NETL the ENERGY lab

Carbon Storage Newsletter

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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."**

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

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

"MRCSP Begins Field Tests in Michigan."

MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

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

ANNOUNCEMENTS

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

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

12th International Conference on Greenhouse Gas Control Technologies.

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

Announcements (Continued)

RGGI Releases Q2 2013 Secondary Market Report.

The Regional Greenhouse Gas Initiative (RGGI) released the "Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2013" as part of the ongoing monitoring of RGGI auctions and secondary markets. The report, prepared by Potomac Economics, found that RGGI CO_2 allowance prices stabilized in the second quarter of 2013, as prices averaged $3.40, prices of Intercontinental Exchange (ICE) futures averaged $3.41, and the clearing price in Auction 20 was $3.21.

NETL Releases Funding Opportunity Announcement DE-FOA-0000886: Applications for Post-Combustion and Pre-Combustion Carbon Dioxide Capture and Gasification Technologies Testing.

This Funding Opportunity Announcement (FOA) is focused on a cost-shared research and development (R&D) effort for operating and maintaining existing test facilities. These test facilities must include the capabilities of providing multiple and simultaneous slipstream testing of bench- and pilot-scale third-party advanced CO_2 capture and gasification technologies from diverse fuel sources at commercially relevant process conditions. The R&D test facilities will also promote and conduct the evaluation of advanced technologies to identify and resolve environmental, health and safety, operational, component, and system development issues in collaboration with the technology developer. The identification of cost-effective and efficient advanced CO_2 capture and gasification technologies will address the Environmental Impact Assessment (EIA) forecast that domestic and international coal-based power generation will remain a critical and primary source of electricity generation through 2035, thereby creating a near-term, market-based opportunity with a global opportunity for the export of U.S.-developed technology. Responses are due by 5:00 p.m. EST on October 18, 2013.

Carbon Storage in the News

"Aquistore Project Prepares to Enter Second Phase of Eight-Year Life."

Aquistore, a commercial-scale, post-combustion CO_2 storage project from a coal-fired power plant, is preparing to enter its second phase and expects to begin CO_2 injection in late 2013. The project, managed by the Petroleum Technology Research Centre (PTRC), will demonstrate that storing CO_2 in a geologic formation is a safe, feasible solution to reducing greenhouse gas (GHG) emissions. The project's first phase began in 2012 with the installation of project infrastructure and monitoring equipment, including: two wells drilled to a depth of 3.4 kilometers outside of Estevan, Saskatchewan (one for CO_2 injection and the other for observations and measurements); seismic monitoring equipment; and additional monitoring equipment (groundwater stations, soil gas equipment, inSAR, GPS stations, and tiltmeters). These monitoring techniques are in accordance with the CSA Z741 standards for monitoring CO_2 in the subsurface. The injection and monitoring equipment also provides environmental monitoring and health and safety assurance. During the summer of 2013, collaborations were established with organizations in Europe, Australia, and Asia. From *Aquistore News Release* on September 17, 2013.

"Germany's Linde to Build Saudi Carbon Capture-and-Use Plant."

Germany's Linde Group has been hired by Saudi Basic Industries Corp (SABIC) to build a carbon capture and utilization (CCU) plant. The plan is for SABIC affiliate United Jubail Petrochemical Company (UNITED) to capture approximately 1,500 tons of CO_2 per day from ethylene plants and then purify the CO_2 for use in petrochemical plants in Jubail. According to officials, the CCU plant is expected to prevent the release of approximately 500,000 tons of CO_2 per year, as well as supply 200 tons of liquid CO_2 per day to the food and drink industry. From *Reuters* on August 21, 2013.

"CO_2 Solutions Completes First Alberta Oil Sands Project Milestones."

CO_2 Solutions Inc. announced that it has met and exceeded the first two technical performance milestones for its Alberta Oil Sands project, demonstrating its patented carbon capture technology is less expensive than existing carbon capture technology in terms of energy consumption, and that it can withstand industrial application. The project will move on to the large-bench scale testing phase (0.5 metric ton/day CO_2 capture) for the remainder of 2013, validating the same performance metrics under flue gas conditions. Upon successful validation, the project would begin field pilot-scale testing (approximately 15 metric ton/day CO_2 capture) in 2014. From *CO_2 Solutions Press Release* on August 29, 2013.

"EOR Upside Anchors OMV-Statoil North Sea Deal."

OMV AG has agreed to acquire $2.65 billion in North Sea and Atlantic assets from Statoil ASA and take options on 11 exploration licenses. In addition to acquiring assets in the North Sea off Norway and the United Kingdom west of Shetlands, OMV will establish an R&D partnership with Statoil to take advantage of OMV's knowledge in enhanced oil recovery (EOR), as well as Statoil's experience with offshore EOR. OMV said it is increasing its reserves and strengthening its presence in Organization for Economic Cooperation and Development (OECD) countries. The Statoil acquisition will generate an increase in proved and probable reserves from the current level and production is set to rise by 2014. OMV will have the option of participating in as many as 11 exploration licenses in the Faroe Islands, West of Shetland area, and the Norwegian North Sea; the majority of the licenses are underexplored areas with high resource potential. The exploration licenses in Norway are near Edvard Grieg field. From *Oil & Gas Journal* on August 19, 2013.

Science

"Climate Change Threatens Crunchy, Tart Apples."

According to a 40-year study of Japanese apple orchards conducted by the National Agriculture and Food Research Organization in Tsukuba, Japan, potential climate change could be affecting the taste and texture of apples – specifically the Fuji. By analyzing the data, researchers found that over the four decades, the apples' hardness and acidity had declined, while their sweetness had increased. The researchers believe that warmer temperatures are causing plants to flower earlier, which yields a riper, sweeter fruit at harvest. From *Nature.com* on August 15, 2013.

"Study: Higher CO_2 Harms All Marine Life-Forms."

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

"African Desert Plantations Could Help Carbon Capture."

According to a study published by Earth System Dynamics, planting trees such as Eucalyptus microtheca and Jatropha curcas in African coastal deserts could help capture CO_2 emissions. Using data compiled in Mexico and Oman, the study states that over a 20-year period, large-scale plantations, specifically of the Jatropha curcas, could capture 17 to 25 tons of CO_2 per hectare per year from the atmosphere. From *UPI.com* on August 27, 2013.

"Sea Otter Populations Could be Key to Carbon [Storage]."

Scientists from the University of California at Santa Cruz have found that sea otters can help keep undersea kelp forests alive by eating plant-eating animals like sea urchins, which can help to mitigate potential climate change. The researchers studied the effect of sea otters on coastal ecosystems over the past 40 years and found that higher sea otter populations shared healthier sea kelp forests. Focusing primarily on the Aleutian islands south near the coast of North America to the U.S.-Canada border, the researchers claim that the sea kelp help to store a sizable amount of CO_2. From *Public Radio International*, on August 29, 2013.

"Climate Change 'Driving Spread of Crop Pests.'"

According to research conducted by the universities of Exeter and Oxford, potential climate change is allowing crop pests and diseases that attack crops to spread to areas once too cold for them to survive. Published in the journal "Nature Climate Change," the study focused on 612 crop pests and pathogens from the around the world that had been collected over the past 50 years. Researchers found that on average, pests have been spreading by two miles each year since 1960. From *BBC News* on September 1, 2013.

Policy

"United States, China, and Leaders of G-20 Countries Announce Historic Progress Toward a Global Phase Down of HFCs."

The United States, China, and the Group of 20 (G-20) announced separate agreements to address potential climate change by reducing the use of hydrofluorocarbons (HFCs). In the first agreement, G-20 leaders expressed support for initiatives that are complimentary to efforts under the United Nation's Framework Convention on Climate Change (UNFCCC), including phasing down the use of HFCs using the Montreal Protocol, while retaining HFCs within the scope of the UNFCCC and its Kyoto Protocol for accounting and reporting of emissions. In a related agreement, the United States and China reaffirmed their June 2013 announcement that the nations would also collaborate with other countries through multilateral approaches to phase down the production and consumption of HFCs using the Montreal Protocol, which was established in 1987 with the goal of protecting the ozone layer. According to the White House, if left unabated, HFC emissions could grow to nearly 20 percent of CO_2 emissions by 2050. From *White House Press Release* on September 6, 2013.

"The social cost of carbon emissions: Seven propositions."

The following is the Abstract of this article: "Determining the social cost of carbon emissions (SCC) is a crucial step in the economic analysis of climate change policy as the US government's recent decision to use a range of estimates of the SCC centered at $77/tC (or, equivalently, $21/t$CO_2$) in cost-benefit analyses of proposed emission-control legislation underlines. This note reviews the welfare economics theory fundamental to the estimation of the SCC in both static and intertemporal contexts, examining the effects of assumptions about the typical agent's pure rate of time preference and elasticity of marginal felicity of consumption, production and mitigation technology, and the magnitude of climate-change damage on estimates of the SCC. [The authors] highlight three key conclusions: (i) an estimate of the SCC is conditional on a specific policy scenario, the details of which must be made explicit for the estimate to be meaningful; (ii) the social discount rate relevant to intertemporal allocation decisions also depends on the policy scenario; and (iii) the SCC is uniquely defined only for policy scenarios that lead to an efficient growth path because marginal costs and benefits of emission–mitigation diverge on inefficient growth paths. [The authors] illustrate these analytical conclusions with simulations of a growth model calibrated to the world economy." **Duncan K. Foley, Armon Rezai, and Lance Taylor,** *Economics Letters*. (Subscription may be required to view article.)

Policy (Continued)

"CO_2 transport strategy and its cost estimation for the offshore CCS in Korea."

The following is the Abstract of this article: "Republic of Korea is the ninth largest CO_2 emission country in 2009 according to the International Energy Agency (IEA). To mitigate the effect of CO_2 on the climate change and global warming, Korea should reduce the anthropogenic CO_2 emissions from sources such as power plants and iron works. [Carbon dioxide] Capture and Storage (CCS) technology is regarded as one of the most promising carbon reduction options. The demonstration project of CCS is funded by the Korean government to demonstrate the capture, transportation and storage of 1 Mt CO_2 per year in Korea by 2020. This study established the CO_2 transport strategies from the sources to [formations] for the CCS demonstration in Korea. Also the cost estimations were carried out with the CO_2 transport strategies. The CO_2 transport methods suggested in this study are the pipelines for both onshore and offshore, and a ship-based concept consisting of a pipeline from the source to coastal terminal (including the liquefaction facility on a barge) and a CO_2 carrier from the terminal to [formation] (including the temporary storage near offshore sink). Although the present study is now [ongoing] to optimize the CO_2 transport infrastructure for the offshore CCS in Korea, the preliminary results show the CO_2 transport cost for the pipeline system is lower than that for the shipping in the present status. The result is meaningful only for the specific source and storage sites studied in this study." **Jung-Yeul Jung, Cheol Huh, Seong-Gil Kang, Youngkyun Seo, and Daejun Chang**, *Applied Energy*. (Subscription may be required to view article.)

"A 'carbonshed' assessment of small- vs. large-scale CCS deployment in the continental [United States]."

The following is the Abstract of this article: "[The authors] present a model for rapidly costing and mapping out the cheapest option for organizing infrastructure to transport and store the CO_2 emissions that might be captured in United States if CCS is deployed. [The authors] present the organization of transport infrastructure in terms of carbonsheds, regions in which it is cheaper to transport and store CO_2 internally than to send the CO_2 to other regions. [The authors] use [the] carbonshed framework to evaluate the effect of economies of scale on transport and storage. This is analyzed as the difference between developing small- vs. large-scale CCS systems on a national level, including how the potential depletion of CO_2 reservoirs over time could impact costs born by coal power plants that capture CO_2. [The authors] find that the average value of transport and storage when sources cooperate to reduce transport costs is roughly $10/ton, with costs decreasing as more storage reservoir options are included, and increasing as storage resources are depleted. [The] depletion analysis indicates that large, centralized reservoirs could form the backbone of a major carbon storage system in the United States. Policymakers and industry planners could rapidly advance large-scale storage networks by skipping fragmented early networks and moving to large-scale systems at a relatively minor cost of $0–2/ton if 1.5 Gt/year are captured from existing power plants by emphasizing cooperation or integrated planning and optimization." **Jordan K. Eccles and Lincoln Pratson**, *Applied Energy*. (Subscription may be required to view article.)

Geology

"A technical assessment of CO_2 Interim Storage in deep saline [formations]."

The following is the Abstract of this article: "[Carbon dioxide] Interim Storage (CIS) involves storing [CO_2] in subsurface reservoirs for a finite period of time to be subsequently withdrawn and utilized in EOR or other industrial processes. Through its potential role in matching CO_2 supply and demand and buffering any variability in each, CIS could facilitate the expansion of EOR operations in a number of small and dispersed oil fields, and it could reduce the cost of CCS by allowing increased flexibility in CO_2 capture and economies of scale in transportation infrastructure. This study identifies and assesses the technical challenges and energy requirements of [CIS] by examining two scenarios simulating different patterns of variable CO_2 injection and production in an underground saline [formation]. The results from reservoir modeling show that the pressure buildup and CO_2 plume associated with variable injection are similar to those of constant injection, and the overall variability in pressure transients reduces away from the injection site and as injection proceeds with time. The position of injection and production zones along the well plays a significant role in controlling CO_2 plume migration; injection throughout the entire reservoir thickness can prevent early water invasion into the well. Furthermore, CIS presents some unique tradeoffs. On the downside, water vaporization by injected CO_2 leads to salt accumulation in the [formation] after every production-then-injection sequence, which is not commonly experienced in underground natural gas storage. High and rapidly fluctuating injection and production rates accelerate salt buildup and may block the flow near the well. On the upside, the same water vaporization phenomenon facilitates the formation of a dry-out zone near the well, which, under relatively high injection and low production rates, allows the recovery of dry CO_2 while preventing the undesirable liquid-water production. Still, a clear compromise exists between produced CO_2 purity and overall CO_2 recovery. In the well, lower water-cut leads to lower pressure drop during CO_2 production, thus reducing the overall energy penalty for interim storage. The energy needed to dehydrate and recompress the produced CO_2 is estimated to be around 88.6 kJ/kg; compared to CO_2 capture and compression, the energy costs for interim storage are small but not insignificant." **Karim Farhat and Sally M. Benson**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Investigation of coalbed methane potential in low-rank coal reservoirs – Free and soluble gas contents."

The following is the Abstract of this article: "In low-rank coal (lignite and subbituminous coal) reservoirs, it is difficult to investigate the potential of free and soluble gases at different burial depths because of the lack of measuring methods available in practice. In this work, Mariotte's law was adopted to predict free gas content and methane solubility in coal seam water was studied to calculate soluble gas content. Coal samples were collected from Chinese typical low-rank coal-bearing basins. This study shows volume of pores occupied by free gas becomes smaller when moisture content and confining pressure are high. Methane dissolving tests in four coal seam water samples under set temperatures and pressures show that methane solubility increases with increasing pressure and temperature. Pressure

Geology (Continued)

seems to be a more effective influencing factor than temperature on methane solubility although temperature effect is enhanced at high temperature and pressure. A mathematical model of in situ methane content containing adsorbed, free and soluble gases, was established to evaluate the in situ gas content of low-rank coal reservoirs at burial depths from 600 m to 1400 m. While the in situ gas content of the studied coal reservoirs increases with burial depth, the percentage of the free and soluble gases in the in situ contents ranges from 8 [percent] to 34 [percent], and hence have to be taken into account in the evaluation of coalbed methane (CBM) potential of low-rank coal reservoirs for CBM recovery." **Aihua Liu, Xuehai Fu, Kexin Wang, Hui An, and Geoff Wang**, *Fuel*. (Subscription may be required to view article.)

"Tracing the movement and the fate of injected CO_2 at the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage project (Saskatchewan, Canada) using carbon isotope ratios."

The following is the Abstract of this article: "Stable isotope data can assist in successful monitoring of the movement and the fate of injected CO_2 in [EOR] and geological storage projects. This is demonstrated for the IEA-GHG Weyburn-Midale CO_2 Monitoring and Storage Project (Saskatchewan) where fluid and gas samples from multiple wells were collected and analyzed for geochemical and isotopic compositions for more than a decade. Carbon isotope ratios of the injected CO_2 (−20.4‰) were sufficiently distinct from median $\delta^{13}C$ values of background CO_2 ($\delta^{13}C = -12.7$‰) and HCO_3^- ($\delta^{13}C = -1.8$‰) in the reservoir to reveal the movement and geochemical trapping of injected CO_2 in the reservoir. The presented 10-year data record reveals the movement of injected CO_2 from injectors to producers, dissolution of CO_2 in the reservoir brines, and ionic trapping of injected CO_2 in conjunction with dissolution of carbonate minerals. [The authors] conclude that carbon isotope ratios constitute an excellent and cost effective tool for tracing the fate of injected CO_2 at long-term CO_2 storage sites with injection rates exceeding 1 million tons per year." **Bernhard Mayer, Maurice Shevalier, Michael Nightingale, Jang-Soon Kwon, Gareth Johnson, Mark Raistrick, Ian Hutcheon, and Ernie Perkins**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Regional capacity estimates for CO_2 geological storage in deep saline [formations] – Upper Miocene sandstones in the SW part of the Pannonian basin."

The following is the Abstract of this article: "Deep saline [formations] are regarded as the most suitable sites or options for CO_2 geological storage, mainly due to their large storage capacity and extensive spatial distribution in most sedimentary basins. The estimation of the storage capacity in this type of sinks presents a problem due to the lack of subsurface data. A significant step from regional towards local capacity estimation is redefinition of regional storage capacity by applying modified methodology for integrated studies of hydrocarbon reservoirs. The suggested procedure was investigated by detailed mapping of the Sava West [formation] in the Croatian part of the Pannonian basin. First, the [caprock] was chosen based on its depth, thickness and lateral continuity, and then the target reservoir – Upper Miocene Poljana sandstone layers underlying the regional [caprock]. Their depth and effective thickness, as well as the subsurface pressure, temperature and resulting density of CO_2 were mapped based on the well data. The [formation] body was then divided into square elements and the storage capacity was calculated for each of them. Mapping of specific storage capacity in this way enables identification of the areas of greater potential for geological storage that should be further investigated for detailed definition of the potential storage objects." **Iva Kolenković, Bruno Saftić, and Dario Perešin**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Dipping open [formations]—The effect of top-surface topography and heterogeneity on CO_2 storage efficiency."

The following is the Abstract of this article: "The Forties [formation] underlying the North Sea is used as an exemplar base case to provide a quantitative framework for assessing the CO_2 storage efficiency of dipping open [formation] storage units. Storage under a set of putative regulatory constraints is considered: pressure, migration distance and migration velocity. The effects of permeability, heterogeneity, [formation] dip and top-surface topography are all assessed and the results presented in terms of quantitative storage regimes. Permeability and [formation] dip are key determinants of storage efficiency, since they control the flow speed of the CO_2 and the amount of pressure build-up. Heterogeneity reduces storage efficiency due to localized pressure build-up, if this is a constraint. However, where pressure does not limit capacity, vertical heterogeneity improves storage efficiency through boosting the lateral sweep of CO_2. Top-surface topography introduces structural closures, regions of higher and lower dip than the model average, and channels. When compared to smooth models, structural closures increase efficiency and channels generally decrease efficiency. The net effect of all the competing topographical effects depends on which storage regime describes the smooth model. Overall, it is demonstrated that the storage regime and topography play important roles in determining storage capacity." **Aaron L. Goater, Branko Bijeljic, and Martin J. Blunt**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

Technology

"Techno-economic assessment of hydrogen production from underground coal gasification (UCG) in Western Canada with carbon capture and [storage] (CCS) for upgrading bitumen from oil sands."

The following is the Abstract of this article: "This paper examines the techno-economic viability of hydrogen production from underground coal gasification (UCG) in Western Canada, for the servicing of the oil sands bitumen upgrading industry. Hydrogen production for bitumen upgrading is predominantly achieved via steam methane reforming (SMR); which involves significant GHG emissions along with considerable feedstock (natural gas) cost volatility. UCG is a formidable candidate for cost-competitive environmentally sustainable hydrogen production; given its negligible feedstock cost, the enormity of deep coal reserves in Western Canada and the [favorable] CO_2 [storage] characteristics of potential UCG sites in the Western Canadian sedimentary basin (WCSB). Techno-economic models were developed for UCG and SMR with and without CCS, to

Technology (Continued)

estimate the cost of hydrogen production including delivery to a bitumen upgrader. In this paper, at base case conditions, a [five percent] internal rate of return (IRR) differential between UCG and SMR was considered so as to account for the increased investment risk associated with UCG. The cost of UCG hydrogen production without CCS is estimated to be $1.78/kg of H_2. With CCS, this increases to range of $2.11–$2.70/kg of H2, depending on the distance of the site for CO_2 [storage] from the UCG plant. The SMR hydrogen production cost without CCS is estimated to be $1.73/kg of H2. In similar fashion to UCG, this rises to a range of $2.14 to $2.41/kg of H_2 with the consideration of CCS. Lastly, for hydrogen production without CCS, UCG has a superior cost competitiveness in comparison to SMR for an IRR differential less than 4.6 [percent]. This competitive threshold rises to 5.4 [percent] for hydrogen production with CCS." **Babatunde Olateju and Amit Kumar**, *Applied Energy*. (Subscription may be required to view article.)

"First field test of linear gas sensor net for planar detection of CO_2 [releases] in the unsaturated zone."

The following is the Abstract of this article: "Gases from subsurface sources can present risks for the biosphere. To extend the lead time in managing such risks, reliable gas detection in the subsurface is required. A monitoring system was developed that is able to: (i) gather information from large areas, (ii) work efficiently within the subsurface; insensitive to changing subsurface environmental conditions while sensitive to changes in target gas concentrations, and (iii) provide a fast response. [The authors] report the first field test of linear membrane-based gas sensors: Fourteen 40 m long sensors were installed in two horizontal nets one above the other within a homogenized soil and scanned from a control station. 10 L/min of CO_2 was injected into a point-like port 25 cm below the lower sensor net. Two operation modes were successfully tested to detect the CO_2 plume: an active mode, which is sensitive to the concentration, and a passive mode, which is sensitive to changes in concentration. By conversion of the monitoring results the minimum contact range of seeping gas and sensor could be determined. Based on this valuable approach, an unexpectedly high level of lateral gas spread within the soil and the formation of a gas pillow below the soil surface could be observed." **Detlef Lazik and Sebastian Ebert**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Sensitivity of injection costs to input petrophysical parameters in numerical geologic carbon [storage] models."

The following is the Abstract of this article: "Numerical simulations are widely used in feasibility studies for geologic carbon [storage]. Accurate estimates of petrophysical parameters are needed as inputs for these simulations. However, relatively few experimental values are available for CO_2–brine systems. Hence, a sensitivity analysis was performed using the STOMP numerical code for supercritical CO_2 injected into a model confined deep saline [formation]. The intrinsic permeability, porosity, pore compressibility, and capillary pressure-saturation/relative permeability parameters (residual liquid saturation, residual gas saturation, and van Genuchten α and m values) were varied independently. Their influence on CO_2 injection rates and costs were determined and the parameters were ranked based on normalized coefficients of variation. The simulations resulted in differences of up to tens of millions of dollars over the life of the project (i.e., the time taken to inject 10.8 million metric tons of CO_2). The two most influential parameters were the intrinsic permeability and the van Genuchten m value. Two other parameters, the residual gas saturation and the residual liquid saturation, ranked above the porosity. These results highlight the need for accurate estimates of capillary pressure-saturation/relative permeability parameters for geologic carbon [storage] simulations in addition to measurements of porosity and intrinsic permeability." **C.-L. Cheng, M.J. Gragg, E. Perfect, M.D. White, P.J. Lemiszki, and L.D. McKay**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Modeling the performance of large-scale CO_2 storage systems: A comparison of different sensitivity analysis methods."

The following is the Abstract of this article: "In this study, [the authors] perform sensitivity analyses using a high-resolution basin-scale reservoir model developed for a hypothetical carbon [storage] project located in the Southern San Joaquin Basin in California, USA. [The authors] use the massively parallel version of the multiphase multicomponent simulator TOUGH2 to simulate CO_2/brine migration and pressure buildup within the CO_2 storage formation and overlying/underlying formations. [The authors] evaluate the impact of parameter uncertainty on risk-related performance measures, i.e., CO_2 saturation and pressure buildup at multiple locations, and the extent of the CO_2 plume and overpressure zone. [The authors] compare three sensitivity analysis methods: a local sensitivity method and the global Morris and Sobol'/Saltelli methods. The uncertainty of sensitivity indices in the global methods is evaluated so that [the authors] can interpret the results even when [the authors] have a limitation in the computational resources. Results show that the three methods provide complementary information for identifying important parameters and system understanding. All three methods give consistent interpretations and importance rankings, except when a parameter has a significant non-linear effect and/or strong interaction with some other parameters. In addition to the magnitude of parameter sensitivity, [the] analysis emphasizes the direction (i.e., favorable or adverse in the risk perspective), non-linearity and/or interaction effects, and physical interpretation of each parameter sensitivity trend. Parameter importance varies with time and space, and also depends on the CO_2 plume or pressure behaviors. In this study, the reservoir permeability is among the most important parameters for all measures, although it has a large trade-off effect in risk such that a higher permeability would tend to reduce reservoir pressure but, at the same time, increase the size of the CO_2 plume footprint." **Haruko M. Wainwright, Stefan Finsterle, Quanlin Zhou, and Jens T. Birkholzer**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

Terrestrial

"Glacial deep ocean [storage] of CO_2 driven by the eastern equatorial Pacific biologic pump."

The following is the Abstract of this article: "The potential influence of low latitude ocean primary productivity on glacial

atmospheric [CO_2] levels has proven challenging to deduce using mass accumulation rates (MARs) of biogenic particulates in deep sea sediment cores. Benthic foraminiferal B/Ca serves as a proxy for past seawater calcite saturation state, and thereby provides a fresh perspective on this outstanding paleoceanographic problem. Here [the authors] employ Cibicidoides wuellerstorfi B/Ca in the Panama Basin region of the eastern equatorial Pacific (EEP) to investigate the nature of deep tropical Pacific carbon storage over the past 50 ka BP. [The authors] present evidence for persistently lower deep Panama Basin calcite saturation state, reflecting an increase in total [CO_2] storage, during the last ice age relative to the Holocene. These results reflect the modification of inflowing deep waters by overlying export productivity, and support the concept of an invigorated glacial EEP soft-tissue pump possibly driven by oceanic nutrient (iron and silica) redistribution. Benthic Cibicidoides spp. carbon-13 is consistent with this conclusion by exhibiting substantially lighter values during glacial time, reflecting the accumulation of metabolic [CO_2] in the deep tropical Pacific. Counterintuitively, downcore application of the Globorotalia menardii calcite fragmentation index (MFI) reveals enhanced glacial sedimentary calcite preservation in the Panama Basin. Together these results point towards a systematic decoupling of bottom water chemistry from biogenic burial fluxes: the crux of the aforementioned traditional paleoproductivity problem."

Whitney Doss and Thomas M. Marchitto, *Earth and Planetary Science Letters*. (Subscription may be required to view article.)

Trading

"21st Auction Marks Five Years of Success for RGGI."

The nine Northeastern and Mid-Atlantic states participating in RGGI announced the results of their 21st auction of CO_2 allowances. The auction marked five years since the launch of the RGGI auctions in 2008. All of the 38,409,043 CO_2 allowances offered were sold at a clearing price of $2.67; bids ranged from $1.98 to $12.85 per allowance. The auction generated $102.5 million for reinvestment by the RGGI states in a variety of consumer-benefit initiatives, such as energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. To date, RGGI auctions have generated a total of $1.4 billion. According to the independent market monitor's report, 84 percent of CO_2 allowances sold in RGGI auctions have been awarded to electricity generators and their corporate affiliates. The next RGGI auction is scheduled for December 4, 2013. From *RGGI News Release* on September 6, 2013.

Recent Publications

"Global and Regional Markets for Carbon Capture and [Storage] (CCS) Infrastructure and Equipment."

The following is a summary of this report: "Portrayed in the past five years as a pipe dream, technological savior and prudent investment to complement existing energy infrastructure, CCS is projected by SBI Energy as a complementary, sometimes marginal, technology in the global effort towards [CO_2] emissions reduction. Representing approximately $(U.S.) 650 million in 2013 investment, global CCS infrastructure deployment is projected to intensify significantly to over $2.4 billion in 2020. Through the end of this report's scope (2037), CCS is not projected to represent more than 25 percent of carbon emissions reductions below baseline even in the most active markets (e.g., North America, Europe). Other regions such as Latin America and Asia-Pacific will rely on CCS for less than [five] percent of necessary carbon emissions reductions. Carbon management is already a prime destination for energy and industrial sector investment dollars. Regulatory limits, taxation and price setting on [CO_2] emissions as a GHG pollutant has spurred industries worldwide to invest in emissions reduction technologies and practices. Improvements to energy efficiency, use of alternative lower- or non-emitting energy resources and economic transformation have largely produced the carbon emissions reductions in the past decade. However, these trends alone will be unable to achieve the global carbon emissions reductions necessary to avert catastrophic climate change. CCS is widely viewed as a technologically viable method for the significant mitigation of fossil fuel-associated carbon emissions worthy of additional development and future deployment. This report provides extensive and detailed projections for global and regional CCS markets through 2037, as well as a review of the historical markets for CCS technology since 2008. Markets are valued by total capital expenditure (CAPEX) investment in CCS infrastructure and by equipment orders. Cumulative estimated equipment orders for the period of 2020-2037 are segmented by carbon post-combustion absorption and removal, compression, air separation (ASU), water-gas shift (WGS), and balance of plant (BoP) equipment. Market segmentation is provided by CCS phase (capture, transportation, storage), region, capture source (power/industry), client or project type (historical market only/merchant capture, EOR, CCS project) and capture method (post-combustion, pre-combustion, oxyfuel). Regional carbon capture capacities and [storage] rates are also provided in terms of million metric tons (MMT) annually. The relative contribution of CCS and other factors to carbon emissions reductions below baseline (or default emissions trajectories) are also provided through 2037."

"Capacity Charging Mechanism for Shared CO_2 Transportation and Storage Infrastructure."

The following is a summary of this National Grid Carbon authored publication: "Technical and legal barriers to CCS and risks associated with the technology are diminishing. A serious obstacle to growth of the CCS industry, however, is difficulty in building a sound commercial case for the development and operation of CCS infrastructure. One way to significantly reduce the cost of CCS is to [realize] economies of scale by sharing a single CO_2 transportation and storage infrastructure system among several operators of separate CO_2 generating plants. This report, prepared by National Grid Carbon (UK), sets out a commercial charging mechanism for the development of, access to, and subsequent use of a shared CCS infrastructure system. The study also explored a number of options for allocating the proportion of system development and operational costs between members of a shared CCS infrastructure."

Recent Publications (Continued)

"Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies."

The following is from the Executive Summary of this Development Technologies International authored publication: "Developing Asia-Pacific Economic Cooperation (APEC) economies are among the most rapidly growing economies in the world, necessitating a major expansion in electric power generation in the next several decades. Much of this new power generation will likely rely on fossil fuels, especially coal. Concern about global climate change and the growth of CO_2 emissions from the region's rapidly expanding coal-fired power generation sector raises the question of when capture and storage of CO_2 emissions from these plants may be implemented. CCS technologies, which can be coupled with CO_2 utilization such as EOR, offer a viable technology solution to address the dramatic growth of CO_2 emissions from the rapidly expanding coal-fired generation sector of many developing APEC economies. This study examines CCS legal and regulatory regimes for nine developing APEC economies: People's Republic of China, Indonesia, Republic of Korea, Malaysia, Mexico, the Philippines, Chinese Taipei, Thailand and Vietnam. These APEC economies were selected for this study based on four criteria: (1) the economy is considered a developing economy; (2) the economy consumes a significant amount of coal as fuel for electricity generation; (3) the economy possesses potential CO_2 storage capacity, and (4) the economy has a likely need for CCS to achieve [GHG] emissions reductions and/or the presence of policies that offer an enabling environment for CCS. Given the importance of CCS regulatory frameworks, there is a clear need for capacity building to prepare for the possible adoption of CCS in developing APEC economies. In line with these broader goals, the objectives of this project are: (1) Review the work in progress in the region and around the world on relevant legal, regulatory, and permitting issues and frameworks; (2) Identify issues likely to arise under a permitting regime for CCS projects in developing APEC economies, and (3) Recommend capacity building efforts needed to advance CCS regulatory framework development and commercial readiness in developing APEC economies."

"CO_2 Storage Prospectivity of Selected Sedimentary Basins in the Region of China and South East Asia."

The following is from the Executive Summary of this Innovative Carbon Technologies Pty. Ltd. authored publication: "This report is a desk top study of the geological prospectivity for [CO_2] subsurface storage in selected member economies of the APEC region. The focus regions were selected by excluding those that have undertaken, or are about to complete, a CO_2 geological storage assessment, and those with very low emissions as documented by IEA (2000). The regions assessed within APEC are China, Indonesia, South Korea, Malaysia, Philippines, Chinese Taipei and Thailand."

"Assessment of the capture and storage potential of CO_2 co-produced with natural gas in South-East Asia."

The following is from the Conclusions and Recommendations section of this CO_2CRC and University of New South Wales authored publication: "The results of this study suggest that, depending on any future carbon price and fiscal policies, there is significant potential for transport and injection of CO_2 emitted from natural gas field developments in South-East Asia. A significant number of projects are likely to be viable with a carbon price up to $20 per [metric ton] in real terms ignoring the effects of the fiscal terms that operate across the region and up to US$60 per [metric ton] in real terms assuming that the fiscal terms that apply to gas field developments also apply to CO_2 transport and injection. However, this study is based on limited high-level data and therefore the findings are only broadly indicative. More detailed project-specific studies are required. In addition, realizing the potential for CO_2 [storage] requires more work in establishing the economic, fiscal and regulatory environment in which such projects could be developed. [The authors] recommend further study based on more specific data on actual gas field developments and potential storage sites, particularly depleted or depleting fields for which data is plentiful. Depending on the circumstances, this might involve a study of enhanced oil or gas recovery in addition to CO_2 storage. In [the authors] view, such a study would first require obtaining the cooperation of oil and gas companies in the region and then working closely with them. The study is likely to proceed in stages. First it would involve contacting companies at a high level to gauge their level of interest in collaborating in such a study. Then it would involve negotiating agreements with interested companies to determine the terms of reference before the study begins. Finally, it would involve preparing the study with the close cooperation of the interested companies."

Legislative Activity

"Media attention for climate change around the world: A comparative analysis of newspaper coverage in 27 countries."

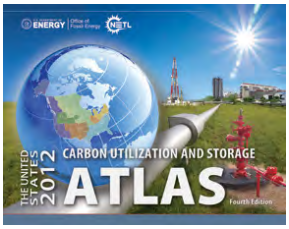
The following is the Abstract of this article: "Climate change is a global phenomenon, and its outcomes affect societies around the world. So far, however, studies on media representations of climate change have mostly concentrated on Western societies. This paper goes beyond this limited geographical scope by presenting a comparative analysis of issue attention in 27 countries. The sample includes, among others, countries that have committed themselves to [GHG] emission reductions under the Kyoto Protocol such as Germany as well as countries that are strongly affected by the consequences of climate change like India. In a first step, it describes the development of media attention for climate change in these countries from 1996 to 2010. Second, it compares the amount of media attention and explores whether it corresponds with indicators measuring the relevance of climate change and climate policies for a country. The analyses show that climate change coverage has increased in all countries. Still, overall media attention levels, as well as the extent of growth over time, differ strongly between countries. Media attention is especially high in carbon dependent countries with commitments under the Kyoto Protocol." **Andreas Schmidt, Ana Ivanova, and Mike S. Schäfer**, *Global Environmental Change*. (Subscription may be required to view article.)

About DOE's Carbon Storage Program

The Carbon Storage Program is implemented by the U.S. Department of Energy's Office of Fossil Energy and managed by the National Energy Technology Laboratory. The program is developing technologies to capture, separate, and store CO_2 in order to reduce greenhouse gas emissions without adversely influencing energy use or hindering economic growth. NETL envisions having a technology portfolio of safe, cost-effective, carbon dioxide capture, transport, and storage technologies that will be available for commercial deployment.

The Carbon Storage Program Overview webpage provides detailed information of the program's structure as well as links to the webpages that summarize the program's key elements.

Carbon Storage Program Resources



The U.S. Department of Energy's 2012 United States Carbon Utilization and Storage Atlas (Atlas IV) shows that the United States has at least 2,400 billion metric tons of potential carbon dioxide storage resource in saline formations, oil and gas reservoirs, and unmineable coal. Data from Atlas IV is available via the National Carbon Sequestration Database and Geographic Information System (NATCARB), which is a geographic information system-based tool developed to provide a view of carbon capture and storage potential.

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more are available via the Carbon Storage Reference Shelf.

Get answers to your carbon capture and storage questions at NETL's Frequently Asked Questions webpage.

There are several ways to join the conversation and connect with NETL's Carbon Storage Program:

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About NETL's Carbon Storage Newsletter

Compiled by the National Energy Technology Laboratory, this newsletter is a monthly summary of public and private sector carbon storage news from around the world. The article titles are links to the full text for those who would like to read more.

National Energy Technology Laboratory

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