NETL the ENERGY lab

Carbon Storage CSN Newsletter

November 2013

What's Inside?

Highlights

"Energy Ministers Endorse CCS as Key to Combating Climate Change."

On November 7, the Carbon Sequestration Leadership Forum (CSLF) member nations endorsed carbon capture and storage (CCS) technologies as a key component of international plans to combat climate change. The CSLF Ministers stated that they are convinced that the demonstration and global deployment of CCS must be accelerated and they are committed to taking individual and collaborative actions. The Ministers' common goal is to ensure that the conditions are right for completing CCS projects currently under construction or in advanced stages of planning. The Ministers also expressed interest in increasing the number of new large CCS demonstrations by 2020 to enable future commercial deployment in the early 2020s. The CSLF Ministers outlined the following actions for CCS deployment: (1) develop predictable financial frameworks and incentives to drive near-term CCS deployment; (2) develop CCS demonstration and deployment strategies in both the power and industrial sectors; (3) stress the importance of global coordinated efforts on CCS research, development, and demonstrations, and actively seek and support such opportunities through bilateral and multilateral collaboration with other key bodies including the International Energy Agency (IEA) and the Global Carbon Capture and Storage Institute (GCCSI); (4) continue establishing permitting frameworks that will ensure the safety and integrity of integrated CCS systems and eliminate deployment obstacles; (5) recognize the need for pre-commercial storage validation and encourage cooperation between countries to identify and assess shared geologic storage resources and develop plans for their orderly development, including development of associated transport systems; (6) strengthen national, regional, and international efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment; and (7) support efforts to grow capacity in CCS and foster appropriate steps in knowledge-sharing and technology transfer. CSLF is a Ministerial-level international climate change initiative organizing worldwide resources to develop technologies for the separation, capture, transport, and long-term storage of carbon dioxide (CO_2) from power plants and industrial facilities. CSLF includes 22 developed and developing nations. From *CSLF News Release* on November 7, 2013.

"Energy Department Invests to Drive Down Costs of Carbon Capture, Support Reductions in Greenhouse Gas [Emissions]."

As part of the Climate Action Plan, the U.S. Department of Energy (DOE) announced the selection of 18 projects to research technologies that will help improve the efficiency and drive down costs of carbon capture processes for new and existing coal-fired power plants. The DOE investment and additional cost-share from industry, universities, and other research institutions will support projects that conduct carbon capture research for two different fossil power generation processes: (1) traditional, combustion-based power plants research will focus on post-combustion carbon capture; and (2) more advanced, gasification-based, electric power plants will work to improve the efficiency and cost-effectiveness of pre-combustion carbon capture. A full list of the projects and accompanying descriptions is available online. From *U.S. Department of Energy News Release* on November 7, 2013.

Announcements

New Course at the Wyoming Carbon Capture and Storage Technology Institute (WCTI).

This WCTI course, titled, "Well Construction, Operation, Monitoring and Testing," is intended to introduce CCS professionals to the construction and operating requirements of Class VI wells. In addition, a variety of techniques for monitoring the injected CO_2 plume in the subsurface and for detecting any potential releases from the well or reservoir will be discussed. The course syllabus is available via the link above.

RGGI States Initiate Bidding Process for Auction 22.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2013 auctions released an Amendment to the Auction Notice for the 22nd CO_2 allowance auction, scheduled for December 4, 2013. The Auction Notice Amendment is available via the RGGI website. RGGI is the first market-based regulatory program in the United States.

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 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.

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 IEAGHG.

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

"CSLF Endorses Five New Carbon Capture Projects."

Five new CCS projects were approved at the CSLF's Fifth Ministerial Meeting in Washington, D.C., in early November. The projects were added to the organization's research and development (R&D) portfolio. The five new projects are the Uthmaniyah CO_2-EOR Demonstration project, the Alberta Carbon Trunk Line Project, the Kemper County Energy Facility, the Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project, and the Southeast Regional Carbon Sequestration Partnership (SECARB) Phase II Anthropogenic Test and Plant Barry CCS Project. The projects are aimed at gathering the knowledge and experience required to initiate widespread carbon capture and conduct safe, secure geologic storage. The CSLF portfolio includes activities to identify potential CO_2 storage capacities and projects dedicated to matters such as CO_2 capture technology costs; developing new methods of combustion; identifying storage capacity and widening the understanding of geologic reservoirs; predicting the behavior of CO_2 in various kinds of reservoirs; and developing technologies for successful, reliable, and long-term monitoring, measurement, and verification (MVA). From *CSLF Media Release* on November 6, 2013.

"Masdar Digs Deep for Middle East's First Carbon Capture Project."

Masdar, Abu Dhabi's state clean tech investment fund, and the Abu Dhabi National Oil Company (ADNOC) signed a joint venture agreement to deliver supporting infrastructure for the development of a $122.5 million carbon capture, utilization, and storage infrastructure project. The engineering, procurement, and construction (EPC) contract was awarded to Dodsal Group to build a CO_2 compression facility and 50-kilometer pipeline to connect Emirates Steel facility with oil fields in

Carbon Storage in the News (Continued)

the Emirate. The project is designed to capture carbon emissions from the steel plant and transport it to ADNOC's oil fields for use in enhanced oil recovery (EOR). From *BusinessGreen* on November 14, 2013.

"Skyonic Begins Construction on Commercial-Scale Carbon Capture and Mineralization Plant."

Construction has started on Skyonic's Capitol SkyMine carbon capture and mineralization plant at Capitol Aggregates Cement Factory in San Antonio, Texas. The plant is expected to capture 75,000 tons of CO_2 annually and offset an additional 225,000 tons from the production of green products. Skyonic's electrolytic carbon capture technology, SkyMine®, will capture CO_2, acid gases, and heavy metals from the flue gas of the Capitol Aggregates Cement Plant, where the Capitol SkyMine plant will be retrofitted. The captured emissions will be mineralized into products, such as sodium bicarbonate, which can then be stored, transported, and sold. Skyonic has operated a demonstration-scale plant at the Capitol Aggregates site since 2010. The plant is expected to be fully operational in 2014. From *Skyonic Press Release* on September 30, 2013.

Science

"Pacific Ocean Warming 15 Times Faster Than Before."

According to a study published in the journal "Science," the middle depths of a part of the Pacific Ocean have warmed 15 times faster over the past 60 years than they did during the previous 10,000 years. Studied from the surface to approximately 2,200 feet below, the temperature of the Pacific Ocean water has increased by approximately one-third of a degree Fahrenheit over the past 60 years. Up until approximately 800 years ago, Pacific Ocean water had been cooling; but then it slowly began to rise and increase at a higher pace over the past few decades, researchers claim. According to the Intergovernmental Panel on Climate Change (IPCC), the majority of atmospheric greenhouse gas (GHG) emissions since the 1970s have been absorbed by the oceans. From *USA Today* on October 31, 2013.

Policy

"[President] Creates Climate Change Task Force."

The White House has announced the creation of a "Task Force on Climate Preparedness and Resilience" that will include state, local, and tribal leaders from across the United States. According to the executive order, the group will "advise the Administration on how the Federal Government can respond to the needs of communities nationwide that are dealing with the impacts of climate change." For more information, view the FACT SHEET: Executive Order on Climate Preparedness. From *USA Today* on November 1, 2013.

"Identification of management strategies for CO_2 capture and [storage] under uncertainty through inexact modeling."

The following is the Abstract of this article: "Geologic [storage] has been considered as an effective and critical means for significant reductions of CO_2 amounts to the atmosphere among various mitigation approaches. A CCS management system must be a complex system to accommodate the relevant social, economic, environmental, and political factors. Effective management of such a complex system involves balancing tradeoffs among these key influencing factors. In addition, carbon-emission trading is increased attention as a mechanism for addressing emissions quota shortage problems. Emissions markets have potentials to mediate between various emission sources and CO_2 capture and [storage] projects in a systematic manner. The objective of this study is to develop an inexact management model (ICSM) to identify optimal strategies for planning CO_2 capture and [storage] with a CCS system involving multiple emission sources, multiple capture technologies and multiple project periods. Two mechanisms are considered including with and without carbon emission trading. The proposed model is based on the interval programming method, where uncertain information is directly incorporated and communicated into the optimization processes through the use of interval numbers. The ICSM model has been applied to a hypothetical case study in CCS management to demonstrate its applicability. The results indicated that total system costs under a trading mechanism would be less than those under a non-trading mechanism through more effective re-allocation of emission quota to different sources within the entire CCS system. The obtained solutions could provide more flexibility for the decision makers in generating appropriate management practices for carbon capture and [storage]." **Xiaodong Zhang, Ian J. Duncan, Gordon Huang, and Gongchen Li**, *Applied Energy.* (Subscription may be required.)

"Greensites and brownsites: Implications for CO_2 [storage] characterization, risk assessment, and monitoring."

The following is the Abstract of this article: "Proposed CO_2 storage sites will require different approaches in characterization, risk assessment, and monitoring, given prior site history and land use. Those sites lacking previous subsurface development are defined as greensites, whereas sites where the subsurface is developed, particularly for hydrocarbon production, are defined as brownsites. Greensite CO_2 injection is specifically for storage of CO_2. Most CO_2 [EOR] operations using incidental storage would be characterized as a brownsite. Application of monitoring approaches developed for greensites is inadequate when applied to brownsites because intrinsically different uncertainties may lead to investment in ineffective monitoring." **Brad D. Wolaver, Susan D. Hovorka, and Rebecca C. Smyth**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

GEOLOGY

"Changes in reservoir heterogeneity and quality as a response to high partial pressures of CO_2 in a gas reservoir, New Zealand."

The following is from the Abstract of this article: "The Kapuni Field is the largest onshore petroleum field in New Zealand and produces CO_2-rich, gas (c. 40–45 mol% CO_2). Diagenesis within the reservoir is dominated by CO_2-related reactions that have resulted in [localized] precipitation of kaolin (abundant), quartz, calcite, dolomite, and siderite, along with [localized] generation of secondary porosity. Most of the CO_2 in the reservoir is thought to have been sourced from intraformational coals, with subsequent up-dip migration to the crest of the Kapuni structure. During migration, CO_2 will have dissolved into undersaturated pore fluids and the resulting acidic pore fluids [catalyzed] feldspar (and minor carbonate) dissolution, thereby providing ions for precipitation of authigenic minerals. Timing of the diagenetic reactions, as determined by paragenetic observations and fluid inclusion analysis, suggests that both quartz and carbonate formed at a very late stage (>100°C, corresponding to 0–4 Ma), which is consistent with [modeled] maturation and expulsion of CO_2 from intraformational source rocks (5 Ma to present). The carbon isotope composition of carbonate cements (median $\delta^{13}C_{PDB}$ −12.4‰) is similar to that of the reservoired CO_2 ($\delta^{13}C_{PDB}$ −14.5‰), and this is supportive of late-stage cement formation with carbon sourced primarily from thermal maturation reactions." **Karen E. Higgs, Rob H. Funnell, and Agnes G. Reyes**, *Marine and Petroleum Geology*. (Subscription may be required.)

"Evaluation of experimentally measured and model-calculated pH for rock–brine–CO_2 systems under geologic CO_2 [storage] conditions."

The following is the Abstract of this article: "Reliable pH estimation is essential for understanding the geochemical reactions that occur in rock–brine–CO_2 systems when CO_2 is injected into deep geologic formations for long-term storage. Due to a lack of reliable experimental methods, most laboratory studies of CO_2–rock–brine interactions conducted under geologic CO_2 [storage] (GCS) conditions have relied on thermodynamic modeling to estimate pH; however, the accuracy of these model predictions is typically uncertain. In this study, [the authors] expanded the measurement range of a spectrophotometric method for pH determination, and [the authors] applied the method to measure the pH in batch-reactor experiments at 75°C and 100 atm utilizing rock samples from five ongoing GCS demonstration projects. A combination of color-changing pH indicators, bromophenol blue and bromocresol green, was shown to enable measurements over the pH range of 2.5–5.2. In-situ pH measurements were compared with pH values calculated using geochemical models. Calculations with four different thermodynamic databases resulted in a maximum difference of 0.16 pH units. Among these databases, the Phrqpitz database generally provided the most accurate pH predictions for rocks comprised of carbonate, siltstone, and sandstone. With Phrqpitz, the differences between measured and calculated pH values were within 0.03 pH units for these three rocks. However, for basalt, significant differences (0.10–0.25 pH units) were observed even with Phrqpitz. These discrepancies may be due to the models' failure to fully account for certain proton consuming and producing reactions that occur between the basalt minerals and CO_2-saturated brine solutions." **Hongbo Shao, Christopher J. Thompson, and Kirk J. Cantrell**, *Chemical Geology*. (Subscription may be required.)

"Effect of fluid topology on residual nonwetting phase trapping: Implications for geologic CO_2 [storage]."

The following is the Abstract of this article: "This work examines the influence of initial (i.e. post drainage) nonwetting (NW) fluid topology on total residual (i.e. after imbibition) NW phase saturation. Brine and air (used as a proxy for supercritical CO_2) flow experiments were performed on Bentheimer sandstone; results were quantified via imaging with X-ray computed microtomography (X-ray CMT), which allows for three dimensional, non-destructive, pore-scale analysis of the amount, distribution, and connectivity of NW phase fluid within the sandstone cores. In order to investigate the phenomenon of fluid connectivity and how it changes throughout flow processes, the Bentheimer sandstone results are compared to previously collected X-ray CMT data from similar experiments performed in a sintered glass bead column, a loose packed glass bead column, and a column packed with crushed tuff. This allows [the authors] to interpret the results in a broader sense from the work, and draw conclusions of a more general nature because they are not based on a single pore geometry. Connectivity is quantified via the normalized Euler number of the NW fluid phase; the Euler number of a particular sample is normalized by the maximum connectivity of the media, i.e. the Euler number of the system at 100 [percent] NW phase saturation. General connectivity-saturation relationships were identified for the various media. In terms of trapping, it was found that residual NW phase trapping is dependent on initial (i.e. post-drainage) NW phase connectivity as well as imbibition capillary number for the Bentheimer sandstone. Conversely, the sintered glass bead column exhibited no significant relationship between trapping and NW topology." **Anna L. Herring, Elizabeth J. Harper, Linnéa Andersson, Adrian Sheppard, Brian K. Bay, and Dorthe Wildenschild**, *Advances in Water Resources*. (Subscription may be required.)

TECHNOLOGY

"Uncertainty quantification for evaluating impacts of caprock and reservoir properties on pressure buildup and ground surface displacement during geological CO_2 [storage]."

The following is the Abstract of this article: "A series of numerical test cases reflecting broad and realistic ranges of geological formation properties was developed to systematically evaluate and compare the impacts of those properties on pressure build-up and ground surface displacement and therefore risks of induced seismicity during CO_2 injection. A coupled hydro-geomechanical subsurface transport simulator, STOMP (Subsurface Transport over Multiple Phases), was adopted to simulate the migration of injected CO_2 and geomechanical behaviors of the surrounding geological formations. A quasi-Monte Carlo sampling method was applied to efficiently sample a high-dimensional parameter space consisting of injection rate and 12 other parameters describing hydrogeological properties of subsurface formations, including porosity, permeability, entry pressure, pore-size index, Young's modulus, and Poisson's ratio for both reservoir and caprock. Generalized cross-validation and analysis of variance methods were used

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to quantitatively measure the significance of the 13 input parameters. For the investigated two-dimensional cases, reservoir porosity, permeability, and injection rate were found to be among the most significant factors affecting the geomechanical responses to the CO_2 injection, such as injection pressure and ground surface uplift. [The authors] used a quadrature generalized linear model to build a reduced-order model that can estimate the geomechanical response instantly instead of running computationally expensive numerical simulations." **Jie Bao, Zhangshuan Hou, Yilin Fang, Huiying Ren, and Guang Lin**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"The role of CO_2 in CH_4 exsolution from deep brine: Implications for geologic carbon [storage]."

The following is the Abstract of this article: "The partial pressure exerted by dissolved CO_2 in water (aqueous phase) containing dissolved [methane (CH_4)] at concentrations near-saturation can lead to the formation of a CH_4-rich gas phase. [The authors] have used numerical simulation with TOUGH2/EOS7C to investigate the process of CH_4 exsolution caused by CO_2 injection for geologic carbon [storage]. [The authors] validated the solubility model in TOUGH2/EOS7C against published measurements of solubility and corresponding Henry's Law coefficients. [The authors] verified [their] simulation results against a previously published 1D test problem, and investigated the effects of numerical dispersion on the CH_4 exsolution and flow processes. In 2D radial simulations of a model system, [the authors] found that highly concentrated CH_4 gas regions form at the leading edge of the CO_2 injection front. Because the gas saturations are small in the CH_4-rich gas regions in the generic system studied here, (i) CH_4 exsolution does not appear to be a problem for seismic monitoring of CO_2 plumes, (ii) reservoir pressurization due to dilution of supercritical CO_2 by CH_4 does not appear to be a concern, and (iii) relative permeability to water is not strongly reduced." **Curtis M. Oldenburg, Christine Doughty, and Nicolas Spycher**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Source terms calculation and atmospheric dispersion for a dynamic release from a CO_2 pipeline containing methane and water as impurities."

The following is the Abstract of this article: "A method for calculating the source terms including values of leak rate, phase fraction, final velocity, and temperature at the position where the leakage jet has expanded to atmospheric pressure from a CO_2 pipeline containing impurities (methane and water) is presented with regard to the time-dependency of the source terms during the [release]. The thermodynamical properties for the mixture are calculated using the Soave-Redlich-Kwong equation of state with modified 1st order Huron-Vidal mixing rule, which is adjustable in PVTsim. The results for the solubility of water in CO_2 have shown that this thermodynamic model provides accurate predictions for the mixture properties. The thermodynamic model has been used along with a robust transient two-phase flow simulator, OLGA, to simulate the [release] from the pipeline. Finally, the predicted time-dependent source terms (Release Rate, Phase Fraction, Final Velocity, and Temperature in the downstream of the [release]) were used as input into the dispersion model (UDM) in form of sequential segments." **Leila Esfahanizadeh and Bahram Dabir**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Modeling and monitoring of geological carbon storage: A perspective on cross-validation."

The following is the Abstract of this article: "Effective monitoring and numerical simulations are essential to understanding the implications of long-term geological carbon storage; in particular, the predictions of CO_2 plume flow under storage conditions, storage integrity of sites, and the design and operational aspects of the CO_2 storage projects could be significantly supplemented. Site monitoring data can assure reliability and accuracy of the numerical simulation while numerical prediction results will provide more detailed information on the storage process. The cross-validation between numerical modeling results and monitoring data can play a major role in the development of carbon capture and storage technology. This paper briefly reviews the monitoring and modeling technologies associated with geological carbon storage. In addition, the spatial and temporal resolutions of the numerical simulations are highlighted, while estimations on the resolutions of some commonly used monitoring technologies are also presented. It is revealed that there are gaps in the correlations and cross-validation between the two technologies, where a possible option to reduce the gaps is to enforce more research efforts on multi-scale modeling and appropriate variable correlations." **Xi Jiang, Wasim A. Akber Hassan, and Jon Gluyas**, *Applied Energy*. (Subscription may be required.)

Terrestrial

"Assessment of variability and uncertainty of soil organic carbon in a mountainous boreal forest."

The following is the Abstract of this article: "Mountain environments are heterogeneous and dynamic geomorphic environments sensitive to land use and climate change. Heterogenic environmental conditions result in a large variability of mountain soil properties, and thus in large uncertainties of inventories of soil organic carbon (SOC). In this study [the authors] analyzed the variability of soil properties associated with the calculation of a SOC inventory in a mountain environment in the Canadian Rocky Mountains (Alberta). Therefore, [the authors] calculated the analytical uncertainty and spatial variability of SOC stocks using Gaussian error propagation and Taylor series expansion along seventeen 36 m long transects to identify major sources of uncertainty. SOC stocks in the upper 10 cm and 30 cm are 2.4 ± 0.7 kg C m^{-2} and 6.4 ± 5.6 kg C m^{-2}, respectively. The bulk densities generated the largest uncertainty associated with the analytical precision (10.0 percent). However, analytical uncertainties (ranging between 2.3 and 24.2 percent) are much smaller than the uncertainty introduced by the spatial variability, for instance of the coarse fraction (63.8 percent) and SOC concentration (40.1 percent). This study contributes to insufficiently considered analysis of uncertainties in SOC stocks and

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demonstrate the high potential of nested sampling approaches to identify sources of uncertainties of SOC stocks. To reduce the uncertainties associated with heterogeneous mountain environments, [the authors] propose to apply more sophisticated statistics (e.g. regression analysis considering frequency distributions of measured coarse fractions in different geomorphic environments) rather than simple mean per unit approaches, as frequently applied in regionalization studies of soil properties." **Ulrike Hoffmann, Thomas Hoffmann, E.A. Johnson, and Nikolaus J. Kuhn**, *CATENA*. (Subscription may be required.)

"Buried black soils on the slopes of Mt. Kilimanjaro as a regional carbon storage hotspot."

The following is the Abstract of this article: "Mt. Kilimanjaro attracts much scientific and public attention due to its dramatically shrinking ice caps, still known as 'the white top' of Africa. In this mountain system forming a type of island within the surrounding savannah, a new phenomenon has recently been discovered. On the slopes of Mt. Kilimanjaro, Late Quaternary paleosol sequences, composed of dark or black buried soils, are widespread in the montane rainforest zone (1800–3000 m a.s.l.). In this study [the authors] investigated in detail the SOC content and SOC stocks in soil profiles (mostly Andosols) along two altitudinal transects, situated on both the humid southern slopes and on the drier northern slopes of the mountain. In the montane forest zone, up to 3 m thick paleosol sequences are frequently found. SOC content is remarkably high, reaching values of up to more than 10 percent. This testifies to good preservation of soil organic matter (SOM) which may be due to such factors as rapid burial by dust, low temperatures alongside more resistant litter during glacial periods, formation of stable organo-mineral complexes and high black carbon (BC) content. The buried black soils are estimated to contain ~ 82 kg m^{-2} mean SOC stocks in the montane rainforest. As compared to the SOC storage in the surrounding savannah soils of the Maasai Steppe, the buried black soils constitute a distinctive regional carbon storage hotspot." **Michael Zech, Claudia Hörold, Katharina Leiber-Sauheitl, Anna Kühnel, Andreas Hemp, and Wolfgang Zech**, *CATENA*. (Subscription may be required.)

Trading

"Costa Rica's Carbon Market is Open for Business."

On October 17, Costa Rica opened "BANCO2," an environmental bank that will trade and verify carbon credits. Part of a series of Costa Rican government programs and investments to reach its goal of carbon neutrality by 2012, BANCO2 will provide commercialization and brokerage services for CO_2 credits, as well as promote, monitor, report, and verify CO_2 mitigation and reduction projects. From *Tico Times* on October 18, 2013.

"Three U.S. States, British Columbia to Ink Climate Pact."

California officials will reportedly sign an agreement to formally align the state's climate and clean energy policies with those of Oregon, Washington and the Canadian province of British Columbia. The four are members of the Pacific Coast Collaborative, formed in 2008 as a forum to share ideas on climate policies. From *Reuters* on October 24, 2013.

"Mexico's Exchange to Launch Platform for Carbon Trading."

Mexico's stock exchange announced it will launch an electronic platform to trade carbon credits. The mechanism, called MEXICO2, is expected to offer different types of carbon credits to companies willing to offset emissions traded in an over-the-counter market. The platform will trade United Nations-certified emissions reduction (CER) units, as well as credits from voluntary markets. From *Trust.org* on November 8, 2013.

"RFID-enabled carbon offsetting and trading."

The following is the Abstract of this article: "This paper presents a novel approach to carbon credit trading with pervasive computing technologies, particularly RFID (or barcode) technology. It introduces RFID tags as certificates for the rights to claim carbon credits in carbon offsetting and trading. It enables buyers, including end-consumers, which buy products with carbon credits to hold and claim these credits unlike existing carbon offsetting schemes. It also supports the simple intuitive trading of carbon credits by trading RFID tags coupled to the credits. The approach was constructed and evaluated with real customers and real carbon credits in a real supply chain. It can also be used to encourage industries and homes to reduce [GHG] emissions." **Ichiro Satoh**, *Pervasive and Mobile Computing*. (Subscription may be required.)

"International carbon emissions trading and strategic incentives to subsidize green energy."

The following is the Abstract of this article: "[The authors] examine strategic incentives to subsidize green energy in a group of countries that operates an international carbon emissions trading scheme. In [the authors'] model, green subsidies of either sign on top of emissions cap regulation reduce the welfare of the group of countries, but this may not hold for individual countries. The cases of small and large countries turn out to exhibit significant differences. While small countries refrain from subsidizing green energy and thus implement the efficient allocation, large permit-importing countries may subsidize green energy in order to influence the permit price in their favor." **Thomas Eichner and Rüdiger Pethig**, *Resource and Energy Economics*. (Subscription may be required.)

"Climate game analyses for CO_2 emission trading among various world organizations."

The following is the Abstract of this article: "This paper simulates the saving in terms of the total abatement cost of CO_2 emission reductions for different trading games reflecting the potential cooperation among organizations including the European Union (EU), the Asia-Pacific Economic Cooperation (APEC) countries, the Union of South American Nations (USAN), and the Indian Ocean Rim Association for Regional Cooperation (IOR-ARC). A game approach is conducted to determine if the cooperation will come into existence among the organizations stated above. A similar idea is applied to the four largest emission countries, China, the United States, Russia, and India, as four individual players in the trading

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game." **Pei-Ing Wu, Chai Tzu Chen, Pei-Ching Cheng, and Je-Liang Liou**, *Economic Modelling*. (Subscription may be required.)

Recent Publications

"The Thermal Enhanced Oil Recovery (EOR) Market 2013-2023."

The following is a summary of this report: "Growth in the thermal EOR market will be driven primarily by increasing production from the Albertan oil sands, though heavy oil developments in several global locations will also be seen. Many thermal EOR projects have been around for a long time and the more established national markets are now looking to maintain production and improve existing technologies. Strong growth is expected in the emerging markets of the Middle East as tertiary recovery methods are applied to various large fields over the coming years. High oil prices, increasing global energy demand and the development of new technologies will all help to drive the thermal EOR industry over the coming decade as the market enters a period of strong growth. Visiongain's analysis indicates that the thermal EOR market will see production of 2.259 million barrels per day in 2013." (Purchase may be required.)

"Synthesis of CCS social research: Reflections and current state of play in 2013."

The following is a summary of this document: "CCS has a critical role to play in mitigating climate change and providing energy security. Fundamental to that advocacy role is a commitment to sharing the best possible research and information about the technology to members and the wider public. This report has been designed to provide an accessible summary of an extremely comprehensive body of research. It is hoped that the review will provide a quick and helpful guide to emerging thinking and best practices for those working to improve public understanding and acceptance of CCS technology, with extended bibliographical references to assist with further research."

"The Global Status of CCS: 2013."

The following is a summary of this document: "The *Global Status of CCS: 2013* is the fifth edition of the Global CCS Institute's key publication on the progress and challenges facing CCS. These reports provide a comprehensive overview of the state of development of CCS projects and technologies, and of actions taken to facilitate the demonstration of those technologies at a large scale."

"Legal and Regulatory Frameworks for CO_2–EOR and CO_2–CCS."

The following is a summary of this document: "This paper seeks to assist policymakers in evaluating the potential for integrating supplies of captured anthropogenic CO_2 into profitable EOR operations as one part of a long-term strategy for developing widespread deployment of CCS technology. Part I reviews the existing legal and regulatory frameworks governing CO_2 transactions, transport, injection and storage in the context of EOR operations. Part II reviews the changes to this existing EOR–based framework that are in various stages of adoption in order to allow for CCS–based storage. Part III builds on these two prior sections to summarize issues that need to be addressed, and to set forth conclusions and recommendations for steps that may be taken by jurisdictions looking to harness the potential value of CO_2–based EOR as part of a long-term strategy of using CCS technology as an emissions reduction tool."

"Technical Aspects of CO_2 Enhanced Oil Recovery and Associated Carbon Storage."

The following is a summary of this document: "Injection of [CO_2] into mature oil reservoirs is a proven effective method for improving oil production that can be applied to a variety of oil reservoirs in different geological settings. Retention of the injected [CO_2] within the reservoir is an intrinsic part of the CO_2 EOR process, and effectively all CO_2 purchased for injection will ultimately remain stored within the oil field at the end of EOR operations. This storage aspect has driven interest in CO_2 EOR as a potential method of CCS that has a supportive business component. The storage opportunities within CO_2 EOR floods are generally not maximized, although there are no over-riding technical impediments preventing using more of the pore space for storage. Transitional, or residual oil zones, and stacked reservoirs all pose significant opportunities to increase storage amounts well beyond that used strictly for EOR. While deploying monitoring equipment and determining suitable baselines may present challenges to some existing operations, technical solutions can be found to address most of these issues."

"Unlocking North Sea CO_2 Storage for Europe: Practical actions for the next five years."

The following is a summary of this document: "Carbon dioxide emissions are the major cause of climate change: that is unequivocal. To limit the effects, [the author] must reduce the amount of fossil carbon combusted and emitted as CO_2. CCS is the only technology that directly reduces emissions at source, and enables countries to manage carbon budgets for both power plants and process industries. The next

Recent Publications (Continued)

five years will be crucial in putting CCS back into position as an enabler of Europe's transition to a low-carbon economy. Practical actions must be combined with durable policy drivers to rebuild confidence and attract investment. This will be essential for large-scale emissions reductions from both industry and power generation to 2030 and 2050 as Europe seeks to manage climate risk, retain jobs and improve its low-carbon competitiveness. The North Sea is the largest CO_2 storage resource in Europe, and offers the ideal location for immediate efforts. By using low-cost available CO_2 from industrial sources, Europe can accelerate the development of enabling infrastructures for CO_2 transport and storage."

"World Energy Outlook 2013."

The following is a summary of this document: "Many of the long-held tenets of the energy sector are being rewritten. Major importers are becoming exporters, while countries long-defined as major energy exporters are also becoming leading centers of global demand growth. The right combination of policies and technologies is proving that the links between economic growth, energy demand and energy-related CO_2 emissions can be weakened. The rise of unconventional oil and gas and of renewables is transforming [the authors'] understanding of the distribution of the world's energy resources. Awareness of the dynamics underpinning energy markets is essential for decision makers attempting to reconcile economic, energy and environmental objectives. Those that anticipate global energy developments successfully can derive an advantage, while those that fail to do so risk making poor policy and investment decisions. This edition of the World Energy Outlook (WEO-2013) examines the implications of different sets of choices for energy and climate trends to 2035, providing insights along the way that can help policymakers, industry and other stakeholders find their way in a fast-changing energy world."

Legislative Activity

"U.K. Lawmakers Propose Amending Energy Law to Set Carbon Goal."

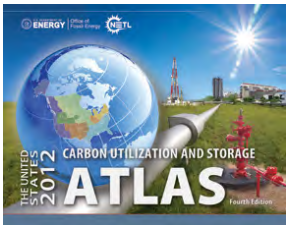
A carbon target for power generation has been proposed by United Kingdom (U.K.) lawmakers in Parliament's upper chamber. Under the plan, the proposed law would be amended to persuade the government to set a target to reduce carbon emissions from the government by 2014 and the power industry by 2030. The proposal includes a provision for a target to be set in 2016, after the U.K.'s fifth carbon budget is set for the five years through 2032. The carbon budgets set limits on how much CO_2 the U.K. can emit in five-year periods, with the goal of cutting the country's overall emissions by 80 percent in the six decades through 2050. From *Businessweek* on October 27, 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:

NETL RSS Feed

NETL on Facebook

NETL on Twitter

NETL on LinkedIn

NETL on YouTube

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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