NETL the ENERGY lab

Carbon Storage Newsletter

June 2014

What's Inside?

Highlights

"DOE-Sponsored Project Shows Huge Potential for Carbon Storage in Wyoming."

A U.S. Department of Energy (DOE)-sponsored study revealed that the Wyoming Rock Springs Uplift (a geologic feature in southwestern Wyoming) could potentially store 14 to 17 billion metric tons of carbon dioxide (CO_2). The project team, led by the University of Wyoming's Carbon Management Institute and sponsored by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), gathered geologic, hydrologic, and geochemical data from a test well. The Rock Springs Uplift was found to have ideal geological characteristics for carbon storage and proximity to CO_2 emission sources. The team performed digital imaging of a core sample to learn about the formation's grain size, mineralogy, facies distribution, and porosity. The team also studied geophysical data from the test well and the overlying formations that would trap the CO_2. The researchers found that the Rock Springs Uplift contains high, commercially viable concentrations of lithium; for every 1 million metric tons of CO_2 stored, approximately 250 metric tons of lithium carbonate could be recovered from processed brine. Lithium, which is used in batteries and other electronics applications, could generate revenue to offset the cost of CO_2 storage and help to reduce the need for lithium import. In addition to testing the characterization well and removing samples, the project team performed a 3-D seismic survey around the test site, allowing researchers to extrapolate the geologic properties measured in the well (e.g., porosity, permeability, and fluid saturation). The Wyoming Rock Springs Uplift storage potential is equal to 250 to 300 years' worth of CO_2 emissions produced by Wyoming's coal-fired power plants and other large, anthropogenic CO_2 sources at current emission levels. This research effort was funded by the American Recovery and Reinvestment Act of 2009 (ARRA). From *U.S. Department of Energy Press Release* on June 3, 2014.

University of Wyoming
Carbon Management Institute

Announcements

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

DOE Announces Demonstration Project Startup.
DOE and Tampa Electric Company (TECO) announced the startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida. The Polk Power Station is the first coal integrated

Announcements (Continued)

gasification combined cycle (IGCC) plant in the United States. IGCC technology has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, while increasing reliability and reducing the cost of capturing CO_2 and other contaminant emissions from power plants.

2014 CO_2 Capture Technology Meeting.

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

International Workshop on Public Education, Training, and Community Outreach for Carbon Capture and Storage.

This workshop is scheduled for July 30-31, 2014, at the National Sequestration Education Center (NSEC) in Decatur, Illinois, USA. The technical program features tools and techniques for public education, training, and community outreach on carbon capture and storage (CCS). Workshop attendees will tour the commercial-scale CCS project at the Archer Daniels Midland facility. The workshop also includes a full day of programing for K-12 teachers with interactive lesson plans related to CCS and Science, Technology, and Mathematics (STEM).

State Approves FutureGen Plans.

The Illinois Commerce Commission approved transportation and storage plans for the FutureGen 2.0 initiative, which will capture and transport CO_2 by pipeline approximately 28 miles to Morgan County, Illinois, for injection. The Illinois Commerce Commission approval is the last needed from the state agency, although approval is contingent upon receiving all necessary permits from Federal agencies.

BSCSP Kevin Dome Carbon Storage Project Blog Available.

The Big Sky Carbon Sequestration Project (BSCSP) has created a "News from the Kevin Dome" blog on the BSCSP website as an effort 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. For more information, please see the "Carbon Storage in the News" section of this newsletter.

Save the Date: MGSC Conference.

The Midwest Geological Sequestration Consortium (MGSC) will hold their annual conference at the I Hotel and Conference Center in Champaign, Illinois, USA, on November 6, 2014. More details will be available in the future.

PCOR Partnership Annual Membership Meeting.

The Plain CO_2 Reduction (PCOR) Partnership Annual Membership Meeting is scheduled for September 16-17, 2014, at the Embassy Suites Denver – Downtown/Convention Center in Denver, Colorado, USA. The meeting will highlight recent program accomplishments, storage strategies and technologies, regulatory developments, and carbon storage infrastructure. Registration, hotel information, and an agenda are available via the link.

12th International Conference on Greenhouse Gas Control Technologies.

GHGT-12 will be held on October 5-9, 2014, in Austin, Texas, USA. This will be the first visit by the conference series to Austin and more than 1,600 participants are expected to attend. The event will be hosted by the University of Texas at Austin and the IEA Greenhouse Gas R&D Programme (IEAGHG).

Carbon Storage in the News

"Wells in Northern Montana Mark Big Step for MSU Carbon Sequestration Research."

As part of BSCSP activities, Montana State University (MSU) researchers drilled two wells for the Kevin Dome Large-Scale Carbon Storage Project in Toole County of northern Montana. The wells will be used to test the formation's ability to store CO_2. Kevin Dome has the potential for large-scale carbon storage because the geologic formation has held naturally occurring CO_2 for millions of years in a deep, porous rock layer, known as the Duperow formation. BSCSP plans to extract CO_2 stored in Kevin Dome through one of the wells and transport CO_2 via pipeline into a portion of the Duperow formation where CO_2 does not naturally occur. The second well will be used to monitor the CO_2 and subsurface geochemistry near the

Carbon Storage in the News (Continued)

injection well. Scientists will monitor geology, geochemistry, water quality, air quality, and underground CO_2 behavior. Researchers also removed rock core to study the geology. One set of cores came from the well where the rock layers were subject to CO_2, while the other cores came from an area not subject to CO_2, allowing researchers to compare the chemical changes related to the presence of CO_2. Researchers conducted a seismic survey before any wells were drilled; this seismic data is being used in geologic modeling efforts and the production of 3-D subsurface images. BSCSP is one of several partnerships involved in DOE's RCSP Program. BSCSP created a short, educational film to highlight seismic survey science, titled, "What's Shaking on Kevin Dome?" From *Montana State University News Release* on June 9, 2014.

"Norway Plots Offshore Areas for CO_2 Storage."

According to atlases for the Norwegian and Barents Sea, as well as the Norwegian waters of the North Sea, Norway's continental shelf has the potential to store more than 80 billion tons of CO_2. The publisher of the atlases, the Norwegian Petroleum Directorate (NPD), claims the volume is the equivalent to 1,000 years' worth of Norwegian CO_2 emissions. From *UPI.com* on May 20, 2014.

"Oil Recovery to Resume at Local, Abandoned Oil Field."

The Michigan Department of Environmental Quality (DEQ) granted approval to Core Energy to begin CO_2-enhanced oil recovery (EOR) operations at the Chester 16 oil field in Otsego County in Michigan. Such EOR methods have been used at seven additional oil fields throughout the county, leading to the recovery of more than 1.7 million barrels of oil. The Chester 16 oil field has been abandoned since 1992. From *Petoskey News-Review* on May 22, 2014

Science

"Global Warming Could Help Bolster Turtle Population Size."

According to a study conducted by Swansea University (United Kingdom) researchers, potential climate change could bolster sea turtle population sizes in the Cape Verde Islands. According to the study, which was published in the journal "*Nature Climate Change*," the sex of sea turtle hatchlings is determined by the incubation temperature, through "temperature-dependent sex determination." The Cape Verde Islands is one of the world's largest rookeries for sea turtles. From *Phys.org* on May 19, 2014.

Policy

"EPA Proposes First Guidelines to Cut Carbon Pollution from Existing Power Plants."

The U.S. Environmental Protection Agency (EPA) released the Clean Power Plan, a proposal to ensure a healthier environment, spur innovation, and strengthen the economy. EPA is proposing guidelines that build on trends underway in states and the power sector to increase efficiency and reduce carbon emissions from existing power plants. By 2030, the proposal would: (1) cut carbon emissions from the power sector by 30 percent nationwide below 2005 levels; (2) cut particle emissions, nitrogen oxides, and sulfur dioxide by more than 25 percent as a co-benefit; (3) provide up to $93 billion in climate and public health benefits; and (4) reduce electricity bills by increasing energy efficiency and reducing demand in the electricity system. DOE will provide technical assistance and engage with state regulators, regional reliability coordinators, independent system operators, regional transmission operators, state public utility commissions, and other stakeholders. The proposal follows the Climate Action Plan and the June 2013 Presidential Memorandum. For more information on how the proposal will reduce carbon emissions, click here. From *U.S. EPA News Release* on June 2, 2014.

"Government Proposes Carbon Offset Plan."

South Africa's government announced policy plans to address the financial impact on business and industry when the nation's first tax on carbon is introduced in January 2016. According to a paper published by South Africa's National Treasury, the new "carbon offsets scheme" has the potential to reduce the total volume of GHGs at a smaller cost, while also reducing carbon intake by up to 10 percent. In addition, the proposed carbon offsets scheme could lead to a domestic trading market where companies could buy and sell carbon credits as part of the government's voluntary pledge to reduce South Africa's projected GHG emissions by 34 percent by 2020 and up to 42 percent by 2025. According to the National Treasury's paper, offsets have the potential to reduce domestic GHGs emissions by 15 million to 41 million tons every year. Currently, there are 111 registered carbon offset projects in South Africa, which were developed under the Kyoto Protocol or other voluntary market standards. From *The Mercury* on May 2, 2014.

"Scottish and Cypriot Scientists Forge Research Link."

The University of Nicosia's Center for Green Development and Energy Policy (CGD) and Scottish Carbon Capture & Storage (SCCS) reached an agreement to seek funding for European Union (EU) researchers to collaborate to identify likely geological CO_2 storage sites beneath the Mediterranean Sea to the south of Cyprus. The scientists, using methodology developed in previous SCCS projects, will study seismic data and other information to search for storage sites with the potential to increase Cyprus' carbon storage capacity. From *SCCS News Release* on May 21, 2014.

"Washington State Enacts New Regulation for Refineries."

A new rule was enacted in the state of Washington that requires refineries

Policy (Continued)

to limit GHG emissions by 2025. According to Washington's Department of Ecology (DEC), the rule establishes "reasonably available control technology" (RACT) to limit GHG emissions from the state's refineries. The rule, titled, "WAC Petroleum Refinery Greenhouse Gas Emissions Requirements," allows the five refineries throughout Washington to choose one of two options to meet the GHG emission reduction requirements: the energy efficiency standard (EES) or the emission reduction requirement (ERR). Under EES, a refinery may demonstrate reasonably available energy efficiency performance by scoring in the 50th percentile of similar-sized U.S. refineries. Under ERR, the refinery must implement GHG emission reduction projects that cumulatively achieve reductions adding up to 10 percent of the refinery's baseline year GHG emissions. From *Oil & Gas Journal* on May 29, 2014.

"Reforming the EU approach to LULUCF and the climate policy framework."

The following is the Abstract of this article: "[The authors] focus on recent progress in reforming the role of forests and other land use in the EU climate policy framework. EU inclusion of LULUCF (Land Use, Land-Use Change and Forestry) in the climate policy framework still lags international developments, remaining at odds even with the United Nations Framework Convention on Climate Change's (UNFCCC) Kyoto framework. Though the EU has made some important changes that eclipse even the UNFCCC framework—in particular regarding the inclusion of cropland and grazing land management in mandatory EU-level carbon accounting practices—in other respects the EU has far to go. As part of a strategy for fulfilling emission reduction commitments within the EU burden-sharing agreement, Member states are not permitted to trade either in domestically nor foreign produced forest-based carbon credits. On the other hand, both the EU and the UNFCCC/Kyoto LULUCF frameworks remain distant from an idealized model that could facilitate increased climate change mitigation and a more efficient and balanced use of forest-based resources. Limiting the incorporation of forests in the climate policy framework has significant consequences for the cost and rapidity of emission reductions. Forest potential thus remains under-mobilized for climate change mitigation. In this context, [the authors] draw particular attention to the fact that forest-based carbon [storage's] potential contribution to negative emissions represents an important missed opportunity. In the context of ongoing discussions over the EU and UNFCCC's Post-Kyoto frameworks, [the authors] propose an all-encompassing LULUCF carbon accounting model incorporating all previously omitted carbon pools and activities, thus weighing LULUCF removals and emissions on a par with emissions from other sectors (industry, the energy sector, end-users). The successful integration of LULUCF into the EU climate policy and carbon-trading frameworks could dovetail neatly with emerging international climate change mitigation efforts." **David Ellison, Mattias Lundblad, and Hans Petersson**, *Environmental Science & Policy.* (Subscription may be required.)

"Investment under uncertain climate policy: A practitioners' perspective on carbon risk."

The following is the Abstract of this article: "This paper introduces the concept of payment probability as an important component of carbon risk (the financial risk associated with CO_2 emissions under uncertain climate policy). In modeling power plant investment decisions, most existing literature uses the expected carbon price (e.g., the price of traded permits or carbon tax) as a proxy for carbon risk. In contrast, this paper identifies expected carbon payment as a more accurate measure of carbon risk as perceived by industry practitioners. This measure of carbon risk incorporates both expected price and the probability that this price would actually be faced in the case of a particular investment. This concept helps explain both the surge of activity in 2005–2006 and the subsequent decline in interest in coal-fired power plant development in the [United States]. The data for this case study comes from an extensive online survey of 700 U.S. energy professionals completed in 2006, as well as interviews conducted with industry representatives from 2007 to 2009. By analyzing industry views on policy uncertainty and future carbon legislation, [the authors] gain a better understanding of investor attitudes toward carbon risk. This understanding will help policy makers design better incentives for investing in low-carbon technologies." **Merrill Jones Barradale**, *Energy Policy*. (Subscription may be required.)

Geology

"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.)

"Molecular Simulation of Carbon Dioxide, Brine, and Clay Mineral Interactions and Determination of Contact Angles."

The following is the Abstract of this article: "Capture and subsequent geologic storage of CO_2 in deep brine reservoirs plays a significant role in plans to reduce atmospheric carbon emission and resulting global climate change. The interaction of CO_2 and brine species with mineral surfaces controls the ultimate fate of injected CO_2 at the nanoscale via geochemistry, at the pore-scale via capillary trapping, and at the field-scale

Geology (Continued)

molecular dynamics simulations to study the behavior of supercritical CO_2 and aqueous fluids on both the hydrophilic and hydrophobic basal surfaces of kaolinite, a common clay mineral. In the presence of a bulk aqueous phase, supercritical CO_2 forms a nonwetting droplet above the hydrophilic surface of kaolinite. This CO_2 droplet is separated from the mineral surface by distinct layers of water, which prevent the CO_2 droplet from interacting directly with the mineral surface. Conversely, both CO_2 and H_2O molecules interact directly with the hydrophobic surface of kaolinite. In the presence of bulk supercritical CO_2, nonwetting aqueous droplets interact with the hydrophobic surface of kaolinite via a mixture of adsorbed CO_2 and H_2O molecules. Because nucleation and precipitation of minerals should depend strongly on the local distribution of CO_2, H_2O, and ion species, these nanoscale surface interactions are expected to influence long-term mineralization of injected [CO_2]." **Craig M. Tennery and Randall T. Cygan**, *Environ. Sci. Technol*. (Subscription may be required.)

Technology

"Evaluation of two alternative carbon capture and storage technologies: A stochastic model."

The following is the Abstract of this article: "In this paper [the authors] evaluate two alternative CCS technologies at a coal-fired power plant from an investor's point of view. The first technology uses CO_2 for EOR paired with storage in deep saline formations (DSF) and the second merely stores CO_2 in DSF. The paper updates and improves on an earlier publication by Tzimas et al. (2005). For projects of this type there are many sources of risk, three of which stand out: the price of electricity, the price of oil and the price of carbon allowances. In this paper [the authors] develop a general stochastic model that can be adapted to other projects such as enhanced gas recovery (EGR) or industrial plants that use CO_2 for either EOR or EGR with CCS. The model is calibrated with UK data and applied to help understand the conditions that generate the incentives needed for early investments in these technologies. Additionally, [the authors analyze] the risks of these investments. Investments with EOR and secondary DSF storage can only be profitable (NPV > 0) when there is a high long-term equilibrium price for oil of more than $56.38/barrel. When the investment decision can be made at any time, i.e. there is an option value, then the trigger value for optimal investment is significantly higher." **Luis M. Abadie, Ibon Galarraga, and Dirk Rübbelke**, *Environmental Modeling & Software*. (Subscription may be required.)

"Power system planning with emission constraints: Effects of CCS retrofitting."

The following is the Abstract of this article: "Today, the world's energy needs are still supplied mainly from fossil fuel based resources. This is true for electricity generation as well, thus making the power sector responsible for 45 [percent] of GHG emissions. The present climate crisis has made it necessary to [minimize] emissions in power generation, with low-carbon energy sources taking on greater significance in recent years. However, most low-carbon sources have inherent problems, like intermittency and high capital expenditure. A suitable alternative is CCS technology which allows continued fossil fuel-based electricity generation at much lower rates of emission. Two approaches are possible in the deployment of CCS technology. The first is to introduce new power plants equipped for CO_2 capture, while systematically shutting down existing coal power plants. Another is to retrofit existing power plants for CO_2 capture. These approaches are compared in this work. The study shows that allowing CCS retrofitting of existing power plants can reduce the overall cost requirement significantly. In addition, a sensitivity analysis is also done to study the effect of nuclear energy on the overall energy mix." **Krishna Priya G.S., Santanu Bandyopadhyay, and Raymond R. Tan**, *Process Safety and Environmental Protection*. (Subscription may be required.)

"Atmospheric measurement techniques to quantify greenhouse gas emissions from cities."

The following is the Abstract of this article: "There is growing interest to constrain and validate GHG emission inventories at urban and intra-urban scales. This contribution reviews methods to identify, quantify and attribute emissions (and [storage]) of [CO_2], methane and nitrous oxide in cities using in-situ measurements in the atmosphere. Measurements of GHG mixing ratios and fluxes in cities will allow validation of inventories, identification and quantification of poorly-known sources and accounting for the effects of urban land-cover change. In-situ measurements of GHG emissions (and [storage]) in the urban atmosphere are possible (i) at the micro-scale by capturing GHG plumes of individual sources using mobile platforms and measuring vertical profiles of GHGs in the urban canopy layer, (ii) at the local-scale by direct eddy-covariance flux measurements of GHGs on towers, and, (iii) at the meso-scale by measurements of mixing ratios and isotopologues of GHGs in the urban and rural boundary layer combined with box and inverse models. This paper reviews all approaches and highlights their potential and current limitations. These observational methods combined with models will support future endeavors in fine-scale GHG emission monitoring in cities and allow for validation of upcoming remote-sensing products of urban-scale GHG emissions." **Andreas Christen**, *Urban Climate*. (Subscription may be required.)

"Parametric sensitivity analysis for CO_2 geosequestration."

The following is the Abstract of this article: "[Carbon dioxide storage] (CCS) in geological formations appears to be a viable technology for large-scale storage of CO_2 to mitigate the impacts of climate change. Simulations of the [behavior] of [storage] systems using mathematical models play a significant role in risk estimation and consequently in decision-making processes. Uncertainty arises in the application of models because of physical complexities, simplifying assumptions, and parameter variability. A sensitivity analysis comparing the influence of different model parameters on predicted CO_2 plume evolution uncertainty is presented. Both the role of the parameter in the model and the parameter uncertainty are included in the measure of sensitivity to distinguish between parameters with equal influence in the model output but having different degrees of intrinsic uncertainty. The sensitivity of the plume interface location, the maximum breakthrough distance of CO_2, and the moment of inertia of the CO_2 plume with respect to intrinsic physical system parameters and

Technology (Continued)

parameters introduced in constitutive relationships is investigated in a hypothetical site. [Parameters] are used, each with a probability density obtained from measurements of the Nisku Aquifer, targeted for CO_2 injection in Alberta, Canada. [The authors] sensitivity analysis shows that formation porosity, residual brine saturation, and entry capillary pressure are the most influential parameters in the uncertainty of plume evolution. Thus, the influence of constitutive relationship parameters in plume evolution uncertainty is as high as that of the physical characteristics of the system. Simulation outputs where insensitive to CO_2 viscosity and the exponents in the Brooks-Corey model for capillary pressure and relative permeability; therefore, it is possible to reduce the dimensionality of future uncertainty and risk analyses, based on the model presented, by neglecting the uncertainty of these parameters and assuming them to be deterministic. While results are specific to the synthetic problem presented in the article, the methodology is general and applicable to other CO_2 geosequestration sites." **Mirhamed Sarkarfarshi, Farshad A. Malekzadeh, Robert Gracie, and Maurice B. Dusseault**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Terrestrial

"Soil carbon stocks and forests biomass following conversion of pasture to broadleaf and conifer plantations in southeastern Brazil."

The following is the Abstract of this article: "Increased soil carbon [storage] can potentially mitigate CO_2 emission and can indicate sustainable forest management. This study aims to determine the relative influence of commercial plantation tree species on soil carbon following establishment on former tropical pastures. Soil carbon (organic horizon plus mineral soil from 0 to 45 cm) and stemwood productivity were quantified from 6 to 34 year-old conifer and broadleaf plantations in a sandy Oxisol (Typic Hapludox) in southeastern Brazil. Study plots consisted of [10] pastures paired with broadleaf plantations and [10] additional broadleaf plantations paired with conifer plantations. Pastures primarily consisted of *Brachiaria decumbens Stapf*., while broadleaf plantations were primarily *Eucalyptus*, but also included one plot each of three other broadleaf species. Conifer stands were made up of *Pinus* species. Average stemwood productivity (± standard error) was 9.7 (±1.0) Mg C ha^{-1} yr^{-1} for broadleaf and 5.7 (±0.5) Mg C ha^{-1} yr^{-1} for conifer plantations, but did not correlate to soil C. The soil C in the paired Pasture–Broadleaf plots averaged 36.0 ± 1.7 Mg C ha^{-1} in pastures and 36.8 ± 1.9 Mg C ha^{-1} in broadleaf plantations. The Broadleaf–Conifer plots averaged 38.3 ± 1.9 Mg C ha^{-1} for broadleaf plantations and 36.0 ± 1.6 Mg C ha^{-1} for conifers. [The authors'] results show little difference in soil C across vegetation types, providing evidence that conifer and broadleaf plantations overall maintain similar levels of soil carbon to pasture land-use up to 34 years following land conversion. Soil C differences between Pasture–Broadleaf pairs indicated a small decline in soil C accretion early after plantation establishment, followed by recovery to slightly higher accretion rates." **Rachel L. Cook, Dan Binkley, João Carlos T. Mendes, and Jose Luiz Stape**, *Forest Ecology and Management*. (Subscription may be required.)

"Assessing carbon storage and [storage] by Canada's urban forests using high resolution earth observation data."

The following is the Abstract of this article: "[Trees] are important components of the landscape and offer numerous benefits; both socio-economical and biophysical. Urban trees act as a sink for CO_2, helping to offset carbon emissions from urban areas by removing the GHG from the atmosphere through photosynthesis. Environment Canada develops estimates of Canada's [GHG] emissions and removals which are submitted annually to the United Nations as part of ongoing commitments under the United Nations Framework Convention for Climate Change. As part of these reporting commitments countries are required to develop estimates of emissions and removals of [GHG] that are the result of direct impact of human activities in the Land-Use, Land-Use Change and Forestry Sector. Here, [the authors] present an approach which involves sampling high resolution aerial photographs to determine urban tree coverage across Canada's major urban areas. [The author's] results suggest Canadian urban areas have an estimated tree canopy cover of 27 [percent]. This tree cover is estimated to store approximately 34,000 kt C and annually [store] approximately 2,500 kilotons of CO_2. These estimates show significant improvement over previous methods used to provide Canadian estimates. The methods developed here are easily repeatable which allow for temporal changes to be analyzed and assessed over time." **Jon Pasher, Mark Mcgovern, Michael Khoury, and Jason Duffe**, *Urban Forestry & Urban Greening.* (Subscription may be required.)

Trading

"Québec and California Announce Plans for Joint Auction of Greenhouse Gas Emission Allowances."

The California Air Resources Board (ARB) and Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change (MDDELCC) announced plans to conduct a joint practice auction for the California and Québec cap-and-trade programs. All registered participants in the two programs will be eligible to participate in the practice auction, which will begin in the last week of July 2014, with the bidding window open one day during the first week of August 2014. The practice auction will give participants the opportunity to test the updated auction platform and familiarize themselves with the new features that support a joint auction. Both ARB and MDDELCC officials will monitor the practice auction, testing and verifying joint oversight and communication procedures. If the practice auction is successful, the two programs will hold the first joint auction of emission allowances in November 2014. From *California Air Resources Board News Release* and *MDDELCC of Québec* on June 6, 2014.

"The timeline of trading frictions in the European carbon market."

The following is the Abstract of this article: "During its trial phase (Phase I), the EU [GHG] Emission Trading Scheme (EU-ETS) collapsed because of an over-allocation of emission allowances. [The authors] evaluate the progress of this market from the trial phase to the next commitment period (Phase II) from a microstructure angle. [The authors] show that trading frictions, as measured by the relative spread, information-asymmetry risk, and market-making profits

Trading (Continued)

decreased from Phase I to Phase II. Although volatility decreased, its noise-related component gained in importance at the expense of its information-related component, resulting in lower quality of the price changes." **Vicente Medina, Ángel Pardo, and Roberto Pascual**, *Energy Economics*. (Subscription may be required.)

"Cross-border electricity market effects due to price caps in an emission trading system: An agent-based approach."

The following is the Abstract of this article: "The recent low CO_2 prices in the European Union Emission Trading Scheme (EU ETS) have triggered a discussion whether the EU ETS needs to be adjusted. [The authors] study the effects of CO_2 price floors and a price ceiling on the dynamic investment pathway of two interlinked electricity markets (loosely based on Great Britain, which already has introduced a price floor, and on Central Western Europe). Using an agent-based electricity market simulation with endogenous investment and a CO_2 market (including banking), [the authors analyze] the cross-border effects of national policies as well as system-wide policy options. A common, moderate CO_2 auction reserve price results in a more continuous [decarbonization] pathway. This reduces CO_2 price volatility and the occurrence of carbon shortage price periods, as well as the average cost to consumers. A price ceiling can shield consumers from extreme price shocks. These price restrictions do not cause a large risk of an overall emissions overshoot in the long run. A national price floor lowers the cost to consumers in the other zone; the larger the zone with the price floor, the stronger the effect. Price floors that are too high lead to inefficiencies in investment choices and to higher consumer costs." **Jörn C. Richstein, Emile J.L. Chappin, and Laurens J. de Vries**, *Energy Policy*. (Subscription may be required.)

Recent Publications

"Geological CO_2 Storage Characterization."

The following is from the Preface of this document: "The primary purpose of this book is to assist future CCS investigations in characterizing potential geological CO_2 storage sites well enough so that all of the information required by regulators to permit commercial CO_2 storage facilities are provided. The Wyoming Carbon Underground Project (WY-CUSP) is part of the [DOE] Geological CO_2 Storage Site Characterization Program. In 2010 DOE awarded funding to 10 CO_2 geological storage characterization projects. The WY-CUSP program under the direction of the University of Wyoming Carbon Management Institute (CMI) was one of the awardees (project DE-FE0002142: Site Characterization of the Highest-Priority Geologic Formations for CO_2 Storage in Wyoming; Principal Investigator, Ronald C. Surdam). The State of Wyoming through the U.W. School of Energy Resources generously provided matching funds for the WY-CUSP program. This book deals with most of the trials and tribulations required to achieve the ultimate goal of the WY-CUSP program: delivery of a certified commercial CO_2 storage site that could be used either as a surge tank for CO_2 utilization or for permanent [storage] of GHG emissions, or for both. The rationale for the WY-CUSP program is manifold: first is the effort to establish a mechanism that provides the potential to stabilize or reduce GHG emissions in order to reduce the rate of global warming; secondly to protect Wyoming's coal extraction and future coal-to-chemical industries by providing storage capacity for anthropogenic CO_2; thirdly to provide a source of anthropogenic CO_2 for EOR projects (at present rates of CO_2 production from gas processing plants it would take 150–200 years to recover Wyoming's stranded oil; fourthly to retrieve reservoir information essential for the expansion of natural gas storage in Wyoming; and lastly to establish more robust databases for two very important hydrocarbon reservoirs in Wyoming (substantially reduce uncertainty for all dynamic models of Tensleep/Weber Sandstone and Madison Limestone fluid-flow and rock/ fluid systems). To satisfy the WY-CUSP program rationale the following goals were set: to improve estimates of CO_2 reservoir storage capacity, to evaluate the long-term integrity and permanence of confining layers, and to manage injection pressures and brine production in order to optimize CO_2 storage efficiency for the most significant storage reservoir (Tensleep/Weber and Madison Formations) at the Rock Springs Uplift (RSU), a premier CO_2 storage site in Wyoming."

"Energy Technology Perspectives 2014 – Harnessing Electricity's Potential."

The following is from the Executive Summary of this document: "Energy Technology Perspectives 2014 (ETP 2014) charts a course by which policy and technology together become driving forces – rather than reactionary tools – in transforming the energy sector over the next 40 years. Recent technology developments, markets and energy-related events have asserted their capacity to influence global energy systems. They have also reinforced the central role of policy in the increasingly urgent need to meet growing energy demand while addressing related concerns for energy security, costs and energy-related environmental impacts. Radical action is needed to actively transform energy supply and end use. In addition to [analyzing] the global outlook to 2050 under different scenarios, across the entire energy system for more than 500 technology options, ETP 2014 explores pathways to a sustainable energy future in which policy support and technology choices are driven by economics, energy security and environmental factors. Starting from the premise that electricity will be an increasingly important vector in energy systems of the future, ETP 2014 takes a deep dive into actions needed to support deployment of sustainable options for power generation, distribution, and end-use consumption. ETP 2014 analyses three possible energy futures to 2050: [(1)] 6°C Scenario (6DS), where the world is now heading with potentially devastating results; [(2)] 4°C Scenario (4DS) reflects stated intentions by countries to cut emissions and boost energy efficiency; [and (3)] 2°C Scenario (2DS) offers a vision of a sustainable energy system of reduced [GHG] and CO_2

Recent Publications (Continued)

emissions. Status and recent trends are highlighted in Tracking Clean Energy Progress, providing a snapshot of advances or lack of progress in major low-carbon energy technologies. Collectively, ETP 2014 lays out the wide range of necessary and achievable steps that can be taken in the near and medium terms to set the stage for long-term energy policy objectives, clearly identifying the roles of energy sector players, policy makers and industry."

"Annual Report on the Market for RGGI CO_2 Allowances: 2013."

The following is from the Executive Summary of this document: "The Regional Greenhouse Gas Initiative (RGGI) became the first mandatory cap-and-trade program to limit CO_2 emissions in the United States in 2009. Electric power generators located in the states participating in RGGI are required to obtain a number of CO_2 allowances equal to the number of tons of CO_2 they emit. RGGI distributes CO_2 emissions allowances to the market primarily through auctions, making it distinctive among existing cap-and-trade programs. Ninety-four percent of the CO_2 allowances that have entered into circulation initially entered the market through one of the auctions. Through the end of 2013, RGGI has conducted 22 successful auctions, selling a total of 651 million CO_2 allowances for $1.6 billion. Following a 2012 Program Review, the Participating States announced changes to the Model Rule, including a new CO_2 emissions cap. The new CO_2 emissions cap is 91 million tons for 2014, and will be reduced by 2.5 percent per year until it reaches approximately 78 million tons for 2020. The Model Rule also included further interim adjustments to the cap to account for the surplus of allowances from 2009 to 2013 in circulation. Since these program adjustments were announced in February 2013, there have been significant changes in market activity which are discussed throughout this report. This report evaluates activity in the market for RGGI CO_2 allowances in 2013, focusing on the following areas: allowance prices, trading and acquisition of allowances in the auctions and the secondary market, participation in the market by individual firms, and market monitoring."

Legislative Activity

"Planning for offshore CO_2 storage: Law and policy in the United Kingdom."

The following is the Abstract of this article: "'Offshore CO_2 storage' refers to the injection of liquefied CO_2 into deep geological formations beneath the seabed (e.g. depleted oil and gas reservoirs, and saline [formations]) for the purpose of storing it there on a permanent basis. The storage in this manner of captured CO_2 emissions from industrial installations and power plants has attracted considerable scientific and technical interest as a potential mitigation response to climate change. A key issue facing policymakers in several countries is how to reconcile policy commitments to develop offshore CO_2 storage with other competing – and potentially conflicting – uses of the marine environment. With a view to informing policy responses to this issue, this paper presents a case study of legal and policy frameworks concerning offshore CO_2 storage in United Kingdom. The paper maps key design features of the United Kingdom's framework for marine permitting and planning, appraising the extent to which they enable orderly development of offshore CO_2 storage in a manner consistent with relevant high-level policy objectives." **Ben Milligan**, *Marine Policy*. (Subscription may be required.)

"Carbon capture and storage and transboundary pollution: A differential game approach."

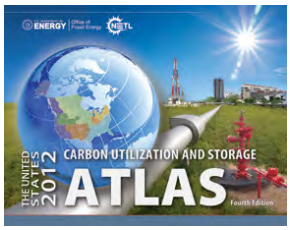
The following is the Abstract of this article: "[The authors] study the strategic behavior of two countries facing transboundary CO_2 pollution under a differential game setting. In [the authors'] model, the reduction of CO_2 concentration occurs through the [CCS] process, rather than through the adoption of cleaner technologies. Furthermore, [the authors] first provide the explicit short-run dynamics for this dynamic game with symmetric open-loop and a special Markovian Nash strategy. Then, [the authors] compare these strategies at the games' steady states and along some balanced growth paths. [The authors'] results show that if the initial level of CO_2 is relatively high, state dependent emissions reductions can lead to higher overall environmental quality, hence, feedback strategy leads to less social waste." **Luisito Bertinelli, Carmen Camacho, and Benteng Zoi**, *European Journal of Operational Research*. (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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