U.S. DEPARTMENT OF ENERGY | OFFICE OF FOSSIL ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

CSN CARBON STORAGE NEWSLETTER

JUNE 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

"Energy Department Selects Projects to Demonstrate Feasibility of Producing Usable Water from CO_2 Storage Sites."

The U.S. Department of Energy (DOE) selected two projects to test enhanced water recovery (EWR) technologies for their potential to produce useable water from carbon dioxide (CO_2) storage sites. The two projects, which will be managed by DOE's National Energy Technology Laboratory (NETL), were selected from the five Brine Extraction Storage Test (BEST) projects awarded in September 2015. The projects will receive funding to implement their field plan to validate their proposed approaches for managing reservoir pressure and the flow of stored CO_2 in saline reservoirs. The purpose of BEST field projects are to develop and validate engineering strategies and approaches for managing formation pressure through brine extraction, as well as to help to find cost-effective ways to treat extracted brines. From *Energy.gov* on June 3, 2016.

"NETL Launches a University Coalition for Fossil Energy Research at Pennsylvania State University."

DOE's NETL selected Pennsylvania State University (PSU) as the lead institution for the University Coalition for Fossil Energy Research. The Coalition brings together a multi-disciplinary team of researchers from different universities to address the research challenges of fossil energy-based technologies. In support of the Office of Fossil Energy's (FE) *Coal Program* and *Oil and Gas Program*, research conducted by the Coalition will focus on a variety of areas, including carbon capture and storage (CCS). The six-year initiative is expected to help accelerate the development and deployment of fossil fuel-based technologies in a cost-effective and environmentally safe manner. From *Energy.gov* on May 11, 2016.

ANNOUNCEMENTS

U.S., Saudi Arabia Announce International Collaboration.

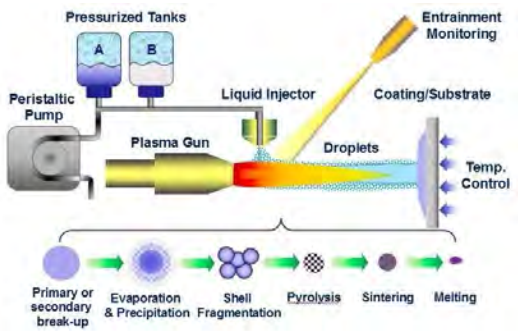
The United States and the Kingdom of Saudi Arabia announced plans to establish an international consortium to promote research, development, and demonstration (RD&D) of supercritical carbon dioxide (sCO_2) power cycles. The collaboration between the United States and Saudi Arabia builds on actions by both nations to advance sCO_2 technologies to reduce technical barriers and risks to commercialization of the sCO_2 power cycle. Other countries that are pursuing sCO_2 research and development (R&D), including the Republic of Korea, will be invited to join the new consortium.

UK Center for Applied Energy Research Receives Grant for U.S.-China Clean Energy Research Center.

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. CERC, created in 2009 by DOE, the China Ministry of Science and Technology, and the China National Energy Administration, facilitates joint R&D on clean energy by research teams from the United States and China.

DOE-Supported Research Has Potential to Reduce CO_2 Emissions.

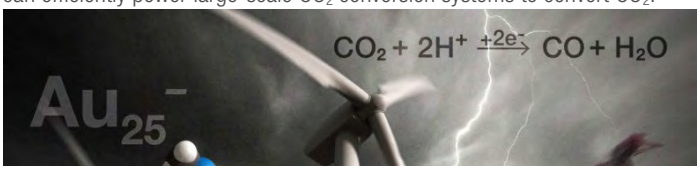
Research under an NETL-sponsored project has led to a discovery that may reduce CO_2 emissions from power plants through a new process called "solution precursor plasma spray" (SPPS). The process provides a thermal barrier coating (TBC) with a potential for use at 1,500°C, which is a 300°C temperature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



ANNOUNCEMENTS *(cont.)*

NETL Researchers Develop New CO_2 Conversion Process.

A new process developed by an NETL-led research team uses gold nanoparticles to convert CO_2 into usable chemicals and fuels. If implemented on a commercial scale, the new process has the potential to reduce atmospheric CO_2 emissions. The research team estimates that renewable energy sources can efficiently power large-scale CO_2 conversion systems to convert CO_2.



Annual Report on Market for RGGI CO_2 Allowances Released.

In reviewing the four Regional Greenhouse Gas Initiative (RGGI) CO_2 allowance auctions held in 2015, an independent market monitor found no material concerns regarding the auction process, barriers to participation, or competitiveness. According to the report, titled *"Annual Report on the Market for RGGI CO_2 Allowances: 2015,"* the average auction clearing price increased 29 percent ($4.72 in 2014 to $6.10 in 2015), and the volume-weighted average prices in the secondary market increased to an average of $6.48 in 2015. In addition, the average number of auction participants increased from 45 in 2014 to 50 in 2015.

CARBON STORAGE in the NEWS

"UK CO_2 Storage Asset Reaffirmed."

A 12-month CO_2 storage appraisal project conducted by the Energy Technologies Institute (ETI) confirmed there are a potential 579 CO_2 storage sites offshore in the United Kingdom (UK) and 20 were identified for potential future storage developers by the UK Department of Energy and Climate Change (DECC)-funded project. Five of the storage sites were then progressed towards readiness for "Final Investment Decisions" due to their potential contribution to mobilize commercial-scale CCS projects for power and industrial use in the UK. The Executive Summary of ETI's report, titled *"Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource,"* is available in the Recent Publications section of this newsletter. From *Carbon Capture Journal* on May 12, 2016.

"PTRC and University of Alberta Sign Agreement to Collaborate on Carbon Capture Storage and Utilization (CCUS) Research in Mexico."

The Petroleum Technology Research Center (PTRC) and the University of Alberta signed a Letter of Understanding (LOU) to collaborate on carbon capture, utilization, and storage (CCUS) in Mexico. The LOU, which was signed at the North American Energy Ministers Trilateral Meeting on CCUS in Mexico City, Mexico, allows the university to access research conducted at the PTRC-managed Aquistore CO_2 storage project in Saskatchewan, Canada. From *PTRC* on May 11, 2016.

"Scotland and Mexico Forge Links on Climate Action."

Representatives from the Secretaria de Energia de Mexico (SENER), the Universidad Nacional Autonóma de México (UNAM), and the Scottish Carbon Capture and Storage (SCCS) Research Partnership held a meeting to explore future research collaborations to develop CCUS technologies. A Letter of Collaboration was signed between Mexican and Scottish scientists, laying the foundation to work jointly on CCUS research and to explore international funding initiatives and potential academic opportunities. From *SCCS News Release* on May 30, 2016.

"Carbon Clean Solutions Announces Breakthrough Test Results from TCM Pilot."

Carbon Clean Solutions Limited (CCSL) announced results of a pilot test designed to measure emissions, corrosion, and energy efficiency at Technology Center Mongstad (TCM). According to the results, plant availability levels were 100 percent and there was no loss of run time due to solvent issues. During the pilot project, which ran from November 2015 through the end of March 2016, more than 25,000 tons of CO_2 were captured. In addition, the pilot demonstrated parts per billion solvent emissions compared to parts per million for traditional solvents. A separate, independent test at the University of Kentucky also confirmed a 50 percent reduction in energy consumption over conventional solvents. From *Carbon Clean Solution Press Release* on May 10, 2016.

SCIENCE

"In Latin America, Forests May Rise to Challenge of Carbon Dioxide."

According to a new study, recently established forests on abandoned Latin American farmland have the potential to store at least 31 billion tons of CO_2 if allowed to grow for another 40 years. The study, published in the journal *Science Advances*, also claims that the abandonment of additional pastures and allowing them to revert to tropical forest could store approximately 7 billion more tons of CO_2. The Abstract of the study, titled "Carbon [storage] potential of second-growth forest regeneration in the Latin American tropics," is available in the Terrestrial section of this newsletter. From *The New York Times* on May 16, 2016.

"Pacific Stores [CO_2] at Depths of Thousands of Meters."

An international team of researchers, led by the Alfred Wegener Institute, has located a CO_2 reservoir in the South Pacific Ocean at an approximate depth of 2,000 to 4,300 meters. This region was selected for sampling due to large amounts of "old" CO_2 (from a reservoir that had not been in contact with the atmosphere for a long period of time) being released into the atmosphere at the end of the last ice age. The scientists concluded that, from a climate historical perspective, the most likely place where the CO_2 was hidden was in deep oceanic water. The Abstract of the study, titled "Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool," is available to the right. From *Alfred Wegener Institute Press Release* on May 10, 2016.

"Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool."

The following is the Abstract of this article: "During the last deglaciation, the opposing patterns of atmospheric CO_2 and radiocarbon activities ($\Delta^{14}C$) suggest the release of ^{14}C-depleted CO_2 from old carbon reservoirs. Although evidences point to the deep Pacific as a major reservoir of this ^{14}C-depleted carbon, its extent and evolution still need to be constrained. Here [the authors] use sediment cores retrieved along a South Pacific transect to reconstruct the spatio-temporal evolution of $\Delta^{14}C$ over the last 30,000 years. In [approximately] 2,500–3,600 m water depth, [the authors] find ^{14}C-depleted deep waters with a maximum glacial offset to atmospheric ^{14}C ($\Delta\Delta^{14}C$=–1,000‰). Using a box model, [the authors] test the hypothesis that these low values might have been caused by an interaction of aging and hydrothermal CO_2 influx. [The authors] observe a rejuvenation of circumpolar deep waters synchronous and potentially contributing to the initial deglacial rise in atmospheric CO_2. These findings constrain parts of the glacial carbon pool to the deep South Pacific." **T.A. Ronge, R. Tiedemann, F. Lamy, P. Köhler, B.V. Alloway, R. De Pol-Holz, K. Pahnke, J. Southon, and L. Wacker**, *Nature Communications*. (Subscription may be required.)

POLICY

"[South] Korea to Double Investment in Clean Energy by 2021."

The South Korean government announced plans to spend more than $841 million on R&D of clean energy by 2021. In addition, the South Korean ministry also announced plans for detailed roadmaps for each of its six research areas, which include CCUS. From *The Korea Times* on June 3, 2016.

"Long-term abatement potential and current policy trajectories in Latin American countries."

The following is the Abstract of this article: "This paper provides perspectives on the role of Latin American and Latin American countries in meeting global abatement goals, based on the scenarios developed through the CLIMACAP–LAMP modeling study. Abatement potential in Latin America, among other things, is influenced by its development status, the large contributions of non-CO_2 and land use change CO_2 emissions, and energy endowments. In most scenarios in this study, the economic potential to reduce fossil fuel CO_2 as well as non-CO_2 emissions in Latin America in 2050 is lower than in the rest of the world (in total) when measured against 2010 emissions, due largely to higher emission growth in Latin America than in the rest of the world in the absence of abatement. The potential to reduce land use change CO_2 emissions is complicated by a wide range of factors and is not addressed in this paper (land use emissions are largely addressed in a companion paper). The study confirms the results of previous research that the variation in abatement costs across models may vary by an order of magnitude or more, limiting the value of these assessments and supporting continued calls for research on the degree to which models are effectively representing key local circumstances that influence costs and available abatement options. Finally, a review of policies in place in several Latin American countries at the time of this writing finds that they would be of varying success in meeting the emission levels proposed by the most recent [Intergovernmental Panel on Climate Change (IPCC)] reports to limit global temperature change to 2°C." **Leon Clarke, et al.**, *Energy Economics*. (Subscription may be required.)

GEOLOGY

"Impacts of Mineral Reaction Kinetics and Regional Groundwater Flow on Long-Term CO_2 Fate at Sleipner."

The following is the Abstract of this article: "[The authors] conducted coupled reactive mass transport modeling of CO_2 storage in a sandy [formation] resembling the uppermost layer in the Utsira Sand, Sleipner, North Sea, in order to investigate the general effects of rate laws and regional groundwater flow on long-term CO_2 fate in saline [formations]. The temporal and spatial evolution of CO_2 plume and the fate of injected CO_2 were simulated with a series of scenarios with different rate law formulations for dissolution and precipitation reactions and different flow regimes. The results indicated the following: (1) Changing the dissolution rate laws of the main soluble silicate minerals can influence the silicate reactions and mineral trapping by impacting the sensitivity of the relevant coupled reaction's rate to the acidification of brine. The steeper the slope of rate–ΔGr (Gibbs free energy of reaction) relationships, the more sensitive the coupled reaction rate and the mineral trapping are to the acidification of brine. The predicted fraction of CO_2 mineral trapping when using the linear rate law for feldspar dissolution is twice as much as when using the nonlinear rate law. (2) Mineral trapping is more significant when regional groundwater flow is taken into consideration. Under the influence of regional groundwater flow, the replenishment of fresh brine from upstream continuously dissolves CO_2 at the tail of CO_2 plume, generating a larger acidified area where mineral trapping takes place. In a Sleipner-like [formation], the upstream replenishment of groundwater results in ~22 [percent] mineral trapping at year 10 000, compared to ~4 [percent] when the effects of regional groundwater are ignored. (3) Using linear rate law for silicate dissolution reactions can exaggerate the effect of groundwater flow on the reaction rates and mineral trapping and can overestimate the theoretical mineral trapping capacity, compared to using the nonlinear rate law." **Guanru Zhang, Peng Lu, Xiaomei Wei, and Chen Zhu**, *Energy Fuels*. (Subscription may be required.)

"Seismic and structural geology constraints to the selection of CO_2 storage sites – The case of the onshore Lusitanian basin, Portugal."

The following is the Abstract of this article: "The Lusitanian sedimentary basin, in Portugal, has a complex tectonic history and a seismic activity determined by its proximity to the Eurasian–Nubian tectonic plate boundary. Seismic activity and geological structure impose serious constraints to the selection of CO_2 storage sites. This article focuses on the constraints imposed by active seismicity, geological structure and, as a direct consequence of the latter, by the hydrogeology and geothermal framework on the identification of onshore CO_2 storage sites in deep saline [formations] of the Lusitanian basin (central and north sectors). Several active faults and areas of higher seismic hazard have been defined, [favoring] the selection of storage sites in the northern part of the basin. The halokinetic tectonics, responsible for emplacement of salt domes, constrains the regional groundwater flow system, and suggests that it is unreasonable to consider post-salt reservoirs. In most of the Lusitanian basin the pre-salt Silves Formation is the only reservoir worth considering. Four areas have been selected where the reservoir is at adequate depth, but given the other criteria for site selection, the area designated as S. Mamede is the most interesting one for CO_2 injection." **Nadine Pereira, Júlio F. Carneiro, Alexandre Araújo, Mourad Bezzeghoud, and José Borges**, *Journal of Applied Geophysics*. (Subscription may be required.)

"Influence of relative permeability on injection pressure and plume configuration during CO_2 injections in a mafic reservoir."

The following is the Abstract of this article: "[CCS] projects have traditionally targeted deep sedimentary basins; however, mafic reservoirs may also be attractive targets for CO_2 disposal on the basis of permanent mineral trapping over relatively short time scales (101 to 102 yr). Nevertheless, CCS development in mafic reservoirs is hampered by substantial uncertainty in fracture-controlled reservoir characteristics, particularly with respect to the effects of multi-phase fluid flow, e.g., relative permeability and capillary pressure. The present study quantifies uncertainty surrounding relative permeability effects in a basalt reservoir by developing a numerical modeling experiment on the basis of site characterization data from the Slack Canyon #2 flow top, which is one of three flow tops comprising the injection zone at the Wallula Basalt Sequestration Pilot Project in southeast Washington State. This numerical modeling experiment controls for the effects of curvature in the relative permeability models by performing an ensemble of 399 CO_2 injection simulations with constant geometry and reservoir properties, while systematically varying the phase interference parameter (λ) and residual CO_2 saturation (S_{gr}), which govern wetting and non-wetting phase relative permeability, respectively. The relative permeability parameter space is defined by selecting combinations of λ and S_{gr} that cover a wide range of experimental laboratory measurements. For each simulation, CO_2 is injected into the reservoir for 10 years at a constant rate of 2.78 kg s^{-1} (87,856 metric tons [MT] yr^{-1}), which is 10 [percent] of the annual injection rate proposed for one injection scenario at the Wallula Site. Results from the ensemble of simulations show that relative permeability alone can account for >50 MPa of variability in the injection pressure and a two-fold difference in lateral CO_2 plume migration. Additionally, this work shows that curvature in the wetting phase relative permeability model is the stronger influence on reservoir pressure accumulation, while curvature in the non-wetting phase relative permeability model strongly governs CO_2 plume geometry." **Ryan M. Pollyea**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

TECHNOLOGY

"Baking Soda 'Sponge' Could Capture Carbon Emissions."

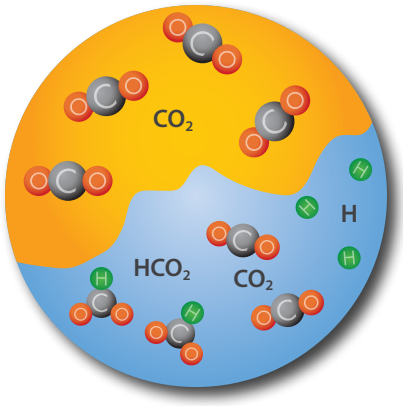
Scientists at the Lawrence Livermore National Laboratory (LLNL) in California, USA, are testing sponges filled with baking soda as a way to capture CO_2 emissions. According to the researchers, who have trialed microcapsules, the "baking soda approach" could be less expensive than currently available technology. The trailed microcapsules were created with a liquid solution of sodium carbonate at their core, surrounded by a polymer shell through which the CO_2 can flow. From *BBC News* on May 31, 2016.

"Evaluation of hydraulic controls for [release] intervention in carbon storage reservoirs."

The following is the Abstract of this article: "Assuring the storage security of geologically [stored] CO_2 is essential for proper project management and long-term emissions reductions. Storage security relies not only on comprehensive site characterization prior to injection and careful reservoir management, but also on having a suite of intervention and remediation strategies available to implement if [release] occurs. In this study sequential stages of intervention are analyzed and evaluated. The first step in halting [release] is likely to be stopping CO_2 injection in the vicinity of the [release] (also termed passive remediation). Results indicate that while passive remediation can reduce the [release] rate by an order of magnitude, completely stopping [release] may often require implementation of additional measures. Additional measures evaluated here focus largely on hydraulic controls, whereby water is injected or produced in or above the CO_2 injection reservoir in order to terminate [release]. The degree of residual trapping determines the extent to which [release] is ultimately reduced. For example, water injection into the overlying [formation] directly above a fault was able to completely terminate [release] for as long as water injection continues. Remediation was even more effective when water injection above the fault was combined with reservoir fluid production. [The authors] also show that in addition to hydraulic control methods, extracting 15–25 [percent] of the injected CO_2 can lead to permanent [release] termination. The role of reservoir heterogeneity on remediation efficacy was also examined and found to reduce the total amount of CO_2 [released] compared to a homogeneous reservoir. Overall this study demonstrates that temporally limited, multi-stage intervention strategies such as hydraulic barriers can permanently stop CO_2 [release] from storage reservoirs into overlying [formations]." **Christopher Zahasky and Sally M. Benson**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"CO_2 solubility measurements in brine under reservoir conditions: A comparison of experimental and geochemical modeling methods."

The following is the Abstract of this article: "The dissolution of CO_2 in brine (solubility trapping) is one of the most secure and permanent trapping mechanisms when considering CO_2 [geologic] storage. In addition, CO_2 dissolution in brine is an important mechanism of CO_2 enhanced oil recovery [(EOR)] as it improves sweep efficiency and increases oil displacement. Currently, there is a range of experimental methods that has been used to measure CO_2 solubility in brine and a critical review of these methods is presented here. Several different geochemical models that can be used to calculate CO_2 solubility in brine are also reviewed and the importance of selecting the correct equation of state (EoS) is addressed. Furthermore, the validity of the experimental results was ascertained through a comparison of the published experimental results with those produced through geochemical modeling. The geochemical modeling software, HydraFLASH, can be used to accurately calculate CO_2 solubilities under a number of conditions provided the correct EoS is selected. For the purpose of CO_2-water systems, the Valderrama-Patel-Teja EoS is the most accurate as it is designed to be used for systems containing polar and non-polar compounds. The published experimental results were compared with those obtained through the geochemical modeling, to ascertain the most accurate means of measuring CO_2 solubility." **Luc Steel, Qi Liu, Eric Mackay, M. Mercedes Maroto-Valer**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)



Trapping refers to the way in which the CO_2 remains underground in the location where it was injected. In solubility trapping, a portion of the injected CO_2 dissolves into the brine water that is present in the pore spaces within the rock.

The figure above depicts the CO_2 interacting with the brine water, leading to solubility trapping. At the CO_2/brine water interface, some of the CO_2 molecules dissolve into the brine water within the rock's pore space. Some of that dissolved CO_2 then combines with available hydrogen atoms to form HCO_3.

More information is available on the *DOE Carbon Storage FAQs website*.

TERRESTRIAL

"Carbon [storage] potential of second-growth forest regeneration in the Latin American tropics."

The following is the Abstract of this article: "Regrowth of tropical secondary forests following complete or nearly complete removal of forest vegetation actively stores carbon in aboveground biomass, partially counterbalancing carbon emissions from deforestation, forest degradation, burning of fossil fuels, and other anthropogenic sources. [The authors] estimate the age and spatial extent of lowland second-growth forests in the Latin American tropics and model their potential aboveground carbon accumulation over four decades. [The authors'] model shows that, in 2008, second-growth forests (1 to 60 years old) covered 2.4 million km^2 of land (28.1 [percent] of the total study area). Over 40 years, these lands can potentially accumulate a total aboveground carbon stock of 8.48 Pg C (petagrams of carbon) in aboveground biomass via low-cost natural regeneration or assisted regeneration, corresponding to a total CO_2 [storage] of 31.09 Pg CO_2. This total is equivalent to carbon emissions from fossil fuel use and industrial processes in all of Latin America and the Caribbean from 1993 to 2014. Ten countries account for 95 [percent] of this carbon storage potential, led by Brazil, Colombia, Mexico, and Venezuela. [The authors] model future land-use scenarios to guide national carbon mitigation policies. Permitting natural regeneration on 40 [percent] of lowland pastures potentially stores an additional 2.0 Pg C over 40 years. [The authors'] study provides information and maps to guide national-level forest-based carbon mitigation plans on the basis of estimated rates of natural regeneration and pasture abandonment. Coupled with avoided deforestation and sustainable forest management, natural regeneration of second-growth forests provides a low-cost mechanism that yields a high carbon [storage] potential with multiple benefits for biodiversity and ecosystem services." **Robin L. Chazdon, et al.**, *Science Advances*. (Subscription may be required.)

"CO_2 emission and structural characteristics of two calcareous soils amended with municipal solid waste and plant residue."

The following is the Abstract of this article: "This investigation examines the effect of different amendments on selected soil physical and biological properties over a 24-month period in two cropland fields. Urban municipal solid waste (MSW) compost and alfalfa residue (AR) were used as different organic amendments at the rates of 0 (control), 10 and 30 Mg ha^{-1} to a clay loam soil and a loamy sand soil in a semiarid region. Results showed that the soil improvement was controlled by the application rate and decomposability of amendments and soil type. The addition of organic amendments to the soils improved aggregate stability and consequently enhanced total porosity, especially macropore fraction. The increased soil organic carbon (SOC) and total porosity values as compared to the control treatment were greater in the loamy sand soil than in the clay loam soil. Moreover, compared to the microbial respiration of control plots, the application of MSW resulted in higher values of microbial respiration in the clay loam soil than in the loamy sand soil, whereas the reverse was found for AR. Linear and power functions were provided for the relationships between microbial respiration and SOC in the loamy sand and clay loam soils, respectively. Also, CO_2 emission was stimulated significantly as power functions of the total porosity and the ratio of macroporosity to microporosity. However, the soil microbial respiration and carbon storage improved aggregate stability and pore size distribution, and as a response, soil porosity, especially the macropore fraction, controlled CO_2 flux." **N. Yazdanpanah**, *Solid Earth*. (Subscription may be required.)

"Carbon [Storage] and Carbon Markets for Tree-Based Intercropping Systems in Southern Québec, Canada."

The following is from the Abstract of this article: "Since agriculture directly contributes to global anthropogenic greenhouse gas (GHG) emissions, integrating trees into agricultural landscapes through agroforestry systems is a viable adaptive strategy for climate change mitigation. The objective of this study was to evaluate the carbon (C) [storage] and financial benefits of C [storage] according to Québec's Cap-and-Trade System for Greenhouse Gas Emissions Allowances (C & T System) or two experimental 10-year-old tree-based intercropping (TBI) systems in southern Québec, Canada. [The authors] estimated total C stored in the two TBI systems with hybrid poplar and hardwoods and adjacent non-TBI systems under agricultural production, considering soil, crop and crop roots, litterfall, tree and tree roots as C stocks. The C [storage] of the TBI and adjacent non-TBI systems were compared and the market value of the C payment was evaluated using the net present value (NPV) approach. The TBI systems had 33 [percent] to 36 [percent] more C storage than adjacent non-TBI systems. The financial benefits of C [storage] after 10 years of TBI practices amounted to of [$1,763.88-$2,153.51] ha^{-1} and [$1,224.33–$1,493.71] ha^{-1} for St. Edouard and St. Paulin sites, respectively. [The authors] conclude that valorizing the C [storage] of TBI systems could be an incentive to promote the establishment of TBI for the purpose of GHG mitigation in Québec, Canada." **Kiara S. Winans, Joann K. Whalen, David Rivest, Alain Cogliastro, and Robert L. Bradley**, *Atmosphere*. (Subscription may be required.)

TRADING

"CO_2 Allowances Sold for $4.53 in 32nd RGGI Auction."

The nine states participating in RGGI, the Nation's first market-based regulatory program to reduce greenhouse gas (GHG) emissions, released results of their 32nd auction of CO_2 allowances. A total of 15,089,652 CO_2 allowances were sold at a clearing price of $4.53, with bids ranging from $2.10 to $12.65 per allowance. None of the 10 million cost containment reserve (CCR) allowances available were sold (CCR is a fixed additional supply of allowances only made available if allowance prices exceed certain levels). More information on Auction 32, which generated a total of $68.3 million for reinvestment in strategic programs, such as energy efficiency and GHG abatement programs, is available in the *"Market Monitor Report for Auction 32."* From *RGGI News Release* on June 3, 2016.

RECENT PUBLICATIONS

"Annual Energy Outlook 2016 Early Release: Annotated Summary of Two Cases."

The following is a description of this U.S. Energy Information Administration (EIS) document: "The Annual Energy Outlook 2016 (AEO2016) Early Release features two cases: the Reference case and a case excluding implementation of the Clean Power Plan (CPP). [1] Reference case: A business-as-usual trend estimate, given known technology and technological and demographic trends. The Reference case assumes CPP compliance through mass-based standards that establish caps on CO_2 emissions from fossil-fired generators covered by the CPP. The mass-based standards are modeled using allowances with cooperation across states at the regional level, with all allowance revenues rebated to ratepayers. [2] No CPP case: A business-as-usual trend estimate, but assumes that CPP is not implemented."

"Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource."

The following is from the Executive Summary of this ETI document: "CCS is widely recognized as a critical technology to meet the 1.5/2°C ambitions agreed at the Paris COP 21 meeting. Much progress is being made on carbon capture technologies, with mature industrial scale projects having been in operation for many years. Whilst the use of CO_2 for [EOR] is commonplace in some parts of the North America, CO_2 storage at industrial scale has only been demonstrated at a small number of sites around the world. Two of these sites are located offshore in the Norwegian sector of the North Sea at Sleipner and Snøhvit, with Sleipner reaching a key milestone in 2016 of 20 years of offshore CO_2 storage operations. The UK is fortunate to have completed three large [front-end engineering design (FEED)] study projects for offshore CO_2 storage, all of which are already or will be placed in the public domain. These were for storage sites called Hewett, Goldeneye and Endurance. Enabling CCS in the UK requires the rapid assembly of mature plans for further offshore CO_2 storage sites around the UK Continental Shelf (UKCS). Collectively, these plans will contribute towards supporting investor confidence around large energy and industrial CCS systems by assuring the presence, location and cost base of high quality offshore CO_2 storage site development options. This will support the early industrial [mobilization] of full chain CCS technology."

"Can technology unlock unburnable carbon?"

The following is a description of this white paper: "To stay within the 2°C carbon budget, a very significant reduction in fossil fuel consumption is required. [If the carbon budget is to be met,] the majority of global fossil fuel reserves cannot be combusted: the unburnable carbon. The role of technologies such as CCS may be critical in enabling a greater quantity of fossil fuel to be combusted within a low-carbon framework. However, the potential for CCS to alleviate the carbon constraint is still controversial and uncertain, with a number of studies reaching different conclusions. This extensive review paper will assess the current state of knowledge regarding the 'unburnable carbon' issue, and attempt to provide clarity by quantitatively defining the potential role of CCS in unlocking the unburnable carbon over the next 85 years."

LEGISLATIVE ACTIVITY

"Ontario Passes Landmark Climate Change Legislation."

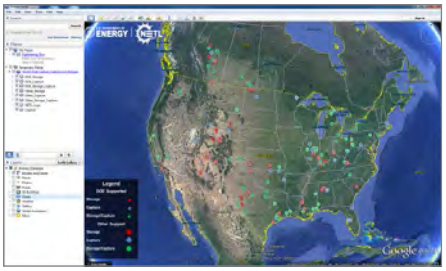
The government of Ontario passed the Climate Change Mitigation and Low-Carbon Economy Act, which lays the groundwork for the province to link its program to a carbon cap-and-trade market set up by Québec and California. Under the legislation, Ontario will deposit allowances under its cap-and-trade program into the "Greenhouse Gas Reduction Account," which invests in initiatives that reduce GHG emissions. From *Government of Ontario News Release* on May 18, 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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