NETL the ENERGY lab

Carbon Storage Newsletter

April 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).

RGGI States Initiate Bidding Process for Auction 24.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2014 auctions released the Auction Notice and application materials for the 24th CO_2 allowance auction scheduled for June 4, 2014. The Auction Notice provides potential auction participants with the information needed to submit a Qualification Application and indicate their intent to bid. States will offer 18,062,384 CO_2 allowances for sale at a reserve price of $2.00.

NETL-Led Laboratory-Industry-Academia Collaboration Is Accelerating Carbon Capture Technologies.

The National Energy Technology Laboratory (NETL) established the Carbon Capture Simulation Initiative (CCSI) to take carbon capture concepts from the laboratory to the power plant more quickly, at a lower cost, and with reduced risk. The CCSI Toolset, a suite of computer models and computational tools that enable the development and deployment of new carbon-capture technologies, is part of this initiative. Five companies from the CCSI industry team have licensed the toolset, with industry partners demonstrating how they are applying the toolset, sharing experiences to help improve the tools, and identifying opportunities for further collaboration.

Draft Permit Approved for FutureGen 2.0.

The U.S. Environmental Protection Agency (EPA) approved a preliminary permit for FutureGen 2.0, a project that expects to store millions of metric tons of CO_2 over a period of more than 20 years in Illinois. An open house and public hearing are scheduled and written comments will be accepted through May 15. The ruling on a final permit depends on the number of public comments submitted to EPA.

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).

Carbon Storage in the News

"Ethanol Plant CO_2 [Storage] Project Reaches New Milestone."

The Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin Decatur Project announced that the carbon storage project has stored 750,000 metric tons of CO_2 from ADM's ethanol plant in Decatur, Illinois. The project is a joint development between DOE/NETL, ADM, the Illinois State Geological Survey, and Schlumberger Carbon Services. The project began capturing CO_2 from the ADM plant in November 2011 and aims to store 1 million tons of CO_2 annually at a depth of approximately 7,000 feet in the Mount Simon Sandstone formation. More information about the project is available via a video from the Weather Channel, titled, "Capturing Carbon Dioxide." From *Ethanol Producer Magazine* on March 25, 2014.

"WMU Partners with Energy Company to Inject Carbon Dioxide Underground, Flush Out Leftover Oil."

With help from Western Michigan University's (WMU) Michigan Geological Repository for Research and Education (MGRRE), Core Energy has recovered 1.6 million barrels of oil through EOR operations. MGRRE states that Michigan has 800 oil fields that could possibly be used for EOR, with the potential to recover in the range of 180 to 200 million barrels of oil. MGRRE has been partners with Core Energy, as well as Battelle Memorial Institute, since 2005 as part of the Midwest Regional Carbon Sequestration Partnership (MRCSP), one of seven DOE/NETL RCSPs. From *Mlive.com* on March 19, 2014.

"Sask. Spending $2 Million on Four Enhanced Oil Recovery Projects."

Innovation Saskatchewan has approved $1.9 million to develop EOR technologies in oil fields in Saskatchewan, Canada. The funding will be used for four projects, including two for the Petroleum Technology Research Center (PTRC) – one project will develop technology to map the flow of oil in reservoirs, while the other will assess the potential of radio frequency heating to increase oil production. From *CTVNews.com* on March 6, 2014.

"Government of Saskatchewan Funds PTRC's Saskatchewan CO_2 Oilfield Use for Storage and EOR Research Project."

The Saskatchewan Ministry of the Economy announced funding was awarded to PTRC to build on 12 years of research into CO_2 geological storage. The Saskatchewan CO_2 Oilfield Use for Storage and EOR

Carbon Storage in the News (Continued)

Research (SaskCO2USER) project builds on the 12 years of research conducted in the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project, including expanding research on storage and wellbore integrity, predicting CO_2 migration underground, and the identification of effective monitoring techniques. From *PTRC Media Release* on April 2, 2014.

"High Tech Spaghetti Shows Promise for Carbon Capture."

A rig has been installed at Delta Electricity's Carbon Capture Research Facility at Vales Point Power Station in Australia to test new hollow-fiber membranes for capturing CO_2 from power stations. The hollow-fiber membrane modules contain tiny "spaghetti-like" tubes that maximize contact between the gas and the membrane surface by allowing only CO_2 to pass through to the inside of the tube; flue gas passes across the outside the tube. Hollow-fiber membranes have the potential to reduce the energy required to capture CO_2, while also having a smaller environmental and physical footprint than existing solvent systems. The rig was installed by Cooperative Research Center for Greenhouse Gas Technologies (CO2CRC) researchers at the University of South Wales. From *CO2CRC Media Release* on March 4, 2014.

"Flagship Carbon Capture Storage Site in WA's South-West."

A joint venture called "The South West Hub" is using a piece of land in Southwest Australia as a national blueprint for CCS. In February, the South West Hub, a venture that incorporates the Department of Mines and Petroleum (DMP), industry, and research bodies like the Commonwealth Scientific and Industrial Research Organization (CSIRO), began a 3-D seismic survey project to map the underground rock layers at the Harvey-Waroona site. The South West Hub is working to determine the composition beneath the site's surface, while DMP is working to expand knowledge for industry to make a commercial decision whether to invest in CCS technology. From *ABC Rural* on March 19, 2014.

"Kinder Morgan to Invest Approximately $1 Billion to Expand Vast CO_2 Network."

Kinder Morgan announced plans to build and operate a 213-mile, 16-inch diameter pipeline to transport CO_2 from the St. Johns field in Apache County, Arizona, to the Cortez Pipeline in Torrance County, New Mexico. The new Lobos Pipeline will have an initial capacity of 300 million standard cubic feet per day and support EOR projects in the Permian Basin. The company plans to invest approximately $300 million on the pipeline and an additional $700 million to drill wells and build field gathering, treatment, and compression facilities at St. Johns field. The project is expected to be in service in late 2016, depending on environmental and regulatory approval(s). From *MarketWatch* on March 26, 2014..

"Magellan Petroleum Begins Pilot CO_2 Injection at Poplar."

Magellan Petroleum Corporation announced that CO_2 injection has initiated in the Charles formation at Poplar Dome through the EPU 202-IW well as part of an EOR pilot program. The pilot program consists of five wells, including the CO_2 injection well and four producer wells. Carbon dioxide injection is expected over a two-year period and preliminary results will be publicly communicated during the fourth quarter of 2014. The CO_2 is supplied by Air Liquide Industrial U.S. LP. From *MarketWatch* on March 25, 2014.

Science

"Climate Change Will Test Turtles' Mettle."

Potential climate change could present new threats to all seven species of marine turtles, which are already considered at risk across the world. The temperature when eggs develop in the nest determines the sex of turtle hatchlings, with higher temperatures favoring the production of females. The reptiles also synchronize their nesting with the times of year when the incubation temperature produces approximately equal numbers of male and female hatchlings. Potential climate change could alter the incubation temperatures, causing the turtle population sex ratios to be distorted, affecting the population. In addition to unbalanced sex ratios, a potentially warming climate could also cause storm surges that could harm turtle nests and nesting beaches. From *National Geographic* on March 17, 2014.

Policy

"South Korean Signs CCS Collaboration with Australian and German Scientists."

Korea CCS R&D Center (KCRC) has signed strategic agreements with Australian and German researchers to advance CCS. Under the agreements, KCRC will work together with CO2CRC and the Helmholtz Centre Postdam GFZ - German Research Centre for Geosciences to develop technologies for reducing CO_2 emissions from power generation and industry. The agreements will also enable knowledge sharing between the two institutes and provide training opportunities for researchers from all three countries. From *Carbon Capture Journal* on March 16, 2014.

"Air District Board Approves Climate Action Work Program."

The San Francisco Bay Area Air Quality Management District (BAAQMD) Board of Directors approved a Climate Action Work Program designed to focus the Air District's climate protection activities and identify necessary resources for future action. The Bay Area climate protection work program includes measures for updating efforts to inventory, forecast, and monitor greenhouse gases (GHGs); imitating development of rules limiting GHG emissions; expanding enforcement; and working with state, regional, and local agencies and stakeholders to develop the regional climate action strategy. From *BAAQMD News Release* on April 3, 2014.

Policy (Continued)

"Spare the details, share the relevance: The dilution effect in communications about carbon dioxide capture and storage."

The following is the Abstract of this article: "The mitigation of climate change may require the implementation of CCS. Both proponents and opponents of CCS will try to convince the public of the (dis)advantages of this technology. This research examines the relative persuasiveness of communications that only contain highly relevant information (e.g., the argument that the implementation of CCS would have important climate benefits) or combine highly relevant with irrelevant or moderately relevant information. The results of three experiments consistently show that adding irrelevant information dilutes the impact of highly relevant information: Irrelevant information reduced the persuasiveness of communications (Experiments 1 and 2) and weakened people's beliefs about the issue (Experiment 3). This dilution effect occurred with both positive (pro-CCS) information and negative (con-CCS) information, but the effect was stronger with positive information. Awareness of the source of the communications moderated the dilution effect. Implications for public communications about CCS are discussed." **Gerdien de Vries, Bart W. Terwel, and Naomi Ellemers,** *Journal of Environmental Psychology*. (Subscription may be required.)

"The impact of carbon capture and storage on a decarbonized German power market."

The following is the Abstract of this article: "The European energy policy is substantially driven by the target to reduce the CO_2-emissions significantly and to mitigate climate change. Nevertheless European power generation is still widely based on fossil fuels. The CCS technology could be part of an approach to achieve ambitious CO_2 reduction targets without large scale transformations of the existing energy system. In this context the paper investigates on how far the CCS-technology could play a role in the European and most notably in the German electricity generation sector. To account for all the interdependencies with the European neighboring countries, the embedding of the German electricity system is modeled using a stochastic European electricity market model (E2M2s). After modeling the European side constraints, the German electricity system is considered in detail with the stochastic German Electricity market model (GEM2s). The focus is thereby on the location of CCS plant sites, the structure of the CO_2-pipeline network and the regional distribution of storage sites. Results for three different European energy market scenarios are presented up to the year 2050. Additionally, the use of CCS with use of onshore and offshore sites is investigated." **S. Spiecker, V. Eickholt, and C. Weber,** *Energy Economics.* (Subscription may be required.)

Geology

"An evaluation of carbon dioxide [storage] potential of the Permian Cedar Mesa Sandstone, northeastern Arizona."

The following is the Description of this article: "Northeastern Arizona encompasses the southwestern part of the Colorado Plateau, an area of gently dipping to slightly tilted Paleozoic and Mesozoic strata that include porous and permeable sandstone units. The Lower Permian Cedar Mesa Sandstone was identified for study as a potential target for CO_2 [storage] in order to reduce anthropogenic CO_2 emissions to the atmosphere. The Cedar Mesa Sandstone is overlain by the impermeable Organ Rock Formation, which is necessary to prevent escape of [stored] CO_2. The salinity of groundwater in the Cedar Mesa Sandstone is unknown, but must be determined before CO_2 can be [stored] because CO_2 [storage] is not permitted in potable groundwater under current regulatory conditions. Well logs for 755 drill holes were used to evaluate the extent, depth, and thickness of subsurface formations. ESRI® ArcMap™ software was then used to calculate the volume of the Cedar Mesa Sandstone where the top of the unit is below 3,000 feet (915 meters) depth, which is the minimum depth necessary for CO_2 [storage] where the CO_2 is under sufficient pressure to remain in a dense, near liquid state. Well logs were used to evaluate porosity, which was then used to calculate the amount of pore space that is theoretically available for CO_2 storage (the effective porosity). [The authors] calculate that there are between 30 km^3 and 80 km^3 of pore space in the Cedar Mesa Sandstone. The fraction of pore-space volume that is accessible to CO_2 injection is estimated to be approximately 0.5 [percent] to 5 [percent]. Applying this storage efficiency to the Cedar Mesa Sandstone indicates that 0.15 km^3 to 4.3 km^3 of pore space is accessible to injected CO_2, and that 0.114 to 3.24 billion tonnes of CO_2 could be [stored] in this pore space at a density of approximately 750 kg/m^3." **Rauzi, S.L., and Spencer, J.E.**, *Arizona Geological Survey Open File Reports*. (Subscription may be required.)

"Permeability and relative permeability measurements for CO_2-brine system at reservoir conditions in low permeable sandstones in Svalbard."

The following is the Abstract of this article: "[Storage] of CO_2 in a saline [formations] is currently being evaluated as a possible way to handle CO_2 emitted from a coal-fueled power plant in Svalbard. The chosen reservoir is a 300-m thick, laterally extensive, shallow marine formation of late Triassic-mid Jurassic age, located below Longyearbyen in Svalbard. The reservoir consists of 300 m of alternating sandstone and shale and is sealed by 400 m of shale. Experimental and numerical studies have been performed to evaluate CO_2 storage capacity. A total of 51 samples of core material from one well (Dh4) were collected and tested to find the potential units for CO_2 injection. Analysis of the results shows that the permeability is generally less than 2 millidarcies and the capillary entry pressure is high. This poses a serious challenge with respect to achieving practical levels of injectivity and injection pressure. For further investigation, two 32-cm-long sandstone samples from the depth 675 m (Sample 1) and 679 m (Sample 2) were selected for laboratory core flooding experiments at reservoir conditions. This review presents the experimental protocol and detailed CO_2-brine drainage and imbibition relative permeability data for these two different samples of rock. Capillary pressure measurements and simulation of the transient process was used to support the interpolation of the experimental flooding data. Initial x-ray computed tomography scan showed no sign of fractures inside the cores, whereas after the core flooding experiment, there were visible fractures especially in Sample 1. Scanning electron microscopy analysis showed a high proportion of diagenetic iron-minerals in the sandstones like Fe-chlorite, Fe-carbonate, and pyrite. A brownish output flow was seen in the sample with highest porosity and permeability. Dissolution of CO_2 in the brine forms a weak acid that reacts with iron-minerals (e.g., siderite) to form iron-hydroxides.

Geology (Continued)

Severe hysteresis effects on one of the samples most likely resulted from changes in the rock composition." **Raheleh Farokhpoor, Erik Gøsta Bruno Lindeberg, Ole Torsaeter, Mai Britt Mørk, and Atle Mørk**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Regional CO_2 [storage] capacity assessment for the coastal and offshore Texas Miocene interval."

The following is the Abstract of this article: "Estimating regional geologic storage capacity potential for [CO_2] will play an important role in determining the feasibility of widespread CCS programs in the United States and worldwide. The sandstone reservoirs of the Miocene Age located off the Texas coast in the northern Gulf of Mexico are a promising target for CCS due to favorable geologic properties (high porosity/permeability, effective traps and seals, etc.) and proximity to high [CO_2] emission sources. The common method for regional storage capacity estimation involves the calculation of a pore volume which is modified by some discount or efficiency factor. Though efficiency factors have a large effect on calculated capacity, little work has been done to validate the use and effectiveness of these terms. In this paper [the authors] aim to provide an estimate for the storage potential of the coastal and offshore Texas Miocene interval using a common calculation methodology and to begin expanding on this calculation by developing and incorporating an additional sand picking refinement step. This step allows for an initial investigation into the accuracy and utility of typical efficiency factors and regional storage calculations. [The authors] find that in [their] study area, capacity that is calculated using the actual net sand thickness, or 'net capacity', is ~25 [percent] less than capacity that is calculated using the total interval thickness, or 'gross capacity', though, ideally, the two should be equal. Discrepancies between the two calculations emphasize the large uncertainty inherent in efficiency factors and highlight the need for further investigation." **Kerstan J. Wallace, Timothy A. Meckel, David L. Carr, Ramón H. Treviño, and Changbing Yang**, *Greenhouse Gases: Science and Technology.* (Subscription may be required.)

Technology

"On the CO_2 storage potential of cyclic CO_2 injection process for enhanced oil recovery."

The following is the Abstract of this article: "In this study, the potential of cyclic CO_2 injection process was examined for CO_2 storage and EOR. For this purpose, a detailed phase behavior study on the light crude oil–CO_2 and brine–CO_2 systems was conducted. CO_2 solubility in the oil and brine samples as well as oil swelling factor as a result of CO_2 dissolution was experimentally measured. The equilibrium interfacial tension of the crude oil–CO_2 system was also determined by applying the axisymmetric drop shape analysis technique for the pendant drop case. Furthermore, the minimum miscibility pressure (MMP) of CO_2 with crude oil was calculated by means of vanishing interfacial tension technique and found to be MMP = 9.18 MPa. Thereafter, series of cyclic CO_2 injection tests were designed and carried out at constant temperature of T = 30°C and various operating pressures in the range of Pop = 5.38–10.34 MPa to cover immiscible and miscible conditions. The results showed that 40–50 [percent] of the injected CO_2 was stored in the porous medium mainly through residual and solubility trappings' mechanisms. It was found that during immiscible injection condition (i.e., Pop < MMP), higher amount of CO_2 can be stored in the porous medium at higher operating pressures. The results also revealed that optimum potential of CO_2 storage is almost at operating pressures near the MMP, while beyond that pressure, the CO_2 storage capacity was not substantially increased. From the EOR point of view, the oil recovery factor was significantly improved when operating pressure increased and reached its maximum value at miscible condition (i.e., Pop $\geqslant$ MMP). During the immiscible injection scenario, mechanisms involved in oil production were mainly oil swelling and reduction of interfacial tension. However, the light component extraction was the major production mechanism contributing to the oil recovery during miscible injection process." **Ali Abedini and Farshid Torabi**, *Fuel*. (Subscription may be required.)

"Above-zone pressure monitoring and geomechanical analyses for a field-scale CO_2 injection project in Cranfield, MS."

The following is the Abstract of this article: "Pressure and temperature monitoring of an above-zone monitoring interval (AZMI), as well as of an injection zone (IZ), has been attempted at a field-scale CO_2 injection site in Cranfield, MS. Recorded pressure data in the AZMI revealed a certain amount of increase with no evidence of direct fluid flow between the IZ and the AZMI. [The authors] therefore attempted to interpret the field-measurement data from a geomechanical perspective. First, [the authors] tried an analytical approach that combined Green's functions with a poroelastic theory that is based on Segall's derivation (1992). The analysis was shown to provide fast first-order and probabilistic estimation. Next, [the authors] attempted a numerical simulation in which fully coupled calculation between fluid flow and poroelasticity was implemented. Numerical-simulation results using COMSOL matched well with the field data at one monitoring location in the AZMI. However, field data differ from those of a numerical simulation at the other monitoring well. [The authors] suggest that field measurement at the other location in the AZMI might be disturbed during the pressure monitoring, based on bottom-hole pressure records in the IZ and thermal signals. Following the numerical simulation, [the authors] discuss the effect of single-phase fluid flow assumption, observations for thermal effect and pore-pressure–stress coupling, and desirable resolution of pressure gauges for the optimal utilization of above-zone pressure monitoring." **Seunghee Kim and Seyyed Abolfazl Hosseini**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Storage compliance in coupled in CO_2-EOR and storage."

The following is the Abstract of this article: "[Carbon dioxide] storage compliance refers to the safe and consistent storage of a captured anthropogenic CO_2 slug in an underground geological structure. This paper investigates the storage compliance in coupled CO_2-EOR and storage projects. Storage compliance requires an oilfield operator to maintain sufficient CO_2 injection and storage capacities throughout an industrial-scale CO_2 capture and EOR-storage operation. [The authors] investigate the uncertainty in two operational parameters that

Technology (Continued)

may raise a compliance consideration: annual captured CO_2 from the power plant and CO_2 injection loss in the oilfield. The objective is to maintain sufficient CO_2 injection and storage capacities and maximize the economic benefits from the EOR-storage operation. [The authors] formulate and optimize the storage compliance problem using the method of optimization with Monte Carlo simulation. The results show that appropriate adjustment of the water-alternating-gas (WAG) ratio increases both the compliance and the economic benefits. Also, a CO_2 storage back-up in a saline [formation] allows the oilfield operator to implement more profitable EOR-storage designs. A risk-seeking operator may practice the saline [formation] back-up option to simultaneously maximize the benefits and mitigate the risk of storage capacity shortage. Finally, EOR-storage operation is less efficient than [formation] storage in terms of storage efficiency, and considerably more profitable in terms of tangible economic benefits." **Amin Ettehad**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Seabed mapping to support geological storage of carbon dioxide in offshore Australia."

The following is the Abstract of this article: "The geological storage of CO_2 has the potential to provide future clean energy solutions. Geoscience Australia has demonstrated how its national seabed mapping [program] can be successfully applied in assessing containment integrity in offshore basins. These assessments include targeted seabed research that aims to reduce uncertainty around the risks of CO_2 storage by developing an integrated understanding of the physical relationships between the deeper basin structures, the shallow (<100 m) sub-surface and seabed environments. This paper presents an overview of the science strategy developed to undertake this work in the Australian context, with reference to case studies." **Andrew D. Heap, Scott L. Nichol, and Brendan P. Brooke**, *Continental Shelf Research*. (Subscription may be required.)

"A unified model for the deployment of carbon capture and storage."

The following is the Abstract of this article: "This paper presents a comprehensive unified model for planning the retrofit of power plants with carbon capture (CC) technologies and the subsequent CO_2 source-sink matching. The planning horizon is divided into time intervals that are not necessarily of equal duration, but which represent time slices generated by specific events (e.g. start and end of plant operation) occurring in the system as well as the required degree of flexibility in planning. In CCS systems, CO_2 sources have variable flow rates and fixed operating lives, while CO_2 sinks have finite injection rate and storage capacity limits, as well as earliest times of availability. The model takes into account such physical and temporal considerations, and also accounts for the need for additional power generation to compensate for energy loss penalties resulting from the capture of CO_2. A case is used to demonstrate the application of the proposed model. Sensitivity analyses are carried out to examine the tradeoff between carbon emissions reduction and power cost, as well as the effects of uncertainties in sink characteristics and properties of compensatory power on CCS." **Jui-Yuan Leea, Raymond R. Tanb, and Cheng-Liang Chen,** *Applied Energy*. (Subscription may be required.)

Terrestrial

"Australia's Soil Carbon Baseline Mapped."

CSIRO created a new map of Australia's stored soil carbon to provide a benchmark for Australia to track future changes in soil carbon storage. The map provides soil organic carbon stocks to a depth of 30 centimeters at a national scale. CSIRO used three datasets, including CSIRO's National Soil and Spectral databases and the national Soil Carbon Research Program. The average amount of soil organic carbon in the top 30 centimeters of Australian soil was estimated at 29.7 metric tons (or "tonnes") per hectare and the total stock for Australia at 25.0 Gigatonnes with a 95 percent confidence within the range of 19.0 to 31.8 Gigatonnes. According to a CSIRO official, the maps could be used to set a baseline for national soil carbon stocks; help design national soil monitoring networks; guide future soil sampling to improve estimates of soil carbon stocks; help assess the potential of the soil to store carbon; improve terrestrial carbon budgeting; and/or assist with strategies to mitigate and adapt to the effects of a changing climate. From *Spatial Source* on March 18, 2014.

"Identifying soil organic carbon fractions sensitive to agricultural management practices."

The following is the Abstract of this article: "Agricultural management practices play a major role in the process of (soil organic carbon [SOC] storage). However, the large background of stable carbon (C) already present in the soil and the long period of time usually required to observe changes in SOC stocks have increased the necessity to identify soil C fractions with a fast response to changes in agricultural management practices. Consequently, [the authors] quantified the response of total SOC, permanganate oxidizable organic carbon (POxC), particulate organic carbon (POC) and the carbon concentration of water-stable macroaggregates, microaggregates within macroaggregates and the silt-plus clay-sized fraction (M-C, mM-C, s+cM-C, respectively) to changes in management. [The authors] chose a long-term tillage and N fertilization field experiment (18 years) located in NE Spain. In the first 5 cm depth under no-tillage (NT) compared with conventional tillage (CT), the POxC fraction and total SOC increased similarly (about 59 [percent]). However, other C pools studied (i.e., M-C, M-POxC, mM-C, POC and s+cM-C) had lower increases with values ranging from 17 [percent] to 31 [percent]. For the 5–20 and 20–40 cm soil depths, the POC was the most sensitive fraction to tillage with 46 [percent] and 54 [percent] decrease when NT was compared to CT, respectively. Likewise, the POC fraction presented the highest response to N fertilization in the three depths studied (i.e., 0–5, 5–20 and 20–40 cm). The mM-C and s+cM-C fractions presented the lowest sensitivity to changes in tillage and N fertilization management. [The authors'] results showed that the POC fraction had the greatest sensitivity to changes in agricultural management practices, proving its ability as an early indicator of optimized practices to [store] C in soil." **Daniel Plaza-Bonilla, Jorge Álvaro-Fuentes, and Carlos Cantero-Martínez**, *Soil and Tillage Research*. (Subscription may be required.)

Terrestrial (Continued)

"Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years."

The following is the Abstract of this article: "Although numerous studies have been conducted on the effect of tillage on soil organic carbon (SOC), there is still no consensus on the importance of [storage] which can be expected from reduced tillage. Most studies have used a synchronic approach in fields or long-term experiments which were often poorly characterized with respect to initial conditions. In this paper, [the authors] used a diachronic approach to quantify SOC changes in a 41 years experiment comparing no-till (NT), shallow till (ST) and full inversion tillage (FIT) combined with crop managements (residues removal, rotation and catch crops). It included SOC measurements at time 0 and every 4 years, calculations at equivalent soil mass within or below the old ploughed layer. Results show that tillage or crop management had no significant effect on SOC stocks after 41 years both in the old ploughed layer (ca. 0-28 cm) and deeper (ca. 0-58 cm). Tillage had no effect on crop yields and residues. In the reduced tillage treatments (ST and NT), SOC accumulated in the surface layer (0-10 cm), reaching a plateau after 24 years but declined continuously in the lower layer (10-28 cm) at a rate of 0.42-0.44 [percent] yr^{-1}. The difference in SOC stocks (ST or NT minus FIT) over the old ploughed layer followed a non-monotonic pattern over time. Reduced tillage caused a rapid SOC [storage] during the first 4 years which remained more or less constant (mean = 2.17 and 1.31 t ha^{-1}, resp.) during the next 24 years and disappeared after 28 years. The drop was attributed to the higher water balance recorded during years 24-28. In the reduced tillage treatments, the changes in SOC over time were negatively correlated with the water balance, indicating that [storage] rate was positive in dry periods and negative in wet conditions. This study highlights the interest of diachronic approaches to understand the effect of tillage and its interaction with environmental and management factors." **Bassem Dimassi, Bruno Mary, Richard Wylleman, Jerome Labreuche, Daniel Couture, Francois Piraux, and Jean-Pierre Cohan**, *Agriculture, Ecosystems & Environment*. (Subscription may be required.)

Trading

"Second Control Period Interim Adjustment for Banked Allowances Announcement."

The nine Northeast and Mid-Atlantic states participating in RGGI conducted a comprehensive 2012 program review and released an updated Model Rule. Each state, in accordance with their independent legal authority, has revised its CO_2 Budget Trading Program in order to be substantially consistent with the updated Model Rule. The updated Model Rule contains language to address the private bank of allowances through two distinct interim budget adjustments. The First Control Period Interim Adjustment for Banked Allowances, made over the seven-year period of 2014 to 2020, is a reduction to the CO_2 allowance base budget equivalent to the private bank of first control period allowances (allocation year 2009, 2010, and 2011). The Second Control Period Interim Adjustment for Banked Allowances, made over the six-year period of 2015 to 2020, is a reduction to the CO_2 allowance base budget equivalent to the private bank of 2012 and 2013 allocation year CO_2 allowances that are in addition to the total quantity of 2012 and 2013 CO_2 emissions. From *RGGI News Release* on March 17, 2014.

"What makes carbon traders cluster their orders?"

The following is the Abstract of this article: "The ability to trade large amounts of assets at low costs could be hindered when the size of the orders is concentrated at specific trade sizes. This paper documents evidence of size clustering behavior in the European Carbon Futures Market and analyzes the circumstances under which it happens. [The authors'] findings show that carbon trades are concentrated in sizes of one to five contracts and in multiples of five. [The authors] have also demonstrated that more clustered prices have more clustered sizes, suggesting that price and size resolution in the European Carbon Market are complementary and that carbon traders round both the price and the size of their orders. Finally, the analysis of the key determinants of the size clustering reveals that traders use a reduced number of different trade sizes when uncertainty is high, market liquidity is poor, and the desire to open new positions and cancel old ones is strong." **Fernando Palaoa and Ángel Pardo**, *Energy Economics*. (Subscription may be required.)

"The construction of Shenzhen's carbon emission trading scheme."

The following is the Abstract of this article: "The Shenzhen [emission trading scheme (ETS)] is the first urban-level 'cap-and-trade' carbon emissions trading scheme to operate in China. This paper gives an overview of the economic and emissions situation in Shenzhen and focuses on the development of the Shenzhen ETS regulatory framework. It is devised as an ETS with an intensity-based cap, output-based allocation and a market for trading of allowances. The design of the Shenzhen ETS attaches great importance to coordinate the dynamic relationships between economic growth, industrial transition and emissions control. The cap and its allocation are determined by carbon intensity reduction targets and economic output, with an aim to slow down emissions growth while mitigating shocks from economic fluctuation and industrial adjustment to market stability. The Shenzhen ETS features extensive coverage consisting of three types of regulated entities and four categories of covered emissions, in order to control carbon emissions by both improving energy efficiency and restraining growing energy demand. A competitive game theory method is created for allocation of free allowances to manufacturing enterprises. Mechanisms for carbon offsets and market stabilization are developed to promote active and orderly trading in the carbon market. Moreover, several challenges and their policy choices are detailed for the development of the Shenzhen ETS." **Jing Jing Jianga, Bin Yeb, and Xiao Ming Maa**, *Energy Policy*. (Subscription may be required.)

"A Microstructure Analysis of the Carbon Finance Market."

The following is the Abstract of this article: "The European Union Emissions Trading Scheme is the key policy instrument of the European Commission's Climate Change Program aimed at reducing greenhouse gas emissions to eight percent below 1990 levels by 2012. The key asset traded under the scheme is the European Union

Trading (Continued)

allowance (EUA). This article examines ultra-high frequency data to assess the extent of the development in the futures market of the EU Emissions Trading Scheme. [The authors'] results indicate significant developments consistent with sequential information arrival. They also indicate a negative contemporaneous relationship between volume and volatility for all contracts. The implication is that liquidity traders dominate any role played by informed traders. Incorporating the duration between trades in [the authors'] analysis has significant impact suggesting that any empirical investigation of the intra-day volume-volatility relationship needs to actively account for the impact of time elapse between trades." **Don Bredina, Stuart Hydeb, and Cal Muckleya**, *International Review of Financial Analysis*. (Subscription may be required.)

Recent Publications

"Cost and Performance Metrics Used to Assess Carbon Utilization and Storage Technologies."

The following is the Background of this DOE/NETL document: "In an effort to reduce CO_2 emissions from various industrial and power generation processes to the atmosphere, DOE NETL is funding research intended to advance state-of-the-art technologies that address the use of CO_2 in a variety of processes. Much of this research is funded and managed in the CO_2 Utilization Focus Area of the Carbon Storage Program. [Carbon dioxide] utilization efforts focus on pathways and novel approaches for reducing CO_2 emissions by developing beneficial uses for CO_2 that will mitigate GHG emissions. Utilization is an important component in carbon sequestration, also called storage. Some of the applicable approaches are conversion of CO_2 into useful chemicals and polycarbonate plastics, storage of CO_2 in solid materials having economic value, indirect storage of CO_2, and other breakthrough concepts. The term sequestration for this report is defined as the segregation of CO_2, either chemically, as in chemical utilization, or physically, as in geologic storage. This concept is therefore named CCS. Critical challenges identified in the utilization focus area include the cost-effective use of CO_2 as a feedstock for chemical synthesis, or its integration into pre-existing products. The efficiency (reaction conversion and the amount of CO_2 sequestered in a product) and energy use (the amount of energy required to utilize CO_2 in existing products) of these utilization processes also represent a critical challenge. In order to meet these challenges, metrics are developed to enable comparison of such technologies and utilization processes. In the not-too-distant past, authors and organizations have described using 'sustainability metrics' to guide decision-making in the process industries for the goals of environmental protection, economic prosperity, and social benefit."

"Opportunities for CO_2 Storage Pilot Projects across Europe."

The following is the Preamble of this document: "In the field of the geological storage of CO_2, a 'pilot' project is one that has a research objective and where less than 100,000 tons of CO_2 are injected into the subsurface, typically over a few years. Although CO_2 Geological Storage (CGS) is well advanced from a technological point of view, research based on real field sites is now strongly needed in order to maximize the efficiency of these technologies, to optimize the tools needed for monitoring and verification, and to be able to adapt to the specificity of local geological conditions. Pilot projects can thus benefit investment decisions for deployment of CCS in the foreseeable future. The CGS Europe Project consortium, involving 34 research institutes from 28 European countries (including the CO_2GeoNet Association), gathers together broad experience in many different fields of research related to CO_2 geological storage, as well as geological knowledge across the whole of Europe. A key aim of CGS Europe is to contribute to research and technological development of storage activities, in order to provide scientific knowledge to the authorities and the society in general, enabling policy makers and the public to have an informed opinion about the potential industrial development of CCS technologies. In this context, the present CGS Europe report 'Opportunities for CO_2 Storage Pilot Projects across Europe' provides an overview of the many potential pilot projects across Europe. Although currently still in the proposal stage, [the authors] take stock here of the wide range of scientific achievements that could be gained if some of the projects become a reality in the near future. CGS Europe hopes this work will contribute to building new knowledge on geological storage that can be used for the industrial demonstration and deployment of these technologies."

Legislative Activity

"Heitkamp Announces Major Legislation To Put Coal On A Viable Path Forward."

The U.S. Senator for North Dakota announced new legislation to help make it affordable for coal plants to lower their carbon emissions through the use of advanced clean coal technologies and provide a path forward for coal-fired power. Heitkamp's bill incentivizes companies to invest in technologies that reduce the carbon footprint of coal-fired power through Federal funding programs, Federal support for private investment, and recommendations to Congress that provide insight on how best to support future CCS projects in the United States. The bill supports the development and implementation of technologies that reduce the carbon footprint of coal-fired power plants through the following: developing large-scale carbon storage programs; increasing the accessibility of funds in existing Federal programs; revamping the existing R&D programs for advanced coal and CCS technologies; increasing the current tax credit for carbon storage from coal facilities; creating a variable price support for companies that capture CO_2; creating clean energy coal bonds; and requiring DOE reports to Congress on the economic and technical status of CCS research and projects. From *U.S. Senator Heidi Heitkamp News Release* on March 24, 2014.

Legislative Activity (Continued)

"Calley Signs Legislation Encouraging Further Recovery of Oil from Existing Wells."

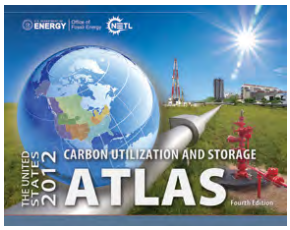
Michigan's Lieutenant Governor signed House Bill 4885 (now Public Act 82 of 2014), which reduces taxes paid by companies that use the EOR process to extract oil. In Michigan, oil and gas production is taxed under the Severance Tax Act. The tax rates are 6.6 percent for oil and 5 percent for natural gas, though the rate is reduced to 4 percent on wells that produce less than 10 barrels per day or 20 to 35 barrels a day. HB 4885 sets a flat four percent severance tax rate for companies using EOR. According to the news release, there are currently eight EOR projects underway that have combined to produce approximately 1.5 million barrels of oil since the first project began in 1997. An additional 200 million to 350 million barrels of oil could potentially be recovered through EOR, totaling 30 to 50 times Michigan's current annual production. Projects can only be undertaken with approval of Michigan's Department of Environmental Quality. Also signed were three bills that provide for the use of eminent domain when laying pipelines to transport CO_2: HB 5254, HB 5255, and HB 5274 (now Public Acts 83, 84 and 85, respectively). From *Governor Rick Snyder Press Release* on April 4, 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:

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About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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