resistivity tomography (ERT) can be a useful tool in imaging and characterizing solute transport in heterogeneous subsurface. In this synthetic study, [the authors] have coupled a 3-D multiphase flow model with a parallel 3-D time-lapse ERT inversion code to explore the feasibility of using time-lapse ERT for simultaneously monitoring the migration of CO_2 plume in deep saline formation and potential brine intrusion into shallow fresh water [formation]. Direct comparisons of the inverted CO_2 plumes resulting from ERT with multiphase flow simulation results indicate the ERT could be used to delineate the migration of CO_2 plume. Detailed comparisons on the locations, sizes and shapes of CO_2 plume and intruded brine plumes suggest that ERT inversion tends to underestimate the area review of the CO_2 plume, but overestimate the thickness and total volume of the CO_2 plume. The total volume of intruded brine plumes is overestimated as well. However, all discrepancies remain within reasonable ranges. [The authors'] study suggests that time-lapse ERT is a useful monitoring tool in characterizing the movement of injected CO_2 into deep saline [formation] and detecting potential brine intrusion under large-scale field injection conditions." **Chuan Lu, Chi Zhang, Hai Hunag, and Timothy C. Johnson**, *Greenhouse Gases: Science and Technology.* (Subscription may be required.))

"Experimental CO_2 injection: Study of physical changes in sandstone porous media using Hg porosimetry and 3-D pore network models."

The following is the Abstract of this article: "Variations in the pore system of sandstones from the so-called Utrillas Formation (Lower Cretaceous, Iberian Peninsula) after CO_2 injection have been investigated in a laboratory on a micro scale. In this study, [the authors] present results regarding variations in the pore spaces of sandstones caused by the injection of CO_2 and its permanence in supercritical conditions in contact with a rock sample for two months. The modifications produced in the porosity and pore size distribution have been evaluated on two geological samples, using a 3-D modelling of the results obtained by Hg intrusion porosimetry. Reconstructions of the pore structure of the rock before and after CO_2 injection from mercury intrusion–extrusion curves, generating virtual models of pores that reproduce the experimental porosity. By analyzing the results, a drastic modification in the mesoporosity of the rock is confirmed, which may have a paramount influence not only on the total storage capacity but also on the percolation of fluid through the rock." **Rocío Camposa, Icíar Barriosa, and Javier Lillo**, *Energy Reports*. (Subscription may be required.)

Terrestrial

"Accelerated foliar litter humification in forest gaps: Dual feedbacks of carbon sequestration during winter and the growing season in an alpine forest."

The following is the Abstract of this article: "Can forest gaps lead to constrained litter decomposability by redistributing heat and moisture conditions, thereby increasing carbon [storage] from plant to soil via litter humification in alpine forests? [The authors] studied mass losses, humic substances, humic acid, fulvic acids, as well humification degrees and humification ratios in six foliar litters with a field litterbag experiment from the gap center, canopy gap and expanded gap to the closed canopy in winter and the growing season in an alpine forest of the east Tibetan Plateau. Humification degrees of [18 to 45 percent] for birch, [15 to 40 percent] for fir, [8 to 30 percent] for willow, [14 to 26 percent] for cypress, [9 to 25 percent] for larch and [7 to 19 percent] for azalea foliar litter were observed in forest gaps and the closed canopy over one year of incubation. Small amounts of humic substances accumulated in winter, whereas considerable humic acid accumulated, but fulvic acid mineralized during the growing season. Compared with the closed canopy, foliar litter humification in forest gaps was lower in winter but greater in the growing season, implying a dual role of forest gaps in carbon [storage] between winter and the growing season. Carbon [storage] could be accelerated in forest gaps. Reduced snow cover under a scenario of winter warming would stimulate soil carbon storage in these alpine forests." **Xiangyin Ni, Wanqin Yang, Bo Tan, Jie He, Liya Xu, Han Li, and Fuzhong Wu**, *Geoderma*. (Subscription may be required.)

Trading

"California Carbon Revenue Hits $1.6 Billion."

According to officials, California's February carbon permit auction raised $629.5 million, bringing the cap-and-trade program's total revenue to nearly $1.6 billion. Revenue generated from the 10 quarterly auctions is used to fund clean energy programs. The program is a component of the state's goal to reduce GHGs to 1990 levels by the end of the decade, with the ultimate goal of reducing GHGs 80 percent below 1990 levels by 2050. California's cap-and-trade program operates in conjunction with the Canadian province of Quebec; the next carbon permit auction will be held in May 2015. From *Reuters* on March 17, 2015.

"CO_2 Allowances Sold for $5.41 in 27th RGGI Auction."

The states participating in RGGI announced that all 15,272,670 CO_2 allowances available for sale were sold at the 27th auction at a clearing

Trading (Continued)

price of $5.41. Bids for the CO_2 allowances ranged from $2.05 to $12.50 per allowance. Ten million cost containment reserve (CCR) allowances were also available for sale. None of the CCR allowances were sold. The auction generated more than $82 million for reinvestment in energy and consumer benefit programs, including energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. The cumulative proceeds from the RGGI CO_2 allowance auctions now exceed $2 billion. From *RGGI News Release* on March 13, 2015.

"CO_2 Budget Source 2015 Interim Compliance."

RGGI's third three-year control period began on January 1, 2015, and extends through December 31, 2017. Starting in 2015, each CO_2 budget source must: (1) hold allowances equal to 50 percent of emissions during each interim control period (the first two calendar years of each three-year control period); and (2) hold allowances equal to 100 percent of their remaining emissions for the three-year control period at the end of the three-year control period. The first interim control period began on January 1, 2015, and each CO_2 budget source must hold allowances available for compliance deduction equal to 50 percent of their emissions by March 1, 2016. Market participants can acquire allowances through the CO_2 allowance auctions and secondary markets. The next CO_2 allowance auction is scheduled for June 3, 2015 (see Announcements section of this newsletter for more information). From *RGGI News Release* on March 16, 2015.

"An optimization decision support approach for risk analysis of carbon emission trading in electric power systems."

The following is the Abstract of this article: "Concerns over dramatic increasing electricity demand, exacerbating power shortage and changing climatic condition are emerging associated with municipal electric power systems (EPS). In this study, a risk-explicit mixed-integer full-infinite programming (RMFP) approach is developed for planning carbon emission trading (CET) in EPS. RMFP-CET has advantages in risk reflection and policy analysis, particularly when the input parameters are provided as crisp and functional intervals as well as probabilistic distributions. The developed method is applied to a real case study of CET planning of EPS in Beijing. Various electricity policies are incorporated within the modeling formulation for enhancing the RMFP-CET's capability. The results indicate that reasonable solutions have been generated, which are useful for making decisions of electricity production and supply as well as gaining insight into the tradeoffs among electricity supply risk, system cost, and CO_2 mitigation strategy." **Y. Zhu, Y.P. Li, and G.H. Huang**, *Environmental Modelling & Software*. (Subscription may be required.)

"Carbon capture and storage: Frames and blind spots."

The following is the Abstract of this article: "The European Union (EU) CCS demonstration [program] stands out for the speed with which financial support was agreed to, the size of this support, and its unusual format. This paper sets out to examine CCS policymaking in the EU by [analyzing] the way this technology was framed. It draws up a simple model of technology framing with two variants. The first one describes the creation of 'mainstream frames' of technologies in policymaking. The second one explains the effects of a 'hegemonic frame', namely the weakening of evaluation criteria and the increased salience of 'blind spots'. On this basis, this paper explains the global mainstreaming of a CCS frame and its transformation into a hegemonic frame in the EU. Finally, the paper reviews the blind spots in this hegemonic frame and their impact on EU policy." **Alfonso Martínez Arranz**, *Energy Policy*. (Subscription may be required.)

Recent Publications

"CO_2 Capture and Storage in Portugal: A Bridge to a Low Carbon Economy."

The following is from the Executive Summary of this document: "Several countries and regions have been setting mitigation targets, and defining GHG reduction policies and measures, mostly linked to their energy supply, transport and industry in their mission to tackle climate change. The EU agreed to cut its GHG emissions by 40 [percent] by 2030 relative to 1990 levels, and by 80 [percent] by 2050, which requires a diverse portfolio of clean technologies, including CCS. This report evaluates the role the CCS technology could play in the Portuguese energy and industry system as a mitigation option to achieve deep GHG emissions reductions. The cost effectiveness of its deployment, and the risks and additional benefits it may provide for economic development are also analyzed. Results show that under a high socio-economic development and -80 [percent] GHG reduction target, CCS technology is deployed as cost-effective technology from 2030, and by 2050 captures more than 20 [percent] of the total GHG emitted in that year compared to a Reference scenario. Power sector and cement production are the only sectors in which CO_2 capture technology is installed and onshore being the primary option for CO_2 storage. Under all mitigation scenarios modelled, CCS is deployed in significant volumes in the cement sector. Given the availability of renewable generation in Portugal, deployment of CCS in the power sector is relatively low and varies significantly depending on the scenario examined. With high socio-economic development and -80 [percent] GHG reduction target, CCS in the power sector is only deployed in significant volumes by 2050. With more modest emissions reduction targets (i.e., 60 [percent] rather than 80 [percent] of emissions reductions by 2050) and with high fossil fuel prices, there are negligible amounts of CO_2 captured in the power sector."

Recent Publications (Continued)

"Tackling Climate Change: Small-scale deliberative engagement with Taranaki community stakeholders on carbon capture and storage (CCS)."

The following is from Chapter 2 (Carbon Capture and Storage – the State of Engagement) of this study: "Public risk perceptions and subsequent protest over the planning of climate change mitigation technologies such as wind farms, hydroelectric power stations and CCS pilot facilities have, at times, hindered their progress and even deployment. With an increased need to understand where these publics were coming from, a series of international studies were undertaken to explore the range of public perceptions about and perceived acceptability of CCS. This chapter briefly explores some of this work, particularly from the perspective of 'how' to engage publics, the role of place, and the potential for deliberative engagement techniques, both to gather data and act as a conduit for effective engagement and decision-making. Whilst the nature of the technology (CCS) did play a limited role in risk perception, this report is framed under the supposition that for diverse publics, there is more to risk assessment than purely a critique of the technology itself. Instead, as Slovic argues, public risk perceptions are mainly judgments about risk, which are colored by individual, social, cultural, political and economic factors. Moreover, there is known to be a significant difference between the way experts 'objectively' perceive risk, and the way lay publics understand it, in context. Furthermore, an increase in information and knowledge about CCS does not necessarily lead to more positive public opinions about the technology, with perceptions taking a much more important role. As 'manifestations of a particular perspective on the technology,' perceptions are neither correct not incorrect, and what counts as a misperception differs between stress the importance of dialogue in exploring and understanding a range of viewpoints and their formation."

"CCS in the Baltic Sea Region – Bastor 2."

The following is from the Executive Summary of this document: "The objective of this report is to document current knowledge, hazards, and risks about environmental impacts in the light of a possible future CCS project in the offshore Baltic Sea Area. The objective is also to present a tentative EIA work plan for a future CO_2-injection field trial. The intention is to add new knowledge to what is already known or applicable to CCS activities in the offshore Baltic Sea Area. The Environmental Impact Assessment reports have documented the ecological and environmental status both regionally and locally in the offshore Baltic Sea Area."

Legislative Activity

"Low Carbon Fuel Bill Passed In Oregon Senate."

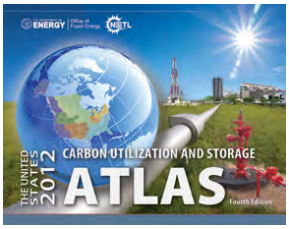
The Oregon State Senate passed Senate Bill 324, which, if passed by the Oregon House of Representatives, would require fuel producers to reduce the amount of carbon in fuels and implement a low-carbon standard in the state. Modeled after California's fuel standard, the measure would require fuel importers to cut the carbon in fuels by 10 percent from 2016 to 2025, resulting in a three percent reduction of emissions across the state. Companies not able to reach the low-carbon standard would be required to buy credits to offset their excess emissions. From *Bergeson & Campbell, P.C.* on March 10, 2015.

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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