NETL the ENERGY lab

Carbon Storage Newsletter

June 2013

What's Inside?

Highlights

"Livermore Develops the World's Deepest ERT Imaging System for CO_2 Sequestration."

Lawrence Livermore National Laboratory (LLNL) researchers have broken the record for tracking the movement and concentration of carbon dioxide (CO_2) in a geologic formation using the Electrical Resistance Tomography (ERT) system. The team obtained time-lapse electrical resistivity images during the injection of more than 1 million tons of CO_2 more than 10,000 feet deep in an oil and gas field in Cranfield, Mississippi. This represents the deepest application of the imaging technique to date. ERT can track the movement and concentration of the injected CO_2 and the degree of geologic containment using time-lapse electrical resistivity changes. The installation of each ERT array in the storage reservoir required designing all cabling and electrodes, which were externally mounted on the borehole casing, some 10,000 feet underground. The team used the ERT array in an environment of high temperature (260 degrees Fahrenheit), high pressure (5,000 pounds per square inch [psi]) and high corrosive fluids to detect CO_2 breakthroughs and saturation changes over time. When converted to CO_2 concentration, the images provided information about the movement of the injected CO_2 within a complex geologic formation and how the storage of the CO_2 changed with time. An LLNL representative said that higher-resolution ERT may also have an application as a warning system for fracture pathways in caprock and another potential application involves monitoring the boundary of a storage lease to ensure that CO_2 does not migrate to an adjacent parcel. The ERT project is part the U.S. Department of Energy (DOE)-sponsored Southeast Regional Carbon Sequestration Partnership (SECARB) Cranfield project near Natchez, Mississippi, which has become the fifth ERT system worldwide and the first in the United States to inject more than 1 million tons of CO_2 into the subsurface. The Cranfield study was funded by DOE's National Energy Technology Laboratory (NETL) to the Southern States Energy Board. From *LLNL News Release* on June 6, 2013.

Announcements

Breakthrough Industrial CCS Project Begins Full-Scale Operations.

The Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas, have successfully begun capturing CO_2 and using it for enhanced oil recovery (EOR). At full-scale operation, more than 90 percent of the CO_2 from the product stream of two methane steam reformers (approximately 1 million metric tons of CO_2 per year) will be delivered for storage and EOR, leading to an estimated annual increase in oil production of 1.6 to 3.1 million barrels from the West Hastings oil field. The approximately $431 million project, supported by $284 million from DOE, included retrofitting the plants with an innovative system that separates CO_2 from the steam reformer product gas during hydrogen production, followed by compression and drying processes.

Announcements (Continued)

Carbon Storage Atlas, Employee Newsletter Earn International Communications Awards.

DOE's Office of Fossil Energy (FE) and NETL won two prestigious 2013 Blue Pencil & Gold Screen Awards presented by the National Association of Government Communicators (NAGC). NETL earned first place honors in the "Technical or Statistical Report" category for the United States 2012 Carbon Utilization and Storage Atlas (Atlas IV); NETL also won the top award last year for the previous version of the Atlas. FE's internal employee newsletter, inTouch, was also recognized for communications excellence.

2013 CO_2 Capture Technology Meeting.

This meeting, scheduled for July 8-11, 2013, in Pittsburgh, Pennsylvania, features more than 50 DOE-sponsored CO_2 capture technology projects. The projects included span three primary technology pathways (post-combustion, pre-combustion, and oxy-combustion) and various stages of development (lab-scale, bench-scale, and small pilot-scale). Presentations of solvent, sorbent, membrane, oxy-combustion, chemical looping, and compression technologies, as well as systems studies and modeling, will be included.

2013 Midwest Carbon Sequestration Science Conference.

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

12th International Conference on Greenhouse Gas Control Technologies.

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

Carbon Storage in the News

"Recycling Carbon Dioxide to Make Plastics."

A project funded in part by DOE's FE has led to the world's first successful large-scale production of a polypropylene (PPC) polymer using waste CO_2 as a key raw material. Conducted by Novomer in collaboration with speciality chemical manufacturer Albermarle Corporation, the PPC polymer production run tested scale-up of Novomer's novel catalyst technology, producing seven tons of finished polymer that will be used to accelerate product qualification. The Novomer process reduces the use of fossil fuels on the conventional production of plastics, such as polyethylene and polypropylene, by replacing up to half of the mass of the petroleum-based product with CO_2. Converting captured CO_2 into products such as chemicals, plastics, fuels, building materials, and other commodities is an important component of FE's Carbon Capture and Storage Program, which is managed by NETL. From *Office of Fossil Energy* on May 20, 2013.

"RTI Partners with Norwegian Firm on $15M Carbon Capture Project."

RTI is partnering with Norcem, part of HeidelbergCement Group, on a $15 million project to test CO_2 capture technology developed by RTI International. The three-year pilot project will be conducted at Norcem's cement plant in Brevik, Norway. The RTI technology has been in development for nearly 10 years and the company is still developing the sorbent-based CO_2 capture technology for coal-fired power plants. This project will provide the opportunity to incorporate it into a cement plant. The technology will first be tested at RTI's Energy Technology Development Facility on RTI's Research Triangle Park campus. The research, intended for applications in coal-fired power plants, has been funded by DOE and developed in collaboration with the DOE's NETL. From *WRAL Tech Wire* on May 28, 2013.

"Research Agreement Signed to Promote Carbon Storage Development."

Researchers from Scottish Carbon Capture & Storage, a partnership of the British Geological Survey, Heriot-Watt University, and the University of Edinburgh signed a new collaborative research agreement aimed at risk reduction and guiding development of offshore CO_2 storage sites. The CO_2 Multi Store project is supported by the Scottish government, Crown Estates, Scottish Enterprise, and Shell. The lessons learned from the project will inform leasing and licensing needs for multi-user CO_2 storage sites across the world; according to the research group, these sites could be developed for secure and permanent CO_2 storage. Specifically, researchers will work to predict the effect(s) of injecting CO_2 into two potential storage sites within an extensive sandstone formation more than one-half mile beneath the sea bed in the UK central North Sea, east of Scotland. The study will use 3-D computer models created from data collected for oil and gas exploration and benefit from the input of industry knowledge and expertise in CO_2 geologic storage. The research project is expected to be completed by Spring 2014. From *New Civil Engineer* on May 30, 2013.

Carbon Storage in the News (Continued)

"South Korea Carbon Capture Plant Begins Operating."

South Korea has initiated operations at its carbon capture and storage (CCS) unit at the Boryeong Thermal Power Plant Complex on the country's west coast. The unit is attached to a 10-megawatt station and expected to capture approximately 80,000 tons, or more than 90 percent, of CO_2 per year from the 10,000-kilowatt power generation facility. The CCS unit would help reduce greenhouse gas (GHG) emissions and meet its voluntary pledge in 2009 to cut GHG emissions by 30 percent from its business-as-usual levels in 2020. From *GlobalPost* on May 24, 2013.

"Government of Canada Investing in Technology to Reduce GHG Emissions in the Oil Sands."

The Government of Canada announced an investment in a new technology to reduce industrial GHG emissions by converting CO_2 into commercial products. The Algal Carbon Conversion Pilot Project will use algae to recycle industrial CO_2 emissions from an oil sands facility into commercial products, such as biofuels. According to the Government of Canada, the three-year joint project has the potential to transform how industrial CO_2 emissions in the oil sands and other industrial facilities are managed. A demonstration-scale algal refinery will be established later this year at Canadian Natural's Primrose South oil sands site in Alberta. Industrial emissions will be recycled at the facility by using CO_2 to grow algal biomass, which will undergo further processing into products such as biofuels, livestock feed, and fertilizer. From *National Research Council Canada News Release* on May 10, 2013.

"Research on Geological Storage of CO_2 to Reduce Greenhouse Gas Emissions."

The Engineering and Physical Sciences Research Council (EPSRC) has awarded [~$5 million] to four research projects to study the geologic viability and safety of underground CO_2 storage in North Sea oil and gas fields or saline formations. The EPSRC funding is part of the Research Council's UK Energy Program and all four projects are part of the UK CCS Research Center. The Parliamentary Committee on Climate Change identified CCS as a key technology to aid the UK government in meeting the goals of the Climate Change Act of 2008, which committed them to reduce GHG emissions by 80 percent by 2050. The UK has a four-year, cross-government CCS research, development, and innovation program funded by the UK Department of Energy and Climate Change (DECC), the Technology Strategy Board (TSB), the Energy Technologies Institute, and the Research Councils. More information on the four research projects is available via the link. From *EPSRC Press Release* on June 7, 2013.

Science

"Mount Everest's Glaciers Shrinking at Increasing Rate, Say Researchers."

According to a University of Milan study, glaciers on or around Mount Everest have shrunk by 13 percent in the last 50 years. The Nepali researchers also found that the ends of glaciers around the peak have retreated by an average of 400 meters since 1962, and some smaller glaciers (less than a square kilometer) have seen a 43-percent decline in surface area since the 1960s. Data was gathered by using satellite imagery of the peak and the 713-mi2 Sagarmatha national park around the mountain, as well as long-term meteorological data. From *The Guardian* on May 23, 2013.

"Climate Change Threatens 82 [Percent] of Native California Fish."

According to a new study, four out of five of California's native freshwater fish will likely be driven to or near extinction within 100 years if climate change continues at its current pace. Of the 121 native fish species, 82 percent will see their population shrink as their need for cool, flowing water diminishes due to rising temperatures and lessening stream flow, according to researchers at the University of California-Davis' Center for Watershed Science. By comparison, 19 percent of the state's 50 non-native fish species face similar extinction risks. The study's findings support previous research that show 80 percent of California's native fish to be ranked as "vulnerable" to possible extinction by NatureServe – a non-profit group that focuses on species conservation. The research was funded by the California Energy Resources Conservation and Development Commission Instream Flow Assessment Program. From *USA Today* on June 1, 2013.

Policy

"China Agrees to Impose Carbon Targets by 2016."

China has proposed to cap its GHG emissions by 2016. The proposal was made by China's National Development and Reform Commission (NDRC), which is responsible for planning China's social and economic development; the proposal still needs to be accepted by China's cabinet, the State Council, for it to be adopted. China has already agreed to reduce its carbon intensity (the amount of CO_2 is produces per dollar of economic output) by approximately 40 percent by 2020 compared to 2005 levels. Nearly 200 countries have pledged to agree to CO_2 emission-reduction targets at the next summit focused on reducing emissions, scheduled for Paris in 2015. From *The Independent* on May 21, 2103.

"Effects of carbon dioxide capture and storage in Germany on European electricity exchange and welfare."

The following is the Abstract of this article: "In the course of European efforts to mitigate global warming, the application of CCS technologies is discussed as a potential option. Some political opposition was raised

Policy (Continued)

– inter alia – by uncertainties about the effective cost of such technologies. Because of the cost structure of CCS power plants with high 'flat' investment cost and – in case of high carbon allowance prices – comparable low variable cost, the application of CCS will induce a merit-order effect causing a decline in wholesale electricity prices on the spot market. On the one hand, the reduction of electricity supply cost raises suppliers' rents, while the decline of wholesale electricity prices augments consumers' surpluses. These positive welfare effects tend to mitigate political opposition against CCS. On the other hand, the merit-order effect reduces electricity suppliers' revenues as the wholesale prices decline. This mitigates their scope for additional investments in CCS capacity. In this study, [the authors] focus on the influence of CCS in Germany on electricity supplier and consumer surpluses and associated impacts on the scope for investments in additional CCS capacity. By means of the applied model of electricity markets, influences on European electricity exchange and welfare levels are investigated." **Dirk Rübbelke and Stefan Vögele**, *Energy Policy*. (Subscription may be required to view article.)

Geology

"CO_2 rock physics as part of the Weyburn-Midale geological storage project."

The following is the Abstract of this article: "To develop confidence in the seismic techniques that are used to (i) qualitatively locate and track the movement of the CO_2 plume, and (ii) quantitatively determine the amount of CO_2 in place in the Weyburn pool, a good understanding of the effects of CO_2 on seismic waves is critical. For this purpose, an extensive series of ultrasonic measurements were performed on over [20] core samples from the Weyburn-Midale carbonates (Marly and Vuggy units) and the overlying and underlying formations. Care was taken to separate pore fluid effects from pore pressure build-up effects during the experiments. This allowed for the sampling of the effects of the CO_2's varying phase states (gas–liquid–supercritical fluid) on the overall rock seismic response. The current paper provides a subset of measurements conducted on four samples from the Marly and Vuggy units. Of the observations arising from the measurements, there are two that are of particular note. First, both the P- and S-wave speeds decrease substantially as the CO_2 transforms from gas to either liquid or supercritical phase. This observation is consistent with the increase of CO_2 fluid density across these phase boundaries. Second, across the gas–liquid phase transition both wave speeds drop abruptly as would be expected for the change in the physical properties of the CO_2 across this first order phase boundary. In contrast, across the gas–supercritical phase boundary the velocities change more gradually. This suggests that it may be difficult to distinguish the gas–supercritical boundary using seismic reflection techniques. Illustrative modelling of seismic reflectivities within a hypothetical geological formation with physical properties equal to that of one of the measured samples, however, suggests that a CO_2 liquid–water contact is a good seismic reflector." **Gautier Njiekak, Douglas R. Schmitt, Helen Yam, and Randolf S. Kofman**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Reactive Transport Modeling to Address the Issue of CO_2 Geological [Storage]."

The following is the Abstract of this article: "One way for a reduction in the release of CO_2 to the atmosphere is to inject CO_2 into deep saline geological formations. Reactive transport modeling of hydrogeochemical processes is necessary to evaluate the behavior and performance of CO_2 geological [storage]. In this paper, [the authors] present two examples, (1) short-term changes in groundwater chemistry, and (2) long-term fate of injected CO_2, to illustrate applicability of the modeling." **T. Xu and J. Li**, *Procedia Earth and Planetary Science*. (Subscription may be required to view article.)

Technology

"Mesoporous Carbon-Supported Solid Amine Sorbents for Low-Temperature Carbon Dioxide Capture."

The following is the Abstract of this article: "A novel solid amine sorbent has been developed based on polyethylenimine (PEI)-impregnated mesoporous carbon (MC) supports for regenerative removal of pure CO_2 at low temperature. The adequate pore volume, proper pore size, and interconnected 3D framework of as-prepared MC allow the easy dispersion and immobilization of PEI within their channels. The structure generates considerable gas/amine interfacial area and provides access to fast CO_2 diffusion for reactivity with the amine groups. In addition, the kinetic inhibition of CO_2 diffusion within the PEI films could be alleviated by the introduction of polymer-based surfactant, offering an increased number of reactive sites and higher utilization efficiency of amine groups. Owing to the advanced support and facilitating kinetic diffusion, as-prepared MC-based solid amines display outstanding sorption features for CO_2 capture at low-temperature range. The highest sorption capacities of 4.67 $mmol \cdot g^{-1}$ at 30°C and 2.80 $mmol \cdot g^{-1}$ at 0°C for pure CO_2 are attained. They also show fast kinetics, a good selectivity for CO_2/[nitrogen (N2)] separation, and very reversible and durable CO_2 capturing performance at low temperature. All the results suggest that MC-based solid amine sorbent is a promising CO_2 sorbent to meet the challenges of the current CO_2 capture and storage technology." **Jitong Wang, Mei Wang, Beibei Zhao, Wenming Qiao, Dong hui Long, and Licheng Ling**, *Ind. Eng. Chem. Res*. (Subscription may be required to view article.)

"Large-Scale Screening of Zeolite Structure for CO_2 Membrane Separations."

The following is the Abstract of this article: "[The authors] have conducted large-scale screening of zeolite materials for CO_2/[methane (CH_4)] and CO_2/N_2 membrane separation applications using the free energy landscape of the guest molecules inside these porous materials. [The authors] show how advanced molecular simulations can be integrated with the design of a simple separation process to arrive at a metric to rank performance of [more than 87,000] different zeolite structures, including the known IZA zeolite structures. [The authors'] novel, efficient algorithm using graphics processing units can accurately characterize both the adsorption and diffusion properties of a given structure in just a few seconds and accordingly

Technology (Continued)

find a set of optimal structures for different desired purity of separated gases from a large database of porous materials in reasonable wall time. [The authors'] analysis reveals that the optimal structures for separations usually consist of channels with adsorption sites spread relatively uniformly across the entire channel such that they feature well-balanced CO_2 adsorption and diffusion properties. [The authors'] screening also shows that the top structures in the predicted zeolite database outperform the best known zeolite by a factor of 4–7. Finally, [the authors] have identified a completely different optimal set of zeolite structures that are suitable for an inverse process, in which the CO_2 is retained while CH_4 or N_2 is passed through a membrane." **Jihan Kim, Mahmoud Abouelnasr, Li-Chiang Lin, and Berend Smit,** *J. Am. Chem. Soc*. (Subscription may be required to view article.)

"Dynamic Evolution of Cement Composition and Transport Properties under Conditions Relevant to Geological Carbon [Storage]."

The following is the Abstract of this article: "Assessing the possibility of CO_2 [release] is one of the major challenges for geological carbon [storage]. Injected CO_2 can react with wellbore cement, which can potentially change cement composition and transport properties. In this work, [the authors] develop a reactive transport model based on experimental observations to understand and predict the property evolution of cement in direct contact with CO_2-saturated brine under diffusion-controlled conditions. The model reproduced the observed zones of portlandite depletion and calcite formation. Cement alteration is initially fast and slows down at later times. This work also quantified the role of initial cement properties, in particular the ratio of the initial portlandite content to porosity (defined here as φ), in determining the evolution of cement properties. Portlandite-rich cement with large φ values results in a localized 'sharp' reactive diffusive front characterized by calcite precipitation, leading to significant porosity reduction, which eventually clogs the pore space and prevents further acid penetration. Severe degradation occurs at the cement–brine interface with large φ values. This alteration increases effective permeability by orders of magnitude for fluids that preferentially flow through the degraded zone. The significant porosity decrease in the calcite zone also leads to orders of magnitude decrease in effective permeability, where fluids flow through the low-permeability calcite zone. The developed reactive transport model provides a valuable tool to link cement–CO_2 reactions with the evolution of porosity and permeability. It can be used to quantify and predict long-term wellbore cement behavior and can facilitate the risk assessment associated with geological CO_2 [storage]." **Jean-Patrick Leopold Brunet, Li Li, Zuleima T. Karpyn, Barbara G. Kutchko, Brian Strazisar, and Grant Bromhal**, *Energy Fuels*. (Subscription may be required to view article.)

"Wettability of Supercritical Carbon Dioxide/Water/Quartz Systems: Simultaneous Measurement of Contact Angle and Interfacial Tension at Reservoir Conditions."

The following is the Abstract of this article: "Injection of [CO_2] in deep saline [formations] is considered as a method of carbon [storage]. The efficiency of this process is dependent on the fluid–fluid and rock-fluid interactions inside the porous media. For instance, the final storage capacity and total amount of capillary-trapped CO_2 inside [a formation] are affected by the interfacial tension between the fluids and the contact angle between the fluids and the rock mineral surface. A thorough study of these parameters and their variations with temperature and pressure will provide a better understanding of the carbon [storage] process and thus improve predictions of the [storage] efficiency. In this study, the controversial concept of wettability alteration of quartz surfaces in the presence of supercritical carbon dioxide (sc-CO_2) was investigated. A novel apparatus for measuring interfacial tension and contact angle at high temperatures and pressures based on Axisymmetric Drop Shape Analysis with no-Apex (ADSA-NA) method was developed and validated with a simple system. Densities, interfacial tensions, and dynamic contact angles of CO_2/water/quartz systems were determined for a wide range of pressures and temperatures relevant to geological [storage] of CO_2 in the subcritical and supercritical states. Image analysis was performed with ADSA-NA method that allows the determination of both interfacial tensions and contact angles with high accuracy. The results show that supercritical CO_2 alters the wettability of quartz surface toward less water-wet conditions compared to subcritical CO_2. Also [the authors] observed an increase in the water advancing contact angles with increasing temperature indicating less water-wet quartz surfaces at high temperatures." **Soheil Saraji, Lamia Goual, Mohammad Piri, and Henry Plancher**, *Langmuir*. (Subscription may be required to view article.)

Terrestrial

"Carbon balance of citrus plantations in Eastern Spain."

The following is the Abstract of this article: "Global warming due to the continuous rise in CO_2 emissions has been documented in the last few decades. This work is a first effort to estimate the net carbon incorporation in citrus plantations cultivated under typical land use. The approach involves a biomass-based study of carbon accumulation and a complementary analysis of the associated CO_2 fluxes. The total C content allocated to trees aged 2–14 years was determined through the direct and destructive harvesting of all tree organs. A stable pattern of biomass production in tree components was observed in plants 12 years old and older and was responsible for the [storage] of more than 50 kg C $tree^{-1}$. Annual C fixation in fruit and new vegetative flushes accounted for up to approximately 75 [percent] of the total amount [stored] per year, whereas the contribution of the old, permanent organs (branches, trunk, and tap-coarse roots) was minor (approximately 25 [percent]). Further experiments were conducted on adult 12-year-old trees to confirm the data and determine the particular contribution of CO_2 fluxes from tree organs and soil to the final values. Data revealed that leaves were responsible for a total net C fixation of 15.4 Mg C ha^{-1} yr^{-1} (higher than 55 [percent] of the total C fixed). The complementary, regular monitoring of fruit respiration rates showed that fruit respiration played only a minor role, responsible for the emission of 2.3 Mg C ha^{-1} yr^{-1}. Minimum losses were also found when soil respiration rates were investigated, accounting for a total annual C loss of 2.7 Mg C ha^{-1} yr^{-1}. Taken together, these results indicate that [the authors'] plantation was responsible for a net C

Terrestrial (continued)

fixation of close to 10 Mg C ha^{-1} yr^{-1}. Assimilatory processes in leaves accounted for the highest proportion of C allocated to the tree, while losses due to leaf and fruit respiration were of minor importance. Under typical culture conditions (drip irrigation and absence of ground cover), soil respiration rates accounted for a low level of C loss to the atmosphere. Because citrus is the second largest fruit crop cultivated in the [European Union (EU)], such data are very relevant to the mitigation of climate change." **Domingo J. Iglesias, Ana Quiñones, Antonio Font, Belén Martínez-Alcántara, María Ángeles Forner-Giner, Francisco Legaz, and Eduardo Primo-Millo**, *Agriculture, Ecosystems & Environment*. (Subscription may be required to view article.)

Trading

"South Korean Parliament Approves Carbon Trading System."

The National Assembly of South Korea passed a bill to establish a cap-and-trade system to cut GHG emissions. The market-based program will require companies that exceed the emission quotas to buy permits from those that emit less. The bill calls for emissions trading to commence in 2015. According to the Global Legislators Organization, carbon markets in Korea, Australia, and China may be linked with the European Union's (EU) emissions trading system (ETS) as early as 2020. At the 2009 United Nations Climate Summit, South Korea pledged to cut GHG emissions by 30 percent from forecast levels by 2020. Click here to view a White Paper produced by Bloomberg New Energy Finance. From *Bloomberg* on May 3, 2013.

"California's Third Carbon Auction Raises $280 Million."

According to results released by the California Air Resources Board, California's third carbon allowance auction raised more than $280 million. Carbon credits for this year sold for $14 a ton; allowances for 2016 sold for the minimum $10.71 a ton. The state-run auctions, part of California's cap-and-trade market, require more than 400 big industrial emitters to cap their emissions at certain levels; if that cap is exceeded, they are then required to buy credits from the state or other market participants. From *The Sacramento Bee* on May 21, 2013.

"38.7 Million CO_2 Allowances Sold at 20th RGGI Auction."

A total of 38,782,076 CO_2 allowances were sold at a clearing price of $3.21 at the 20th Regional Greenhouse Gas Initiative (RGGI) auction, held on June 5, 2013. The auction generated $124.4 million for reinvestment by the nine Northeastern and Mid-Atlantic states that participate in RGGI. Bids for the CO_2 allowances ranged from $1.98 to $5.55 per allowance; 100 percent of the allowances offered for sale by the nine states were sold. This is the second RGGI CO_2 allowance auction held since the RGGI states released the "Updated Model Rule" and "Program Review Recommendations Summary" in February 2013, guiding the RGGI states as they follow state-specific statutory and regulatory processes to propose updates to their CO_2 Budget Trading Programs. More information is available in the "Market Monitor Report for Auction 20." From *RGGI Press Release* on June 7, 2013.

"Planning carbon emission trading for Beijing's electric power systems under dual uncertainties."

The following is the Abstract of this article: "In this study, a full-infinite interval-stochastic mixed-integer programming (FIMP) method is developed for planning carbon emission trading (CET) under dual uncertainties. FIMP has advantages in uncertainty reflection and policy analysis, particularly when the input parameters are provided as crisp and functional intervals as well as probabilistic distributions. The developed FIMP is applied to a real case study for managing CO_2 emissions with trading scheme of Beijing's electric power system (EPS). Electric power industry is one of the major sources of CO_2 emission in China. It is essential to accumulate relevant experience to provide a reliable basis for establishing a regional or national CET market, so as to prepare for docking with the international market. This is the first attempt to introduce CET scheme into Beijing's EPS to mitigate CO_2 emissions. The solutions for energy supply, electricity generation, carbon-quota allocation, and capacity expansion are obtained. They cannot only be used for formulating CO_2-reduction policies and assessing the associated economic implications in purchasing emission permits or bearing economic penalties, but also facilitate analyzing various policies when pre-regulated electricity-generation plans and pre-defined CO_2-emission schemes are violated." **Y. Zhu, Y.P. Li, and G.H. Huang**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required to view article.)

Recent Publications

"Comparison of Publicly Available Methods for Development of Geologic Storage Estimates for Carbon Dioxide in Saline Formations."
The following is from the Executive Summary of this NETL-published document: "Prospective CO_2 storage resource estimates for application to saline formations at the national, regional, and basin scale are required to assess the potential for CCS technologies to reduce CO_2 emissions. Both private and public entities worldwide rely on CO_2 storage resource estimates for broad energy-related government policy and business decisions. As prospective estimates, they embody inherent uncertainties arising from simplifying assumptions and data limitations pertaining to subsurface geology. Carbon storage resource estimates provide important bounds for energy planning at the national and regional levels. Several methods have been developed to provide storage-resource estimates, originating with efforts as early as 1993. This study compares estimates that several commonly used methods produce when applied to common data sets to assess the impact that the choice of method has on the results."

Recent Publications (Continued)

"CCS Cost Reduction Taskforce: Final Report."

The following is from the Executive Summary of this document: "This Final Report builds on the Interim Report of November 2012 which focused on identifying the opportunities for cost reduction across the CCS chain to achieve cost competitive CCS in the 2020s. The Final Report presents to [the UK] Government what the Task Force has identified as Agreed Actions and recommended Next Steps to achieve these cost reductions and develop the CCS industry in the UK… The Key Conclusion of the Interim Report of the UK CCS Cost Reduction Task Force (CRTF) remains intact. This is: 'UK gas and coal power stations equipped with carbon capture, transport and storage have clear potential to be cost competitive with other forms of low-carbon power generation, delivering electricity at a [levelized] cost approaching [~$155]/MWh by the early 2020s, and at a cost significantly below [~$155]/MWh soon thereafter.' The contents of the Interim Report of the CRTF remain largely unchanged. The work of the CRTF over the last four months, and this Final Report, have built on the Interim Report findings by: [1] converting the Interim Report Candidate Actions into Agreed Actions; and [2] laying out the Next Steps which should be followed to develop the CCS industry in the UK, to enable the roll-out of follow-on projects after the DECC Commercialisation Programme projects and ultimately to deliver cost-effective CCS in the UK."

"Carbon Capture and Storage – Global Strategic Business Report."

The following is from the Summary of this document: "CCS is a valuable tool in the drive to minimize [GHG] emissions. The rationale for opting for CCS comes from the fact that the current large dependence on fossil fuels would continue to exist for several years to come, due in part to a wide installed base in the fossil fuel industry and early stages of renewables. The sheer magnitude of existing fossil-fuel based energy infrastructure makes it difficult for complete replacement by sustainable and eco-friendly alternative energy sources that can serve the global energy needs. The situation creates demand for technologies that allow use of fossil fuels as a source of energy while reducing CO_2 emissions. [CCS] is one such low-carbon technology that promises to achieve a part of this goal by reducing CO_2 emissions across various sectors. While a few large-scale integrated projects (LSIPs) are already operational, several more such projects are in various stages of development worldwide. Furthermore, the technology also finds use in industries that depend on biomass for its energy needs, where capture and storage of CO_2 would assist in net CO_2 reduction from the atmosphere. Use of CCS along with other emission gas reducing strategies is critical for achieving emission targets set for the decades to come to prevent large-scale changes to earth's climate. EOR remains a major driver of CCS projects. The overall progress of CCS projects worldwide is currently limited due to factors such as associated high costs, nascent stage of the technology, weaker economic environment and public opposition in some countries. Funding, an important aspect of the technology's deployment due to its huge associated costs, mainly comes from governments. The sluggish progress in global CCS deployment is hampering private sector investment, which in turn is hindering technology development in the industry."

"Future Electricity Part 1: Power from Fossil Fuels."

The following is from the Executive Summary of this document: "The [UK] Government's approach in pursuing fossil fuels with [CCS] as one of three key low carbon options for the power sector is consistent with available evidence. Whilst there is strong support for [CCS] through the current demonstration [program], it is unlikely to result in significant levels of fossil fuels with [CCS] being deployed by 2030, which models consistently indicate will be needed to achieve the 2050 target cost effectively. More rapid and widespread deployment of [CCS] may be achievable by supporting industrial applications, and focusing on the development of shared transport and storage infrastructure, alongside existing plans for power sector demonstration and deployment. There is strong evidence of the value of developing [CCS] in future. Electricity supply will likely need to increase substantially between 2030 and 2050 as additional sectors such as heating and possibly transport are largely electrified. Doing so without abated fossil fuels would significantly increase reliance on renewable and nuclear deployment, which is likely to be more expensive and politically challenging. [CCS] could be at least as important in cost-effective [decarbonization] outside the power sector. It is the only known option to [decarbonizes] many industrial processes, could provide alternative low carbon energy vectors such as hydrogen for use in powering transport and could deliver negative emissions in conjunction with biomass combustion. Overall, it is estimated that without [CCS], total energy system costs could be [~$47-63 billion] higher per year by 2050."

"Effects of a Carbon Tax on the Economy and the Environment."

The following is the Summary of this document: "Lawmakers could increase [Federal] revenues and encourage reductions in emissions of CO_2 by establishing a carbon tax, which would either tax those emissions directly or tax fuels that release CO_2 when they are burned (fossil fuels, such as coal, oil, and natural gas). Emissions of CO_2 and other [GHGs] accumulate in the atmosphere and contribute to climate change—a long-term and potentially very costly global problem. The effects of a carbon tax on the U.S. economy would depend on how the revenues from the tax were used. Options include using the revenues to reduce budget deficits, to decrease existing marginal tax rates (the rates on an additional dollar of income), or to offset the costs that a carbon tax would impose on certain groups of people. This study examines how a carbon tax, combined with those alternative uses of the revenues, might affect the economy and the environment."

Recent Publications (Continued)

"Redrawing the Energy-Climate Map."

The following is from the Introduction of this document: "Climate change is a defining challenge of our time. The scientific evidence of its occurrence, its derivation from human activities and its potentially devastating effects accumulate. Sea levels have risen by 15-20 [centimeters], on average, over the last century and this increase has accelerated over the last decade. Oceans are warming and becoming more acidic, and the rate of ice-sheet loss is increasing. The Arctic provides a particularly clear illustration, with the area of ice covering the Arctic Ocean in the summer diminishing by half over the last 30 years to a record low level in 2012. There has also been an increase in the frequency and intensity of heat waves, resulting in more of the world being affected by droughts, harming agricultural production. Global awareness of the phenomenon of climate change is increasing and political action is underway to try and tackle the underlying causes, both at national and international levels. Governments agreed at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties in Cancun, Mexico in 2010 (COP-16) that the average global temperature increase, compared with pre-industrial levels, must be held below 2°C, and that this means [GHG] emissions must be reduced. A deadline was set at COP-18 in Doha, Yatar in 2012 for agreeing and enacting a new global climate agreement to come into effect in 2020. But although overcoming the challenge of climate change will be a long-term endeavour, urgent action is also required, well before 2020, in order to keep open a realistic opportunity for an efficient and effective international agreement from that date."

Legislative Activity

"Understanding barriers to commercial-scale carbon capture and sequestration in the United States: An empirical assessment."

The following is the Abstract of this article: "Although a potentially useful climate change mitigation tool, CCS efforts in the United States remain mired in demonstration and development. Prior studies suggest numerous reasons for this stagnation. This article empirically assesses those claims. Using an anonymous opinion survey completed by 229 CCS experts, [the authors] identified four primary barriers to CCS commercialization: (1) cost and cost recovery, (2) lack of a price signal or financial incentive, (3) long-term liability risks, and (4) lack of a comprehensive regulatory regime. These results give empirical weight to previous studies suggesting that CCS cost (and cost recovery) and liability risks are primary barriers to the technology. However, the need for comprehensive rather than piecemeal CCS regulation represents an emerging concern not previously singled out in the literature. [The authors'] results clearly show that the CCS community sees fragmented regulation as one of the most significant barriers to CCS deployment. Specifically, industry is united in its preference for a [Federal] regulatory floor that is subject to state-level administration and sensitive to local conditions. Likewise, CCS experts share broad confidence in the technology's readiness, despite continued calls for commercial-scale demonstration projects before CCS is widely deployed." **Lincoln L. Davies, Kirsten Uchitel, and John Ruple**, *Energy Policy*. (Subscription may be required to view article.)

"Public climate-change skepticism, energy preferences and political participation."

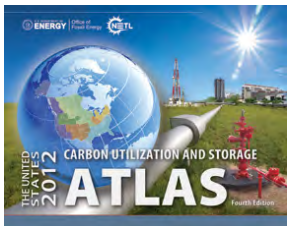
The following is the Abstract of this article: "Many studies have shown a general decline of public concern about climate change or vice versa a rise in public climate-change skepticism, in particular in the U.S. and other Anglo-Saxon countries. There is a vivid debate on whether this is a global phenomenon, on which factors explain the decline, and on the broader societal implications of these trends in the context of the transformation toward a low-carbon society. [The authors] add to this literature by presenting the results of a recent general population survey in Germany in which [the authors] looked for systematic linkages between public climate-change skepticism on one hand, and energy preferences and political participation on the other. Germany is an interesting testbed as it is currently involved in a large-scale restructuring of its system of energy supply toward renewable energy sources (the 'Energiewende'). [The authors'] results indicate that climate-change skepticism has not diffused widely in Germany, but that it correlates with less support of renewable energy sources. However, skepticism correlates negatively with political participation, and there is no strong political outlet for public climate-change skepticism in Germany. Alternative potential barriers for the successful implementation of the 'Energiewende' are also discussed." **Anita Engels, Otto Hüther, Mike Schäfer, and Hermann Held**, *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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