NETL the ENERGY lab

Carbon Storage Newsletter

October 2013

What's Inside?

Highlights

"MSU and Partners Send Carbon Dioxide Deep Underground in Regional Experiment" and **"Ancient Lava Flows Trap CO_2 for Long-Term Storage in Big Sky Injection."**

A Big Sky Carbon Sequestration Partnership-managed (BSCSP) project injected 1,000 tons of carbon dioxide (CO_2) into geological formations that consist of ancient basalt flows. Scientists will examine fluid samples from the injection well to look for changes in chemical composition and compare results to predictions that were made using Pacific Northwest National Laboratory's (PNNL) supercomputer. More information is available via YouTube and the BSCSP project website. From *Montana State University News Release* on July 26, 2013, and *Fossil Energy Techline* on August 13, 2013.

"MRCSP Begins Field Tests in Michigan."

The Midwest Regional Carbon Sequestration Partnership (MRCSP) has begun a large-scale CO_2 field project. The project is designed to inject and monitor at least 1 million metric tons of CO_2 into a series of oil fields that are in different stages of their production life cycles. The CO_2 will be injected into the geologic structures known as the northern Niagaran pinnacle reef trend. From *Battelle News Release* on July 9, 2013.

Announcements

DOE's NETL Releases Revised Editions of Best Practice Manuals (BPMs).

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) released revised editions of the following Best Practice Manuals (BPMs): "Public Outreach and Education for Carbon Storage Projects"; "Risk Analysis and Simulation for Geologic Storage of CO_2"; "Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations"; and "Carbon Storage Systems and Well Management Activities." The BPMs are available via the Carbon Storage Program Reference Shelf.

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 International Energy Agency Greenhouse Gas Research and Development (R&D) Programme (IEAGHG).

Announcements (Continued)

13th Annual CCUS Conference: Call for Papers Released.

The call for papers has been released for this year's conference, titled, "Accelerating Deployment to Meet New CO_2 Emission Reduction Mandates," to be held April 28-May 1, 2014, in Pittsburgh, Pennsylvania. The conference will highlight governmental frameworks and ongoing carbon capture and storage (CCS) research, development, demonstration, and deployment (RDD&D) efforts for existing and projected new coal-fired and natural gas-fired power plants and industrial processes; the potential utilization of anthropogenic carbon emissions; and progress to develop commercially viable carbon capture technologies and infrastructure for industrial processes that would make utilization possible. Abstracts are due January 20, 2014.

IEAGHG Social Research Network Meeting.

Registration for the 4th IEAGHG Social Research Network Meeting is now open. The meeting will be held in Calgary, Alberta, Canada, from January 14-15, 2014, and will be hosted by the Institute for Sustainable Energy, Environment and Economy (ISEEE) at the University of Calgary. The agenda is under development and will be available in the near future. The meeting will focus on recent social science research and issues around CCS and related energy technologies.

Geochemistry of Geologic CO_2 [Storage] Short Course Open for Enrollment.

The Mineralogical Society of America and The Geochemical Society will host a short course on December 7-8, 2013, to accompany the American Geophysical Union's 46th Annual Fall Meeting. The short course will provide a summary of the fundamental geochemical and mineralogical processes associated with gas-water-mineral-interactions encountered during geologic storage of CO_2.

Carbon Storage in the News

"China and UK Announce CCS Collaboration."

The UK Carbon Capture and Storage Research Center (UKCCSRC), Scottish Carbon Capture and Storage (SCCS), Guangdong Low-Carbon Technology and Industry Research Center (GDLRC), and the Clean Fossil Energy Development Institute (CFEDI) have formed a new initiative for research, development, and demonstration of innovative CCS technologies. The 10-year Memorandum of Understanding (MOU) will lead to the establishment of an international CCS network to promote joint R&D, advise local and regional governments, and develop ways to exchange knowledge. The partners also expect to demonstrate CCS technologies. The MOU builds upon more than five years of joint CCS activities. From *UK Carbon Capture and Storage Research Center News Release* on September 27, 2013.

"Petronas Looking to Implement EOR Technology at 14 Maturing Oilfields."

Petronas has identified 14 of its projects for possible implementation of enhanced oil recovery (EOR) technology to advance production. Five of the maturing oil fields are located offshore Sarawak, four are located offshore Sabah, and the rest are located in Peninsular Malaysia. According to the company, the Tapis oilfield, which will be the first to have EOR technologies implemented, could be enhanced to reach in the range of 25,000 to 35,000 barrels per day (bpd) in 2016 to 2017; the current rate of production at Tapis is in the range of 4,000 and 6,000 bpd. In total, the company projects the introduction of EOR technology to have the potential to recover from 750 million to 1 billion barrels of oil from the maturing oilfields within the Malaysian waters. From *The Star Online* on September 25, 2013.

"SaskPower Signs Carbon Capture and Storage Monitoring System MOU with Chugai Technos, K-Coal."

SaskPower and Chugai Technos have signed an MOU regarding a ground CO_2 monitoring system on CCS. Under the MOU, SaskPower will begin storing a portion of the CO_2 captured from the Boundary Dam Integrated CCS Demonstration Project in April 2014. With an investment from SaskPower, the Provincial Government of Saskatchewan, and the Federal Government of Canada, Boundary Dam Power Station generating unit #3 was rebuilt to be integrated with the newly constructed carbon capture facility. The new facility has the potential to capture approximately 1 million metric tons of CO_2 emissions per year, which would be sold to Cenovus Energy. A surplus of the captured CO_2 would be injected into a nearby saline formation. Chugai Technos' role will be to establish a monitoring system that allows access to the condition of the ground CO_2 concentration at a carbon capture storage site. Prototypes of such a ground monitoring system will be deployed at several onsite locations. From *SaskPower News Release* on September 30, 2013.

Science

"Global Warming to Spawn More Severe U.S. Thunderstorms: Study."

According to a new study published in the journal "Proceedings of the National Academy of Sciences," potential climate change could create atmospheric conditions in the United States that would be susceptible to the development of severe thunderstorms and tornadoes. The findings

Science (Continued)

are based on computer modeling work of the two main atmospheric ingredients believed to contribute to thunderstorm formation: (1) convective available potential energy (CAPE), which is created as air in the lower atmosphere warms; and (2) vertical wind shear, which is the change in wind speed and height. Scientists from Stanford University and Purdue University conducted new computer simulations revealing that when CAPE is high, vertical wind shear is more likely to be high as well, meaning the frequency of occurrences of severe thunderstorm environments increases as a result of potential climate change. According to scientists, the simulations also showed that continued potential climate change could lead to increases in storm days over large areas of the eastern United States in the spring, winter, and autumn. In springtime alone, the result would be a 40 percent increase of severe thunderstorms over the eastern United States by the end of the century. From *National Geographic* on September 24, 2013.

"New Study Suggests Earthworms [Store] More CO_2 Than They Release."

According to a study conducted by German researchers at the Alfred Wegener Institute, rising CO_2 levels are causing harm to marine life due to acidification. As the CO_2 dissolves into the oceans, carbonic acid is formed, lowering the pH level. Published in the journal "Nature Climate Change," the study claims that the oceans' uptake of CO_2 has an impact on mollusks, corals, and echinoderms, like starfish and sea urchins. Researchers examined 167 previous studies regarding the effects of acidifying oceans on 153 species. Their findings were analyzed and forecasts of future emissions were used to predict impact(s). The research will be used for the second part of a United Nations' three-part study into the science of potential climate change scheduled to be released by the end of 2014. From *Pittsburgh Post-Gazette* on August 26, 2013.

Policy

"EPA Proposes Carbon Pollution Standards for New Power Plants."

The U.S. Environmental Protection Agency (EPA) has proposed Clean Air Act standards to reduce CO_2 emissions from new power plants in order to combat potential climate change. In addition, EPA also initiated outreach and direct engagement with state, tribal, and local governments; industry and labor leaders; non-profits; and others to establish CO_2 emissions standards for existing power plants. The proposal achieves the first milestone outlined in a Memorandum to EPA, titled, "Power Sector Pollution Standards." Under the proposal, new large gas-fired turbines would need to meet a limit of 1,000 pounds of CO_2 per megawatt-hour, while new small gas-fired turbines, as well as new coal-fired units, would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour. New coal-fired units would have the option to choose to meet a tighter limit if they average their emissions over multiple years. The proposed standards are expected to ensure that new power plants are built with available clean technology to limit CO_2 emissions. Click here for a statement by the Energy Secretary on the new standards. From *EPA News Release* on September 20, 2013.

"A comparison of techniques used to collect informed public opinions about CCS: Opinion quality after focus group discussions versus information-choice questionnaires."

The following is the Abstract of this article: "Both focus group discussions and information-choice questionnaires (ICQs) have previously been used to examine informed public opinions about [CCS]. This paper presents an extensive experimental study to systematically examine and compare the quality of opinions created by these two research techniques. Depending on experimental condition, participants either participated in a focus group meeting or completed an ICQ. In both conditions participants received identical factual information about two specific CCS options. After having processed the information, they indicated their overall opinion about each CCS option. The quality of these opinions was determined by looking at three outcome-oriented indicators of opinion quality: consistency, stability, and confidence. Results for all three indicators showed that ICQs yielded higher-quality opinions than focus groups, but also that focus groups did not perform poor in this regard. Implications for the choice between focus group discussions and ICQs are discussed." **Emma ter Mors, Bart W. Terwel, Dancker D.L. Daamen, David M. Reiner, Diana Schumann, Sorin Anghel, Ioanna Boulouta, Diana M. Cismaru, Carmencita Constantin, Chris C.H. de Jager, Alexandra Dudu, Andrea Esken, Oana C. Falup, Rebecca M. Firth, Vassiliki Gemeni, Chris Hendriks, Loredana Ivan, Nikolaos Koukouzas, Angelos Markos, Robert Naess, Katja Pietzner, Irene R. Samoila, Constantin S. Sava, Michael H. Stephenson, Claudia E. Tomescu, Hans Y. Torvatn, Sturle D. Tvedt, Daniel Vallentin, Julia M. West, and Fotini Ziogou**, *International Journal of Greenhouse Gas Control.* (Subscription may be required to view article.)

"Pressure profiles for CO_2-EOR and CCS: Implications for regulatory frameworks."

The following is from this article: "Analysts and regulators around the world have devoted a great deal of effort in recent years to crafting a regulatory framework for geologic storage of CO_2. The work has been premised largely on the assumption that CO_2 will be captured from emissions sources and then injected and geologically stored solely for the purpose of reducing atmospheric emissions of a [GHG], as is done in several of the high-profile demonstration projects (such as Sleipner and In Salah). While well-suited for its intended purpose, this approach risks creating a serious regulatory obstacle to the successful deployment of [CCS] technology in the United States or other jurisdictions where the captured CO_2 will be used – and incidentally stored – in EOR operations. Although EOR is not intended as a CCS technology strategy, the geologic storage of CO_2 that occurs during routine EOR operations can provide tangible and measureable emission reduction benefits where the CO_2 has been captured from an emissions source. Hence a sound CCS policy should avoid creating regulatory barriers to integrating supplies of captured CO_2 into traditional EOR operation. A problem may arise, however, where the regulatory paradigm fails to recognize the fundamental operational differences between geologic storage

Policy (Continued)

in active CO_2-based EOR operations and the storage operations in non-EOR-based projects (whether in saline formations or non-producing hydrocarbon reservoirs). This feature focuses on the regulatory implications of the differing pressure profile of CO_2-EOR operations, a point that is little discussed in the relevant literature. As explained later, the subsurface formation pressure profile of a CO_2-EOR operation is essentially constant as a result of the continual removal of formation fluids from production wells (oil, water, and CO_2) at the same time as incremental quantities of CO_2 are added via injection wells." **Marston, P. M.**, *Greenhouse Gases: Science and Technology*. (Subscription may be required to view article.)

Geology

"Permeability prediction of coalbed methane reservoirs during primary depletion."

The following is the Abstract of this article: "Permeability increase in coalbed methane (CBM) reservoirs during primary depletion, particularly in the San Juan Basin, is a [well-accepted] phenomenon. It is complex since it is influenced by stress conditions and coal matrix shrinkage associated with gas desorption. Understanding the variations in coal permeability is critical in order to reliably project future gas production, or consider other gas migration issues in the reservoir. Since sorption-induced strain plays a critical role in changing the permeability, typically observed, the theoretical strain model should be incorporated into the permeability prediction models. An effort is made in this paper to couple the recently developed Liu and Harpalani sorption-induced strain model with various permeability models. The model first calculates the theoretical coal matrix shrinkage strain and, using the calculated strain, various commonly used permeability models are applied to two sets of field data. The results of the coupled models show that the agreement between the predicted permeability and that observed in the field is very good. The merit of the coupled models is that it can theoretically predict the permeability with less experimental work, making it a more time efficient and economical technique compared to models used in the past." **Shimin Liu and Satya Harpalani**, *International Journal of Coal Geology*. (Subscription may be required to view article.)

"CO_2-Induced Dissolution of Low Permeability Carbonates, Part I: Characterization and Experiments."

The following is the Abstract of this article: "The effect of elevated dissolved CO_2 concentrations on compositionally and structurally distinct carbonate sample cores from the Weyburn-Midale CO_2-EOR and storage site (Canada) was measured from analysis of 3-D sample characterization and fluid chemistry data from core-flood experiments. Experimental conditions (60°C; 24.8 MPa confining pressure) and brine composition were chosen to mimic in situ reservoir conditions. Mineralogy and pore space distributions within the eight individual cores were characterized with X-ray computed microtomography and scanning electron microscopy both before and after exposure to brine with $0.5 \leqslant pCO_2 \leqslant 3$ MPa, while solution chemistry and differential fluid pressures were monitored during experiments. [The authors'] experimental study aimed to quantify the relationship between fluid flow, heterogeneity, and reaction specific to carbon storage at the Weyburn-Midale field by integrating characterization imaging, pressure data, and solution chemistry. Through the use of non-invasive microtomographic imaging, a variety of dissolution behaviors were observed, with variable effects on the evolution of solution chemistry and permeability as a result of heterogeneity within these two relatively low permeability carbonate samples. Similar-sized, evenly distributed pores, and steadily advancing dissolution fronts suggested that uniform flow velocities were maintained throughout the duration of the higher permeability 'Marly' dolostone core experiments. The development of unstable dissolution fronts and fast pathways occurred in the 'Vuggy' sample experiments when fluid velocities varied widely within the sample (as a result of increased pore structure heterogeneity). The overall effect of fast pathway development was to increase bulk permeability values by several orders of magnitude, allowing CO_2-acidified fluids to travel through the cores largely unmodified by carbonate mineral reaction, as indicated by a lack of change in later-time solution pH levels at the core outlet. Given the impact of heterogeneity within low permeability cores, effort should be taken to incorporate smaller-scale heterogeneity into predictive models and such an averaging approach (utilizing the data and observations discussed here) is the topic of [the authors'] companion manuscript. Solution chemistry results indicated that steady-state carbonate mass transfer conditions were attained in the Marly dolostone experiments and during the earlier (pre-pressure breakthrough) portions of the Vuggy limestone experiments. Steady-state calcium and magnesium concentrations coincided with outlet solutions that were calculated to be at or very near to equilibrium with respect to both calcite and dolomite, relative to available thermodynamic data and considering experimental data scatter. Carbonate mass transfer data were evaluated against a variety of proposed carbonate dissolution mechanisms, including both pH- and pCO_2-dependent expressions as well as a simplified pH-independent formulation. Based on this analysis, the calcite reaction rate coefficient was estimated to be ~17 times faster than that for dolomite dissolution under [the authors'] experimental conditions. This ratio is consistent with the use of rate equations that depend on carbonate mineral saturation without specifying additional dependence on solution pH or CO_2 levels, and may be a result of the narrow experimental pH range. In addition, solution chemistry data were combined with time-dependent pressure data to constrain the exponent in a power-law expression describing the relationship between evolving porosity and permeability within the Vuggy limestones. This relationship as well as proposed carbonate kinetic expressions are further evaluated in [the authors'] companion paper." **Megan Smith, Yelena Sholokhova Yue Hao, and Susan Carroll**, *Advances in Water Resources*. (Subscription may be required to view article.)

"Effect of temperature on permeability of geopolymer: A primary well sealant for carbon capture and storage wells."

The following is the Abstract of this article: "Geological [storage] of [CO_2] has been found to be the most promising solution to reduce anthropogenic [GHG] emissions without affecting the usage of fossil fuel. Wellbore integrity needs to be maintained for [release]-free storage and well cement plays a major role in wellbore integrity as it provides the required zonal isolation. Ordinary Portland cement (OPC)-based sealant has been used in injection wells and it has been found that it experiences

Geology (Continued)

cement degradation and is unstable under CO_2-rich down-hole conditions. Therefore, an experimental program was conducted to study the suitability of geopolymer as well cement and the apparent CO_2 permeability of geopolymer was tested under the following test conditions using a high pressure triaxial experiment: (a) temperatures of 23–70°C; (b) CO_2 injection pressures of 6–17 MPa; and (c) confining pressures of 12–20 MPa. From the preliminary experimental results, it was noted that the apparent CO_2 permeability of geopolymer increases with the curing temperature and increment rates are as high as 200–1000 [percent]. However, the maximum permeability (0.04 μD) value obtained for any temperature studied is approximately 5000 times lower than the permeability value (200 μD) recommended by the American petroleum industry (API) for a typical well sealant. The increase in permeability is related to increased pore diameter and highly heterogeneous pore structure at elevated temperatures for longer curing periods. Even though the permeability of geopolymer increases with the temperature, the values are well below those of traditional OPC cement and API recommended limits. Therefore, geopolymers have potential as primary sealant material in a typical wellbore. An attempt is made to develop an empirical formulation to predict the permeability of geopolymer at different temperatures under various confining pressures." **M.C.M. Nasvi, P.G. Ranjith, J. Sanjayan, and H. Bui**, *Fuel*. (Subscription may be required to view article.)

Technology

"Dense gas dispersion modeling of CO_2 released from carbon capture and storage infrastructure into a complex environment."

The following is the Abstract of this article: "Two scenarios for atmospheric dispersion relevant for consequence assessment associated with the loss of containment from [CCS] related infrastructure was investigated using a physics-based mathematical model: namely, the [release] of CO_2, which is a heavier-than-air (or, dense) gas, from storage tanks and transportation pipelines. Simulations of these two scenarios (viz., a storage tank release in the vicinity of a cubical obstacle and a pipeline rupture in a complex topography involving two axisymmetric hills) were performed using computational fluid dynamics, in which the density variations of the fluid (containing the dense gas) were simplified using the Boussinesq approximation. It is shown that the presence of an obstacle and/or complex terrain has a significant influence on the dispersion of the dense gas. Owing to the 'slumping' of the dense gas under the action of gravity, regions well upwind of the source of the gas release can also lie within the hazard zone. The research reported herein provides an improved model for analyzing hazards associated with the dispersion of dense gas clouds and their interaction with local building wakes and/or topographic (terrain) features and contributes to providing a sophisticated method for the assessment of safety and security related to the transportation and geological storage of CO_2." **Kun-Jung Hsieh, Fue-Sang Lien, and Eugene Yee**, *International Journal of Greenhouse Gas Control.* (Subscription may be required to view article.)

"Selection of monitoring techniques for a carbon storage and enhanced coalbed methane recovery pilot test in the Central Appalachian Basin."

The following is the Abstract of this article: "The goals of monitoring, verification, and accounting (MVA) for CCS studies include improved understanding of injection and storage processes, evaluation of interactions among CO_2, reservoir fluids, and formation solids, and assessment and minimization of environmental impacts. Site-specific selection of tools for a well-rounded MVA program may include technologies for atmospheric, near-surface, and subsurface monitoring. An upcoming small-scale CCUS study in an active coalbed methane field in Buchanan County, Virginia, presents a unique application for several established, effective MVA methods. The study will involve injecting up to 20,000 tonnes of CO_2 into three injection wells over a one-year period in order to test the injection and storage potential of the coal seams and to assess the potential for enhanced coalbed methane (ECBM) recovery at offset production wells. The reservoir consists of approximately 15 to 20 coal seams, averaging 0.3 m (1.0 ft) in thickness and distributed over 300 m (1000 ft) of vertical section. This reservoir geometry creates an unusual target for CO_2 injection and also a challenging one for many monitoring and imaging techniques. MVA for the Buchanan County test will include gas content measurements at offset wells, groundwater monitoring, injectate tracer analysis, well logging, surface deformation measurement, passive microseismic monitoring, and tomographic fracture imaging. Multiple monitoring wells will be drilled in order to facilitate the MVA efforts. Surface deformation measurement, microseismic monitoring, and tomographic fracture imaging are state-of-the art tools that have potential to define the subsurface CO_2 plume beyond the borehole scale. The results of the MVA program for the Buchanan County injection demonstration can be used to improve design for potential future studies of CCUS in thin coals." **Ellen S. Gilliland, Nino Ripepi, Matthew Conrad, Michael J. Miller, and Michael Karmis**, *International Journal of Coal Geology*. (Subscription may be required to view article.)

"Comparison of CO_2 capture economics for iron and steel mills."

The following is the Abstract of this article: "One of the largest energy consuming manufacturing industries in the world is the iron and steel industry which emits almost [five percent] of the total world CO_2 emissions. Previous studies examining the application of CO_2 capture at iron and steel mills evaluated capture at conventional and Corex iron and steel mills. This study extends the analysis to include Hismelt, Midrex and the mini mill. In the first part of [the authors'] study, [the authors] present a high level scoping assessment of the opportunities for implementing CO_2 capture at existing direct atmospheric CO_2 emission points. Implementing CO_2 capture using commercial [monoethanolamine (MEA)] solvent at a conventional iron and steel mill costs from A$80 to A$250 per tonne of CO_2 avoided. Estimated costs to capture from the existing point sources at the Hismelt and Corex iron and steel mills also range from A$80 to A$250 per tonne of CO_2 avoided. At a direct reduction iron process such as Midrex, the cost of CO_2 capture from the process stack gas is estimated at about A$90 per tonne of CO_2 avoided. A cost of approximately A$110 to A$130 per tonne of CO_2 avoided is estimated to capture from the EAF unit of the steel production route for the Midrex and mini mill processes. Alternatively, CO_2 can also be captured where it is produced from processes such as the blast furnace or reduction

Technology (Continued)

vessel. Although these streams contain a high level of CO_2, they are used as a low-grade fuel throughout the plant and the produced CO_2 is vented elsewhere. This study also estimates the cost of capturing the CO_2 before further combustion and venting. The costs are estimated for the conventional iron and steel mill blast furnace, the top gas recycling blast furnace (TGRBF), Hismelt and Corex reduction vessel gases. Capture using MEA solvent absorption, the costs range from A$65 to almost A$80 per tonne CO_2 avoided. Using Vacuum Pressure Swing Adsorption technology in place of MEA solvent absorption, the capture costs for these gases reduce by approximately 25–40 [percent]." **Minh T. Ho, Andrea Bustamante, and Dianne E. Wiley**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

Terrestrial

"Development and testing of allometric equations for estimating above-ground biomass of mixed-species environmental plantings."

The following is the Abstract of this article: "To quantify the impact that planting indigenous trees and shrubs in mixed communities (environmental plantings) have on net [storage] of carbon and other environmental or commercial benefits, precise and non-biased estimates of biomass are required. Because these plantings consist of several species, estimation of their biomass through allometric relationships is a challenging task. [The authors] explored methods to accurately estimate biomass through harvesting 3139 trees and shrubs from 22 plantings, and collating similar datasets from earlier studies, in non-arid (>300 mm rainfall year) regions of southern and eastern Australia. Site-and-species specific allometric equations were developed, as were three types of [generalized], multi-site, allometric equations based on categories of species and growth-habits: (i) species-specific, (ii) genus and growth-habit, and (iii) universal growth-habit irrespective of genus. Biomass was measured at plot level at eight contrasting sites to test the accuracy of prediction of tonnes dry matter of above-ground biomass per hectare using different classes of allometric equations. A finer-scale analysis tested performance of these at an individual-tree level across a wider range of sites. Although the percentage error in prediction could be high at a given site (up to 45 [percent]), it was relatively low (<11 [percent]) when [generalized] allometry-predictions of biomass was used to make regional- or estate-level estimates across a range of sites. Precision, and thus accuracy, increased slightly with the level of specificity of allometry. Inclusion of site-specific factors in generic equations increased efficiency of prediction of above-ground biomass by as much as [eight percent]. Site-and-species-specific equations are the most accurate for site-based predictions. Generic allometric equations developed here, particularly the generic species-specific equations, can be confidently applied to provide regional- or estate-level estimates of above-ground biomass and carbon." **Keryn I. Paul. Stephen H. Roxburgh, Jacqueline R. England, Peter Ritson, Trevor Hobbs, Kim Brooksbank, R. John Raison, John S. Larmour, Simon Murphy, Jaymie Norris, Craig Neumann, Tom Lewis, Justin Johnson, Jenny L. Carter, Geoff McArthur, Craig Barton, and Ben Rose**, *Forest Ecology and Management*. (Subscription may be required to view article.)

Trading

"Air Resources Board Prepares to Issue First Carbon Offset Credits."

The California Air Resources Board (CARB) announced that it will issue the first compliance offset credits eligible for use in the state's cap-and-trade GHG emissions reduction program. Each credit, issued for GHG emission reductions that take place in sectors not covered under California's cap-and-trade program, represents one metric ton of CO_2. Facilities covered under the program may use the carbon offsets to cover up to eight percent of their compliance obligation. A total of 600,000 credits are expected to be issued. More information on the Compliance Offset Program is available on the CARB website. From *California Air Resources Board News Release* on September 17, 2013.

"California and Quebec Sign Agreement to Integrate, Harmonize Their Cap-and-Trade Programs."

Representatives from CARB and Quebec's Minister of International Relations signed an agreement to fully integrate their respective cap-and-trade programs. The linkage, which will enable carbon allowances and offset credits to be exchanged between participants in both jurisdictions' programs, is set to begin on January 1, 2014. The California EPA is expected to release a report in November detailing the progress toward linking. For more information on the linkage, including both English and French versions of the "Agreement between the California Air Resources Board and the Government of Quebec Concerning the Harmonization and Integration of Cap-and-Trade Programs for Reducing Greenhouse Gas Emissions," visit the CARB website. From the *California Air Resources Board News Release* on October 1, 2013.

"An integrated optimization modeling approach for planning emission trading and clean-energy development under uncertainty."

The following is the Abstract of this article: "The growing concern for global warming caused by the increased atmospheric concentration of CO_2 has a significant effect on environmental and energy policies and economic activities, due to the ever-increasing use of fossil fuels such as coal, oil and natural gas throughout the world. A variety of complexities and uncertainties exist in CO_2-emission-related processes and various impact factors, such as CO_2-emission inventory, mitigation measure, and cost parameter. Decision makers face problems of how many clean-energy resources (or carbon credits) are needed to be replaced (or bought) by measuring electric-power benefits and uncertain economic penalties from random excess CO_2 exceeding to given discharge permits. In this study, an integrated optimization modeling approach is developed for planning CO_2 abatement through emission trading scheme (ETS) and clean development mechanism (CDM), where uncertainties presented in terms of fuzzy sets, interval values, and random variables can be addressed. The developed model is also applied to a case study of planning CO_2-emission mitigation for an electric-power system (EPS) that involves three fossil-fueled power plants (i.e., gas, oil and coal-power plants). Different trading schemes and clean-energy development plans corresponding to different CO_2-emission management policies have been analyzed. The results demonstrate that CO_2-emission reduction

Trading (Continued)

program can be performed cost-effective through emission trading and clean-energy development projects. Violation analyses are also conducted to demonstrate that different violation levels for model's objective and constraints have different effects on system benefit and satisfaction degree as well as emission trading and clean-energy development." **Y.P. Li, G.H. Huang, and M.W. Li**, *Renewable Energy*. (Subscription may be required.)

Recent Publications

"Evaluation of Options to Handle CO_2 Capture, Transport and [Storage] Disruption: Amine-, Oxycombustion-, and IGCC-based Plant Design Issues."

The following is from the Executive Summary of this document: "This report highlights potential issues with CCS system operation that may prevent CO_2 from being captured and/or [stored] from fossil-based power plants. It identifies potential modes of failure of CCS equipment/system operation, CO_2 transport, and [storage]. Finally, it proposes appropriate system design considerations for the issues identified. This report was produced at a level of engineering consistent with Class 4 as defined by the Association for the Advancement of Cost Engineering International (AACE); this is consistent with the level of engineering considered in typical system studies. As such, proposed corrective or preventive actions were developed at this level of rigor. Key findings of the report were: [a] Major disruptions in CO_2 [storage] are related to pipeline failures and are determined to be unlikely, with most, if not all, corrective action understood to be common industrial knowledge through previous experiences in related pipeline operations; [b] Disruptions in capture operations are determined to be manageable with detailed hazardous operations analyses. Most mitigating actions here are related to (1) system redundancy, (2) CO_2 venting and, (3) alternate design; [c] In no case was the anticipated result of any failure mode considered to be reason to decide against CCS implementation, from either cost or safety considerations; [d] As with all projects, as more detailed design information is produced, corrective actions may need to be implemented and their costs more explicitly defined. In general, the potential CCS system disruptions examined in this report include: [a] Problems in any part of the CO_2 supply chain involving capture, pipeline transport, and geologic storage; [b] Off-specification CO_2 product stream composition, temperature, or pressure. The above is presented in detail with respect to three different types of fossil-based power plants. [Pulverized coal (PC) plant with 90 percent amine-based post-combustion carbon capture; supercritical oxycombustion plant with 100 percent carbon capture; and integrated gasification combined cycle (IGCC) plant with 90 percent carbon capture.]"

"U.S. Department of Energy Investment in Carbon, Capture and Storage (CCS)."

The following is from the Introduction of this document: "[DOE's] Office of Fossil Energy (FE) is the Department's primary lead for CCS. FE's key activities are funded through annual Congressional appropriations. In recent years, FE's overall annual budget for fossil energy [R&D] has fluctuated from approximately $420 million to $875 million dollars, of which $270 to $580 million has supported CCS-related activities. Before 2009, FE's annual budget mainly funded CCS [R&D], but it also provided support for the development of commercial-scale CCS projects, including the FutureGen project and Southern Company's Kemper County Energy Facility. The Congressional Research Service report estimates that between FY1997 and FY2008, DOE provided $900 million for activities related to CCS. In 2009, DOE greatly increased its funding for CCS by allocating approximately $3.38 billion in funding for CCS under the American Recovery and Reinvestment Act of 2009 (ARRA). FE has used a large portion of this ARRA funding to support the development of multiple commercial-scale CCS projects in both the power and industrial sectors. Currently, DOE is involved in the development of eight active commercial-scale CCS projects, both in the industrial and electric power sectors. As of September 2013, FE had awarded more than $3.23 billion under ARRA to over 90 recipients, including companies, universities, national laboratories, and others in the private sector working on CCS. Of the $3.23 billion awarded, approximately $1.03 billion, or approximately 32 percent, has been spent to date. Approximately $153 million in funding has not been awarded. Beyond FE, DOE selected four commercial-scale CCS projects to receive loan guarantees in 2009 under its 1703 program (though these projects have not moved forward), and the Advanced Research Projects Agency-Energy (ARPA-E) has funded numerous projects involving the [R&D] of next generation CCS technologies. In July 2013, DOE announced that it will be providing $8 billion in new loan guarantees to CCS and other clean energy projects. Overall, DOE's financial support for the eight active commercial-scale CCS projects has been an important factor in determining whether these projects have moved forward. Currently, only a small number of commercial-scale CO_2 capture projects, mostly natural gas processors, where the cost and difficulty of capturing CO_2 are relatively low have come online without DOE support. At the same time, despite DOE support, several of the active projects have been subject to delays and setbacks in progressing toward construction or financial close and in line with original estimates of overall cost. In addition, several commercial-scale projects have been cancelled despite being selected for DOE support. While the track record of commercial-scale projects receiving DOE support has been mixed, the perception among CCS stakeholders is that DOE's support for the [R&D] of CCS component technologies (particularly through the NETL and Regional Carbon Sequestration Partnerships) has been essential. Going forward, however, it is uncertain whether DOE and FE will have sufficient funding to support the development of the next generation of commercial-scale CCS projects, but its involvement in [ongoing R&D] is expected to continue."

Recent Publications (Continued)

"Carbon Reduction Opportunities in the California Petroleum Industry."

The following is from the Summary of this document: "As industry leaders and policymakers seek to reduce the carbon [emissions] impacts caused by human activity, the petroleum supply chain and the use of petroleum products present numerous and significant opportunities for emission reductions. From crude oil production and refining to gasoline and diesel use in vehicles, each portion of the supply chain contributes to the oil industry's carbon footprint. While substitution of cleaner energy sources for oil is a key strategy to reduce carbon [emissions], it is also important to take advantage of the technologies currently available that can directly reduce the carbon footprint of petroleum from production to final use. Opportunities to shrink this footprint include, but are not limited to: (1) renewable steam generation: generating steam for EOR using solar power, rather than combusting fossil fuels in once-through steam generators; (2) steam generation with CCS: capturing and storing the flue gas emissions from once-through steam generators used in EOR; (3) refinery energy efficiency: enabling refineries to use less energy in their operations, thereby reducing their carbon emissions; (4) refinery CCS: capturing and storing carbon emissions resulting from the energy-intensive hydrogen processes needed for refining crude oil; and (5) renewable refinery feedstocks: displacing part of the refinery's crude oil with natural oils, such as animal fats and waste oils, thereby reducing the full-fuel-cycle carbon intensity of the final refinery products."

Legislative Activity

"Canadian energy and climate policies: A SWOT analysis in search of federal/provincial coherence."

The following is the Abstract of this article: "This paper presents an analysis of Canadian energy and climate policies in terms of the coherence between federal and provincial/territorial strategies. After briefly describing the institutional, energy, and climate contexts, we perform a SWOT analysis on the themes of energy security, energy efficiency, and technology and innovation. Within this analytical framework, we discuss the coherence of federal and provincial policies and of energy and climate policies. [The authors'] analysis shows that there is a lack of consistency in the Canadian energy and climate strategies beyond the application of market principles. Furthermore, in certain sectors, the Canadian approach amounts to an amalgam of decisions made at a provincial level without cooperation with other provinces or with the federal government. One way to improve policy coherence would be to increase the cooperation between the different jurisdictions by using a combination of policy tools and by relying on existing intergovernmental agencies." **Camille Fertel, Olivier Bahn, Kathleen Vaillancourt, and Jean-Philippe Waaub**, *Energy Policy*. (Subscription may be required.)

"Incorporating ecosystem services into the implementation of existing U.S. natural resource management regulations: Operationalizing carbon storage."

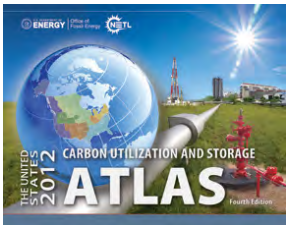
The following is the Abstract of this article: "Many agencies and organizations, including in the United States federal government, are expressing interest in the measurement and valuation of ecosystem services. Despite this interest, specific guidance on whether and how to incorporate ecosystem services into federal activities remains scarce. This analysis examines three regulations that are important parts of the National Oceanic and Atmospheric Administration's mission to protect coastal and marine habitats: the Clean Water Act, the Coastal Zone Management Act, and the Natural Resources Damage Assessment process that is part of the Oil Pollution Act. Case studies of each reveal that it is possible to incorporate the carbon [stored] in coastal habitats, or 'carbon services,' into existing processes—consultative, regulatory, and mitigative—that are employed to implement these regulations. Specific examples illustrate how carbon services could be incorporated into the implementation of each federal regulation. The study concludes that incorporating carbon services into the implementation of existing environmental regulations could provide increased protection or restoration of coastal habitats. Increased conservation outcomes could result from changing the way the federal government implements national policy and/or by stimulating increased investment in coastal habitat conservation through private carbon markets. These outcomes would result in a 'win-win' for both climate regulation and habitat conservation and would preserve not only the carbon services, but also the many ecosystem services these habitats provide." **Ariana E. Sutton-Grier, Amber K. Moore, Peter C. Wiley, and Peter E.T. Edwards**, *Marine Policy*. (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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