Carbon Storage Newsletter

JANUARY 2015

WHAT'S INSIDE?

HIGHLIGHTS

"Energy Department Project Captures and Stores One Million Metric Tons of Carbon."

The U.S. Department of Energy (DOE) announced that the Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of carbon dioxide (CO_2) in a saline formation. The CO_2 is captured from the Archer Daniels Midland Company ethanol-production facility in Decatur, Illinois. It is then compressed and transported by pipeline for injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. Since initiation in November 2011, the injection has sustained pressure increases below regulatory limits. The injected CO_2 is expected to remain hundreds of feet below a 300-foot thick shale formation that acts as a seal. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying carbon capture and storage (CCS) technologies across the United States. MGSC, led by the Illinois State Geological Survey (ISGS), is evaluating CCS options for the 60,000-square-mile Illinois Basin, which underlies most of Illinois, southwestern Indiana, and western Kentucky. From *NETL News Release* on January 8, 2015.

"Oil Operators Gain Powerful, User-Friendly Enhanced Oil Recovery Planning Software."

Under a cooperative agreement with DOE's National Energy Technology Laboratory (NETL), NITEC LLC developed new software, called COZView/COZSim, that enables quicker, more affordable technical studies of CO_2-enhanced oil recovery (CO_2-EOR) for small- to mid-sized U.S. oilfield operators. The software has the following features: (1) addresses the physical and chemical factors that impact the flow and recovery of reservoir fluids, such as solubility of CO_2 in water and oil or swelling of oil in the presence of CO_2; (2) allows an integrated feasibility study to be completed within one month, compared to the six or more months required for other approaches; and (3) integrates a friendly, interactive user interface (COZView) for pre- and post-processing of simulation results with a reservoir simulator (COZSim). The COZView/COZSim software can reduce the cost to small- and mid-sized operators for commissioning technically sophisticated studies to assess the feasibility of CO_2 EOR. The NETL-funded version of the software can be downloaded from the NITEC LLC website at no cost. The website also includes a comprehensive user manual and a number of tutorials. As of December 2014, more than 80 copies of the software had been downloaded. By injecting CO_2 into oilfields that are nearing the end of prime oil production, operators can extract a portion of the remaining oil and increase geologic CO_2 storage. From *NETL News Release* on December 15, 2014.

ANNOUNCEMENTS

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

NETL's CCS Database includes active, proposed, and terminated CCS projects worldwide. The information is sourced from publically available information to provide the public with information regarding efforts by various industries, public groups,

Announcements (Continued)

and governments towards development and eventual deployment of CCS technology. As of November 2014, the database contained 274 CCS projects worldwide. The 274 projects include 69 capture, 60 storage, and 145 for capture and storage in more than 30 countries across 6 continents. While several of the projects are still in the planning and development stage, 128 are actively capturing and injecting CO_2. NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.

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

The United States of America and the People's Republic of China announced bilateral cooperation on climate change and will collaborate with other countries to adopt a protocol, another legal instrument, or an agreed outcome at the United Nations (UN) Climate Conference in Paris, France, in 2015. Under the agreement, the United States would cut its 2005 level of carbon emissions by 26 to 28 percent before the year 2025. China would peak its carbon emissions by 2030 and will also aim to increase the share of non-fossil fuels in primary energy consumption to approximately 20 percent by 2030.

NETL Collaborations Advance Carbon Management Strategies.

The Carbon Capture Simulation Initiative (CCSI) and the National Risk Assessment Partnership (NRAP) are using predictive computational modeling to help DOE meet its goal of having CCS technologies ready for demonstration in the 2020 to 2025 timeframe. For more information, visit DOE's national laboratories webpage.

ETI Seeks Partners for New CCS Storage Project.

The United Kingdom's (UK) Department for Energy and Climate Change (DECC) made approximately 3 million dollars available through the Energy Technologies Institute (ETI) for the further evaluation of CO_2 storage sites beneath the North Sea. The project will identify the next phase of storage sites that are suitable for secure, long-term storage of CO_2 captured from coal or gas power stations and heavy industry, such as steel and cement factories.

BSCSP Kevin Dome Carbon Storage Project Blog Available.

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

RGGI States Initiate Bidding Process for Auction 27.

The Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for the 27th CO_2 allowance auction scheduled for March 11, 2015. The Auction Notice provides participants with the information needed to submit a Qualification Application and indicate their intent to bid in Auction 27. The states will offer 15,272,670 CO_2 allowances for sale at a reserve price of $2.05 in 2015. There is also a 10 million CO_2 allowance cost containment reserve (CCR) available for this auction, which will be accessed if the interim clearing price exceeds the CCR price of $6.00.

Carbon Storage in the News

"Drax CCS Well Drilling Design Contract Signed."

National Grid awarded the front-end engineering and design (FEED) contract to Applied Drilling Technology International (ADTI) for well drilling in the North Sea to store CO_2 from the White Rose CCS project in the United Kingdom. ADTI will design a shallow water well envelope with features making the wells suitable for storing CO_2. ADTI will also research suitable materials and programming and estimate these costs. The White Rose CCS project is a collaborative effort of Capture Power, a consortium of Drax Power, Alstom, and BOC. The project will capture carbon from a 426-megawatt power plant planned for land next to Drax Power Station in North Yorkshire. The White Rose CCS project was awarded European Union funding in July 2014 and also won initial FEED funding from the UK government in December 2013. From *The Chemical Engineer* on December 22, 2014.

Science

"Wall Brown Butterfly 'May Be a Victim of Climate Change.'"

According to Belgian scientists, the population decline of the wall brown butterfly from areas of southern England may be the result of potentially warming weather patterns. Recent research claims that

Science (Continued)

warming conditions are causing the butterfly to hatch too late in the year to survive, falling into a "development trap." Instead of spending the entire winter as a caterpillar, the wall butterfly offspring are turning into butterflies later in the year (September and October), when it is too cold and there is insufficient food supply. Since 1976, the wall butterfly has decreased by 86 percent in England. The butterfly has nearly disappeared from most of central and southern England, but continues to survive at coastal sites. The research, published in the online journal "Oikos," showed that the micro-climate at the inland sites was an average of 1.2°C warmer than the coastal sites, leading scientists to suggest that the butterfly can maintain its traditional life cycle at coastal sites due to cooler conditions by the sea. From *The Guardian on* December 24, 2014.

"Mussel Shells Being Affected Due to Climate Change."

According to researchers from the University of Glasgow in Scotland, the mussel population may be affected by potential climate change, as their shells have become more brittle as water becomes more acidic. The more acidic oceanic water may also be affecting the yields of mussels available for the fishing industry. According to the study, mussels growing in the wild may be more prone to attacks by predators and may also be affected by other ocean forces. The researchers came to their conclusions by studying common blue mussels in laboratory tanks and changing the water temperature and pH levels to simulate different types of ocean waters. Some experts' projections claim the world's oceans may become more acidic in the coming decades. From *Austrian Tribune* on December 29, 2014.

"Top Weather Conditions that Amplify Lake Erie Algal Blooms Revealed."

A study conducted by researchers at Ohio State University claims that wind is the most important weather-related factor contributing to harmful algal blooms (HABs) in Lake Erie, suggesting that potential climate change may have to be incorporated into HAB prevention efforts by environmental agencies. The researchers analyzed nine environmental factors in Lake Erie from 2002 to 2012, using data from the sensor onboard the European Space Agency's Envisat satellite Medium Resolution Imaging Spectrometer (MERIS) to examine how the lake water changed colors (an indication of the concentration of the toxic blue-green algae present in HABs). The study found that spanning the 10-year period, wind speed contributed to HABs more consistently than other environmental factors, such as sunshine, precipitation, water temperature, and water quality. From *Science Daily* on December 17, 2014.

Policy

"Alberta's Climate Change Regulations Extended."

The Government of Alberta announced the extension of four climate change regulations through the end of June 2015 to allow for the continued analysis of new approaches and partnership opportunities discussed at the UN climate change conference in Peru in early December 2014. The four regulations are the Specified Gas Emitters Regulation (SGER), the Specified Gas Reporting Regulation (SGRR), the Administrative Penalty Regulation, and the Climate Change and Emissions Management Fund Administration Regulation. The SGER outlines compliance options and sets Alberta's greenhouse gas (GHG) emissions reduction target from business as usual at 12 percent for facilities emitting more than 100,000 metric tons of GHGs. The SGRR requires facilities emitting more than 50,000 metric tons of GHGs annually to report emission levels. The Administrative Penalty Regulation provides authority to issue a penalty for compliance breaches under SGER and SGRR. Finally, the Climate Change and Emissions Management Fund Administration Regulation enables the Climate Change Emissions Management Corporation to decide how to administer money paid to the corporation. The regulations were set to expire on December 21, 2014. The new climate change framework will be introduced in 2015. From *Government of Alberta News Release* on December 19, 2014.

"In silico science for climate policy: How policy-makers process and use carbon storage simulation data."

The following is the Abstract of this article: "Knowledge gained from computer simulations in new earth-related technologies is not limited to the scientific community itself but impacts other domains of society such as politics, business and industry, and the public at large. In general business and industry in the oil and gas business are using computer simulations on a daily basis. In this case it is using computer simulations to gain understanding of the risk of a new technology which would affect the subsurface on a large scale and hence in Europe a substantial amount of people. So far, research did not consider in depth patterns of in silico science for policy. This paper [analyzes] how policymakers process and use simulation data based on a case-study of geo-scientific [CO_2] capture modeling. The empirical results are based on 19 qualitative interviews with decision-makers from politics, business and industry, and society. The empirical results reveal a great variety of co-existing perception, evaluation and use patterns of how decision-makers deal with simulations. The field work reveals that the current state-of-the-art in research literature which emphasizes an overall misperception, misunderstanding and misuse of simulation data by policy-makers is, in general, not backed by the case-study results. However, scientific simulations do leave considerable room for misunderstandings for experts not disposing on specific geo-scientific and simulation expertise." **Dirk Scheer**, *Environmental Science & Policy*. (Subscription may be required.)

Geology

"Fractal analysis in pore structure of coal under conditions of CO_2 sequestration process."

The following is the Abstract of this article: "A high pressure supercritical CO_2 (HP-ScCO_2) geochemical reactor was used to simulate CO_2 [storage] into deep coal seam under around 40 °C and 9.8 MPa for 72 h and fractal analysis were employed to study the mercury intrusion data of 4 different coal rank samples before and after the ScCO_2–H_2O treatment, focusing on the pore structure.

Geology (Continued)

It is revealed from the mercury porosimetry data that after exposure to the $ScCO_2$–H_2O fluid, the true density of coal samples are changed as well as total pore volume and porosity most importantly in the increase of micro-pore range. Fractal analysis is introduced to distinguish inter- and intraparticle pores at lower mercury intrusion pressure and to identify the initial pressure associated with the coal compressibility. Three values of fractal dimension (D_1, D_2, and D_3) are obtained under different pressure ranges, which can be classified corresponding to three different mercury intrusion processes. Varied D_1 values are mainly due to the accumulation mode of samples in the penetrometer and can be used to distinguish the interpore and intrapore intrusion process at lower pressure range of mercury intrusion. D_2 values represent the mercury intrusion into intrapores. D_3 value is decreasing as coal rank increased and can be used to describe the initial pressure when coal samples begin to be compressed or deformed at higher pressure of mercury intrusion. The experiments revealed that CO_2 [storage] process changed the physical properties of coal samples, especially in compression resistance. Coal rank and ash content in coal are important factors which will affect the variation of coal structure during CO_2 [storage]." **C.J. Liu, G.X. Wang, S.X. Sang, W. Gilani, and V. Rudolph**, *Fuel.* (Subscription may be required.)

"Mineral carbon storage in pre-treated ultramafic ores."

The following is the Abstract of this article: "Mineral carbon [storage] (MCS) is a type of carbon storage based on natural rock weathering processes where CO_2, dissolved in rainwater, reacts with alkaline minerals to form solid carbonates. Although MCS has advantages over other carbon storage techniques, an economic MCS process has not yet been developed. Two approaches were taken in this work to attempt to reduce the cost of MCS. The first approach was to use a waste material, serpentine waste from ultramafic nickel ore processing, as a feedstock. The second approach was to develop pre-treatments to increase the carbon storage capacity of the feedstock. Two pre-treatments were investigated in this work, including microwave pre-treatment and leaching with ligands at neutral to alkaline pH. The carbon uptake of ultramafic ores was found to increase with increasing microwave pre-treatment after a threshold heating time of 4 min was surpassed. A maximum carbon uptake of 18.3 g CO_2/100 g ore (corresponding to a carbonate conversion of 36.6 [percent]) was observed for microwave pre-treated ore. The increase in carbon uptake was attributed primarily to the conversion of serpentine to olivine in ultramafic ores that occurs as result of microwave pre-treatment. The effect of five different ligands (catechol, citrate, EDTA, oxalate and tiron) on the carbon uptake of ultramafic ores was investigated. Of the ligands tested, only catechol and tiron were found to both improve the leaching of magnesium from the ores and the quantity of CO_2 stored. A maximum carbon uptake of 9.7 g/100 g ore (corresponding to a carbonate conversion of 19.3 [percent]) was observed for ultramafic ore pre-leached and carbonated in tiron solution at pH 10. This is the first time ligands have been reported to improve the carbon uptake of mineral carbon [storage] feedstock. Although process optimization work was not conducted, both microwave pre-treatment and leaching with ligands at neutral to alkaline pH show promise as ways to lower the cost of MCS." **Erin R. Bobicki, Qingxia Liu, and Zhenghe Xu**, *Minerals Engineering*. (Subscription may be required.)

"APTES grafted ordered mesoporous silica KIT-6 for CO_2 adsorption."

The following is the Abstract of this article: "Pure KIT-6 was synthesized using pluronic P123 ($PEO_{20}PPO_{70}PEO_{20}$, mw ~ 5800 Da) surfactant in mild acidic condition. It was functionalized with (3-aminopropyl) triethoxysilane (APTES) by grafting in dry and aqueous solvent at 80 °C. Cubic (Ia3d) structure and uniformity of the adsorbents were analyzed by small angle powder X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM). Physical properties of the adsorbents were characterized by nitrogen adsorption/desorption behavior, infrared spectroscopy (IR) and thermo gravimetric (TG) analysis. CO_2 adsorption/desorption behavior of the adsorbents was studied in a gravimetric analyzer. Optimum amine loading was substantially increased from 1.74 mmol N g^{-1} in dry grafting to 2.75 mmol N g^{-1} in aqueous grafting. The adsorption capacity was also remarkably increased from 0.90 mmol CO_2 g^{-1} (An_K_9.0A) to 1.56 mmol CO_2 g^{-1} (Aq_K_0.20W_9.0A) at 30 °C. The heat of adsorption of the process was in the range of 20–32 kJ mol^{-1}. The adsorbent showed its stability with the adsorption capacity remaining constant over 10 adsorption/desorption cycles." **Rupak Kishor and Aloke Kumar Ghoshal**, *Chemical Engineering Journal*. (Subscription may be required.)

"Molecular dynamics simulation on volume swelling of CO_2–alkane system."

The following is the Abstract of this article: "The microscopic mechanism of the volume swelling of CO_2–alkane (decane, octane, hexane and cyclohexane) systems and the effects of temperature, pressure and alkane structure on the volume swelling of CO_2–alkane systems are investigated by performing molecular dynamics simulation. It is shown that the increase in pressure, the reduction in temperature and the straight-chain structure of the alkane are of benefit to the volume swelling of CO_2–alkane systems by calculating the volume swelling coefficient; CO_2 in supercritical state plays a dominant role in the volume swelling of CO_2–alkane systems. The microscopic process of the volume swelling of CO_2–decane system shows that the increase in the average separation distance between decane molecules and the stretch of decane molecules result in the volume swelling of decane as CO_2 dissolve into decane. The calculations of interaction energies in CO_2–decane system indicate that the interaction between CO_2 and decane molecules is responsible for the volume swelling of CO_2–alkane system. Further study on the interaction between CO_2 and decane molecules shows that the dispersion interaction, resulting in the different solubility of CO_2 in alkanes, is the essence of the volume swelling for CO_2–alkane system. This work is a good start on understanding the mechanism of alkane swelling influenced by CO_2 at the molecular level and provides useful information for guiding CO_2 enhancing oil recovery." **Bing Liu, Junqin Shi, Baojiang Sun, Yue Shen, Jun Zhang, Xu Chen, and Muhan Wang,** *Fuel*. (Subscription may be required.)

TECHNOLOGY

"Assessment of the recovery and front contrast of CO_2-EOR and sequestration in a new gas condensate reservoir by compositional simulation and seismic modeling."

The following is the Abstract of this article: "While mature oil reservoirs and [formations] are considered to be good potential candidates for CO_2 [storage], [the authors] proposed and investigated an alternative which combines CO_2 [storage] and CO_2-EOR at the start of production in a gas condensate reservoir. First, [the authors] established a co-simulation workflow with a combination of compositional reservoir simulation and synthetic seismic simulation. Next, [the authors] conducted compositional reservoir simulation and synthetic seismic simulation in a five-spot well pattern to investigate whether seismic data can monitor the CO_2 front and gas condensate bank with CO_2 injected from the beginning of well production. Then, [the authors] compared the compositional simulation results with the seismic simulation results. Although the density contrast among reservoir gas, injected CO_2, and condensate is lower than the density contrast in the case of CO_2 [storage] in [formations], the seismic signal may have the potential to capture this smaller difference, monitor the CO_2 injection front, and locate the condensate zone, depending on the temperature, pressure and phase properties. When no adequate data are available for reservoir characterization at an early period of production, the seismic data is the only direct measurement of inter-well properties. It may be valuable for reservoir characterization and for the evaluation of the condensate block. It can serve as the basis for time-lapse monitoring. [The authors] compare production by natural depletion with production by CO_2-EOR and [storage] started at the beginning of well production. It shows that the latter will speed up the recovery process and increase the recovery rate while simultaneously storing a large amount of CO_2 in the reservoir." **Chengwu Yuana, Zhong Zhang, and Kaijian Liu**, *Fuel.* (Subscription may be required.)

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

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

"Ground Gas Monitoring: Implications for Hydraulic Fracturing and CO_2 Storage."

The following is the Abstract of this article: "Understanding the exchange of CO_2 and methane (CH_4) between the geosphere and atmosphere is essential for the management of anthropogenic emissions. Human activities such as CCS and hydraulic fracturing ('fracking') affect the natural system and pose risks to future global warming and to human health and safety if not engineered to a high standard. In this paper an innovative approach of expressing ground gas compositions is presented, using data derived from regulatory monitoring of boreholes in the unsaturated zone at infrequent intervals (typically 3 months) with data from a high frequency monitoring instrument deployed over periods of weeks. Similar highly variable trends are observed for time scales ranging from decades to hourly for boreholes located close to sanitary landfill sites. Additionally, high frequency monitoring data confirm the effect of meteorological controls on ground gas emissions; the maximum observed CH_4 and CO_2 concentrations in a borehole monitored over two weeks were 40.1 [percent] v/v and 8.5 [percent] v/v respectively, but for 70 [percent] of the monitoring period only air was present. There is a clear weakness in current point monitoring strategies that may miss emission events and this needs to be considered along with obtaining baseline data prior to starting any engineering activity." **Christopher J. Teasdale, Jean A. Hall, John P. Martin, and David A. C. Manning**, *Environ. Sci. Technol*. (Subscription may be required.)

TERRESTRIAL

"The importance of soil sampling depth for accurate account of soil organic carbon sequestration, storage, retention and loss."

The following is the Abstract of this article: "Soil organic carbon distribution within soil profile is highly influenced by management practices, especially tillage systems where soil environment is altered. Such changes in soil environment will affect soil carbon retention or accumulation in different layers of the soil profile. However, much published research in the area of soil organic carbon (SOC) sequestration focuses on shallow sampling depths within the 0–30 cm tillage zone when determining SOC stocks and sequestration. The objectives of this study are to quantify the SOC stock differences with depth between tillage treatments after 20 years and to determine the appropriate sampling depth when assessing SOC stocks as influenced by management practices. A 20-year moldboard plow (MP), chisel plow (CP) and no-tillage (NT) study was established with a maize–soybean rotation. The 75-cm root zone was sampled in 5-cm intervals to measure SOC stocks. The SOC sequestration, storage, retention and loss were determined for the0–5 cm, 0–15 cm, 15–75 cm and 0–75 cm layers. The NT treatment did retain more SOC stock than the MP treatment to a 20 cm depth but the SOC stock of the 20–35 cm layer NT system was lower than the MP system. It is recommended that the depth of soil sampling has to include the entire root zone to accurately report SOC stock and the effect of tillage system on change in SOC." **K.R. Olson and M.M. Al-Kaisi**, *CATENA*. (Subscription may be required.)

Terrestrial (Continued)

"Short-term carbon dioxide emission under contrasting soil disturbance levels and organic amendments."

The following is the Abstract of this article: "Agriculture can be either a source or sink of atmospheric CO_2 depending on soil management. The application of swine slurry in conventional tilled soils could enhance soil CO_2 emission depleting soil organic C stocks. However, the use of recalcitrant C-rich organic fertilizers in no-till soils can offset soil CO_2 emission promoting soil C [storage]. This hypothesis was tested by evaluating short-term CO_2-C emissions from a Rhodic Nitisol under contrasting soil disturbance levels (disturbed (DS) and undisturbed soil (US)) top-dressed with mineral or organic fertilizers (urea (UR), raw swine slurry (RS), anaerobically digested swine slurry (ADS), and composted swine slurry (CS)). Soil CO_2 emission was evaluated for 64 days using static chambers where gas samples were collected and [analyzed] by photoacoustic infrared spectroscopy. Soil water-filled pore space (WFPS), temperature and meteorological data were concomitantly registered and a first-order exponential decay model was used to assess the decomposition of organic fertilizers and CO_2 emissions induced by soil disturbance. Soil CO_2-C emission was correlated with soil temperature, while limiting soil aeration impaired CO_2-C efflux when WFPS >0.6 $cm^3\ cm^{-3}$. Disturbance increased soil CO_2-C efflux (36.3 ± 2.2 kg CO_2-C $ha^{-1}\ day^{-1}$) in relation to US (33.3 ± 1.6 kg CO_2-C $ha^{-1}\ day^{-1}$). Extra labile C input through RS amendment induced an increased soil CO_2-C efflux for a longer period ($t_{1/2}$ = 16.9 and 9.6 days in DS and US treatments, respectively), resulting in higher CO_2-C emissions than soil amended with other fertilizers. The recalcitrant C input by ADS and CS had limited effect on soil CO_2-C emissions. CS presented a genuine potential for substantial soil organic C accumulation while offsetting increased CO_2-C emissions in comparison to RS amended soils." **Roberto André Grave, Rodrigo da Silveira Nicoloso, Paulo Cezar Cassol, Celso Aita, Juliano Corulli Corrêa, Morgana Dalla Costa, and Diego Daniel Fritz**, *Soil and Tillage Research*. (Subscription may be required.)

Trading

"South Korea Launches World's Second-Biggest Carbon Market."

South Korea opened its CO_2 cap-and-trade system on January 12, 2015, limiting CO_2 emissions from power generators, petrochemical firms, steel producers, car makers, electro-mechanical firms and airlines. The market covers 525 South Korean companies that will be allotted a fixed amount of permits (totaling 1.687 million metric tons of CO_2 equivalent) to cover emissions for the next three years. Any company that exceeds its allotment must buy credits from another firm. South Korea's goal is to reduce GHG emissions by 30 percent by 2020. South Korea follows Kazakhstan as the second country in Asia to launch a nationwide emissions market; China and Japan operate regional schemes. The South Korean market is considered the second largest cap-and-trade system in the world behind Europe. From *Reuters* on January 12, 2015.

"Carbon pricing versus emissions trading: A supply chain planning perspective."

The following is the Abstract of this article: "Carbon pricing (taxes) and carbon emissions trading are two globally practiced carbon regulatory policy schemes. This paper presents an analytical supply chain planning model that can be used to examine the supply chain performance at the tactical/operational planning level under these two policy schemes. Model implementation and analyses are completed using actual data from a company operating in Australia, where these environmental regulatory policies are practiced. Numerical results provide important managerial and practical implications and policy insights. In particular, the results show that there are inflection points where both carbon pricing and trading schemes could influence costs or emissions reductions. An erratic nonlinear emissions reduction trend is observed in a carbon pricing scheme as the carbon price increases steadily; whereas emissions reduction in a carbon trading scheme follows a relatively linear trend with a nonlinear cost increase. Overall, a carbon trading mechanism, although imperfect, appears to result in better supply chain performance in terms of emissions generation, cost, and service level; even though a carbon tax may be more worthwhile from an uncertainty perspective as emissions trading costs depend on numerous uncertain market conditions." **Atefe Zakeri, Farzad Dehghanian, Behnam Fahimnia, and Joseph Sarkis**, *International Journal of Production Economics*. (Subscription may be required.)

"Gains from Emissions Trading Under Multiple Stabilization Targets and Technological Constraints."

The following is the Abstract of this article: "This study quantified the effectiveness of emissions trading by considering multiple technological constraints, burden sharing schemes, and climate stabilization targets. [The authors] used a global computable general equilibrium model, and evaluated the effectiveness of emissions trading using welfare losses associated with climate mitigation for scenarios with and without emissions trading, as measured by the Hicksian Equivalent Variation (HEV). [The authors] found that emissions trading contributed to a reduction in the economic losses associated with climate mitigation for all technological assumptions, burden sharing schemes, and stabilization targets. The net global welfare losses in scenarios without emissions trading ranged between 0.7 [percent] and 1.9 [percent], whereas emissions trading reduced the losses by 0.1 [percent] to 0.5 [percent]. The range depended on the assumptions in the burden sharing schemes, technological constraints, and stabilization targets. The percentage change in welfare gain from emissions trading varied regionally, and was relatively high in low-income or middle-income countries (0.2 [percent] to 1.0 [percent] and − 0.1 [percent] to 1.2 [percent], respectively) compared to high-income countries (− 0.1 [percent] to 0.3 [percent]). Some regions displayed negative values with regard to the effectiveness of emissions trading, which might be due to the change in goods and service trades associated with emissions trading. If the usage of [CCS] was constrained, welfare loss became large and the effectiveness of emissions trading ultimately increased. The use ofa burden sharing scheme was a significant factor in changing the effectiveness of emissions trading, and the per capita emissions convergence in 2050 was more effective for emissions trading than a per income convergence." **Shinichiro Fujimoria, Toshihiko Masuia, and Yuzuru Matsuokab**, *Energy Economics*. (Subscription may be required.)

Recent Publications

"Imaging Techniques for Analyzing Shale Pores and Minerals."

The following is from the Introduction of this NETL-published document: "Shales have long played an important role in acting as seals for oil and gas reservoirs, and more recently have been exploited as reservoirs themselves. Shale gas and oil reserves around the world are now estimated at 7,299 trillion cubic feet of natural gas and 345 billion barrels of oil that are now technically recoverable due to advances in horizontal drilling and hydraulic fracturing. The same properties that allow shale formations to seal hydrocarbon reservoirs may also allow them to act as seals for carbon storage, and unconventional oil and gas shales show that it may be possible to simultaneously exploit shales as seals and reservoirs. Studies have shown that CO_2 can be used as a hydraulic fracturing fluid, and in the future it may prove advantageous to couple hydrocarbon extraction and carbon storage through the injection of waste CO_2 to enhance shale, production during drawdown. In order to take full advantage of shale's potential either as a carbon storage caprock or reservoir, it is important to understand the void spaces within shales that control flow pathways and potential storage volumes. Various imaging techniques can be applied to the study of this problem. The goal of this report is to ease the learning curve of researchers attempting to examine shale for the first time by presenting various imaging techniques, basic explanations of their operations, their capabilities and limits, and their potential application to the study of shales. Particular focus will be given to visualizing pores and compositional variations, both of which are important to shale's sealing properties. While the descriptions and analyses presented in this report are applicable to the study of all shales, samples presented are mainly Marcellus Shale due to regional availability."

Legislative Activity

"Inslee Announces Slate of Proposals to Curb Pollution, Transition Washington to Cleaner Sources of Energy."

Washington's Governor announced a set of proposals to transition Washington to cleaner sources of energy and meet statewide CO_2 emission limits adopted by the state Legislature in 2008. The proposed "Carbon Pollution Accountability Act" (CPAA) would create a new, market-based program that limits CO_2 emissions and requires major emitters to pay for their emissions. The emissions limit would decrease over time, allowing emitters time to transition to cleaner technologies and/or improved operations. According to the release, the program would generate approximately $1 billion in the first year. The proceeds could be used for transportation, education, tax relief, and other purposes. The proposal is founded upon recommendations provided by the Carbon Emissions Reduction Taskforce, which included representative input from several groups, including business, labor, health care, utilities, at-risk communities, government, and others. The proposals build on an executive order previously issued by the Governor. In addition to the CO_2 emission limits, the proposals aim to promote cleaner transportation options for consumers, growth in the clean energy industry, and lower energy costs through energy efficiency. More information on the proposal is available online. From *Washington Governor Jay Inslee News Release* on December 17, 2014.

"Constructing a Legal Framework for Carbon Capture and Storage in New Zealand: Approaches to Legislative Design."

The following is the Abstract of this article: "In 2009 the International Energy Agency called attention to the need for states to regulate [CCS] activities. The New Zealand Government has responded to this call by, among other things, commissioning a report on the regulation of CCS. This report, authored by Professor Barry Barton, Kimberley Jordan and the author of this paper, was launched in December 2013. This paper starts by providing a brief overview and update of the New Zealand legal and regulatory position on CCS. The bulk of the paper then seeks to address in more detail one particular issue - that of legislative design for a fledgling CCS regime." **Greg Severinsen**, *Energy Procedia*. (Subscription may be required.)

"Implementation of the EU CCS Directive in Europe: Results and Development in 2013."

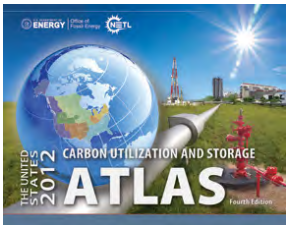
The following is the Abstract of this article: "Directive 2009/31/EC of the European Parliament on the geological storage of [CO_2], entered into force on June 25th 2009. By the end 2013 the CCS Directive has been fully transposed into national law to the satisfaction of the EC in 20 out of 28 EU Member States, while six EU countries (Austria, Cyprus, Hungary, Ireland, Sweden and Slovenia) had to complete transposing measures. In July 2014 the European Commission closed infringement procedures against Cyprus, Hungary and Ireland, which have notified the EC that they have taken measures to incorporate the CCS Directive into national law. Among other three countries Sweden has updated its legislation and published a new law in their country in March 2014, permitting CO_2 storage offshore. The evaluation of the national laws in Poland, which were accepted at national level in November 2013, and Croatia, which entered the EU on 7 July 2013 and simultaneously transposed the CCS directive, is still ongoing in 2014. The first storage permit under the Directive (for the ROAD Project in the offshore Netherlands) has been approved by the EC." **Alla Shogenova et al.**, *Energy Procedia*. (Subscription may be required.)

About DOE's Carbon Storage Program

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

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

Carbon Storage Program Resources



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

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

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

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

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About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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