CSN CARBON STORAGE NEWSLETTER

MAY 2016

This newsletter is compiled by the National Energy Technology Laboratory to provide information on recent activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news in the following areas:

CARBON STORAGE PROGRAM DOCUMENTS and REFERENCE MATERIALS

HIGHLIGHTS

"UK Center for Applied Energy Research Receives $2.4M Grant for U.S.-China Clean Energy Research Center."

The U.S. Department of Energy (DOE) selected the University of Kentucky's Center for Applied Energy Research (CAER) for a renewal of its *U.S.-China Clean Energy Research Center (CERC)* grant. The five-year DOE grant will support CAER efforts to develop advanced coal technologies. CAER is a member of CERC's Advanced Coal Technologies Consortium, whose purpose is to advance American and Chinese collaboration in advanced coal technologies, specifically carbon capture and utilization, advanced combustion systems, and geologic carbon dioxide (CO_2) storage. CERC, created in 2009 by DOE, the China Ministry of Science and Technology, and the China National Energy Administration, facilitates joint research and development (R&D) on clean energy by research teams from the United States and China. From *University of Kentucky Center for Applied Energy Research* on April 29, 2016.

ANNOUNCEMENTS

U.S. to Lead International Carbon Capture Test Network.

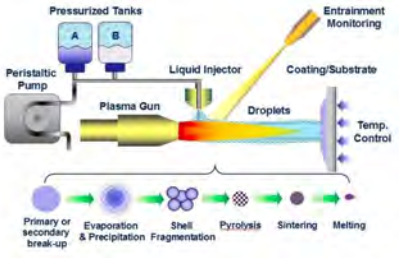
The International Test Center Network (ITCN), a global consortium of facilities conducting R&D on carbon capture technologies, will be led by the United States (represented by the Office of Fossil Energy [FE]). The ITCN was formed by the DOE-sponsored *National Carbon Capture Center (NCCC)* and Norway's *Technology Centre Mongstad (TCM)* to facilitate knowledge transfer from carbon capture test facilities around the world.

Tools to Monitor Carbon Storage Released.

Simulation tools developed by the DOE-led National Risk Assessment Partnership (NRAP) are under review by members of industry, regulatory agencies, universities, and other organizations, such as the *Regional Carbon Sequestration Partnerships (RCSPs)*. The successful deployment of the tools will enable users to predict the safety and permanence of carbon storage systems. Following review, the NRAP project team will implement improvements based on the feedback, with the final tool release expected in late 2016. For more information on NRAP and the new tool set, visit the *NRAP website*.

DOE-Supported Research Has Potential to Reduce CO_2 Emissions.

Research under a National Energy Technology Laboratory (NETL)-sponsored Small Business Technology Transfer Project has led to a discovery that may reduce CO_2 emissions from power plants through a new process called "solution precursor plasma spray" (SPPS). The process provides a thermal barrier coating (TBC) with a potential for use at 1,500°C, which is a 300°C temperature advantage compared to current state-of-the-art air plasma-sprayed TBCs.



Wyoming Integrated Test Center Groundbreaking.

Construction has begun on Wyoming's Integrated Test Center, a laboratory where researchers will test new carbon-conversion technologies on a coal-fired power plant. Wyoming has pledged $15 million toward construction of the laboratory. Construction of the Integrated Test Center, located at Basin Electric's Dry Fork Station coal-fired power plant near Gillette, Wyoming, USA, is expected to be completed in 2017.

Shell Publishes 2015 Sustainability Report.

Royal Dutch Shell published its *Sustainability Report for 2015*, detailing its focus on energy transitions, such as carbon capture and storage (CCS), as well as other investments in low-carbon technologies.

CARBON STORAGE in the NEWS

"[NIST Studying New CO_2 Monitoring Technique]."

Scientists from the National Institute of Standards and Technology (NIST) are studying a CO_2 monitoring technique that may allow for more effective monitoring of storage sites under real-world conditions. Under a cooperative agreement with NETL, the NIST team, in collaboration with Harris Corporation and Atmospheric and Environmental Research (AER), built a laser-based measurement system that collected data from a mock storage site in Ft. Wayne, Indiana, USA. NIST developed a mathematical model based on the analysis of the data, the results of which allowed them to pinpoint potential releases from the ground ten times more accurately than previous monitoring techniques. From *NIST* on April 20, 2016.

"[Geologic] Carbon Dioxide Storage Technology Research Association Established in Japan."

Japan's Ministry of Economy, Trade and Industry (METI) authorized the establishment of the "Geological Carbon Dioxide Storage Technology Research Association," which will promote the development of technologies related to large-scale CCS at storage sites in Japan. According to the press release, the "Geological Carbon Dioxide Storage Technology Research Association" will target the commercialization of CCS, the establishment of safety management technologies for large-scale CCS, the establishment of injection technologies for large-scale subsurface storage, and the development of criteria and standards for improved CCS awareness. From *Research Institute of Innovative Technology for the Earth (RITE) Press Release* on March 31, 2016.

"[Carbon Storage Tested with $1.5 Billion Project in Australia]."

A CCS project will be conducted at Barrow Island in northwest Australia next year. The project will store as much as 4 million tons of CO_2 per year approximately 1.25 miles underground. Led by Chevron Corp., the project is part of the Gorgon liquified natural gas development, which began production earlier this year. From *Bloomberg* on April 19, 2016.

"Arup Appointed to Undertake Carbon Capture and Storage Study."

Arup, a global firm of consulting engineers, has been awarded funding from the Scottish Government and the U.K. Department of Energy and Climate Change (DECC) to conduct a feasibility study for a CCS plant in Grangemouth, Scotland. Appointed by Summit Power Caledonia UK Ltd (Summit), Arup will provide environmental and permitting guidance for the Caledonia Clean Energy Project, conduct risk assessments, and assist with the development of a stakeholder and engagement strategy. From *Arup News* on April 20, 2016.

"[CCS Technology Paves Way...]."

The European Commission's Horizon 2020 grant program will provide funding to the Low-Emissions Intensity Lime and Cement (LEILAC) consortium, whose project will focus on reducing the environmental impact of the construction industry through the cement sector. The technology will capture CO_2 released from limestone with potentially no additional energy costs. From *edie.net* on April 25, 2016.

"[MSU and CO_2 Storage Company Complete Phase I Algae Trial]."

$PHYCO_2$, an algae growth and CO_2 storage company, and Michigan State University (MSU) have completed the first phase of their partnership to capture CO_2 and create renewable alternative energy feedstock. Phase I set out to prove $PHYCO_2$'s technology could capture CO_2 for algae cultivation with their patented algae photo bioreactor. According to their joint ***press release***, the $PHYCO_2$ and MSU partnership's focus is to demonstrate the $PHYCO_2$-developed technology to store CO_2, reclaim water, and continuously grow multiple types of algae at an accelerated rate without sunlight. From *Carbon Capture Journal* on May 3, 2016.

SCIENCE

"Carbon Dioxide Fertilization Greening Earth, Study Finds."

According to a study published in the journal "Nature," potential rising levels of CO_2 in the atmosphere may have led to greening of 25 to 50 percent of the Earth's vegetated lands over the last 35 years. The research involved the use of data from the National Aeronautics and Space Administration's (NASA) Moderate Resolution Imaging Spectrometer and the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer instruments to determine the amount of leaf cover over Earth's vegetated regions. The results showed that CO_2 fertilization explains 70 percent of the greening effect. The Abstract of the study, titled "Greening of the Earth and its drivers," appears below. From *ScienceDaily* on April 26, 2016.

"Greening of the Earth and its drivers."

The following is the Abstract of this article: "Global environmental change is rapidly altering the dynamics of terrestrial vegetation, with consequences for the functioning of the Earth system and provision of ecosystem services. Yet how global vegetation is responding to the changing environment is not well established. Here [the authors] use three long-term satellite leaf area index (LAI) records and ten global ecosystem models to investigate four key drivers of LAI trends during 1982–2009. [The authors] show a persistent and widespread increase of growing season integrated LAI (greening) over 25 [percent] to 50 [percent] of the global vegetated area, whereas less than 4 [percent] of the globe shows decreasing LAI (browning). Factorial simulations with multiple global ecosystem models suggest that CO_2 fertilization effects explain 70 [percent] of the observed greening trend, followed by nitrogen deposition (9 [percent]), climate change (8 [percent]) and land cover change (LCC) (4 [percent]). [Carbon dioxide] fertilization effects explain most of the greening trends in the tropics, whereas climate change resulted in greening of the high latitudes and the Tibetan Plateau. LCC contributed most to the regional greening observed in southeast China and the eastern United States. The regional effects of unexplained factors suggest that the next generation of ecosystem models will need to explore the impacts of forest demography, differences in regional management intensities for cropland and pastures, and other emerging productivity constraints such as phosphorus availability." **Zaichun Zhu, Shilong Piao, Ranga B. Myneni, Mengtian Huang, Zhenzhong Zeng, Josep G. Canadell, Philippe Ciais, Stephen Sitch, Pierre Friedlingstein, Almut Arneth, Chunxiang Cao, Lei Cheng, Etsushi Kato, Charles Koven, Yue Li, Xu Lian, Yongwen Liu, Ronggao Liu, Jiafu Mao, Yaozhong Pan, Shushi Peng, Josep Peñuelas, Benjamin Poulter, Thomas A. M. Pugh, Benjamin D. Stocker**, *Nature Climate Change*. (Subscription may be required.)

POLICY

"China's Hunan Province Sets Absolute CO_2 Target for 2020."

According to the Hunan Provincial People's Government Office, the south-central China province will limit its 2020 CO_2 emissions to approximately 510 million metric tons. The target was outlined in the government's low-carbon implementation plan for 2016-2020. In addition, government officials announced plans to finalize work on a carbon emissions trading system (ETS) as part of preparations to join the national ETS. To meet the target, the provincial government will introduce advanced climate finance tools, increase international collaboration, and introduce a low-carbon building program. From *Carbon Pulse* on May 2, 2016.

"The political economy of carbon capture and storage: An analysis of two demonstration projects."

The following is the Abstract of this article: "CCS technology is considered key to mitigating climate change by international institutions and governments around the world. The technology is considered advantageous because it may enable the continued utilization of fossil fuels while curbing carbon emissions. However, development of the technology remains slow on the ground. It is generally argued that large-scale, integrated demonstration projects are needed as a next step toward commercialization. Despite government support in several countries, few projects exist so far worldwide. This paper asks why it is so difficult to get demonstration projects off the ground. The argument is that it is not only project-specific factors that determine the feasibility of demonstration, but given the need for government support, a variety of political economy factors influence decision-making processes by policy makers and companies. The paper introduces an analytical framework developed on the basis of the political economy literature that considers six sets of factors that influence outcomes. It discusses two specific projects, Longannet in the UK and Quest in Canada, and explains why one failed and the other one is under construction. The analysis shows that although climate change has been a more important policy concern in the UK compared to Canada, the specific political economy situation of fossil fuel rich provinces like Alberta has led to the Quest project going forward." **Florian Kern, James Gaede, James Meadowcroft, and Jim Watson**, *Technological Forecasting and Social Change*. (Subscription may be required.)

GEOLOGY

"Wettability, hysteresis and fracture-matrix interaction during CO_2 EOR and storage in fractured carbonate reservoirs."

The following is the Abstract of this article: "Relative permeabilities show significant dependence on the saturation path during CO_2 enhanced oil recovery (EOR) and storage. This dependence (or hysteresis) is particularly important for water-alternating-gas (WAG) injection, a successful CO_2 EOR and storage method for clastic and carbonate reservoirs. WAG injection is characterized by an alternating sequence of drainage and imbibition cycles. Hysteresis is hence common and results in residual trapping of the CO_2 phase, which impacts the volume of CO_2 stored and the incremental oil recovery. The competition between hysteresis and geological heterogeneity during CO_2 EOR and storage, particularly in carbonate reservoirs, is not yet fully understood. In this study, [the authors] use a high-resolution simulation model of a Jurassic Carbonate ramp, which is an analogue for the highly prolific reservoirs of the Arab D formation in Qatar, to investigate the impact of hysteresis during CO_2 EOR and storage in heterogeneous carbonate formations. [The authors] then compare the impact of residual trapping (due to hysteresis) on recovery to the impact of heterogeneity in wettability and reservoir structure. End-member wettability scenarios and multiple wettability distribution approaches are tested, while, effective fracture permeabilities are computed using discrete fracture networks (DFN), ranging from sparsely distributed background fractures to fracture networks where intensity varies with proximity to faults. The results enable [the authors] to analyze the efficiency of oil recovery and CO_2 [storage] in carbonate reservoirs by comparing the impact of physical displacement processes (e.g., imbibition, drainage, residual trapping) and heterogeneous rock properties (e.g., wettability, faults, fractures, layering) that are typical in carbonate reservoirs. [The authors] show that although the fracture network properties have the greatest impact on the fluid flow, the effect of wettability and hysteresis is nontrivial. [The authors'] results emphasize the need for wettability to be accurately measured and appropriately distributed in a reservoir simulation model. Similarly, [the authors'] results indicate that hysteresis effects in cyclic displacement processes must be accounted for in detail to ensure that simulation models give accurate predictions." **Simeon Agada, Sebastian Geiger, and Florian Doster**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Molecular dynamics study of CO_2 sorption and transport properties in coal."

The following is the Abstract of this article: "An understanding of gas transport in nano-scale porous media is crucial for many industrial applications, for example, processes associated with CO_2 injection, storage and enhanced coalbed methane (ECBM) production. In this study, [the authors] carried out combined molecular dynamics (MD) and Grand Canonical Monte Carlo (GCMC) simulations on the transport properties (i.e. self- and transport diffusivities and permeability) of CO_2, in a realistic intermediate rank bituminous coal (flexible coal model) at a temperature of 328 K (55°C) and a range of pressures up to 25 MPa. Self-diffusivity and sorption isotherms of CO_2 are obtained directly from the MD and GCMC simulations. The Maxwell–Stefan diffusion model was then applied to correlate the self- and transport diffusivities. The permeability was computed through an integration of the transport diffusivity over the sorption concentration obtained from the simulations. The results show that CO_2 self-diffusivity decreases with increasing reservoir gas pressure up to 8 MPa, then increases with pressure due to the interaction between coal and CO_2. The transport diffusivity increases with the reservoir gas pressure as a result of an enhanced thermodynamic factor. The simulation results reveal a negative correlation between the sorption-induced coal swelling and CO_2 self-diffusivity due to the interaction between CO_2 and coal. Rigorous modeling of gas recovery and production thus requires consideration of specific interaction of the gas and coal matrix. Permeability of CO_2 exponentially increases with the decreasing reservoir gas pressure, which is comparable with published field data." **Junfang Zhang, Michael B. Clennell, Keyu Liu, David N. Dewhurst, Marina Pervukhina, and Neil Sherwood**, *Fuel*. (Subscription may be required.)

GEOLOGY *(cont.)*

"Comparison of relative permeability-saturation-capillary pressure models for simulation of reservoir CO_2 injection."

The following is the Abstract of this article: "Constitutive relations between relative permeability (k_r), fluid saturation (S), and capillary pressure (P_c) determine to a large extent the distribution of brine and supercritical CO_2 ($scCO_2$) during subsurface injection operations. Published numerical multiphase simulations for brine–$scCO_2$ systems so far have primarily used four $k_r - S - P_c$ models. For the $S - P_c$ relations, either the Brooks–Corey (BC) or Van Genuchten (VG) equations are used. The $k_r - S$ relations are based on Mualem, Burdine, or Corey equations without the consideration of experimental data. Recently, two additional models have been proposed where the $k_r - S$ relations are obtained by fitting to experimental data using either an endpoint power law or a modified Corey approach. The six models were tested using data from four well-characterized sandstones (Berea, Paaratte, Tuscaloosa, Mt. Simon) for two radial injection test cases. The results show a large variation in plume extent and saturation distribution for each of the sandstones, depending on the used model. The VG–Mualem model predicts plumes that are considerably larger than for the other models due to the overestimation of the gas relative permeability. The predicted plume sizes are the smallest for the VG–Corey model due to the underestimation of the aqueous phase relative permeability. Of the four models that do not use fits to experimental relative permeability data, the hybrid model with Mualem aqueous phase and Corey gas phase relative permeabilities provide the best fits to the experimental data and produce results close to the model with fits to the capillary pressure and relative permeability data. The model with the endpoint power law resulted in very low, uniform gas saturations outside the dry-out zone for the Tuscaloosa sandstone, as the result of a rapidly declining aqueous phase relative permeability. This observed behavior illustrates the need to obtain reliable relative permeability relations for a potential reservoir, beyond permeability and porosity data." **M. Oostrom, M.D. White, S.L. Porse, S.C.M. Krevor, and S.A. Mathias**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

TECHNOLOGY

"Using pulse testing for [release] detection in carbon storage reservoirs: A field demonstration."

The following is the Abstract of this article: "Monitoring techniques capable of deep subsurface detection are desirable for early warning and [release] pathway identification in geologic carbon storage formations. This work demonstrates the feasibility of a pulse-testing-based [release] detection procedure, in which the storage reservoir is stimulated using periodic injection patterns and the acquired pressure perturbation signals are analyzed in the frequency domain to detect potential deviations in the reservoir's frequency domain responses. Unlike the traditional well testing and associated time domain analyses, pulse testing aims to minimize the interference of reservoir operations and other ambient noise by selecting appropriate pulsing frequencies such that reservoir responses to coded injection patterns can be uniquely determined in frequency domain. Field demonstration of this pulse-testing [release] detection technique was carried out at a CO_2 [EOR] site—the Cranfield site located in Mississippi, USA, which has long been used as a carbon storage research site. During the demonstration, two sets of pulsing experiments (baseline and [release] tests) were performed using 90-min and 150-min pulsing periods to demonstrate feasibility of time-lapse [release] detection. For [release] tests, an artificial [release] source was created through rate-controlled venting of CO_2 from one of the monitoring wells because of the lack of known [release] pathways at the site. [The authors'] results show that [release] events caused a significant deviation in the amplitude of the frequency response function, indicating that pulse testing may be deployed as a cost-effective active monitoring technique, with a great potential for site-wide automated monitoring." **Alexander Y. Sun, Jiemin Lu, Barry M. Freifeld, Susan D. Hovorka, and Akand Islam**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"A review on well integrity issues for CO_2 geological storage and enhanced gas recovery."

The following is the Abstract of this article: "The world's rapid economic growth has contributed to the ever increasing demand for energy which results in the increase of fossil fuels usage. On the other hand, renewable energies, which are considered environmentally friendly, cannot replace the fossil fuels in the short term. For this, CCS technologies could work as transitional technology. To ensure a meaningful underground storage, well integrity is potentially the greatest challenge. On one hand, the injected CO_2 may cause severe corrosion to metallic tubulars and cement in the wellbore. Identification, quantification and mitigation of this corrosion are the key to achieve satisfactory well conditions. On the other hand, the mechanical integrity loss due to cyclic and thermal loading in the well life will also occur, so to investigate and evaluate well integrity is of paramount importance to ensure a safe operation and storage. This paper presents a definition of well integrity in the scope of CSEGR as well as the mechanisms of well integrity loss. Overview on corrosion issues of metallic and cement corrosion along with the remedial measures is discussed. Through a thorough literature review, well integrity criteria for new and old wells are introduced to provide a guidance for material selection for the usage in CSEGR. Moreover, in order to evaluate the integrity of operational and abandoned wells, this paper provides a review on the existing monitoring methods, as well as risk based methods such as FEPs analysis, Performance and Risk Management, CO_2-PENS, and put forward a new concept of well integrity evaluation." **Mingxing Bai, Zhichao Zhang, and Xiaofei Fu**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

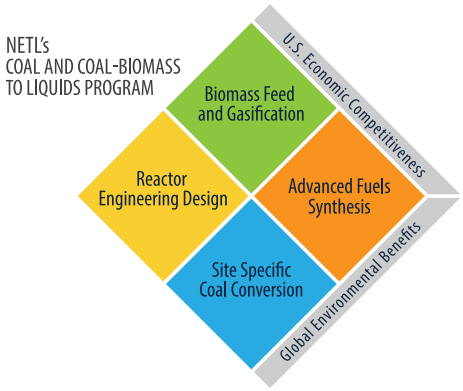
"A novel sub-seabed CO_2 release experiment informing monitoring and impact assessment for geological carbon storage."

The following is the Abstract of this article: "[CCS] is a mitigation strategy that can be used to aid the reduction of anthropogenic CO_2 emissions. This process aims to capture CO_2 from large point-source emitters and transport it to a long-term storage site. For much of Europe, these deep storage sites are anticipated to be sited below the [seabed] on continental shelves. A key operational requirement is an understanding of best practice of monitoring for potential [release] and of the environmental impact that could result from a diffusive [release] from a storage complex. Here [the authors] describe a controlled CO_2 release experiment beneath the seabed, which overcomes the limitations of laboratory simulations and natural analogues. The complex processes involved in setting up the experimental facility and ensuring its successful operation are discussed, including site selection, permissions, communications and facility construction. The experimental design and observational strategy are reviewed with respect to scientific outcomes along with lessons learnt in order to facilitate any similar future." **Peter Taylor, Henrik Stahl, Mark E. Vardy, Jonathon M. Bull, Maxine Akhurst, Chris Hauton, Rachel H. James, Anna Lichtschlag, Dave Long, Dmitry Aleynik, Matthew Toberman, Mark Naylor, Douglas Connelly, Dave Smith, Martin D.J. Sayer, Steve Widdicombe, Ian C. Wright, and Jerry Blackford**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

TERRESTRIAL

"Global zero emissions scenarios: The role of biomass energy with carbon capture and storage by forested land use."

The following is the Abstract of this article: "[The authors] investigate the prospects of three zero-emission scenarios for achieving the target of limiting global mean temperature rise to 2°C or below, and compare them with the business-as-usual (BAU) scenario involving no climate policy intervention. The '2100 zero' emissions scenario requires zero emissions after 2100 until 2150. The '350 ppm zero' emissions scenario entails zero emissions in the latter half of this century, which can be achieved by the cumulative emissions constraints of the Wigley–Richels–Edmonds (WRE) 350 from 2010 to 2150. Finally, the 'net zero' scenario requires zero cumulative emissions from 2010 to 2150, allowing positive emissions over the coming several decades that would be balanced-out by negative emissions in the latter half of the century. The role of biomass energy carbon capture and storage (BECCS) with forested land is also assessed with these scenarios. The results indicate that the 2°C target can be achieved in the 'net zero' scenario, while the '350 ppm zero' scenario would result in a temperature rise of 2.4°C. The '2100 zero' scenario achieved a 4.1°C increase, while the BAU reached about 5.2°C. BECCS contributed to achieving zero-emission requirements while providing a limited contribution to energy supply. The findings indicate substantial future challenges for the management of forested land." **Koji Tokimatsu, Rieko Yasuoka, and Masahiro Nishio**, *Applied Energy*. (Subscription may be required.)



"Long-term effects of crop rotation, manure and mineral fertilization on carbon [storage] and soil fertility."

The following is the Abstract of this article: "Carbon [storage], recently advocated to mitigate climate change, needs a thorough knowledge of the dynamics of soil organic carbon (SOC), whose study requires long-term experiments. A field trial started in 1967 is still in progress in the Southeast Po valley (Italy). It compares a [nine]-year rotation (corn–wheat–corn–wheat–corn–wheat–alfalfa–alfalfa–alfalfa), two [two]-year successions (corn–wheat and sugarbeet–wheat), continuous corn and continuous wheat. During the first 18 years (up to 1984) wheat crops were always followed by catch crops of silage corn. Within each rotation, three rates of cattle manure have been factorially combined with three mineral NP rates. In 1984 the highest manure application was stopped. Wheat straw and corn stalks have always been removed from the field. Since 1972 up to now every year [the authors] have determined the organic C and total N contents in soil samples collected from 0.40-m depth. During the first 18 years (in the presence of the catch crop) SOC exponentially declined, probably as a consequence of the intensification of tillage depth and crop succession with respect to the previous conventional agriculture. The intensification regarded ploughing, which became deeper, the number of cropped species that in most treatments was reduced, and mineral N application, which, on average, increased. The drop was faster in the sugarbeet–wheat succession than in the [nine]-yr rotation and continuous wheat. After 1985, without the catch crop, SOC linearly increased, faster in the [nine]-yr rotation and continuous wheat than in sugarbeet–wheat. The results can be ascribed to the amount and C/N ratio of debris remaining in the field after each crop, even after having taken away wheat straw and corn stalks. The debris consisted of sugarbeet tops, with a low C/N ratio, and of roots and basal culms of the two cereal crops with higher C/N ratio. Mineral fertilizers significantly increased SOC, probably for the greater amount of cereal roots and sugarbeet tops in more fertilized plots. The influence of manure was less intense, but its benefits lasted longer than 18 years after its interruption. Soil N content was more related to accumulated organic matter than to mineral N fertilisation. In conclusion the highest C [storage] was obtained with manure addition, with the highest rate of mineral fertilizers, and in the rotation containing the alfalfa ley. The effects of these factors were not additive." **Loretta Triberti, Anna Nastri, and Guido Baldoni**, *European Journal of Agronomy*. (Subscription may be required.)

TRADING

"Washington State Readies Revised CO_2 Market Plan."

Washington State plans to unveil a revised CO_2 market plan that could potentially limit out-of-state carbon credits and set new targets for industry. Once the plan is announced, the Washington State Department of Ecology will open a consultation and host webinars before adopting the measure. The revised scheme is designed to aid the state in reducing its greenhouse gas (GHG) emissions in half from 1990 levels by 2050. From *Carbon Pulse* on April 28, 2016.

"How to improve the market efficiency of carbon trading: A perspective of China."

The following is the Abstract of this article: "Emissions trading scheme (ETS) is one of the effective measures to realize energy conservation and emission reduction. In order to set up a nationwide carbon emissions trading mechanism, seven ETS pilots have been launched in China. Firstly, based on empirical investigation and research of seven pilots, this paper analyzed the market efficiency of ETS pilots from four aspects: carbon price, trading volume, market liquidity, and information transparency. The result showed that the market efficiency of ETS pilots is not satisfactory in spite of the fact that system designs of ETS have achieved preliminary result. Then, the reason for low market efficiency of ETS pilots was discussed from some factors such as institutional arrangements, market participants, the supply and demand, etc. Finally, this paper puts forward some policy suggestions to improve the market efficiency of China's carbon trading market." **Xin-gang Zhao, Gui-wu Jiang, Dan Nie, and Hao Chen**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

RECENT PUBLICATIONS

"Modeling the Impact of Carbon Dioxide [Release] into an Unconfined, Oxidizing Carbonate [Formation]."

The following is the Abstract of this Pacific Northwest National Laboratory (PNNL) document: "Multiphase, reactive transport modeling was used to identify the mechanisms controlling trace metal release under elevated CO_2 conditions from a well-characterized carbonate [formation]. Modeling was conducted for two experimental scenarios: batch experiments to simulate sudden, fast, and short-lived release of CO_2 as would occur in the case of well failure during injection, and column experiments to simulate more gradual [releases] such as those occurring along undetected faults, fractures, or well linings. Observed and predicted trace metal concentrations are compared to groundwater concentrations from this [formation] to determine the potential for [releasing] CO_2 to adversely impact drinking water quality. Finally, a three-dimensional multiphase flow and reactive-transport simulation of CO_2 [release] from an abandoned wellbore into a generalized model of the shallow, unconfined portion of the [formation] is used to determine potential impacts on groundwater quality. As a measure of adverse impacts on groundwater quality, both the EPA's MCL limits and the maximum trace metal concentration observed in the [formation] were used as threshold values."

Pacific Northwest NATIONAL LABORATORY

"Analysis Of Options For Funding Large Pilot Scale Testing Of Advanced Fossil-Based Power Generation Technologies With Carbon Capture And Storage."

The following is a description of this document: "[The Coal Utilization Research Council (CURC)] and Japan's New Energy and Industrial Technology Development Organization (NEDO) released a study titled Analysis of Options for Funding Large Pilot Scale Testing of Advanced Fossil-Based Power Generation Technologies with Carbon Capture. The paper is the product of an effort led by CURC pursuant to a contract with NEDO of Japan and as a component of the continuing collaboration between NEDO and [DOE]. Other participants to the study include Natural Resources Canada and the Korean Institute of Energy Research of the Republic of Korea."

"Carbon Capturing & Storage Technology Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2014 – 2020."

The following is from a description of this document: "Governmental agencies of developed economies are accelerating their drive to combat climatic changes, specifically focusing on the power sector as it is a major source of CO_2 emissions. [CCS] technology might play an essential role in establishing the emission reduction targets set by different countries. This technology is designed to capture the [CO_2] emissions which are primarily produced from the use of fossil fuels in industrial process and electricity generation. The captured [CO_2] can then be transported by ships and pipelines for safe storage enclosures. The stored [CO_2] can also be utilized for several commercial purposes such as [EOR] techniques. The [CCS] technology is still in the stages of development and the European Union has planned to implement this technology in large scale in 2015. Though this method has been technologically proven to work, it is not yet commercially viable on a large scale in several circumstances. The market for [CCS] technology is expected to grow at a considerable rate in future years owing to increasing investment in emission reduction technologies."

LEGISLATIVE ACTIVITY

"[U.S.] Senate OKs Bill to Promote Wide Variety of Energy Sources."

The U.S. Senate approved a wide-ranging energy bill that encourages clean coal technology, including coal-fired power plant carbon capture projects, and a variety of energy sources (e.g., solar, wind, natural gas, hydropower, geothermal). The measure would cost approximately $32 billion over five years. From *The Pittsburgh Post-Gazette* on April 20, 2016.

ABOUT DOE'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** advances the development and validation of technologies that enable safe, cost-effective, permanent geologic storage of CO_2. The Carbon Storage Program also supports the development of best practices for CCS that will benefit projects implementing CCS at a commercial scale, such as those being performed under NETL's Clean Coal Power Initiative and Industrial Carbon Capture and Storage Programs. The technologies being developed and the small- and large-scale injection projects conducted through this program will be used to benefit the existing and future fleet of fossil fuel power-generating facilities by developing tools to increase our understanding of the behavior of CO_2 in the subsurface and identifying the geologic reservoirs appropriate for CO_2 storage.

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 *National Energy Technology Laboratory's CCS Database* includes active, proposed, and terminated CCS projects worldwide. The information is taken from publically available sources to provide convenient access to information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more are available via the *Carbon Storage Program Publications webpage*.

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

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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