NETL the ENERGY lab

Carbon Storage Newsletter

January 2014

What's Inside?

Highlights

"Celebrating a Decade of Carbon Storage Research Through Partnership."

For the past decade, the U.S. Department of Energy (DOE) Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) has managed a nationwide network of partnerships that team government, industry, academia, and nonprofit organizations to identify the best approaches for permanently storing carbon dioxide (CO_2) in deep geologic formations. Research performed by the Regional Carbon Sequestration Partnerships (RCSPs) helps validate the most suitable technologies and infrastructure needs for carbon capture and storage (CCS). Research has resulted in lessons learned, with each leading to more effective ways to contain and monitor CO_2. The RCSPs are intended to address the unique characteristics of their respective regions throughout the United States. Each RCSP evaluates potential storage sites in its geographic area and determines the optimal approach for CCS. Testing conducted at the sites prior to, during, and after injection provides insight regarding injectivity, capacity, and containment of CO_2 in the formations. Determining best practices for each region leads the RCSPs to identify regulatory and infrastructure requirements for future commercial deployment, making CCS easier and more effective. NETL and the RCSPs also make the results of their research available. To augment the information-sharing, DOE will post a series of lessons learned from the RCSPs' carbon storage projects over the next several weeks. These blog posts will include like topics as site characterization; industry partnerships; public outreach and education; and monitoring, verification, accounting (MVA), and assessment. More information on the RCSPs is available via the NETL website.

"Department of Energy Releases $8 Billion Solicitation for Advanced Fossil Energy Projects."

DOE published a solicitation on December 12, 2013, making up to $8 billion in loan guarantee authority available to support innovative advanced fossil energy projects that avoid, reduce, or store greenhouse gases (GHGs). The loan guarantees under this new solicitation will help provide financing to support new or significantly improved advanced fossil energy projects, such as advanced resource development, carbon capture, low-carbon power systems, and efficiency improvements, which reduce emissions of CO_2, methane (CH_4), and other GHGs. DOE published a draft solicitation on July 9, 2013, which opened a 60-day comment period. During this time, DOE listened to potential applicants and other stakeholders and incorporated their feedback into the solicitation, which includes new provisions intended to facilitate applications, ensure quick review, and foster successful public-private partnerships. Currently, DOE's Loan Programs Office (LPO) supports a portfolio of more than $30 billion for more than 30 closed and committed projects. With the publication of the Advanced Fossil Energy Projects solicitation, the Department is accepting applications through the LPO web portal at apply.loanprograms.energy.gov, and expects to receive the initial applications by the end of February 2014. A copy of the solicitation, which includes application deadlines and eligibility requirements, and a fact sheet can be found at lpo.energy.gov. The solicitation is part of the Climate Action Plan. The loan guarantees are authorized by Title XVII of the Energy Policy Act of 2005. From *U.S. Department of Energy News Release* on December 12, 2013.

Announcements

Carbon Sequestration Leadership Forum (CSLF) Endorses CCS.

The CSLF member nations endorsed CCS technologies as a key component of international plans to combat potential climate change. The CSLF Ministers believe that the demonstration and global deployment of CCS must be accelerated and they are committed to taking individual and collaborative actions. The Ministers' common goal is to ensure that the conditions are right for completing CCS projects currently under construction or in advanced stages of planning.

Sequestration Training and Education Program (STEP) and World Resources Institute (WRI) Workshop.

STEP is working with WRI to offer a Financial Assurances Workshop on March 13, 2014, in Washington, D.C., USA. The workshop will provide an overview of financial assurance with a focus on the regulations of the Underground Injection Control (UIC) Class VI well operator. The workshop includes: financial assurance terms and concepts; discussion of the current financial assurance framework for Class VI wells; and discussion of financial assurance requirements by geologic storage phases. Please contact Kathy Atchley (katchley@illinois.edu) for registration materials.

Meeting Announcement and Call for Papers: International Workshop on Public Education, Training, and Community Outreach for Carbon Capture and Storage.

This workshop is scheduled for July 30-31, 2014, at the National Sequestration Education Center (NSEC) in Decatur, Illinois, USA. The technical program features tools and techniques for public education, training, and community outreach on CCS. Workshop attendees will tour the commercial-scale CCS project at the Archer Daniels Midland (ADM) facility. Papers are requested related to the following topics: (1) Ongoing Programs in CCS Education and Training; (2) Project Developer/Industry Experience in Public Communications; (3) Sharing Knowledge/Lessons Learned for Effective CCS Outreach; and/or (4) Advancing CCS Education, Training, and Outreach Programs, Key Messages, and FAQs. Abstracts are due by February 14, 2014. The workshop also includes a full day of programming for K-12 teachers with interactive lesson plans related to CCS and Science, Technology, and Mathematics (STEM).

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

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

12th International Conference on Greenhouse Gas Control Technologies.

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

Carbon Storage in the News

"ADM Seeks to Expand Carbon Capacity."

ADM is seeking regulatory approval for the underground storage of 5 million metric tons of CO_2 from the Illinois Basin Decatur Project (IBDP), where researchers are monitoring sandstone formations at depths of 7,000 feet to determine the long-term viability of carbon storage. Since CO_2 injection began in November 2011 at a pace of approximately 1,000 tons per month, ADM has stored 685,000 tons of CO_2. The Illinois State Geological Survey (ISGS) and the Midwest Geological Sequestration Consortium (MGSC), one of DOE's RCSPs, are tracking the carbon storage results. From *The State Journal-Register* on December 19, 2013.

"Capture Power Welcomes FEED Contract Award."

The UK Government awarded Capture Power Limited (a consortium of Alstom, Drax, and BOC) a Front-End Engineering Design (FEED) contract for the planned White Rose CCS Project. Also included in the contract is the planned development of a CO_2 transportation and storage network, to be undertaken by National Grid Carbon Limited, called the Yorkshire Humber CCS Trunkline. During the FEED study, Capture Power and National Grid Carbon will work with the UK Department of Energy and Climate Change (DECC) on the construction and operation of the CCS project. Approximately 90 percent of all CO_2 produced by the proposed 426-MW CCS power plant, located near Shelby in North Yorkshire, will be captured and transported by pipeline for permanent storage beneath the North Sea seabed. From *Carbon Power Limited News Release* on December 9, 2013.

"UW Researchers Unveil Tool to Aid in Enhanced Oil Recovery."

Researchers at the University of Wyoming (UW) and the Enhanced Oil Recovery Institute (EORI) have developed a software program to help oil operators understand the economic viability of CO_2 flooding in

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their legacy fields. Available for download as an Excel-based spreadsheet tool, CO2Scope™ can assist with estimating the economic feasibility of using CO_2 as an enhanced oil recovery (EOR) method by allowing operators to quickly scope various economic scenarios for CO_2 injection. UW researchers estimate that implementing EOR operations in Wyoming could increase production by 0.7 billion to 1 billion barrels of oil from already-developed reservoirs. Based on the average oil price of $70 per barrel, 1 billion barrels of incremental oil produced in Wyoming with EOR would generate approximately $8 to $9 billion in ad valorem and severance taxes for Wyoming state and county governments. Click here for more information on CO2Scope. From *University of Wyoming News Release* on December 20, 2013.

"Air Products and SIRE Sign Liquid CO_2 Agreement for Iowa Facility."

Air Products and Southwest Iowa Renewable Energy, LLC (SIRE) signed an agreement for the production of liquid CO_2. Under the agreement, Air Products will build a facility with the capability to capture 400 tons per day (tpd) of liquid CO_2 at SIRE's ethanol production facility in Council Bluffs, Iowa. Air Products will market food- and beverage-grade liquid CO_2 from the new plant, which is expected to begin production in early 2014. From *Air Products News Release* on December 17, 2013.

Science

"Global Warming Impacts Bats: New Study Says Climate Change Hurts Bat Communities."

According to a study conducted by researchers from the Max Planck Institute in Germany, potential climate change could be altering some bat species' ability to hunt using sound. Published in the "Royal Society Interface," the study found that change(s) in air temperatures could impact bats' abilities to navigate and hunt prey in the dark (known as echolocation). Naturally nocturnal, bats fly in the dark by releasing ultrasonic sounds that bounce back to them after hitting an object. Factors such as humidity, wind, and heat can alter the sound waves, causing them to lose volume and clarity. According to the study, certain bat species living in temperate regions may face more challenges than bats living in tropical regions. From *International Business Times* on December 12, 2013.

"Climate Change is Scaring the Fish Due to Acidified Oceans, Study Says."

Potential increases of atmospheric CO_2 that lead to ocean acidification could be making rockfish more anxious, according to a study conducted at Edmonton's MacEwan University. Previous research of ocean acidification's effect on reef-dwelling fish was expanded upon by studying fish that live in areas that experience more upwelling currents, such as the juvenile rockfish, a common species along the Pacific coast. Researchers placed one group of fish in a tank with normal sea water, and another group of fish in a tank with sea water levels of acidification expected in approximately 100 years; both tanks were also divided into black and white areas. The researchers found that fish swam freely between the two areas in the normal tank, but tended to huddle in the dark area in the acidic tank. According to the study, the acidic water stimulated activity in a part of the fish's neural system that caused it to struggle to restore electrochemical balance, creating anxiety, and leading them to be more fearful. From *The Globe and Mail* on December 11, 2013.

Policy

"EPA Rule Provides a Clear Pathway for Using Carbon Capture and Sequestration Technologies."

On December 19, 2013, the U.S. Environmental Protection Agency (EPA) issued a final rule that helps create a consistent national framework to ensure the safe, effective deployment of CCS technologies. The new rule clarifies that CO_2 captured from emission sources, injected underground via UIC Class VI wells approved for the purpose of geologic storage under the Safe Drinking Water Act (SDWA), and meeting certain other conditions, will be excluded from EPA's hazardous waste regulations. EPA also clarifies that CO_2 injected underground via UIC Class II wells for EOR is not expected to be a waste management activity. EPA added that the management of CO_2 under the specified conditions does not present a substantial risk to human health or the environment. The final rule is available online.

"[Wyoming] to Regulate Greenhouse Gases."

On December 23, 2013, the U.S. EPA handed over authority for GHG permitting in Wyoming to the Wyoming Department of Environmental Quality (DEQ). A DEQ official said that the department will add CH_4 and CO_2 to the list of reviewed emissions in the state. The GHG rule, which was finalized in 2010, applies to large emitters. From *Wyoming Public Media* on December 30, 2013.

"South City Moves Forward with Climate Action Plan."

According to city officials, South San Francisco's Climate Action Plan (CAP), currently in its final draft form, includes an approach to reduce GHG emissions, adapt to potential climate change, and support similar statewide efforts. The CAP includes a 15 percent reduction target by 2020 and identifies the three methods for achieving the reduction target as statewide reduction efforts, existing local programs, and energy efficiency and conservation. These three methods combine for 63 percent of the total goal. From *San Francisco Examiner* on December 27, 2013.

"Engaging the public with low-carbon energy technologies: Results from a Scottish large group process."

The following is the Abstract of this article: "This paper presents the results

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of a large group process conducted in Edinburgh, Scotland investigating public perceptions of climate change and low-carbon energy technologies, specifically CCS. The quantitative and qualitative results reported show that the participants were broadly supportive of efforts to reduce [CO_2] emissions, and that there is an expressed preference for renewable energy technologies to be employed to achieve this. CCS was considered in detail during the research due to its climate mitigation potential; results show that the workshop participants were cautious about its deployment. The paper discusses a number of interrelated factors which appear to influence perceptions of CCS; factors such as the perceived costs and benefits of the technology, and people's personal values and trust in others all impacted upon participants' attitudes towards the technology. The paper thus argues for the need to provide the public with broad-based, balanced and trustworthy information when discussing CCS, and to take seriously the full range of factors that influence public perceptions of low-carbon technologies." **Rhys Howell, Simon Shackley, Leslie Mabon, Peta Ashworth, and Talia Jeanneret**, *Energy Policy*. (Subscription may be required.)

"Not Under Our Back Yards? A case study of social acceptance of the Northern Netherlands CCS initiative."

The following is the Abstract of this article: "[The authors] analyze the decision-making process of the abandonment of a CCS initiative in the Northern-Netherlands. [The authors] investigate the social acceptance of the Northern-Netherlands CCS initiative using the results from a survey among the key stakeholders. [The authors] find that local opposition can only be held partially responsible for the abandonment of the CCS project. This result differs from the broadly accepted notion 'no local public acceptance, no CCS.' [The authors'] study finds that the views from key stakeholders regarding the prospects of the CCS initiative were conflicting and this played a role in abandoning the initiative. [The authors] conclude that the way in which responsibilities between key stakeholders were arranged has had a dominant impact on the level of acceptance. [The authors] recommend that future policy and policy instruments for subsurface activities, like CCS, should be designed in accordance with the object, subject and inter-subject dimension of the decision-making process. In addition there should be a strategic framework, which accounts for the interaction between social-political, market and community acceptance." **Herman W.A. van Os, Rien Herber, and Bert Scholtens**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

Geology

"Sensitivity study of surface waves for CO_2 storage monitoring."

The following is the Abstract of this article: "CCS is a potential technology to reduce [GHG] emission. Suitable techniques are essential for site characterization as well as CO_2 injection and storage monitoring. A surface wave seismic method was explored in this study to investigate its feasibility for this purpose. Elastic wave responses of CO_2 flooded rock were first investigated numerically in two types of rocks, carbonate rock and sandstone. It is indicated that elastic wave velocities change more significantly as there is greater difference for bulk modulus between the injected CO_2 and the existing media in pore spaces. With the wave velocity and density variation ranges estimated from the rock sample study, the sensitivity of surface wave velocity was examined by perturbing parameters of the CO_2 storage layer in two layered reservoir models. It is found that the surface waves are more sensitive to the changes of shear wave velocity and thickness of CO_2 storage layer; but they are less sensitive to density and compressional wave velocity variations. The fundamental mode of Rayleigh waves is most sensitive to the physical parameter perturbation of the CO_2 storage layer for the carbonate case. However, high frequency modes were observed to be more active for shear wave velocity and thickness variation scenarios in the sandstone reservoir simulations. The simulations demonstrate that the monitoring feasibility increases as the CO_2 reservoir layer becomes thicker and the bury depth goes shallower. However, with the geological setting parameters found in existing CCS projects, it is concluded to be a challenge to detect abnormalities in a CO_2 storage reservoir by comparing the shift of shear wave velocity profiles that are derived from analysis of surface wave response data. It is, therefore, proposed to consider other microtremor attributes during the development of CO_2 monitoring techniques based on passive measurement of microseismicity, which is explored by some researchers." **Xuehang Song, Kaoshan Dai, Gen Chen, Yongdong Pan, and Zheng Zhong**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Sensitivity of Joule-Thomson cooling to impure CO_2 injection in depleted gas reservoirs."

The following is the Abstract of this article: "Depleted hydrocarbon reservoirs are key targets for geological storage of CO_2. It is well known that Joule–Thomson cooling can potentially occur in reservoirs during CO_2 injection. In this paper [the authors] investigate the impact of the presence of other gases (impurities) in the injected CO_2 stream on Joule–Thomson cooling. A coupled heat and mass transport model is presented that accurately accounts for the pressure-, temperature-, and gas-compositional influences on the thermo-physical transport properties such as density, viscosity, specific heat capacity and Joule–Thomson coefficient. With this model it is shown that impurities affect both the spatial extent of the zone around the well bore in which Joule–Thomson cooling is induced and the magnitude of the cooling. [Sulfur dioxide (SO_2)] expands the zone of cooling, [oxygen (O_2), nitrogen (N_2)], and CH_4 contract this zone, and [hydrogen sulfide (H_2S)] has a small influence on the spatial extent of cooling. These relative [behaviors] are primarily controlled by the impact of the impurities on the specific heat capacity of the gas mixtures. The influence of impurities on the magnitude of cooling also depends on the operational conditions of gas injection. Enhanced cooling is caused by O_2, N_2, and CH_4 in combination with constant pressure injection, while for constant rate injection cooling enhancement is minimal or absent. Presence of SO_2 strongly suppresses Joule–Thomson cooling at low injection temperatures. Apart from the Joule–Thomson coefficient, the density of the gas mixture plays an important role in controlling these thermal responses. The thermal risks associated with impure gas injection appear small. Enhanced cooling >5 K requires high-pressure, low-temperature injection in a low permeability reservoir and presence of O_2, N_2, and/or CH_4 in the injectate. Co-injection of SO_2 has clear beneficial thermal consequences for low-temperature injection, by suppressing Joule–Thomson cooling,

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and may therefore be of special interest to help bring down the costs of CO_2 [storage] in depleted gas reservoirs." **Zaman Ziabakhsh-Ganji and Henk Kooi**, *Applied Energy*. (Subscription may be required.)

"Basin-scale modeling of CO_2 storage using models of varying complexity."

The following is the Abstract of this article: "Geological carbon storage can significantly contribute to climate-change mitigation only if it is deployed at a large scale. This means that injection scenarios must occur, and be analyzed, at the basin scale. Various mathematical models of different complexity may be used to assess the fate of injected CO_2 and/or resident brine. These models span the range from multi-dimensional, multi-phase numerical simulators to simple single-phase analytical solutions. In this study, [the authors] consider a range of models, all based on vertically integrated governing equations, to predict the basin-scale pressure response to specific injection scenarios. The Canadian section of the mid-continent Basal [Formation] is used as a test site to compare the different modeling approaches. The model domain covers an area of approximately 811,000 km^2, and the total injection rate is 63 Mt/yr, corresponding to [nine] locations where large point sources have been identified. Predicted areas of critical pressure exceedance are used as a comparison metric among the different modeling approaches. Comparison of the results shows that single-phase numerical models may be good enough to predict the pressure response over a large [formation]; however, a simple superposition of semi-analytical or analytical solutions is not sufficiently accurate because spatial variability of formation properties plays an important role in the problem, and these variations are not captured properly with simple superposition. [The authors] consider two different injection scenarios: injection at the source locations and injection at locations with more suitable [formation] properties. Results indicate that in formations with significant spatial variability of properties, strong variations in injectivity among the different source locations can be expected, leading to the need to transport the captured CO_2 to suitable injection locations, thereby necessitating development of a pipeline network." **Xinwo Huang, Karl W. Bandilla, Michael A. Celia, and Stefan Bachu**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Technology

"Carbon dioxide injection for enhanced gas recovery and storage (reservoir simulation)."

The following is the Abstract of this article: "[Carbon dioxide] injection for EOR had been broadly investigated both physically and economically. The concept for enhanced gas recovery (EGR) is a new area under discussion that had not been studied as comprehensively as EOR. In this paper, the 'Tempest' simulation software was used to create a three-dimensional reservoir model. The simulation studies were investigated under different case scenarios by using experimental data produced by Clean Gas Technology Australia (CGTA). The main purpose of this study is to illustrate the potential of enhanced natural gas recovery and CO_2 storage by re-injecting CO_2 production from the natural gas reservoir. The simulation results outlined what factors are [favorable] for the CO_2-EGR and storage as a function of CO_2 breakthrough in terms of optimal timing of CO_2 injection and different injection rates. After [analyzing] the results for each case scenario, it had been concluded that CO_2 injection can be applied to increase natural gas recovery simultaneously [storing] a large amount of the injected CO_2 for this particular gas reservoir. In addition, various CO_2 costs involved in the CO_2-EGR and storage were investigated to determine whether this technique is feasible in terms of the CO_2 content in the production as a preparation stage to achieve the economic analysis for the model." **Chawarwan Khan, Robert Amin, and Gary Madden**, *Egyptian Journal of Petroleum*. (Subscription may be required.)

"Economic analysis of a supercritical coal-fired CHP plant integrated with an absorption carbon capture installation."

The following is the Abstract of this article: "Energy investments in Poland are currently focused on supercritical coal-fired unit technology. It is likely, that in the future, these units are to be integrated with CCS installations, which enable a significant reduction of [GHG] emissions into the atmosphere. A significant share of the energy market in Poland is constituted by coal-fired combined heat and power (CHP) plants. The integration of these units with CCS installation can be economically inefficient. However, the lack of such integration enhances the investment risk due to the possibility of appearing on the market in the near future high prices of emission allowances. The aforementioned factors and additional favorable conditions for the development of cogeneration can cause one to consider investing in large supercritical CHP plants. This paper presents the results of an economic analysis aimed at comparing three cases of CHP plants, one without an integrated CCS installation and two with such installations. The same steam cycle structure for all variants was adopted. The cases of integrated CHP plants differ from each other in the manner in which they recover heat. For the evaluation of the respective solutions, the break-even price of electricity and avoided emission cost were used." **Lukasz Bartela, Anna Skorek-Osikowska, and Janusz Kotowicz**, *Energy*. (Subscription may be required.)

"Numerical assessment of CO_2 geological [storage] in sloping and layered heterogeneous formations: A case study from Taiwan."

The following is the Abstract of this article: "[CO_2] geological [storage] (CGS) has been recognized as one of the potential solutions for reducing anthropogenic CO_2 emissions. The Changhua Coastal Industrial Park (CCIP) in central Taiwan has been preliminarily evaluated as a potential site for CGS. The CCIP site possesses sloping and layered heterogeneous formations with stagnant groundwater flow. Previous geophysical investigations of seismic reflection survey have found no significant faults near this site. Prior to the actual application of CGS in the field, it is important to carry out numerical simulations to predict the short- and long-term evolution of injected CO_2 into deep geological formations. In this study, the TOUGHREACT/ECO2N simulator is employed in order to conduct comprehensive CGS assessments at the CCIP site. Field scale CGS simulations are utilized to capture the details of the physical features, such as the displacement of saline brine by the injection of CO_2, buoyancy/gravity convection, and salt precipitation due to pore water dry-out, in the vicinity of the CO_2 injection well. Simulation results show that (1) the migration of CO_2 plume did not

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penetrate the low permeability formation at 500 years, (2) formation tilting caused a slightly asymmetric CO_2 plume oriented toward the up-tilt direction, and (3) the amount of solubility and residual gas trapping accounted for 26.8 [percent] and 19.0 [percent], respectively, of injected CO_2 by weight at 500 years." **Rui-Tang Sung, Min-Hsu Li, Jia-Jyun Dong, Andrew Tien-Shun Lin, Shu-Kun Hsu, Chien-Ying Wang, and Chien-Nan Yang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Terrestrial

"Impact of total organic carbon (in sediments) and dissolved organic carbon (in overlying water column) on Hg [storage] by coastal sediments from the central east coast of India."

The following is the Abstract of this article: "Total organic carbon (TOC) (in sediment) and dissolved organic matter (DOM) (in water column) play important roles in controlling the mercury [storage] process by the sediments from the central east coast of India. This toxic metal prefers to associate with finer size particles (silt and clay) of sediments. Increasing concentrations of DOM in overlying water column may increase complexation/reduction processes of Hg^{2+} within the water column and decrease the process of Hg [storage] by sediments. However, high concentrations of DOM in water column may increase Hg [storage] process by sediments." **Parthasarathi Chakraborty, Brijmohan Sharma, P.V. Raghunath Babu, Koffi Marcellin Yao, and Saranya Jaychandran**, *Marine Pollution Bulletin*. (Subscription may be required.)

"Managing wheat stubble as an effective approach to [store] soil carbon in a semi-arid environment: Spatial modelling."

The following is the Abstract of this article: "Attention to farm management practices that enhance soil organic carbon (SOC) stock is increasing because of the latter's importance of soil fertility, crop production and the global carbon cycle. [Storing] atmospheric CO_2 as SOC has potential feedback to climate change. Spatial modelling of the effects of wheat stubble incorporation by tillage on SOC storage was studied in a semi-arid rainfed wheat cropping system, using the Agricultural Production Systems Simulator (APSIM). The model was validated against a long-term (1979–2004) experiment and yielded a Ratio of Performance to Deviation (RPD) of 1.6 and R2 of 0.63, indicating a moderate accuracy in predicting SOC turnover. In the Liverpool Plains and the southern slopes of NSW, SOC at top 30 cm layer is in a higher range of 40–50 t ha^{-1}, while from the southern west plains to the northern plains extending to the New England tablelands, SOC is in a lower range of 25–35 t ha^{-1}. It is notable that SOC in the central slopes is also in the lower range of 25–35 t ha^{-1}. There is large simulated variation to changes in SOC from stubble management under the current climate that ranges from 0 to –200 kg ha^{-1} $year^{-1}$ when 100 [percent] of the wheat stubble is removed. When 100 [percent] of the wheat stubble is 100 [percent] incorporated, the changes in SOC become positive, from 0 to 200 kg ha^{-1} $year^{-1}$. The SOC change patterns associated with the rates of wheat stubble incorporation are similar under a projected future climate. However, as future temperatures rise, less SOC will be [stored]. For example, under the 100 [percent] removal of wheat stubble, the averaged SOC is decreased by 126 ± 40 kg ha^{-1} yr^{-1} under the current climate, while under the 18 GCM projected climate (2049–2098), the reduction is 135 ± 15 kg ha^{-1} yr^{-1}. In contrast, when 100 [percent] wheat stubble is incorporated into the soil, the averaged SOC is increased by 100 ± 34 kg ha^{-1} yr^{-1} under the current climate, while under the 18 GCM projected climate, the averaged SOC is increased by 80 ± 23 kg ha^{-1} yr^{-1}. To maintain the current level of SOC in the south-western wheat growing region (lower rainfall) of the state 20–40 [percent] wheat stubble is required to be incorporated into soil, compared to that in the north-eastern area (high rainfall), where the rate is about 40–60 [percent]. Across the actual wheat growing area in NSW, the decreased SOC with the 100 [percent] removal of wheat stubble results in 3.90 ± 1.23 Mt CO_2 emissions per year under the current climate. Under the 18 GCM projected climate, the mean emission per year is 4.06 ± 0.50 Mt CO_2 if 100 [percent] wheat stubble is removed from field. In contrast, when 100 [percent] wheat stubble is incorporated into soil, the amount of increased SOC will reduce the atmospheric CO_2 emissions by 3.29 ± 1.11 Mt yr^{-1} under the current climate or by the mean of 2.68 ± 0.77 Mt yr^{-1} under the GCM projected climate. There is a clear trend to theoretically decrease CO_2 emissions with the increased incorporation of wheat stubble." **De Li Liu, Muhuddin R. Anwar, Garry O'Leary, and Mark K. Conyers**, *Geoderma*. (Subscription may be required.)

Trading

"RGGI States Make Major Cuts to Greenhouse Gas Emissions from Power Plants."

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced that the 2014 RGGI cap is 91 million tons, representing a 45 percent reduction to the RGGI CO_2 cap. The RGGI cap will decline 2.5 percent each year from 2015 to 2020. This would result in a projected 50 percent decrease from 2005 levels of power plant CO_2 emissions in the RGGI states by 2020. The first CO_2 allowance auction under the new cap (23rd RGGI auction) will take place on March 5, 2014. The RGGI states also announced the first of the interim adjustments to the RGGI cap to help account for the private bank of allowances held by market participants before the new cap was implemented. The RGGI states also included two interim adjustments to the RGGI cap to account for banked allowances. From *RGGI News Release* on January 13, 2014.

"Guangdong Launches World's Second Largest Carbon Market."

China's Guangdong province launched a carbon trading scheme, with carbon allowances selling at approximately $9.58. According to analysts, the first auction saw 28 companies buy 3 million metric tons of allowances for $9.58 per metric ton. On the first day of exchange, approximately 120,000 metric tons of allowances were sold, each priced in the range of $9.84 to $10. More than 200 companies from the power, cement, iron, and steel sectors are required to participate in Guangdong's pilot project, which is part of a wider pilot being rolled out across China over the next two years. Shanghai and Beijing began carbon trading in November 2013; other schemes are expected

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to follow in 2014 in Tianjin, Chongqing, and the province of Hubei. According to China's National Development and Reform Commission, Guangdong's carbon trading scheme will allow the province to meet an emissions intensity reduction target of 19.5 percent from 2010 to 2015. From *BusinessGreen* on December 23, 2013.

"Introducing carbon taxes in South Africa."

The following is the Abstract of this article: "South Africa is considering introducing a carbon tax to reduce [GHG] emissions. Following a discussion of the motivations for considering a carbon tax, [the authors] evaluate potential impacts using a dynamic economy wide model linked to an energy sector model including a detailed evaluation of border carbon adjustments. Results indicate that a phased-in carbon tax of US$30 per ton of CO_2 can achieve national emissions reductions targets set for 2025. Relative to a baseline with free disposal of CO_2, constant world prices and no change in trading partner behavior, the preferred tax scenario reduces national welfare and employment by about 1.2 and 0.6 percent, respectively. However, if trading partners unilaterally impose a carbon consumption tax on South African exports, then welfare/employment losses exceed those from a domestic carbon tax. South Africa can lessen welfare/employment losses by introducing its own border carbon adjustments. The mode for recycling carbon tax revenues strongly influences distributional outcomes, with tradeoffs between growth and equity." **Theresa Altona, Channing Arndtb, Rob Daviesa, Faaiqa Hartleya, Konstantin Makrelova, James Thurlowc, and Dumebi Ubogua**, *Applied Energy*. (Subscription may be required.)

"Carbon tariffs and cooperative outcomes."

The following is the Abstract of this article: "In the absence of an international environmental agreement (IEA) on climate change, a country may be reluctant to unilaterally implement environmental actions, as this may lead to the relocation of firms to other, lax-on-pollution countries. To avoid this problem, while still taking care of the environment, a country may impose a carbon tariff that adjusts for the differences between its own carbon tax and the other country's tax. [The authors] consider two countries with a representative firm in each one, and characterize and contrast the equilibrium strategies and outcomes in three scenarios. In the first (benchmark) scenario, in a first stage the regulators in the two countries determine the carbon taxes non-cooperatively, and in a second stage, the firms compete à la Cournot. In the second scenario, the regulators cooperate in determining the carbon taxes, while the firms still play a non-cooperative Cournot game. In the third scenario, [the authors] add another player, e.g., the World Trade Organization, which announced a border tax in a prior stage; the game is then played as in the first scenario. [The authors'] two major results are (i) a border-tax adjustment (BTA) mimics quite well the cooperative solution in setting the carbon taxes as in scenario two. This means that a BTA may be a way around the lack of enthusiasm for an IEA. (ii) All of [the authors'] simulations show that a partial correction of the difference in taxes is sufficient to maximize total welfare. In short, the conclusion is that a BTA may be used as a credible threat to achieve an outcome that is close to the cooperative outcome." **Terry Eyland and Georges Zaccour**, *Energy Policy*. (Subscription may be required.)

"When to invest in carbon capture and storage technology: A mathematical model."

The following is the Abstract of this article: "[The authors] present two models of the optimal investment decision in carbon capture and storage technology (CCS)-one where the carbon price is deterministic (based on the newly introduced carbon floor price in Great Britain) and one where the carbon price is stochastic (based on the [European Union's Emission Trading Scheme (ETS)] permit price in the rest of Europe). A novel feature of this work is that in both models investment costs are time dependent which adds an extra dimension to the decision problem. [The authors'] deterministic model allows for quite general dependence on carbon price and consideration of time to build and simple calculus techniques determine the optimal time to invest. [The authors] then [analyze] the effect of carbon price volatility on the optimal investment decision by solving a Bellman equation with an infinite planning horizon. [The authors] find that increasing the carbon price volatility increases the critical investment threshold and that adoption of this technology is not optimal at current prices, in agreement with other works. However reducing carbon price volatility by switching from carbon permits to taxes or by introducing a carbon floor as in Great Britain would accelerate the adoption of carbon abatement technologies such as CCS." **D.M. Walsh, K. O'Sullivan, W.T. Lee, and M.T. Devine**, *Energy Economics*. (Subscription may be required.)

Recent Publications

"Policy instruments for large-scale CCS."

The following is from the Executive Summary of this document: "This report analyses possible policy instruments for the [realization] of large-scale deployment of CCS for all large emissions sources, both in industry and power generation. Seven instruments are assessed: [1] Government funding; [2] Investment funding via market mechanisms (as NER300); [3] Carbon tax; [4] Emission-trading systems (ETS); [5] Feed-in tariffs; [6] Certificate systems (portfolio standard); [7] Emission performance standards (EPS). In order to ensure large-scale deployment of CCS, ZERO considers a mix of instruments indispensable: at the core, an instrument giving sufficient incentive to make business cases for CCS viable and trigger investments in deployment and innovation. For industry to embark on large-scale investments, a long-term predictable framework is needed. The best policy instruments for scaling up CCS deployment to emerge from this analysis are a CCS certificate system combined with an appropriate EPS. The certificate system finances the cost for CCS deployment through a cost-sharing model, while the EPS sets a clear regulation, stopping investments in high-emission conventional solutions. General CCS instruments are preferable to

Recent Publications (Continued)

sector-specific instruments, covering emissions beyond power production to give competition for reduced CCS cost across all sectors. And policy instruments for the whole CCS chain are preferable to separate instruments for each part of the chain in the long term perspective. Serving as a basis for the analysis, a thorough assessment of existing CCS policy worldwide as well as qualitative interviews with stakeholders have been conducted. The assessment of today's CCS policy shows that a combination of instruments has been used for large-scale CCS projects today, with public funding, investment support and tax credits for CO_2 used for EOR being the most important. The most successful policy for building CCS has been in the [United States] and Canada, where an EPS has been important part of the policy mix to trigger CCS. The need for CCS will vary depending on country and region. A sincere CCS policy must take renewable energy developments into account. In power markets, shares of variable renewable energy are increasing fast. CCS must therefore adjust to changing dynamics in the power sector. Even in a scenario where renewables are taking over totally in power generation, there are industry sectors where CCS is the only available mitigation solution today, such as production of cement, steel, ammonia, hydrogen and in natural gas cleaning. CCS may also be necessary on bioenergy production, producing negative emissions."

"Carbon Capture and Storage: Designing the Legal and Regulatory Framework for New Zealand."

The following is from the Executive Summary of this document: "CCS is a method of reducing emissions of CO_2 in order to reduce the effects of human activity on the global climate. At thermal power stations and industrial plants where large amounts of CO_2 are generated, various capture technologies can separate CO_2 from other gases that will be discharged to the atmosphere and compress it. It can then be transported by pipeline to a location where it can be injected deep underground (at least 800 meters) for permanent storage or sequestration. Several different types of geological formation can provide effective CCS storage, allowing CO_2 to be injected in sufficient quantity and containing it permanently under impermeable [caprock] formations. CCS brings together technologies that are well understood, and a number of large CCS operations have been operating in different countries for some time. Although CCS will be a new activity in New Zealand, there is a great deal of experience with it elsewhere. Work in New Zealand has identified a number of possible sources of CO_2 that would justify CCS operations. Some of them are coal and natural gas fired power stations, although New Zealand has less fossil-fuel electricity generation than many countries. Other sources are industrial activities such as gas processing, oil refining, cement making and steel making. Suitable geological formations for CCS injection and storage have also been identified."

"CO_2 Storage Atlas: Barents Sea."

The following is from the Preface of this document: "The CO_2 Storage Atlas of the Barents Sea has been prepared by the Norwegian Petroleum Directorate, at the request of the Ministry of Petroleum and Energy. The studied areas are located in opened parts of the Norwegian Continental Shelf (NCS). The main objectives have been to identify the safe and effective areas for long-term storage of CO_2 and to avoid possible negative interference with ongoing and future petroleum activity. [The authors] have also built on the knowledge [they] have from the petroleum industry and from the two CO_2 storage projects on NCS (Sleipner and Snøhvit). This study is based on detailed work on all relevant geological formations, discoveries and hydrocarbon fields in the Barents Sea. The work is based on several studies as well, as data from more than 40 years of petroleum activity on the [NCS]. [Nine] geological formations have been assessed, and grouped into saline [formations]. The [formations] were evaluated with regard to reservoir quality and presence of relevant sealing formations. Those [formations] that may have a relevant storage potential in terms of depth, capacity and injectivity have been considered. Structural maps and thickness maps of the geological formations are presented in the atlas, and were used to calculate pore volumes. Several structural closures have been identified and some of them were further assessed. A study of the CO_2 storage potential in relevant dry-drilled structures and mapped structures in the area is provided. [Carbon dioxide] storage in [EOR] projects is also discussed and a new study of CO_2 for EOR and CO_2 injected in residual oil zones has been outlined. The methodology applied for estimating storage capacity is based on previous assessments, but the storage efficiency factor has been assessed individually for each [formation] based on simplified reservoir simulation cases. The assessed [formations] have been ranked according to guidelines developed for the CO_2 Storage Atlas of the Norwegian part of the North Sea (2011). This atlas is based on data from seismic, exploration and production wells, together with production data. The data base is essential for the evaluation and documentation of geological storage prospectivity. [The authors] hope that this study will fulfill the objective of providing useful information for future exploration for CO_2 storage sites. [The authors] have not attempted to assess the uncertainty range for storage capacities in this atlas, but [the authors] have made an effort to document the methods and main assumptions. The assessments described in this atlas will be accompanied by a [geographical information system (GIS)] database."

Legislative Activity

"Carbon Capture and Storage and the London Protocol: Recent Efforts to Enable Transboundary CO_2 Transfer."

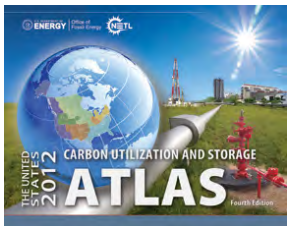
The following is the Abstract of this article: "In the absence of new energy policies or supply constraints, the International Energy Agency (IEA) estimates that energy-related CO_2 emissions in 2050 will be twice 2007 levels. However, the ETP 2012 2DG Scenario provides a technically achievable, low-cost strategy to reduce greenhouse gas emissions to a level consistent with a 2°C temperature increase. Under the 2DG Scenario, CCS would contribute just under one-fifth of total emissions reductions by 2050. To enable CCS to contribute at the levels in the 2DG Scenario, rapid growth in the number CCS projects is needed between today and 2020, and then the number of projects must grow steadily through 2050. As well as being a major financial, technical and logistical challenge, this is a significant regulatory challenge. Legal obstacles associated with global CCS deployment must be removed today including the prohibition on transboundary CO_2 transfer under the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Protocol). This paper reviews recent international actions to remove this prohibition; undertakes a legal analysis to identify possible options available to contracting parties under international law to allow transborder movement, pending entry into force of a formal, 2009 amendment enabling cross-border transportation of CO_2; and makes clear recommendations on the next best approach. It then looks at efforts undertaken by contracting parties and other organizations in 2011 and 2012 to update the 2007 Specific Guidelines for Assessment of Carbon Dioxide Streams for Disposal into Sub-seabed Geological Formations (2007 CO_2 Storage Guidelines) in light of the 2009 amendment." **Justine Garrett and Sean McCoy**, *Energy Procedia*. (Subscription may be required.)

About DOE's Carbon Storage Program

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

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

Carbon Storage Program Resources



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

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

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

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

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About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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