U.S. Department of Energy • Office of Fossil Energy • National Energy Technology Laboratory

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Carbon Storage Newsletter

May 2014

What's Inside?

Highlights

"DOE Marks Major Milestone with Startup of Recovery Act Demonstration Project."

The U.S. Department of Energy (DOE) and Tampa Electric Company (TECO) announced the startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida. The Polk Power Station is the first coal integrated gasification combined cycle (IGCC) plant in the United States. IGCC technology has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, while increasing reliability and reducing the overall cost of capturing carbon dioxide (CO_2) and other contaminant emissions from power plants. The technology increases the possibility that the captured CO_2 can be turned into a new revenue stream for operators by converting it for other uses, like fertilizer or enhanced oil recovery (EOR). From *U.S. Department of Energy Press Release* on April 9, 2014.

Announcements

SAVE THE DATE: DOE/NETL Carbon Storage R&D Project Review Meeting.
DOE's 2014 Carbon Storage R&D Project Review meeting will be held at the Sheraton Station Square Hotel in Pittsburgh, Pennsylvania, USA, on August 12-14, 2014. Among a number of other technical sessions, this year's meeting will include plenary sessions on a number of carbon storage topics and lessons learned over the past 10 years from the Regional Carbon Sequestration Partnerships (RCSPs). Participants will share knowledge and resources to assist in planning future carbon storage efforts. Based on past attendance, this meeting is expected to attract 200 or more attendees.

2014 CO_2 Capture Technology Meeting.
The 2014 CO_2 Capture Technology meeting will feature more than 50 DOE-sponsored CO_2 capture technology projects. The meeting is scheduled for July 29-August 1, 2014, at the Sheraton Station Square Hotel in Pittsburgh, Pennsylvania, USA. The projects included span three primary technology areas (post-combustion, pre-combustion, and advanced combustion systems) at various stages of development (lab-scale, bench-scale, and small pilot-scale). Presentations will be included on solvent, sorbent, membrane, oxy-combustion, and chemical looping combustion technologies, as well as systems studies and modeling.

International Workshop on Public Education, Training, and Community Outreach for Carbon Capture and Storage.
This workshop is scheduled for July 30-31, 2014, at the National Sequestration Education Center (NSEC) in Decatur, Illinois, USA. The technical program features tools and techniques for public education, training, and community outreach on carbon

Announcements (Continued)

capture and storage (CCS). Workshop attendees will tour the commercial-scale CCS project at the Archer Daniels Midland (ADM) facility. The workshop also includes a full day of programing for K-12 teachers with interactive lesson plans related to CCS and Science, Technology, and Mathematics (STEM).

BSCSP Breaks Ground at Kevin Dome.

The Big Sky Carbon Sequestration Partnership (BSCSP) broke ground for the first production well for the Kevin Dome Carbon Storage project. Well drilling is scheduled to begin in early May, dependent on weather conditions. The production well will be used to extract naturally occurring CO_2 located at an approximate depth of 3,800 feet. BSCSP will be logging and coring the well, in addition to testing CO_2 chemical composition and measuring "producibility." BSCSP is also preparing a nearby site for drilling the first monitoring well for geochemical monitoring throughout the project.

National Climate Assessment Available.

The National Climate Assessment summarizes the present and future impacts of climate change on the United States. The report includes analyses of impacts on seven sectors (human health, water, energy, transportation, agriculture, forests, and ecosystems) and the interactions of these sectors at the national level. The report also assesses impacts on U.S. regions (Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawaii and Pacific Islands, and U.S. coastal areas, oceans, and marine resources). A team of individuals guided by a Federal Advisory Committee produced the report, which was reviewed by the public and experts, including Federal agencies and a panel of the National Academy of Sciences (NAS).

Global CCS Map Re-Launched.

The Scottish Carbon Capture & Storage (SCCS) organization re-launched their Global CCS Map to provide information on projects that support the development of the full CCS chain. The database contains information on more than 200 small- to large-scale CCS projects. The map offers display buttons allowing the user to filter information in the viewing window (e.g., the project's developer, current status, CO_2 capture method, planned volume of CO_2 storage, project data, useful links, and news updates).

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) . The GHGT-12 Technical Program is now available.

Carbon Storage in the News

"Construction Hits Midway Point on Shell's Quest Carbon-Capture Project."

Company officials announced that construction on Shell Canada's Quest CCS project has reached the halfway point and the facility is expected to begin operation in late 2015. The project is expected to reduce emissions from the bitumen upgrader at Scotford by 1 million metric tons of CO_2 each year. The Quest project is being built by joint-venture owners Shell (60 percent), Chevron (20 percent), and Marathon Oil (20 percent) at an expected cost of $1.35 billion. The large-scale carbon-capture units under construction at Scotford will recover CO_2 from flue gases, which will then be compressed and transported via pipeline to an injection site approximately 60 kilometers north in Thorhild County, Alberta, Canada. The CO_2 will be injected into three storage wells, each more than two kilometers underground. The Government of Alberta has already invested in CCS projects; over 15 years, the province and the federal government will provide funding for Quest and a separate project, the Alberta Carbon Trunk Line. The 240-kilometer pipeline will carry 1.8 million metric tons of CO_2 each year from a bitumen refinery and a fertilizer plant in the Industrial Heartland area to Clive, Alberta. The CO_2 will be used at a depleted oilfield for EOR. The construction of the Quest facility is currently employing 600 workers. From *Edmonton Journal* on April 17, 2014.

"Kinder Morgan Set to Expand CO_2 Footprint in Southwestern Colorado and New Mexico."

Kinder Morgan Energy Partners, L.P. announced it will invest approximately $671 million to expand CO_2 infrastructure in the Cow Canyon area of the McElmo Dome source field in Montezuma County, Colorado, and expand the approximately 500-mile Cortez Pipeline that transports CO_2 from southwestern Colorado to eastern New Mexico and West Texas for use in EOR projects. The Cow Canyon development will increase CO_2 production in the McElmo Dome source field by 200 million cubic feet per day (MMcf/d). The plan includes ongoing 3-D seismic acquisition; 16 new wells; one production well and one produced water disposal well; water separation facilities; one central compressor station; and water disposal pipelines. Pending regulatory approvals, it is anticipated that 100 MMcf/d of CO_2 will come online by July 2015, with the remaining 100 MMcf/d expected by the end of 2015. The Cortez Pipeline expansion will increase the pipeline's capacity from

Carbon Storage in the News (Continued)

1.35 billion cubic feet per day (Bcf/d) to 2 Bcf/d by constructing a 64-mile loop in New Mexico and three new pump stations and updating five existing pump stations. The expansion will accommodate the increased CO_2 supply from the McElmo Dome field at the St. Johns source field and other sources in southwestern Colorado. Pending regulatory approvals, the northern portion of the Cortez Pipeline expansion is expected to be completed by July 2015 to handle the additional volumes from Cow Canyon, while the southern portion is expected to be completed by mid-2016 to handle the 300 MMcf/d of CO_2 expected from the St. Johns source field. From *MarketWatch* on May 6, 2014.

"Shell Joins CO_2-EOR Project."

Shell has joined the second phase of a joint industry project (JIP) to study a potential CO_2-EOR industry in the North Sea. Shell joins project leader, SCCS, and its existing partners, the Scottish Government, Scottish Enterprise, 2Co Energy, and Nexen Petroleum UK Ltd. The project is focused on gaining a better understanding of CO_2-EOR operations and extending the life of North Sea oil fields by capturing CO_2 from large emitters and permanently storing the greenhouse gas (GHG) in offshore oil reservoirs. The first phase of research investigated issues that could affect CO_2-EOR development, such as the legal and regulatory frameworks, taxation, and public and private perception. During the second phase of research, the project partners will focus on research ranging from reservoir modeling, further analysis of fiscal arrangements and the carbon balance of CO_2-EOR operations, and public engagement. From *GasWorld.com* on May 2, 2014.

"ETI to Collaboratively Develop a Marine Monitoring System for Underwater CCS Sites."

The Energy Technologies Institute (ETI) is developing a monitoring system using marine robotics to ensure that CO_2 stored below the seabed is secure. The project will develop a monitoring system that could be deployed using static monitoring equipment and marine robotics like autonomous underwater vehicles (AUVs). While technology exists to detect CO_2 in a marine environment, there are no commercially available systems that can record and report CO_2 levels above a large offshore storage site. The first 12 months of the project will study the economic and technological plans for the monitoring system at an approximate investment of $1.37 million. The project will be led by Fugro GEOS in collaboration with Sonardyne, the National Oceanography Centre (NOC) and the British Geological Survey (both part of National Environment Research Council [NERC]), Plymouth Marine Laboratory, and the University of Southampton. A video description of the project from ETI's Project Manager is available online. From *ETI News Release* on May 12, 2014.

"Elk Acquires the Singleton Unit in Nebraska."

Elk Petroleum announced that it has acquired 19 wells in the Singleton Unit in Nebraska, USA, to conduct CO_2-EOR operations to tap the remaining oil potential in the Singleton Oil Field. The CO_2 source for the project is the Bridgeport Ethanol plant, located 25 miles northeast; Elk Petroleum is working to acquire a CO_2 pipeline right-of-way from the plant to the Singleton Oil Field. The Singleton Oil Field has produced 10.9 million barrels of oil and the potential exists to recover an additional 2 to 4 million barrels of incremental oil from the field through EOR. The Singleton Unit also has water injection facilities and a water source well that will be used. From *Elk Petroleum Ltd. News Release* on April 23, 2014.

"CO_2 Solutions Successfully Completes Second Oil Sands Project Milestones."

CO_2 Solutions Inc. announced that it has achieved technical performance milestones for its oil sands project by operating its carbon capture technology process at the 0.5 ton/day scale. The project will now advance to the pilot demonstration phase at an approximately 15 metric ton CO_2/day scale. The milestones are included in the Contribution Agreements for the Government of Canada's ecoENERGY Innovation Initiative (ecoEII) and Alberta's Climate Change and Emissions Management (CCEMC) Corporation grants funding the project. From *MarketWatch* on April 10, 2014.

Science

"Urbanization, Higher Temperatures Can Influence Butterfly Emergence Patterns."

According to a recent study, a subset of common butterfly species are emerging later than usual in urban areas located in warmer regions. A team of international researchers studied data from 1996 to 2011 on 20 of the most common butterfly species in Ohio, focusing on (1) when each species emerged at each site every year, (2) when their population numbers peaked at each site every year, and (3) the last recorded observation of each species at each site every year. The research also looked at the temperature and urban density around each monitoring site. The data showed that in urban areas in a warmer part of the state, seven of the species emerged days or weeks after other butterflies of the same species in other areas and/or climates. The research was conducted by researchers from North Carolina State University, Case Western Reserve University, the Instituto de Pesquisas Ecológicas in Brazil, and the University of Maryland. From *ScienceDaily* on April 28, 2014.

"Climate Change Robs Frogs, Salamanders of Refuge."

A potentially warming climate may dry up ponds and shallow waterways that frogs and salamanders had used for refuge from trout introduced to the Western United States' high-mountain lakes for recreational fishing. According to the study, which appeared in "Frontiers in Ecology and Environment," researchers are looking into novel tools that could determine where these amphibians are in the most need of help and use the data to develop plans for possible fish removal from selected areas. Aquatic species like frogs and salamanders thrived in high-elevation habitats due to the abundance of food and safety from predators. Beginning in the late 1800s, trout were brought to mountain lakes and ponds in the Western United States for recreational

Science (Continued)

fishing. Today, 95 percent of the large mountain lakes have trout, putting these amphibians at risk. From *ScienceDaily* on May 1, 2014.

Policy

"Ricardo-AEA to Support Evaluation of Carbon Capture and Storage Directive."

Ricardo-AEA won a European Commission contract to study the European Union (EU) Directive on CCS technology. The CCS Directive (Directive 2009/31/EC on geologic CO_2 storage), which provides a legal framework for safe geological CO_2 storage in the EU, sets forth requirements for the lifetime of a storage site and has provisions on CO_2 capture and transport. The European Commission is required to review its implementation and will submit a report to the European Parliament and Council by March 2015. The project will deliver an assessment of the CCS Directive, including stakeholder consultation, literature review, and recommendations. Ricardo-AEA will work in collaboration with Triple E Consulting (TEC) and research organization TNO. More information on the CCS Directive is available via the European Commission Climate Action website. From *Ricardo-AEA Newsroom* on April 29, 2014.

"MOU Signals New Era of Cooperation between Research Centers."

Representatives from CMC Research Institutes, Inc., (CMC) and the United Kingdom Carbon Capture and Storage Research Center (UKCCSRC) signed a memorandum of understanding (MOU) for research to ensure CCS projects are designed and operated in a cost-effective, safe, secure manner. The agreement builds on the current relationship between the two organizations, which have funded a researcher exchange program and participated in meetings. Potential areas for collaboration under the MOU include: research projects by CMC and UKCCSRC researchers; joint workshops, seminars, and webinars; regular bi-annual meetings of management teams; further researcher exchanges; and research publication. From *UKCCS Media Release* on May 8, 2014.

"Resolving or managing uncertainties for carbon capture and storage: Lessons from historical analogues."

The following is the Abstract of this article: "CCS technologies are often highlighted as a crucial component of future low carbon energy systems in the UK and internationally. While these technologies are now in the demonstration phase worldwide, they are still [characterized] by a range of technical, economic, policy, social and legal uncertainties. This paper applies a framework for the analysis of these uncertainties that was previously developed by the authors to a historical evidence base. This evidence base comprises nine case studies, each of which focuses on a technology that is partly analogous to CCS. The paper's analysis of these case studies examines the conditions under which the uncertainties concerned have been at least partly resolved, and what lessons can be drawn for CCS. The paper then uses the case study evidence to discuss linkages between the uncertainties in the analysis framework, and how these linkages differ from those that were originally expected. Finally, the paper draws conclusions for the methodological approach that has been used and for strategies to develop and deploy CCS technologies." **Jim Watson, Florian Kern, and Nils Markusson**, *Technological Forecasting and Social Change*. (Subscription may be required.)

"When to invest in carbon capture and storage technology: A mathematical model."

The following is the Abstract of this article: "[The authors] present two models of the optimal investment decision in CCS—one where the carbon price is deterministic (based on the newly introduced carbon floor price in Great Britain) and one where the carbon price is stochastic (based on the [emissions trading system (ETS)] permit price in the rest of Europe). A novel feature of this work is that in both models investment costs are time dependent which adds an extra dimension to the decision problem. [The authors'] deterministic model allows for quite general dependence on carbon price and consideration of time to build and simple calculus techniques determine the optimal time to invest. [The authors] then [analyze] the effect of carbon price volatility on the optimal investment decision by solving a Bellman equation with an infinite planning horizon. [The authors] find that increasing the carbon price volatility increases the critical investment threshold and that adoption of this technology is not optimal at current prices, in agreement with other works. However reducing carbon price volatility by switching from carbon permits to taxes or by introducing a carbon floor as in Great Britain would accelerate the adoption of carbon abatement technologies such as CCS." **D.M. Walsh, K. O'Sullivan, W.T. Lee, and M.T. Devine**, *Energy Economics*. (Subscription may be required.)

"Perceptions of sub-seabed carbon dioxide storage in Scotland and implications for policy: A qualitative study."

The following is the Abstract of this article: "The geological storage of CO_2 offers notable potential, as part of larger CCS processes, to be a significant climate change mitigation technology. This paper challenges the argument often put forward that, due to the greater distances from [centers] of population, it will be 'easier' to garner public and stakeholder support for offshore CO_2 storage than onshore. Based on the results of research interviews carried out with stakeholders and informed publics in Scotland, challenges for public and stakeholder acceptance of sub-seabed CO_2 storage that may require further policy attention are identified. Whilst existing policy for sub-seabed CO_2 storage is [cognizant] of the need for societal engagement, it may be the case that these regulations may need further reinforcement to ensure future developments are able to address social acceptability issues as fully as possible. The value of taking into account social as well as physical characteristics at the site selection phase, the need for mechanisms to take seriously stakeholder conceptions of uncertainty, and the importance of extending social engagement beyond risk communication are discussed." **Leslie Mabon, Simon Shackley, and Nathan Bower-Bir,** *Marine Policy*. (Subscription may be required.)

"Predictors of risk and benefit perception of carbon capture and storage (CCS) in regions with different stages of deployment."

The following is the Abstract of this article: "CCS is a technological option for mitigating climate change. Public risk perception plays a key

Policy (Continued)

role in the decision whether it should be adopted at a large scale. In this study, a comparison was made between regions with different levels of CCS deployment: the three Canadian provinces of British Columbia, Alberta and Saskatchewan. While familiarity with the technology differed greatly among the different regions, predictors of risk perception were stable and unrelated to familiarity. Results were similar for benefit perceptions, but a comparison with results from a similar Swiss study seems to suggest that benefit perceptions of CCS are likely to be influenced by the national context of deployment." **Selma L'Orange Seigo, Joseph Arvail, Simone Dohle, and Michael Siegrist**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Geology

"Experimental Observation of Permeability Changes In Dolomite at CO_2 [Storage] Conditions."

The following is the Abstract of this article: "Injection of cool CO_2 into geothermally warm carbonate reservoirs for storage or geothermal energy production may lower near-well temperature and lead to mass transfer along flow paths leading away from the well. To investigate this process, a dolomite core was subjected to a 650 h, high pressure, CO_2 saturated, flow-through experiment. Permeability increased from $10^{-15.9}$ to $10^{-15.2}$ m^2 over the initial 216 h at 21°C, decreased to $10^{-16.2}$ m^2 over 289 h at 50°C, largely due to thermally driven CO_2 exsolution, and reached a final value of $10^{-16.4}$ m^2 after 145 h at 100°C due to continued exsolution and the onset of dolomite precipitation. Theoretical calculations show that CO_2 exsolution results in a maximum pore space CO_2 saturation of 0.5, and steady state relative permeabilities of CO_2 and water on the order of 0.0065 and 0.1, respectively. Post-experiment imagery reveals matrix dissolution at low temperatures, and subsequent filling-in of flow passages at elevated temperature. Geochemical calculations indicate that reservoir fluids subjected to a thermal gradient may exsolve and precipitate up to 200 cm^3 CO_2 and 1.5 cm^3 dolomite per kg of water, respectively, resulting in substantial porosity and permeability redistribution." **Benjamin M. Tutolo, Andrew J. Luhmann, Xiang-Zhao Kong, Martin O. Saar, and William E. Seyfried, Jr.**, *Environ. Sci. Technol.* (Subscription may be required.)

"Inverse Modeling of Water-Rock-CO_2 Batch Experiments: Potential Impacts on Groundwater Resources at Carbon [Storage] Sites."

The following is the Abstract of this article: "This study developed a multicomponent geochemical model to interpret responses of water chemistry to introduction of CO_2 into six water-rock batches with sedimentary samples collected from representative potable [formations] in the Gulf Coast area. The model simulated CO_2 dissolution in groundwater, aqueous complexation, mineral reactions (dissolution/precipitation), and surface complexation on clay mineral surfaces. An inverse method was used to estimate mineral surface area, the key parameter for describing kinetic mineral reactions. Modeling results suggested that reductions in groundwater pH were more significant in the carbonate-poor [formations] than in the carbonate-rich [formations], resulting in potential groundwater acidification. Modeled concentrations of major ions showed overall increasing trends, depending on mineralogy of the sediments, especially carbonate content. The geochemical model confirmed that mobilization of trace metals was caused likely by mineral dissolution and surface complexation on clay mineral surfaces. Although dissolved inorganic carbon and pH may be used as indicative parameters in potable [formations], selection of geochemical parameters for CO_2 [release] detection is site-specific and a stepwise procedure may be followed. A combined study of the geochemical models with the laboratory batch experiments improves understanding of the mechanisms that dominate responses of water chemistry to CO_2 [release] and also provides a frame of reference for designing monitoring strategy in potable [formations]." **Changbing Yang, Zhenxue Dai, Katherine D. Romanak, Susan D. Hovorka, and Ramón H. Treviño**, *Environ. Sci. Technol*. (Subscription may be required.)

"Effects of Carbon Dioxide on the Mobilization of Metals from [Formations]."

The following is the Abstract of this article: "Potential [releases] of CO_2 from storage sites to shallow [formations] could have adverse impacts on the quality of potable groundwater. The mineralogy of well-sorted silica sand is modified by the pH-controlled precipitation of eight metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd). Continuous flow tests are performed in two fixed-bed columns packed with the modified sand by coinjecting gas CO_2/distilled water (2-phase column) and distilled water (1-phase column/control test) at constant influx rates for a period of two months. The concentration of dissolved metals is measured in the effluents of columns with atomic absorption spectroscopy (AAS). Mineralogical analysis of the surface of sand grains is done before and after the flow tests with scanning electron microscopy–X-ray energy dispersive spectroscopy (SEM–EDS) and X-ray photoelectron spectroscopy (XPS), whereas the precise quantitative measurement of the metal content in the sand is done with AAS. A dynamic numerical model that couples the flow and mass-transfer processes in porous media with the equilibrium and kinetically driven metal desorption processes is developed. Inverse modeling of the continuous flow test enables us to quantify and rank the selectivity of metal mobility in terms of equilibrium and kinetic desorption parameters. The continuous CO_2 dissolution and water acidification causes significant mobilization and dissolution of several metals (Mn, Ni, Cu, Zn, Co), moderate mobilization of Cr, acceleration of Cd dissolution, whereas Fe remains strongly bonded on the sand grains as goethite. The parameters estimated from lab-scale column tests might be helpful for interpreting field-scale CO_2 [release] scenarios and installing relevant early warning monitoring systems." **Katerina Terzi, Christos A. Aggelopoulos, Ioannis Bountas, and Christos D. Tsakiroglou**, *Environ. Sci. Techno.* (Subscription may be required.)

"Control of CO_2 Permeability Change in Different Rank Coals during Pressure Depletion: An Experimental Study."

The following is the Abstract of this article: "The gas permeability of different rank coals varies because of the summative effects of increasing effective stress, gas slippage, and coal matrix shrinkage during gas pressure depletion. In this paper, the natures of CO_2 permeability change were primarily investigated in a high-volatile A bituminous

Geology (Continued)

coal (core D2-2), a moderate volatile bituminous coal (core S1), and an anthracite coal (core P11-2-1). Under a 4.3 MPa confining stress condition, as the gas pressure declines, the CO_2 permeability of core D2-2 gradually decreases and then has a slight increase at mean gas pressures of less than approximately 0.8 MPa, the CO_2 permeability of core S1 initially decreases but subsequently increases above a mean gas pressure of approximately 1.3 MPa, and the CO_2 permeability of core P11-2-1 continuously increases, especially at mean gas pressures of less than approximately 1.8 MPa. These pressure-depletion observations on CO_2 permeability are considered to be the result of three effects: (a) increasing effective stress decreases CO_2 permeability; (b) increased gas slippage increases CO_2 permeability exponentially, becoming significant at mean gas pressures of less than approximately 0.8 MPa for the three cores; and (c) a positive effect on CO_2 permeability from matrix shrinkage occurs at mean pressures of less than approximately 1.3 and 1.8 MPa for cores S1 and P11-2-1, respectively, whereas the CO_2 permeability of core D2-2 is negatively affected by matrix shrinkage at all tested pressures. Additionally, it is found that the three effects on the CO_2 permeability depend upon the permeability of the coal and gas pressure." **Junqian Li, Dameng Liu, Yanbin Yao, Yidong Cai, Lulu Xu, and Saipeng Huang**, *Energy Fuels*. (Subscription may be required.)

Technology

"3D geomechanical modeling for CO_2 geological storage in faulted formations. A case study in an offshore northern Adriatic reservoir, Italy."

The following is the Abstract of this article: "One of the six CCS demonstration projects recently selected within the European Energy Programme for Recovery (EEPR) is located in Italy. In the framework of the feasibility study, the selection of a geological formation suitable to store the required 1 Mt/yr of CO_2 over 10 years and the safety of the CO_2 disposal are two major issues. In the present modeling study, [the authors] investigate the role played by geomechanics in assessing the maximum CO_2 amount that can be [stored] into a 2000 m deep multi-compartment reservoir seated in the off-shore northern Adriatic sedimentary basin. [The authors] use a three-dimensional finite element–interface element geomechanical model to simulate the possible mechanical failure in both the injected formation and caprock, the fault reactivation, and the ground surface displacement. The faulted geological structure is reproduced based on detailed seismic surveys, with petrophysical/geomechanical properties based on the several well-logs available from several oil/gas explorations in the area. The pore pressure distribution due to two injection wells is provided by a fluid-dynamic simulator and a sensitivity analysis is carried out to investigate the role of the major uncertainties in the geomechanical setting. The modeling results suggest that a safe and permanent containment may be secured over a few years only. Afterwards, mechanical failure by shear stress is likely to be experienced by a significant portion of reservoir's injected compartments. Shear failure and fault reactivation can occur much before attaining the hydraulic fracturing pressure, hence represent two major issues in assessing the maximum allowable CO_2 injection overpressure." **Pietro Teatini, Nicola Castelletto, and Giuseppe Gambolati**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Microfluidic Studies of CO_2 [Storage] by Frustrated Lewis Pairs."

The following is the Abstract of this article: "Frustrated Lewis pairs (FLPs) comprising sterically hindered Lewis acids and bases offer the capability to reversibly capture CO_2 under mild reaction conditions. The determination of equilibrium constants and thermodynamic properties of these reactions should enable assessment of the efficiency of a particular FLP system for CO_2 [storage] and provide insights for design of new, efficient formulations of FLP catalysts for CO_2 capture. [The authors] have developed a microfluidic approach to studies of FLP–CO_2 reactions, which provides their thermodynamic characterization that is not accessible otherwise. The approach enables the determination of the equilibrium reaction constants at different temperatures, the enthalpy, the entropy, and the Gibbs energy of these reactions, as well as the enhancement factor. The microfluidic methodology has been validated by applying it to the well-characterized reaction of CO_2 with a secondary amine. The microfluidic approach can be applied for fundamental thermodynamic studies of other gas–liquid reactions." **Dan Voicu, Milad Abolhasani, Rachelle Choueiri, Gabriella Lestari, Caroline Seiler, Gabriel Menard, Jesse Greener, Axel Guenther, Douglas W. Stephan, and Eugenia Kumacheva**, *J. Am. Chem. Soc.* (Subscription may be required.)

Terrestrial

"Pyrogenic carbon stocks and storage mechanisms in podzolic soils of fire-affected Quebec black spruce forests."

The following is the Abstract of this article: "Wildfire, a recurrent disturbance in the boreal, converts part of the forest floor into pyrogenic carbon (PyC). The latter is an important component of the global soil carbon pool, yet knowledge of its stocks and storage mechanisms in these boreal ecosystems is scarce. Podzolization processes, which are frequent under boreal vegetation, result in distinctive patterns of soil organic carbon (SOC) accumulation in the mineral subsoil; how this may affect PyC storage remains largely unknown. The objectives of this study were to estimate SOC and PyC stocks in podzolic soils from fire-affected black spruce forests, and to explore the storage mechanisms taking place in their mineral horizons. [The authors] also compared PyC stocks in mineral soils to forest floor stocks. Samples were collected from 23 soil profiles under black spruce forests located throughout the province of Quebec. To further explore the relationship between podzolization and PyC storage mechanisms, [the authors] measured SOC and PyC contents in size and density fractions of a subset of 11 podzolic B horizons. Total SOC stocks in the mineral horizons and forest floors were comparable. Pyrogenic carbon stocks in the mineral soils, estimated by a H_2O_2/dilute HNO_3 digestion, averaged 0.2 (± 0.1) kg C m^{-2}. This was significantly lower than forest floor stocks, which ranged from 0.2 to 1.2 kg C m^{-2}. Consequently, PyC constituted a smaller fraction of total SOC (2–15 [percent]) in mineral soils than in forest floors, where it was as high as 68 [percent] (± 5) in some horizons. In the mineral soils, SOCand PyC concentrations were strongly correlated. While some PyC was found in unprotected particulate organic matter (POM),

Terrestrial (Continued)

the rest was associated with organo-mineral and organo-metallic complexes in the micro-aggregate protected POM and fine fraction. Patterns of PyC accumulation in mineral soils were similar to SOC, and the greater PyC stocks were found in podzolic B horizons." **Laure N. Soucémarianadin, Sylvie A. Quideau, and M. Derek MacKenzie**, *Geoderma*. (Subscription may be required.)

"Soil carbon stock and accumulation in young mangrove forests."

The following is the Abstract of this article: "Mangrove reforestation and afforestation programs have been initiated in many countries recently to compensate for historical losses. At the same time, awareness of the high carbon (C) sink potential of mangrove forests is growing, and C [storage] is beginning to be considered among forestation goals. To assess whether and at what rate C accumulates in the soil of young mangrove forests following afforestation, [the authors] conducted a field study at an afforestation project in southeast China, including repeated measures taken over six years at two young forests (consisting of Kandelia obovata and Sonneratia apetala, aged 0–6 years old), and also a chronosequence of forests aged 0 (mudflat), 6 (both species), 20 (S. apetala), and 70 (K. obovata) years old. In the repeated measures, surface (0–10 cm) soil C concentration ([percent] C of dry soil mass) increased significantly over six years, from 1.14 [percent] to 1.52 [percent] (K. obovata) and 1.23 [percent] to 1.68 [percent] (S. apetala). The rates of increase did not differ significantly between the two species, despite much greater biomass of S. apetala. In the chronosequence, soil C also increased with age across sites, but only the 70-year-old forest was statistically different, suggesting that localized environmental differences may obscure age-related patterns in soil C. At all sites, soil C concentration for 1-m soil depth (0.62 [percent] –2.43 [percent]) was low compared to published global averages, yet the estimated soil C accumulation rate (155 g C m^{-2} y^{-1}) was comparable to published averages for mature forests. [The authors] supported this field study with a literature review of similar studies containing soil C concentration data from young mangrove forests: data compiled from 15 studies, comprising 31 sites, showed consistent, positive changes in soil C concentration with forest age, even in the youngest (<5 years old) forests, supporting [the authors'] field observation that soil C increases over time following mangrove afforestation." **Abby Lunstrum and Luzhen Chen**, *Soil Biology and Biochemistry*. (Subscription may be required.)

Trading

"Gov. Inslee Announces Executive Action to Reduce Carbon and Promote Clean Energy."

Washington State's Governor signed an executive order that outlines a series of steps to reduce carbon emissions in Washington State and advance development and use of clean energy technologies. Instead of implementing new programs, the executive order builds upon earlier studies and work groups to create an action plan in six key areas: reducing carbon emissions through a new cap-and-trade program; ending the use of electricity generated by coal; developing clean transportation options and cleaner fuels; accelerating development and deployment of clean energy technology; improving the energy efficiency of offices and homes; and reducing the state government's carbon footprint. More information on the executive order is available via a policy brief. From *Washington Governor Jay Inslee News Release* on April 29, 2014.

"Reducing energy consumption and CO_2 emissions by energy efficiency measures and international trading: A bottom-up modeling for the U.S. iron and steel sector."

The following is the Abstract of this article: "Using the [Industry Sector Energy Efficiency Modeling (ISEEM)] modeling framework, [the authors] analyzed the roles of energy efficiency measures, steel commodity and international carbon trading in achieving specific CO_2 emission reduction targets in the U.S iron and steel sector from 2010 to 2050. [The authors] modeled how steel demand is balanced under three alternative emission reduction scenarios designed to include national energy efficiency measures, commodity trading, and international carbon trading as key instruments to meet a particular emission restriction target in the U.S. iron and steel sector; and how production, process structure, energy supply, and system costs change with those scenarios. The results advance [the authors] understanding of long-term impacts of different energy policy options designed to reduce energy consumption and CO_2 emissions for U.S. iron and steel sector, and generate insight of policy implications for the sector's environmentally and economically sustainable development. The alternative scenarios associated with 20 [percent] emission-reduction target are projected to result in approximately 11–19 [percent] annual energy reduction in the medium term (i.e., 2030) and 9–20 [percent] annual energy reduction in the long term (i.e., 2050) compared to the Base scenario." **Nihan Karali, Tengfang Xu, and Jayant Sathaye**, *Applied Energy*. (Subscription may be required.)

Recent Publications

"Methods to assess geologic CO_2 storage capacity: status and best practice."

The following is from the Executive Summary of this document: "To understand the emission reduction potential of CCS, decision makers need to understand the amount of CO_2 that can be safely stored in the subsurface and the geographical distribution of storage resources. Estimates of storage resources need to be made using reliable and consistent methods. This report offers recommendations for an internationally shared approach to quantifying this potential. Previous estimates of CO_2 storage potential for a range of countries and regions have been based on a variety of methodologies, with access to widely differing amounts of data, resulting in a correspondingly wide range of capacity estimates. Some

Recent Publications (Continued)

of these estimates have even been in conflict with others. Consequently, there has been uncertainty about which of the methodologies were most appropriate in given settings, and whether the estimates produced by these methods were useful to policy makers trying to determine the appropriate role for CCS. In 2011, the International Energy Agency (IEA) convened two workshops, which brought together experts from six national geological survey [organizations] to review geologic CO_2 storage assessment methodologies and make recommendations on how to [harmonize] CO_2 storage estimates worldwide. This workshop report presents the outcome of the workshops. It first gives an overview of factors to consider before undertaking a CO_2 storage assessment on saline [formations]. This is followed by a comparison of ten of the more recently published CO_2 storage resource assessment methods and resource estimates, which are [characterized] according to ten parameters and the results tabulated. The method comparison is then followed by a set of steps that can be used to assess geologic CO_2 resources. As the overall goal of the workshops was to [harmonize] CO_2 storage estimates, the participants identified best practice in the form of steps that can be followed to conduct a thorough assessment of storage resource, throughout the world, across geologic settings, regardless of the amount of available geologic data… ”

“Moving Below Zero: Understanding Bioenergy with Carbon Capture & Storage.”

The following is from the Summary of this document: “Carbon dioxide (CO_2) in the air is already at dangerous levels – 40 [percent] above pre-industrial quantities, and rising fast. To reduce the level of CO_2 in the air and limit dangerous climate change, [humans] need to boost carbon sinks. [Humans] need to find ways to remove that excess carbon from the air. In this report [the authors] turn attention to one of the more prospective large-scale carbon removal technologies: bioenergy with carbon capture and storage (also known as bio-CCS, BECCS or renewable-CCS). As plants grow, they harness energy from the sun and CO_2 from the air. Certain plants can be harvested, transported and processed to form a fuel which can be combusted or fermented to produce bioenergy (heat, power or transport). This process releases the CO_2 which can be captured, compressed and transported to a location for geological storage. This means the CO_2 absorbed from the air during plant growth can be removed from the natural carbon cycle...”

“Modelling Bio-[storage] to Reduce Greenhouse Gas Emissions.”

The following is the Introduction of this document: “The Climate Change Authority has outlined the task Australia faces in reducing emissions to achieve global ambitions to [minimize] the rise in temperatures to [2°C]. According to the Authority this task translates to zero emissions from activities in Australia by 2040. As it could be difficult to achieve zero emissions across all sectors it is likely that [bio-storage] options will have a major role to play to offset emissions. Such options include storage of carbon from native plantations and agricultural soils. Another option includes using biomass fuel to generate power or heat and then capturing the carbon emissions and storing them underground. The focus of this study is on the role that bioenergy carbon capture and storage (BECCS) technology can play in achieving long term ambitions to reduce emissions. This report describes the assumptions and methods used to determine the impact of adoption of BECCS in the power sector and for large applications entailing direct combustion. A number of scenarios were modelled with and without the availability of BECCS to determine the relative contribution of BECCS. The results of the modelling are discussed in this report.”

“Enhanced Oil Recovery (EOR) Market: Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 – 2023.”

The following is from the Description of this document: “The EOR market report by Transparency Market Research provides an in-depth analysis of the global EOR industry. The report segments the market on the basis of technology and region and also provides the forecasts and estimates for each technology. The report also analyses the demand and supply characteristics of the market by providing a detailed forecast and analysis of volume and revenue for the period 2013 to 2023. EOR method mainly uses three technologies including Thermal injection, Gas injection and Chemical injection…The report provides a detailed analysis of the various factors influencing the EOR industry with the help of Porter’s five force analysis. The analysis also helps to understand the degree of competition in the market. The report also analyses the value chain and the various drivers and restraints of the EOR market.”

Legislative Activity

“Rockefeller Announces Major Initiatives to Promote Clean Coal Technology.”

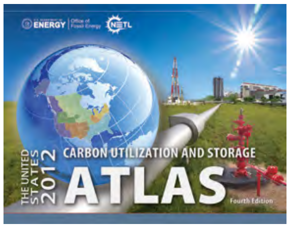
A U.S. Senator from West Virginia introduced two bills to advance commercial deployment of clean coal technologies. The legislation, “Carbon Capture and Sequestration Deployment Act of 2014” and “Expanding Carbon Capture through Enhanced Oil Recovery Act of 2014,” would, among other provisions, invest in Federal CCS research and development (R&D); expand tax credits for innovative companies investing in CCS technologies; and create loan guarantees for construction of new CCS facilities, as well as retrofits of existing facilities that utilize CCS. From *U.S. Senator Jay Rockefeller News Release* on May 5, 2014.

About DOE's Carbon Storage Program

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

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

Carbon Storage Program Resources



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

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

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

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

- NETL RSS Feed
- NETL on Facebook
- NETL on Twitter
- NETL on LinkedIn
- NETL on YouTube

About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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