NETL the ENERGY lab

Carbon Storage Newsletter

August 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 beneath Boise Inc. property. The Boise pulp and paper mill is located in the Columbia Basin between the Tri-Cities and Walla Walla, Washington. The site is located on top of dozens of volcanic lava flows, extending down 8,000 feet or more; these geologic layers were formed as volcanic lava flowed and cooled. According to a project official, laboratory tests have been conducted on basalts from the region for several years that demonstrate the unique geochemical nature of basalts to react with CO_2 and form carbonate minerals or solid rock. Over the next 14 months, 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. At the end of the monitoring period, rock samples from the well are expected to show the formation of carbonate mineralization, or limestone crystals, as a result of CO_2 reacting with minerals in the basalt. In 2009, an injection well at the site confirmed that basalt flows located above and below the injection zone were nearly impermeable and additional research in late 2012 indicated that the location is well suited for the pilot test. BSCSP is one of seven Regional Carbon Sequestration Partnerships (RCSPs) funded by the U.S. Department of Energy (DOE) and managed by the National Energy Technology Laboratory (NETL). 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.

Announcements

"MRCSP Begins Field Tests in Michigan."

The Midwest Regional Carbon Sequestration Partnership (MRCSP), one of DOE's RCSPs, has begun a large-scale CO_2 field project 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.

Announcements (Continued)

"Research Without Borders: NETL Pens MOU with Brazilian Coal Association."

DOE's NETL and the Brazilian Coal Association (BCA) signed a Memorandum of Understanding (MOU) on carbon capture and storage (CCS) in Florianópolis, Brazil. Under the MOU, both parties will work together to assess the potential of CCS in fossil fuel-based systems over the next five years, as well as the development of clean coal technologies applicable to Brazilian coals.

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

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.

Webinar on Proposed Government-Provided Incentives to Promote the Capture and Use of CO_2 for EOR: Options for Incentivizing.

A Global CCS Institute (GCCSI) webinar was held on June 26 to discuss how additional large-scale projects are needed to advance CCS. The participants discussed how capture costs and incentives influence new projects and existing large-scale projects.

Western Climate Initiative, Inc., Upgrades Compliance Instrument Tracking System Service (CITSS).

The Western Climate Initiative, Inc., is upgrading its Compliance Instrument Tracking System Service (CITSS) to provide cap-and-trade program participants with improved features and more detailed account information. CITSS version 3.0 provides expanded functionality and information, including facility information (entity management/account consolidation), corporate association management, limited exemption and holding limit management, and enhanced reporting features.

CCS Browser: A Guide to CCS.

The CCS Browser was created by the CO_2 Capture Project to help individuals learn more about CCS, including how the CCS process works, how CO_2 is securely stored, techniques used to ensure safe CCS operations, and the differences that CCS can achieve.

2013 Midwest Carbon Sequestration Science Conference.

The Midwest Geological Sequestration Consortium (MGSC) annual Project Advisory Meeting is scheduled for October 7-9, 2013, at the I Hotel and Conference Center in Champaign, Illinois. This conference will include a full day of Illinois Basin Decatur Project (IBDP) research presentations covering the MGSC Phase III research activities. The conference will also include a Sequestration Training and Education Program (STEP)-sponsored workshop and an optional tour of the IBDP site. Registration is now open.

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

"National Grid Completes Test Drilling for North Sea Carbon Dioxide Storage."

National Grid has completed test drilling of a CO_2 storage site in the North Sea and early indications are that the undersea site, 40 miles off the Yorkshire coast, is viable for storing CO_2 and could store approximately 200 million metric tons. The site is located close to a number of power stations, oil refineries, and industrial plants in the Humber region, which create nearly a tenth of the United Kingdom's CO_2 emissions. National Grid officials said that the organization could use its experience with gas pipelines to create a network to transport CO_2 to a storage site. From *The Herald Scotland* on August 8, 2013.

"Magellan Petroleum Initiates CO_2-EOR Pilot at Poplar Dome, Montana."

Magellan Petroleum Corporation announced that permits have been obtained from the U.S. Bureau of Land Management to drill five wells on its leases at Poplar Dome in Roosevelt County, Montana. The permits are the final regulatory requirement prior to commencing drilling operations for the previously announced CO_2-enhanced oil recovery (EOR) pilot program. Magellan Petroleum Corporation also announced a CO_2 supply contract with Air Liquide Industrial U.S. LP for the CO_2 for approximately two years. The project is intended to increase production and validate the reserves potential of EOR. The company has begun drill site preparation work and drilling is expected to occur in the August to November 2013 timeframe. The current plan is to arrange the five pilot wells in a "five-spot" pattern, with a single CO_2-injection well in the

Carbon Storage in the News (Continued)

center surrounded by four producing wells. All five wells will be vertical and drilled to a depth of approximately 5,800 feet with CO_2 injection expected to commence in October 2013. Following the first injection, the company expects it will take in the range of 12 - 15 months to evaluate the effectiveness of CO_2-EOR and announce results. Magellan Petroleum Corporation is an independent oil and gas exploration and development company focused on the development of a CO_2-EOR program at Poplar Dome in eastern Montana. From *Magellan Petroleum Corporation* on August 12, 2013.

"University of Newcastle Wins $290,000 for Low Emissions Coal Research."

A University of Newcastle team received a $290,000 grant from the Australian Low Emission Coal R&D (ANLEC R&D) agency to continue their research of low-emissions coal technologies. The research addresses oxyfuel, which is fossil fuel burnt in the presence of pure oxygen. Oxyfuel is one of three CCS technologies in development and has the ability to reduce carbon emissions from an operating power station by up to 90 percent. A project official said the technology will be tested at the Callide Power Station in Queensland. From *University of Newcastle Newsroom* on August 7, 2013.

"UW Enhanced Oil Recovery Research Lab Targets Stranded Reserves."

The University of Wyoming's new Enhanced Oil Recovery Research Laboratory in its Energy Innovation Center is expected to help small oil operators in Wyoming retrieve 5 to 15 percent of the state's stranded oil through enhanced recovery methods. During 2011, approximately 14 percent of Wyoming's oil was produced using CO_2-EOR. According to the director of the University of Wyoming's Enhanced Oil Recovery Institute (EORI), infrastructure already exists at older fields, although some locations would need retrofitted to meet safety standards. The Enhanced Oil Recovery Research Laboratory provides researchers the ability to determine the types of rock and fluids that make up the reservoirs. Researchers can use the geographic information to create models of reservoirs; create descriptions of reservoirs and generate state-of-the-art, three-dimensional visualizations of the subsurface; experiment with cores in oil and water to see how the cores behave and fluids flow through them; and develop simulations to determine how the various EOR technologies work. From *University of Wyoming News Release* on August 8, 2013.

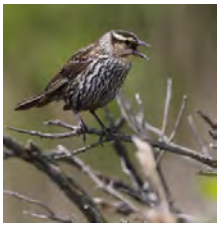
Science

"Climate Change, Ticks Claiming Moose in New Hampshire."

Biologists believe that climate change is affecting moose in New Hampshire due to winter ticks and other parasites. Specifically, the shorter winters are impacting moose because if the weather stays too warm, tick numbers remain high. A recent paper reveals that the number of

winter ticks is related to fall and spring weather. If those seasons are mild and snowless, ticks can thrive. The winter ticks attach to the moose, mate, and lay eggs; the cycle repeats unless the state gets a long, cold winter. In the recent issue of New Hampshire Wildlife Journal, a biologist reported that the average number of winter ticks on a single moose in Alberta, Canada, is 32,000, but can rise as high as 150,000. New Hampshire approved a four-year study of the state's moose population to put radio collars on 80 to 100 moose and track their reproduction and mortality rates; the results of the study will help the state develop a moose management plan. Similar trends in moose population are being seen in Minnesota and Maine. From *Concord Monitor* on July 28, 2013.

"Young or Old, Song Sparrows Experience Climate Change Differently from Each Other."



According to two recent studies, young and old song sparrows are experiencing the effects of climate change in different ways. In one study, the research shows the importance of examining the various stages and ages of individuals in a species to understand how and why climate change could affect a whole species. Researchers found that climate change had opposite effects for adult and juvenile song sparrows in central coastal California. The researchers found that adult survival was sensitive to cold winter weather and expected a similar response from the young. However, warmer, drier winters translated to less food for the juvenile sparrows during the following summer. The research showed that juveniles have to survive their first summer and they are sensitive to how much food is available; thus, as winters get warmer, adults and juveniles respond in opposite directions. In another study, researchers found that parents provided a buffer against the weather for baby sparrows, but independent juveniles newly out on their own were more sensitive to changes in the weather because they lacked their parents' skills and experience. From *ScienceDaily* on August 12, 2013.

Policy

"IOGCC Task Force Continues Work to Pave Way for CO_2 Storage."

The Interstate Oil and Gas Compact Commission's (IOGCC) Carbon Geologic Storage (CGS) Task Force is finalizing work on liability issues related to CO_2 storage in geologic formations. DOE's Plains CO_2 Reduction (PCOR) Partnership is participating with other task force members, including state and provincial regulators and representatives of both industry and the environmental community. The task force focuses on assisting states and provinces in identifying the critical issues and developing model statutes and regulations necessary to allow and encourage the development of a carbon storage industry in U.S. states and Canadian provinces. The final work product (the third phase of the task force's effort) will provide further guidance to U.S. states and Canadian provinces on issues relating to pre-operational, operational, and post-operational liabilities in the geologic storage of carbon in

Policy (Continued)

non-hydrocarbon bearing subsurface formations. The Phase III Final Report is expected in Fall 2013. Previous CGS Task Force publications include: (1) a 2005 Phase I report examining "the legal, policy and regulatory issues related to the safe and effective geologic storage of CO_2 for both enhanced recovery and long-term CO_2 storage"; (2) a 2007 Phase II report, titled "Storage of Carbon Dioxide in Geologic Structures: A Legal and Regulatory Guide for States and Provinces"; and (3) a 2010 Phase II report entitled "Biennial Review of the Legal and Regulatory Environment for the Storage of Carbon Dioxide in Geologic Structures." All publications can be found on the IOGCC website. The PCOR Partnership is a part of DOE's RCSP Initiative. From *Digital Journal News Release* on August 14, 2013.

"Emissions reduction potential from CO_2 capture: A life-cycle assessment of a Brazilian coal-fired power plant."

The following is the Abstract of this article: "CCS is an effective technology for the mitigation of [greenhouse gas (GHG)] emissions from large-scale fossil fuel use. Nonetheless, it is not yet commercially viable on a large scale, and its inclusion into countries' energy planning agendas depends on realistic assessments of its emission reduction benefits. The use of CCS leads to energy penalties resulting from direct consumption of additional energy, and results in indirect CO_2 equivalent emissions outside plant boundaries, due to both energy consumption and [releases]. Accounting for these emissions allows for an evaluation of the mitigation benefits of CCS. This study performs a life-cycle assessment (LCA), with and without CCS, for a coal-fired power plant located in Brazil. Findings show that when indirect emissions are taken into account, a plant which captures 90 [percent] of its CO_2 will have its CO_2 equivalent emissions capture potential, based on a global warming potential metric with a 100-year time horizon, reduced to 72 [percent]. The advantage of the use of carbon capture towards climate change mitigation is reduced mainly as a result of an increase in [methane (CH_4)] emissions, significant in the coal-mining stage, an effect which is only taken into account when a LCA is performed." **David A. Castelo Branco, Maria Cecilia P. Moura, Alexandre Szklo, and Roberto Schaeffer**, *Energy Policy*. (Subscription may be required to view article.)

"A proposed methodology for CO_2 capture and storage cost estimates."

The following is the Abstract of this article: "There are significant differences in the methods employed by various organizations to estimate the cost of CCS systems for fossil fuel power plants. Such differences often are not apparent in publicly reported CCS cost estimates, and thus contribute to misunderstanding, confusion, and [misrepresentation] of CCS cost information, especially among audiences not familiar with the details of CCS costing. Given the international importance of CCS as an option for climate change mitigation, efforts to harmonize methods of estimating CCS costs and improving the communication of cost assumptions and results are especially urgent and timely. Based on an analysis of current deficiencies, this paper recommends a common costing methodology plus guidelines for CCS cost reporting to improve the clarity and consistency of cost estimates for [GHG] mitigation measures." **Edward S. Rubin, Christopher Short, George Booras, John Davidson, Clas Ekstrom, Michael Matuszewski, and Sean McCoy**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Characterizing CCS learning: The role of quantitative methods and alternative approaches."

The following is the Abstract of this article: "A number of energy scenario studies have suggested that CCS could make a significant contribution to reducing global CO_2 emissions. This would require efforts to ensure rapid development and deployment. Since there is limited experience of CCS systems, it is hard to define 'business as usual' development. This leads to significant uncertainty for policy makers and other stakeholders with regard to characterizing potential CCS pathways and assessing the scope for and risks of acceleration. Quantitative analytical approaches to projecting costs and other parameters typically depend on best current estimates of critical input data, as well as implicit or explicit assumptions about technology development pathways and contextual factors such as evolving regulatory requirements. There are significant limitations in current quantitative (and qualitative) data on CCS that lead to significant difficulties in identifying robust assumptions. One way to handle this is to develop multiple scenarios to illustrate the uncertainty. Another strategy is to make more use of qualitative methods for analyzing CCS innovation processes. This latter approach could help to avoid some of the issues associated with CCS cost uncertainty and instead re-focus attention on understanding critical aspects of innovation processes." **Niles Markusson and Hannah Chalmers**, *Technological Forecasting and Social Change*. (Subscription may be required to view article.)

Geology

"Pore system changes during experimental CO_2 injection into detritic rocks: Studies of potential storage rocks from some sedimentary basins of Spain."

The following is the Abstract of this article: "The effects of experimental injection of CO_2 into potential deep sedimentary formations are investigated, focusing on detrital rocks with interconnected pore networks. This approach consisted in the qualitative and quantitative determination of mineralogical and textural changes in selected sedimentary rock samples after injection of supercritical CO_2 ($P \approx 75$ bar, $T \approx 35$°C, 12–970 h exposure time and dry conditions). The mineralogy and texture were studied before and after the injection by optical and scanning electron microscopy, and quantification was done with digital image analysis. The studied rocks were sampled from different sedimentary basins in Spain and consist of feldspar sandstones with similar mineralogy but different textures (homogeneous vs. heterogeneous). The results obtained in the CO_2-treated samples indicate a porosity increase ($\Delta n = 3.75$ [percent]) and a qualitative permeability rise. Intergranular clay matrix detachment and partial removal from the rock sample (due to CO_2 input/release drag and electrical-polarity forces) are the main processes that explain the porosity increase. In contrast, carbonate cements were stable and no substantial changes were observed. Additional textural changes were minor and consisted on variations in the roughness of grain-pore contacts,

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pore shape and aspect ratio. Primary texture of the rock subjected to CO_2 injection is an important factor and seems to enhance textural/mineralogical changes in heterogeneous systems. These results simulate the CO_2 injection nearest to the injection well and indicate that, in this environment, where CO_2 push out the brine fluids and interacts with rocks in dry conditions, several mineralogy/texture re-adjustments take place. Consequences derived from these changes are variable. Possible porosity and permeability increases could facilitate further CO_2 injection but textural re-adjustment could also affect the rock physical properties." **E. Berrezueta, L. González-Menéndez, D. Breitner, and L. Luquot**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Strategy for ranking potential CO_2 storage reservoirs: A case study for Belgium."

The following is the Abstract of this article: "CCS is likely to become a necessary option in mitigating global climate change. However, lack of detailed knowledge on potential deep geological reservoirs can hamper the development of CCS. In this paper a new methodology is presented to assess and create exploration priority lists for poorly known reservoirs. Geological expert judgements are used as a basis in a two-stage geo-techno-economic approach, where first an estimate of the practical reservoir capacity is calculated, and secondly source–sink matching is used for calculating an estimate of the matched capacity and the reservoir development probability. This approach is applied to Belgium, demonstrating how a priority ranking for reservoirs can be obtained based on limited available data and large uncertainties. The results show the Neeroeteren Formation as the most prospective reservoir, followed by the Buntsandstein Formation and the Dinantian reservoirs. The findings indicate that CO_2 export to reservoirs in [neighboring] countries seems inevitable; still, there is a 70 [percent] chance storage will happen in Belgian reservoirs, with an average matched capacity estimate of 110 Mt CO_2. These quantitative results confirm the qualitative resource pyramid classification of potential reservoirs. For Belgium, a high economic risk is attached to reservoir exploration and development. Exploration remains however a necessity if CCS is to be deployed. Furthermore, it is shown that the presented methodology is indeed capable of producing realistic results, and that using expert judgements for reservoir assessments is valid and beneficial." **Kris Welkenhuysen, Andrea Ramírez, Rudy Swennen, and Kris Piessens**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Development of a rate-based model for CO_2 absorption using aqueous NH_3 in a packed column."

The following is the Abstract of this article: "A rigorous rate-based model for CO_2 absorption using aqueous ammonia in a packed column has been developed and used to simulate results from a recent pilot plant trial of an aqueous ammonia-based post-combustion capture process at the Munmorah Power Station, New South Wales, Australia. The model is based on the RateSep module, a rate-based absorption and stripping unit operation model in Aspen Plus, and uses the available thermodynamic, kinetic and transport property models for the NH_3–CO_2–H_2O system to predict the performance of CO_2 capture. The thermodynamic and transport property models satisfactorily predict experimental results from the published literature. The [modeling] results from the rate-based model also agree reasonably well with pilot plant results, including CO_2 absorption rate, NH_3 loss rate, temperature profiles and mass transfer coefficients in the absorber. To gain insights into absorption performance, [the authors] used the rate-based model to [analyze] the species concentration profile, temperature profile, mass transfer rate and coefficient in the gas and liquid bulk phase along the packing height." **Guojie Qi, Shujuan Wang, Hai Yu, Leigh Wardhaugh, Paul Feron, and Changhe Chen**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

Technology

"Benchmarking of CO_2 transport technologies: Part I – Onshore pipeline and shipping between two onshore areas."

The following is the Abstract of this article: "This paper focuses on illustrating the CCS chain methodology and the functionality of two transport assessment modules developed within the BIGCCS Research Centre for onshore pipeline and shipping between onshore areas. On the basis of these two modules, technical, costs and climate impact assessments of transport infrastructure and conditioning processes were assessed and compared for a base case. In this case study, onshore pipeline and CO_2 shipping between two onshore harbors are compared for different distances and capacities. As expected, for a given annual capacity, onshore pipeline transport should be used for 'short' distances, while shipping between harbors is employed for longer distances. Regarding the distance at which the cost-optimal technology switches between the two options, the results show that higher annual capacity and volume would lead to a preference for onshore pipeline transport. The base case can be used as a guide to draw conclusions on particular case studies under the hypotheses presented in this paper. The results also appear to be consistent with the few papers that have compared onshore pipeline and shipping between harbors. Sensitivity analyses were used to address and quantify the impact of several important parameters on the choice of technology. The influences of the individual parameters were then ranked showing that the four most influent parameters on the technology choice are the geographical context, the regional effect of pipeline costs, the First-Of-A-Kind effect, and the ownership effect. Additional work that focuses on transport between a coastal area and an offshore site using either an offshore pipeline or shipping will be presented in Part II of this paper." **Simon Roussanaly, Jana P. Jakobsen, Erik H. Hognes, and Amy L. Brunsvold**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"A mechanistic model for pipeline steel corrosion in supercritical CO_2-SO_2-O_2-H_2O environments."

The following is the Abstract of this article: "A mechanistic model was established to predict uniform corrosion rate and investigate the corrosion mechanisms of pipeline steel in supercritical CO_2–SO_2–O_2–H_2O environments. A six-region division (SIWDES: Supercritical CO_2, Interface, Water film, Deposition, Electrodic, and Solid) was applied to mathematically describe the model. The modified three-characteristic-

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parameter correlation model was used to calculate the ion activity coefficients, which calculates the activity coefficients of ions in thin water film with high ionic strength. The model can reasonably predict the corrosion rate of pipeline steel for the primary variables, determine the concentration distribution of each component in the water and product films, and also reflect the impact of corrosion product film on corrosion rate. A comparative analysis between the model and the experimental results showed that the model reasonably predicted the effects of the main factors on corrosion rate." **Yong Xiang, Zhe Wang, Minghe Xu, Zheng Li, and Weidou Ni**, *The Journal of Supercritical Fluids*. (Subscription may be required to view article.)

"Investigating the effect of salt and acid impurities in supercritical CO_2 as relevant to the corrosion of carbon capture and storage pipelines."

The following is the Abstract of this article: "A series of corrosion exposure tests were performed in a supercritical CO_2 environment used to represent the potential conditions for CCS pipelines. Impurities from various CO_2 capture processes are potentially present, which segregate to the aqueous phase, hence combining with any free water present in the pipeline. Herein, salt ($NaNO_3$, Na_2SO_4, NaCl) and acid (HNO_3) impurities were added, along with 10 g of water, to an autoclave at 7.6 MPa and 50°C (supercritical CO_2) for a [seven] day steel specimen exposure. The tests conducted in supercritical CO_2 were also compared with aqueous tests in atmospheric conditions. Weight loss and optical profilometry revealed that corrosion rates for all samples are significant, along with the potential for [localized] attack. The corrosion mechanism differs for each solution tested. The work herein contributes to a holistic appraisal of understanding the corrosion of CO_2 pipelines." **S. Sim, I.S. Cole, F. Bocher, P. Corrigan, R.P. Gamage, N. Ukwattage, and N. Birbilis**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Direct electrolytic dissolution of silicate minerals for air CO_2 mitigation and carbon-negative H_2 production."

The following is the Abstract of this article: "[The authors] experimentally demonstrate the direct coupling of silicate mineral dissolution with saline water electrolysis and H_2 production to effect significant air CO_2 absorption, chemical conversion, and storage in solution. In particular, [the authors] observed as much as a 105-fold increase in OH^- concentration (pH increase of up to 5.3 units) relative to experimental controls following the electrolysis of 0.25 M Na_2SO_4 solutions when the anode was encased in powdered silicate mineral, either wollastonite or an ultramafic mineral. After electrolysis, full equilibration of the alkalized solution with air led to a significant pH reduction and as much as a 45-fold increase in dissolved inorganic carbon concentration. This demonstrated significant spontaneous air CO_2 capture, chemical conversion, and storage as a bicarbonate, predominantly as $NaHCO_3$. The excess OH^- initially formed in these experiments apparently resulted via neutralization of the anolyte acid, H_2SO_4, by reaction with the base mineral silicate at the anode, producing mineral sulfate and silica. This allowed the NaOH, normally generated at the cathode, to go unneutralized and to accumulate in the bulk electrolyte, ultimately reacting with atmospheric CO_2 to form dissolved bicarbonate. Using nongrid or nonpeak renewable electricity, optimized systems at large scale might allow relatively high-capacity, energy-efficient (<300 kJ/mol of CO_2 captured), and inexpensive (<$100 per [metric ton] of CO_2 mitigated) removal of excess air CO_2 with production of carbon-negative H_2. Furthermore, when added to the ocean, the produced hydroxide and/or (bi)carbonate could be useful in reducing sea-to-air CO_2 emissions and in neutralizing or offsetting the effects of ongoing ocean acidification." **Greg H. Rau, Susan A. Carroll, William L. Bourcier, Michael J. Singleton, Megan M. Smith, and Roger D. Aines**, *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required to view article.)

Terrestrial

"Extreme CO_2 disturbance and the resilience of soil microbial communities."

The following is the Abstract of this article: "[CCS] technology has the potential to inadvertently release large quantities of CO_2 through geologic substrates and into surrounding soils and ecosystems. Such a disturbance has the potential to not only alter the structure and function of plant and animal communities, but also soils, soil microbial communities, and the biogeochemical processes they mediate. At Mammoth Mountain, [the authors] assessed the soil microbial community response to CO_2 disturbance (derived from volcanic 'cold' CO_2) that resulted in localized tree kill; soil CO_2 concentrations in [the authors'] study area ranged from 0.6 [percent] to 60 [percent]. [The authors'] objectives were to examine how microbial communities and their activities are restructured by extreme CO_2 disturbance, and assess the response of major microbial taxa to the reintroduction of limited plant communities following an extensive period (15–20 years) with no plants. [The authors] found that CO_2-induced tree kill reduced soil carbon (C) availability along [the authors'] sampling transect. In response, soil microbial biomass decreased by an order of magnitude from healthy forest to impacted areas. Soil microorganisms were most sensitive to changes in soil organic C, which explained almost 60 [percent] of the variation for microbial biomass C (MBC) along the CO_2 gradient. [The authors] employed phospholipid fatty acid analysis and quantitative PCR (qPCR) to determine compositional changes among microbial communities in affected areas and found substantial reductions in microbial biomass linked to the loss of soil fungi. In contrast, archaeal populations responded positively to the CO_2 disturbance, presumably due to reduced competition of bacteria and fungi, and perhaps unique adaptations to energy stress. Enzyme activities important in the cycling of soil C, nitrogen (N), and phosphorus (P) declined with increasing CO_2, though specific activities (per unit MBC) remained stable or increased suggesting functional redundancy among restructured communities. [The authors] conclude that both the direct (microaerobiosis) and indirect (loss of plant C inputs) effects of elevated soil CO_2 flux have significant impacts on the composition and overall structural trajectory of soil microbial populations within disturbed areas." **Jack W. McFarland, Mark P. Waldrop, and Monica Haw**, *Soil Biology and Biochemistry*. (Subscription may be required to view article.)

Trading

"UN Takes Steps to Boost Demand for Carbon Market Credits."

The United Nations (UN) is opening a regional collaboration center in Grenada to accelerate the development of carbon markets in the Caribbean. The office will help identify projects and opportunities for local governments, non-governmental organizations (NGOs), and other businesses interested in the Clean Development Mechanism (CDM). This is the third regional collaboration center established by the United Nations Framework Convention on Climate Change (UNFCCC) – the first was in Lomé, Togo, and the second was in Kampala, Uganda. From *RTCC.org* on July 26, 2013.

"EWSI Launches Carbon Trading Software for E-Waste Industry."

E-Waste Systems, Inc. (EWSI) is launching software to identify and quantify the energy use of electronics to aid companies in reducing energy consumption and facilitate carbon trading. According to EWSI, the eWaste Carbon Credit technology brings carbon credit trading ability to the e-waste industry. The software is integrated with VGG's SMARTWeb system – an energy reporting and carbon accounting tool offered to large GHG emitters to reduce their energy and operating costs, validate their emissions, document their reductions, and support carbon trading. According to the 2007 IEEE International Symposium on Electronics and the Environment, emissions from electronic goods imported to the United States increased 300 percent from 1997 to 2004. From *Environmental Leader* on August 5, 2013.

"Towards a comprehensive system of methodological considerations for cities' climate targets."

The following is the Abstract of this article: "Climate targets for cities abound. However, what these targets really imply is dependent on a number of decisions regarding system boundaries and methods of calculation. In order to understand and compare cities' climate targets, there is a need for a generic and comprehensive framework of key methodological considerations. This paper identifies eight key methodological considerations for the different choices that can be made when setting targets for GHG emissions in a city and arranges them in four categories: temporal scope of target, object for target setting, unit of target, and range of target. To explore how target setting is carried out in practice, the climate targets of eight European cities were analyzed. The results showed that these targets cover only a limited part of what could be included. Moreover, the cities showed quite limited awareness of what is, or could be, include in the targets. This makes comparison and benchmarking between cities difficult." **Anna Kramers, Josefin Wangel, Stefan Johansson, Mattias Hojer, Goran Finnveden, and Nils Brandt**, *Energy Policy*. (Subscription may be required to view article.)

"Taxing International Emissions Trading."

The following is the Abstract of this article: "[The authors] investigate the efficiency and effectiveness consequences of emissions trading taxation. A theoretical partial equilibrium model is developed, showing that permits taxation distorts the equilibrium price and abatement efforts. Potentially counterintuitive conclusions concerning the tax revenue are also derived. A [Computable General Equilibrium (CGE)] model complements theoretical results, suggesting that the change in the equilibrium permits price brought about by taxation can be significant. Finally, [the authors] conclude that policy design based on cost effectiveness might lead to wrong conclusions: the socially desirable design of emissions trading taxation requires homogenous tax rates applied to net sellers and no rebate rates allowed for net buyers." **Valeria Costantini, Alessio D'Amato, Chiara Martini, Maria Cristina Tommasino, Edilio Valentini, and Mariangela Zoli**, *Energy Economics*. (Subscription may be required to view article.)

"Frameworks for pricing greenhouse gas emissions and the policy objectives they promote."

The following is the Abstract of this article: "Four cost-effective frameworks for pricing [GHG] emissions currently receive widespread attention: cap-and-trade, emission fees, and hybrid cap-and-trade approaches that include upper or lower limits on permit prices (price ceilings or floors). This paper develops a fifth framework that uses an emission fee with an upper limit on the quantity of emissions—a quantity ceiling—and compares the impact of each framework on emission prices and quantities. Cap-and-trade with a price ceiling minimizes price increases for emitting activities in all cases whereas an emission fee with a quantity ceiling maximizes emissions reductions. Thus, the choice of framework influences policy outcomes because each framework is more or less suited to particular policy goals. Whether pursuing one potential policy goal serves society's interests best depends on the eventual consequences of climate damage and emissions pricing, which are uncertain when policy choices are made. Policy updating over time may reduce but likely cannot entirely eliminate the differences in outcome that arise due to framework choice. Therefore, the 'best' framework for emissions pricing depends on subjective preferences regarding the relative importance of different policy objectives, most notably whether one is more risk averse to climate damages or emissions price increases." **Paul A.T. Higgins**, *Energy Policy*. (Subscription may be required to view article.)

Recent Publications

"Global Action to Advance Carbon Capture and Storage: A Focus on Industrial Applications."

The following in from the Summary and Recommended Global Action chapter of this publication: "Energy-intensive industries account for a significant part of global CO_2 emissions. Industrial sectors such as cement, iron and steel, chemicals and refining represent one-fifth of total global CO_2 emissions, and the amount of CO_2 they produce is likely to grow over the coming decades. CCS in industrial applications refers to the prevention of CO_2 emissions through the capture, transport and storage or use of CO_2 from these sectors. Analysis by the International Energy Agency shows that CCS in industrial applications could represent around half of the emission reductions achieved through CCS

Recent Publications (Continued)

by 2050. CCS is the only option to decarbonize many industrial sectors. CCS is currently the only large-scale mitigation option available to cut the emissions intensity of production by over 50 [percent] in these sectors. Further energy efficiency improvements, while urgently needed, have limited potential to reduce CO_2 emissions, partly due to the non-energy related emissions from many industrial processes. As a result, it may not be possible to decarbonize industrial sectors without CCS. Failure to make the case for CCS in industrial applications and to undertake the actions needed for deployment poses a significant threat to the world's capacity to tackle climate change. In addition, economies where CCS is available may be better placed to host and benefit from industrial production in the future. Developing and deploying CCS in energy intensive industries is of critical importance. CCS in industrial applications requires more attention from policy makers…"

"Pioneer's Sequestration Research and Proposed MMV [Program]."

The following is a summary of this document: "This report represents the work and results accomplished during the initial phase of work done on Project Pioneer, with respect to [storing] CO_2 in a deep geological formation. This report will also discuss some early geological studies (one of which preceded the inception of Pioneer), the drilling and testing of the evaluation well, as well as the detailed geological and reservoir models and the risk analysis that enabled the Project to develop a [storage] and [measurement, monitoring, and verification (MMV)] program complete with a cost estimate and schedule."

"European Commission CCS Consultation paper: Global CCS Institute submission."

The following is from the Executive Summary of this document: "Under the Energy Roadmap 2050, the European Commission (EC) envisions the broad scale deployment of CCS technologies in Europe from 2030 onwards. However, in response to challenges in successfully establishing any large-scale demonstration projects in the European Union (EU), the EC has released a Consultative Communication (the Consultation) seeking advice on how to reinvigorate the CCS demonstration program, with a view to achieving earlier deployment of CCS. The Global Carbon Capture and Storage Institute (the Institute) considers CCS to be the single most promising set of technologies capable of bridging the dual objectives of cost effective large-scale abatement and security of supply in a carbon constrained environment. The Institute acknowledges challenges will arise in undertaking initial commercial-scale demonstration activities for such a transformational clean energy solution, particularly with regard to permitting the initial projects as well as bringing the local community along with the project. It is important to [recognize] that, to a very large extent, the proposals examined in the Consultation will take effect in the medium to long term. While long-term signals are important in giving visibility to project proponents, there is an urgent need to address the short-term funding issues (both CAPEX and OPEX) facing projects here and now. It is clear that the way CCS is currently promoted in Europe needs enhancing and the Institute agrees with the EC assessment that the 'available funding is not sufficient' to support an effective demonstration program. This submission explains the Institute's preferred approach to supporting CCS in Europe and makes [several recommendations]."

"Predicting CO_2 injectivity properties for application at CCS sites."

The following is from the Executive Summary of this ANLEC R&D document: "This project aims to investigate the injectivity of potential Australian carbon storage reservoirs, and to provide some understanding of their capacity to store CO_2. A parallel work-flow is developed to allow the efficient movement of a core sample through the four laboratory test stages. Berea sandstone core is used to commence tests as a standard calibration example due to its well-documented characteristics in the international literature. Three other cores are tested afterwards, namely Otway (Waarre-C), Pinjarra-1 (Lesueur) and Harvey-1 (Lesueur). Geomechanical tests and CT scanning are performed and the results provide new insights into the injectivity of CO_2."

Legislative Activity

"Governor Martin Governor Martin O'Malley Hosts Maryland Climate Change Summit, Releases Final Greenhouse Gas Reduction Act Plan."

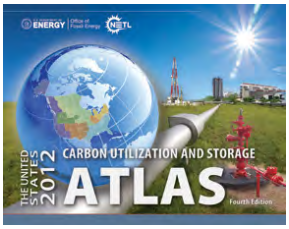
Maryland Governor Martin O'Malley hosted a climate change summit to highlight the release of Maryland's Greenhouse Gas Reduction Act, which will help the state reach its goal of reducing GHG emissions 25 percent by 2020. The plan is a framework to strengthen current programs with new technologies and policies over the next seven years, resulting in a reduction in GHG emissions and economic benefits. Key programs in the Greenhouse Gas Reduction Act include: Maryland Renewable Energy Portfolio Standard (RPS) (establishes a market for new sources of renewable electricity generation); EmPOWER Maryland (designed to reduce both Maryland's per capita total electricity consumption and peak load demand by 15 percent by 2015); Zero Waste (aims to ensure all products in Maryland can be reused, recycled, or composted); Maryland Clean Cars Program (regulates CO_2 emissions from motor vehicles); and the Regional Greenhouse Gas Initiative (RGGI). RGGI is a regional cap-and-trade initiative among nine northeast states to reduce CO_2 emissions from fossil fuel-fired power plants to support energy efficiency programs and enhance EmPOWER and RPS. The plan is projected to create 37,000 additional jobs. More information can be found at Maryland's Greenhouse Gas Reduction Act Plan. From *Governor Martin O'Malley Press Release* on July 25, 2013.

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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NETL on LinkedIn

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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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