NETL the ENERGY lab

# Carbon Storage Newsletter

DECEMBER 2013

## What's Inside?



# Highlights

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

The U.S. Department of Energy (DOE) published a solicitation on December 12, making up to $8 billion in loan guarantee authority available to support innovative advanced fossil energy projects that avoid, reduce, or store greenhouse gases (GHGs). The loan guarantees under this new solicitation will help provide financing to support new or significantly improved advanced fossil energy projects, such as advanced resource development, carbon capture, low-carbon power systems, and efficiency improvements, which reduce emissions of carbon dioxide ($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.

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

The Carbon Sequestration Leadership Forum (CSLF) member nations endorsed carbon capture and storage technologies (CCS) as a key component of international plans to combat climate change. The CSLF Ministers stated that they are convinced that the demonstration and global deployment of CCS must be accelerated and they are committed to taking individual and collaborative actions. The Ministers' common goal is to ensure that the conditions are right for completing CCS projects currently under construction or in advanced stages of planning. The Ministers also expressed interest in increasing the number of new large CCS demonstrations by 2020 to enable future commercial deployment in the early 2020s. The CSLF Ministers outlined the following actions for CCS deployment: (1) develop predictable financial frameworks and incentive mechanisms to drive near-term CCS deployment; (2) develop workable CCS demonstration and deployment strategies in both the power and industrial sectors; (3) stress the importance of global coordinated efforts on CCS research, development, and demonstrations, and actively seek and support such opportunities through bilateral and multilateral collaboration with other key bodies including the International Energy Agency (IEA) and the Global Carbon Capture and Storage Institute (GCCSI); (4) continue establishing permitting frameworks that will ensure the safety and integrity of integrated CCS systems, and eliminate deployment obstacles; (5) recognize the need for pre-commercial storage validation and encourage cooperation between countries to identify and assess shared geological storage resources and develop plans for their orderly development, including development of associated transport systems; (6)

# HIGHLIGHTS (CONTINUED)

strengthen national, regional and international efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment; and (7) support efforts to grow capacity in CCS and foster appropriate steps in knowledge sharing and technology transfer. The CSLF is a Ministerial-Level international climate change initiative organizing worldwide resources to develop improved, cost-effective technologies for the separation, capture, transport, and long-term storage of $CO_2$ from power plants and industrial facilities. CSLF membership includes 22 developed and developing nations. From *CSLF News Release* on November 7, 2013.

# ANNOUNCEMENTS

**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.

**13th Annual CCUS Conference: Call for Papers Released.**

The call for papers has been released for this year's conference, titled, "Accelerating Deployment to Meet New $CO_2$ Emission Reduction Mandates," to be held April 28-May 1, 2014, in Pittsburgh, Pennsylvania. The conference will highlight governmental frameworks and ongoing CCS research, development, demonstration, and deployment (RDD&D) efforts for existing and projected new coal-fired and natural gas-fired power plants and industrial processes; the potential utilization of anthropogenic carbon emissions; and progress to develop commercially viable carbon capture technologies and infrastructure for industrial processes that would make utilization possible. Abstracts are due January 20, 2014.

**IEAGHG Social Research Network Meeting.**

Registration for the 4th IEA Greenhouse Gas R&D Program (IEAGHG) Social Research Network Meeting is now open. The meeting will be held in Calgary, Alberta, Canada, from January 14-15, 2014, and will be hosted by the Institute for Sustainable Energy, Environment and Economy (ISEEE) at the University of Calgary. The agenda is under development and will be available in the near future. The meeting will focus on recent social science research and issues around CCS and related energy technologies.

**12th International Conference on Greenhouse Gas Control Technologies.**

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

**Regional Greenhouse Gas Initiative (RGGI) Q3 2013 Secondary Market Report.**

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) market, Potomac Economics, found no evidence of anti-competitive conduct in the RGGI $CO_2$ allowance secondary market. The report also showed that that RGGI $CO_2$ allowance prices fell 11 percent in the third quarter of 2013, as prices recorded in RGGI's $CO_2$ Allowance Tracking System averaged $3.03 and prices of ICE futures averaged $3.01. Secondary market prices exhibited a premium over the auction clearing price in the third quarter of 2013. The Auction 21 clearing price was $2.67. At the end of the third quarter of 2013, 82 percent of RGGI $CO_2$ allowances were held by compliance entities and their affiliates.

# CARBON STORAGE IN THE NEWS

**"Discovery of Offshore Carbon Capture Site."**

A drilling operation in the North Sea funded by a European Union (EU) grant has led to the discovery of a site suitable for the storage of up to 200 million metric tons of $CO_2$. Located off Flamborough Head, the storage site could be connected by pipeline to the industry and power stations around the Humber Estuary and inland in Yorkshire, where a number of proposed and existing coal-fired power stations exist. The plan would be to link the power stations to a central $CO_2$ hub at Camblesforth, where a pipeline would then take the $CO_2$ to existing pipelines on the coast at Barmston for transport to the storage site. The test drilling by National Grid is part of the program to establish a viable $CO_2$ storage system. Partners include Alstom, which will be responsible for the construction of the $CO_2$ hub, and Drax, which owns the major power station. From *Maritime Journal* on November 20, 2013.

**"Hitachi Carbon Capture Test Facility Construction Begins."**

Hitachi has commenced construction of its Carbon Capture Test Facility (CCTF) at SaskPower's Shand Power Station, located near Estevan, Saskatchewan. Expected to be operational by the end of 2014, the goal of the

# Carbon Storage in the News (Continued)

demonstration project is to determine the necessary properties required to scale-up to a large, commercial-size facility. In addition, demonstration tests will be conducted to evaluate the facility's overall reliability and economic feasibility. The CCTF will be capable of capturing 120 tons of $CO_2$ per day from the flue gas emitted from the 298-MW Shand Power Station by using a chemical scrubbing method with an amine-based absorbent. From *Carbon Capture Journal* on November 24, 2013.

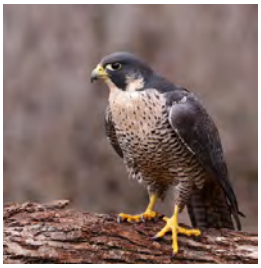
**"Chevron $CO_2$ Injection Wells to Cut GHG Emissions 40 [Percent]."**

According to the Oil & Gas Journal, Chevron has commenced drilling $CO_2$ injection wells as part of its liquefied natural gas (LNG) project in Western Australia. The $CO_2$ injection project involves the design, construction, and operation of facilities to inject and store $CO_2$ extracted from the natural gas feed into the LNG plant. Part of Chevron's Gorgon-Jansz LNG project, the injection wells are expected to reduce the project's GHG emissions by approximately 40 percent. Chevron anticipates 3.4 to 4 million metric tons of $CO_2$ to be injected into the storage reservoir each year, with an approximate total of 100 million metric tons injected during the 40-year project life. From *Environmental Leader* on December 4, 2013.

# Science

**"Climate Change May Disrupt Flight Season of Canadian Butterflies."**

According to a recent study, the flight season of a wide variety of butterflies is responsive to temperature and could be altered by potential climate change. Researchers from the University of British Columbia (UBC), the Université de Sherbrooke, and the University of Ottawa studied Canadian museum collections of more than 200 species of butterflies, matching them with station data from the past 130 years. The data showed that, on average, the flight seasons of the butterflies occur 2.4 days earlier per degree Celsius of temperature increase. From *University of British Columbia News Release* on November 19, 2013.



**"Rainfall to Blame for Decline in Arctic Peregrines."**

A study published in Oecologia shows that an increase in the frequency of heavy rain resulting from warmer summer temperatures is posing a threat for young peregrine falcons. The researchers employed a nest-box experiment to provide evidence that gradual changes in Arctic temperature and precipitation are responsible for a long-term decline in reproduction for the peregrine. In combination with historical weather data and measures of breeding success dating to 1980, the researchers conducted a nest-box experiment from 2008 to 2010 in a dense population of peregrines breeding near Rankin Inlet in Nunavut on the shores of the Hudson Bay. The falcon nests were monitored using motion-sensitive cameras, and images showed that more than one-third of the chick deaths recorded were caused by rain, whether they were raised in nest boxes or on natural ledges. Researchers said the nestlings died from hypothermia and, in some cases, from drowning in flooded nests. The study is among the first to directly link rainfall to survival of wild birds in Canada. From *Science Daily* on December 3, 2013.

# Policy

**"[Nine] States Tighten Carbon Dioxide Pollution Rules."**

Final amendments were issued to a regulation that is expected to reduce up to 90 million tons of $CO_2$ emissions over the next six years from power plants across the states participating in RGGI. Beginning in 2014, the revisions to the GHG initiative standards will lower the existing cap on power plant emissions in the RGGI states from the its current level of 165 million tons per year to 91 million tons per year, with additional cuts anticipated. Officials expect the lowered cap to generate approximately $350 million in revenue for Massachusetts by 2020, at which point the power plant emissions from the nine states will be half of what they were when the program was initiated in 2005. From *The Seattle Post-Intelligencer* on December 9, 2013.

**"A 'carbonshed' assessment of small- vs. large-scale CCS deployment in the continental [U.S.]"**

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

# Policy (Continued)

**"A novel modeling based real option approach for CCS investment evaluation under multiple uncertainties."**

The following is the Abstract of this article: "In this study, a trinomial tree modeling-based real option approach was developed to evaluate the investment in CCS retrofitting for two typical types of power plants from the perspective of power generation enterprises. A method based on the cumulative probability was proposed using trinomial decision tree calculations for the exercising of options in order to evaluate the optimal retrofit timing. Uncertainties in carbon prices, government incentives, annual running time, power plant lifetime, and technological improvements were considered. From the result, the cost saving effect of CCR pre-investment was apparent. When the current carbon price increased to 350.0 RMB/ton $CO_2$, a power plant with CCR pre-investment would execute CCS retrofitting immediately, while this value would have to increase to 371.8 RMB/ton $CO_2$ for the SC scenario. The two typical types of power plants were not optimal for immediate investment in CCS technology in the current market situation. Given a full government subsidy, the critical carbon prices for SC and SC + CCR were 239.2 and 230.0 RMB/ton $CO_2$, respectively, while the current carbon price in the voluntary emission reduction market was 3.5 RMB/ton $CO_2$. By introducing $CO_2$ utilization technology, the critical carbon prices fell to 195.5 and 186.3 RMB/ton $CO_2$, but they were still not optimal for immediate investment. CCR pre-investment was conducive to CCS retrofitting deployment; this would be more significant when considering $CO_2$ utilization technologies. The results indicated that a large gap existed between the carbon price needed for CCS retrofitting of both typical types of power plants and the current prices in the voluntary emission reduction market. Moreover, the results obtained could also provide useful information for the CCS policy-making of power enterprises in an uncertain environment." **Xian Zhang, Xingwei Wang, Jiajun Chen, Xi Xie, Ke Wang, and Yiming Wei**, *Applied Energy*. (Subscription may be required.)

# Geology

**"$CO_2$ geological storage in the Italian carbonate successions."**

The following is the Abstract of this article: "Carbonate successions have a large distribution in the Italian territory, both onshore and offshore, and they are commonly hydrocarbons exploration targets. However, an evaluation of the suitability of these sedimentary successions for CCS projects has never been performed. The present study has allowed for the first time the recognition and the geological and structural characterization of areas potentially suitable for $CO_2$ geological storage in carbonate rocks in Italy. To achieve this objective, public available well data and 2-D multichannel seismic profiles were analyzed and interpreted, allowing to define eight areas (Malossa–San Bartolomeo, Lachiarella–Binasco, Abruzzi offshore, Abruzzo–Molise, Southern Adriatic, Northern Bradanic Trough, Southern Bradanic Trough, Sicily Channel) characterized by potential reservoirs in carbonate rocks sealed by relatively thick and laterally continuous caprocks. The present results have also highlighted marked spatial heterogeneities in the recognized reservoirs, inferred to result from primary depositional processes, diagenesis and fracturing due to tectonic events. Most reservoirs were recognized within shallow marine carbonate platform succession, among which the most suitable for CCS purposes are those composed of dolostones, showing maximum porosity and permeability values of 25 [percent] and 400-450 mD, respectively. Among the identified areas, the so called 'Sicily Channel' and 'Abruzzi offshore' are probably those most promising because of their location in offshore settings, closeness to significant sources of $CO_2$ and distance from the main seismogenetic tectonic structures, as well as for the occurrence of one or multiple reservoir–caprock systems. However, the information provided by this study is at a regional scale, and therefore more detailed analyses are needed to identify and characterize potential individual storage sites for CCS projects." **Dario Civile, Massimo Zecchin, Edy Forlin, Federica Donda, Valentina Volpi, Barbara Merson, and Sergio Persoglia**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

**"Metal release from limestones at high partial-pressures of $CO_2$."**

The following is the Abstract of this article: "[Carbon dioxide release] from underground $CO_2$ [storage] poses potential risks to degradation of water quality in shallow [formations]. Increased $CO_2$ concentrations can result in decreased pH and lead to subsequent metal release from mineral dissolution or desorption from mineral surfaces. Dissolution of carbonate minerals present in [formation] sediments or rocks will buffer pH and is generally thought to reduce the potential risk of metal release in the event of a $CO_2$ [release]. As a result, much of the research on geochemical impacts of $CO_2$ [release] has focused on siliciclastic [formations] with little to no carbonate minerals present. However, carbonate minerals contain trace amounts of metals in their crystal structure that will be released into solution with dissolution and may pose a risk to drinking water quality. Here, [the authors] perform laboratory water–rock experiments to analyze the potential for metal release due to carbonate mineral dissolution in limestone [formations]. Rock samples from three limestone [formations] were dissolved in batch reactors with varying partial-pressures of $CO_2$ (from 0.01 to 1 bar) in the headspace. As $CO_2$ dissolved into the fluid and decreased the pH, the carbonate minerals dissolved and released metals into solution. The concentrations of calcium, magnesium, strontium, barium, thallium, uranium, and cobalt increased but remained below any regulatory limits...." **Assaf Wunsch, Alexis K. Navarre-Sitchler, Joel Moore, and John E. McCray**, *Chemical Geology*. (Subscription may be required.)

**"Long-term assessment of geochemical reactivity of $CO_2$ storage in highly saline [formations]: Application to Ketzin, In Salah and Snøhvit storage sites."**

The following is the Abstract of this article: "Saline [formations] are choice targets for geological storage of $CO_2$ because of their storage potential and because these formations are not suitable for other uses. Geochemical modeling is an interesting tool to assess the geochemical behavior of $CO_2$ in the saline [formation], including its dissolution in the brine and its interactions with minerals. Two key parameters which determine the confidence one can have in the results of geochemical modeling are tested in this paper: (i) the establishment of the conceptual model, including the selection of the primary and secondary minerals expected to react; and (ii) the activity

# Geology (Continued)

model and the associated thermodynamic databases to calculate the interaction energies within the saline solution. In this study, [the authors] performed an analysis of a large set of $CO_2$ storage natural analogs, which makes it possible to identify the minerals that are likely to precipitate and dissolve during $CO_2$–brine–rock interactions. Interestingly, this analysis indicates a strong dependence of Dawsonite precipitation on the initial sandstone mineralogy…" **Joachim Trémosa, Christelle Castillo, Chan Quang Vong, Christophe Kervévan, Arnault Lassin, and Pascal Audigane**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

**"PET2OGS: Algorithms to link the static model of Petrel with the dynamic model of OpenGeoSys."**

The following is the Abstract of this article: "A set of three algorithms named PET2OGS is developed to integrate the static model (Petrel) with the dynamic model (OpenGeoSys). PET2OGS consists of three sub-algorithms that convert finite difference methods (FDMs) grids to finite element methods (FEMs) grids. The algorithms and the workflow of the integration procedures are described in detail. After the proposed algorithms are tested on a variety of grids both in homogeneous and heterogeneous media, the integrated platform of the static and dynamic models is applied to model $CO_2$ storage in a saline aquifer. A successful demonstration of the proposed algorithms proved a robust integration of the platform. With some minor modifications of the algorithms in the part of input and output, the proposed algorithms can be extended to integrate different combinations of FDM-based static models and FEM-based dynamic models beyond the example combination in the paper." **C.-H. Park, Y.J. Shinn, Y.-C. Park, D.-G. Huh, and S.K. Lee**, *Computers & Geosciences*. (Subscription may be required.)

**"[Caprock] efficiency and fluid circulation of natural hydrothermal systems by means of XRD on clay minerals (Sutri, Northern Latium, Italy)."**

The following is the Abstract of this article: "[The authors] performed XRD investigations on the sedimentary [caprock] of the geothermal system developed in the area of Vico volcano (Northern Latium) to assess its effectiveness and degree of interaction with fluids. The system consists of a positive thermal anomaly, a permeable carbonate reservoir at shallow depths and a low permeability siliciclastic [caprock]. Unfractured [caprock] shows maximum paleo-temperatures <50–60°C, interpreted as the thermal signature of the original sedimentary basin. Fractured [caprock] is characterized by kaolinite, calcite, short-range ordered mixed layers illite-smectite with paleo-temperatures between 85 and 110°C indicating strong interaction with hot fluids from a carbonate reservoir." **Sveva Corrado, Luca Aldega, Antonio Stefano Celano, Arnaldo Angelo De Benedetti, and Guido Giordano**, *Geothermics*, (Subscription may be required.)

**"Risks attributable to water quality changes in shallow potable [formations] from geological carbon [storage release] into sediments of variable carbonate content."**

The following is the Abstract of this article: "The consequences of $CO_2$ [release] from geological [storage] into shallow [formations] must be fully understood before such geo-engineering technology can be implemented. A series of $CO_2$ exposure batch reactor experiments were conducted utilizing 8 sediments of varying composition obtained from across Denmark including; siliceous, carbonate and clay materials. Sediments were exposed to $CO_2$ and hydro-geochemical effects were observed in order to improve general understanding of trace metal mobility, quantify carbonate influence, assess risks attributable to fresh water resources from a potential [release] and aid [monitoring, verification, and accounting] program design. Results demonstrate control of water chemistry by sediment mineralogy and most significantly carbonate content, for which a potential semi-logarithmic relationship with pH and alkalinity was observed. In addition, control of water chemistry by calcite equilibrium was inferred for sediments containing >2 [percent] total inorganic carbon (TIC), whereby pH minima and alkalinity maxima of approximately 6 and 20 mequiv./l respectively were observed. Carbonate dominated (i.e. >2 [percent] TIC) and mixed (i.e. clay containing) sediments showed the most severe changes in water chemistry with large increases in all major and trace elements coupled to minimal reductions in pH due to high buffering capacity. Silicate dominated sediments exhibited small changes in dissolved major ion concentrations and the greatest reductions in pH, therefore displaying the greatest propensity for mobilization of high toxicity pH sensitive trace species." **Aaron G. Cahill, Rasmus Jakobsen,Tina Bay Mathiesen, and Christian Kjær Jensen**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

# Technology

**"Effect of different mix compositions on apparent carbon dioxide permeability of geopolymer: Suitability as well cement for $CO_2$ [storage] wells."**

The following is the Abstract of this article: "The wellbore integrity is a key factor for a successful oil, gas and CCS projects and the durability of the cement used in the wellbore plays a vital role in the long term safety of those projects. To date, Ordinary Portland cement (OPC) has been used in the wells used in oil and gas industry, and it is found to be unstable under down-hole pressures and temperatures conditions. Therefore, this research work intends investigating an alkali activated inorganic binder, geopolymer, as well cement and study the apparent $CO_2$ permeability of different types of geopolymer. Three different types of geopolymer was prepared by adding 0 [percent], 8 [percent] and 15 [percent] of alkali activated slag (by mass) with fly ash, and existing class G oil cement was tested for the comparison of results. Sub and supercritical $CO_2$ permeability was experimented at different injection and confining pressures expected under deep down-hole environment. The experimental results reveal that the apparent $CO_2$ permeability of geopolymers (0.0005–0.002 μD) is two to three orders lower than class G cement (0.12–2.6 μD) depending on the mix compositions of geopolymer. The addition of 15 [percent] slag reduces the permeability by approx. 10 times compared to fly ash based geopolymer and 1000 times compared to class G cement. Alkali activated geopolymer materials can be a good replacement for existing OPC based cement as they have lower $CO_2$ permeability, and can be employed in shallow and deeper depths of injection wells by changing the mix composition." **M.C.M. Nasvia, P.G. Ranjitha, and J. Sanjayanb**, *Applied Energy*. (Subscription may be required.)

# Technology (Continued)

**"Modeling and economic evaluation of the integration of carbon capture and storage technologies into coal to liquids plants."**

The following is the Abstract of this article: "This paper analyzes the technical and economic feasibility of the integration of Fischer–Tropsch process based Coal to Liquid (CTL) plants with CCS technologies. CTL plants could be multipurpose, and for this reason, starting from coal can produce different energy products like liquid fuels, such as diesel and gasoline, chemicals, electricity and hydrogen. Different plant configurations are possible especially in the case of integration with CCS technologies. Obviously, the choice of the optimal process configuration is one that better meets technical and economical requirements. In order to make a first assessment, a screening of suitable technologies has been made. The CTL facility study here proposed is based on commercial coal gasification and Fischer–Tropsch technologies. The system configuration selected and the plant performance has been evaluated using Aspen Plus software. The plant size considered is [approximately] 10,000 bbl/d of liquid fuel products, equivalent to a consumption of [approximately] 4,500 ton/d of coal fed to the gasification island. The declared objective is to evaluate the potential of the identified plant and to perform a first economic evaluation. The ultimate goal is to determine the specific cost of produced liquid fuels and to evaluate the economic performance of the system. The economic analysis was done to estimate the Internal Rate of Return (IRR), the payback period and the net present value for configurations with CCS or without $CO_2$ capture. Results show that the CCS introduction in CTL plants has a lighter impact on plant costs and performance since $CO_2$ capture is already included in the base plant." **Claudia Bassano, Paolo Deiana, and Giuseppe Girardi**, *Fuel*. (Subscription may be required.)

**"Efficient modeling of seismic signature of patchy saturation for time lapse monitoring of carbon sequestrated deep saline reservoirs."**

The following is the Abstract of this article: "Various mechanisms controlling the multiphase flow in a real geological porous medium such as those associated with $CO_2$ storage in a saline reservoir can lead to a patchy saturation distribution. Successful monitoring of $CO_2$ plumes using time-lapse seismic data under these conditions is a challenge due to the degree of uncertainty in the relationship between $CO_2$ saturation and elastic (seismic) responses. Moreover, efficient modeling of these responses is vital for practical bookkeeping of stored volumes. [The authors] investigate the potential of using seismic methods to monitor $CO_2$ in the subsurface by using reservoir simulation data generated in two types of models. The first one consists of a random distribution of absolute permeability, not unlike typical representation of geostatistical models of permeability. A second model, more geologically meaningful, represents an eolian sand deposit containing bounding surfaces. By combining reservoir flow modeling with seismic modeling, [the authors] demonstrate that the patchy nature of the saturation distribution, resulting from small-scale multiphase flow features commonly neglected in reservoir simulation exercises, can be seismically modeled with an equivalent stack of homogeneous isotropic/anisotropic layers and the elastic properties of this equivalent stack of layers can potentially predict the actual $CO_2$ saturation within the reservoir to reasonable accuracy. [The authors] conclude that using efficient waveform inversions to extract homogeneous equivalent layer properties from time lapse seismic data and relating them back to the $CO_2$ saturations is the key to the development of an effective monitoring strategy for carbon [storage] reservoirs. [The authors] also believe that such an effective monitoring will require integrating reservoir flow simulation with seismic simulation for the given reservoir so that appropriate and feasible seismic modeling assumptions (like including anisotropy) can be determined prior to monitoring." **Amit Padhia, Subhashis Mallicka, Hamid Behzadib, and Vladimir Alvaradob**, *Applied Energy*. (Subscription may be required.)

**"An experimental study of the effect of $CO_2$ rich brine on artificially fractured well-cement."**

The following is the Abstract of this article: "The performance of structural seals overlying reservoirs targeted for $CO_2$ storage relies upon the integrity of well-bore cements, which will be affected by interactions with $CO_2$. Microfractures within the well-bore cement may lead to seepage of $CO_2$ to the surface and/or fresh water [formations]. Thus, understanding $CO_2$-rich brine induced changes to the imperfections in cement matrix is vital for safe and effective implementation of this technology named CCS. This paper presents an experimental study that depicts the changes of the cement internal structure due to interaction with acidic brine through a system of artificial fractures within the cement matrix during 100 days flow through experiments. Helical computerized axial tomography and high resolution micro-computed tomography were used to visualize several sub-volumes of flow-through cores. Furthermore, a complementary high-resolution surface profilometry allowed quantification of changes of the roughness of fracture walls and their impact on the fracture aperture." **Mustafa Hakan Ozyurtkana and Mileva Radonjicb**, *Cement and Concrete Composites*. (Subscription may be required.)

# Terrestrial

**"A time series sequestration and storage model of atmospheric carbon dioxide."**

The following is the Abstract of this article: "One of the main challenges of environment planning is to identify a model that connects all factors that determine the carbon cycle, that is: ocean–terrestrial ecosystem–anthropogenic emissions–atmosphere. Basic principle of mass conservation can be applied in statistical modeling with a historic time series to obtain the atmospheric $CO_2$ concentration, making it possible to create scenarios that will help in the decision making process. A model that links all carbon cycle factors has been developed this article, focusing on the Boreal, Temperate, Tropical, and Polar thermal climatic zones to calculate atmospheric $CO_2$ level. It was developed with nonparametric models based on [$CO_2$] records from measurement stations: EIA (Energy Information Administration), CDIAC (Carbon Dioxide Information Analysis Center), FAO (Food and Agriculture Organization), and SIO (Scripp Institution Oceanography). The advantage of the model developed here is that it is able to analyze different scenarios, considering both the behavior of particular countries or groups of countries in each thermal zone and their influence on the predicted concentrations of atmospheric $CO_2$. Results show that in 2100, the atmospheric $CO_2$ concentration will be four times that of the

# Terrestrial (Continued)

pre-industrial period..." **G.L.A.F. Arcea, J.A. Carvalho Jra, and L.F.C. Nascimentob**, *Ecological Modelling*. (Subscription may be required.))

**"Soil organic carbon mineralization rates in aggregates under contrasting land uses."**

The following is the Abstract of this article: "Measuring soil organic carbon (SOC) mineralization in macro-aggregates (250–2000 μm), micro-aggregates (250–53 μm) and the < 53 μm fraction helps to understand how spatial separation of SOC inside soil aggregates regulates its dynamics. [The authors] hypothesized that (i) compared with macro-aggregates SOC mineralization rate of micro-aggregates would be slower, (ii) adsorption of SOC on < 53 μm fraction decreases the SOC mineralization rate, and (iii) land use has a significant influence on SOC decomposition rate. To test these hypotheses [the authors] collected topsoil from Dermosol (Acrisols in FAO Soil Classification) sites under three contrasting land uses namely native pasture (NP), crop–pasture rotation (CP) and woodland (WL). Macro-aggregates, micro-aggregates and the < 53 μm fraction were separated from bulk soil by wet sieving. The three aggregate size ranges were then incubated for six months and $CO_2$ evolution was measured at different time intervals. The chemically stable SOC of < 53 μm fraction of macro-aggregates, micro-aggregates and the < 53 μm fraction (separated by wet sieving) was measured by oxidation of SOC with 10 [percent] $H_2O_2$. On average, cumulative mineralization, $C_{min}$ (g $CO_2$–C $kg^{-1}$ aggregate) of the < 53 μm fraction, was 28 [percent] lower than that of macro-aggregates and micro-aggregates. However, SOC mineralized ($SOC_{min}$) was similar in all size fractions. The size of slow SOC pool (percent of SOC concentration in aggregates) was also significantly higher in the < 53 μm fraction and ranged from 58 [percent] to 96 [percent], across aggregate sizes. However, the chemically stable SOC (percent of SOC concentration in aggregates) was significantly higher in macro-aggregates and micro-aggregates than that of the < 53 μm fraction. Mean residence time (MRT) of slow SOC pool (MRTs) was higher in the < 53 μm fraction than for either macro-aggregates or micro-aggregates. Among the land uses NP had higher $SOC_{min}$ compared with CP and WL. In conclusion, the insignificant difference in $SOC_{min}$, slow SOC pool sizes and MRTs between macro-aggregates and micro-aggregates indicated that SOC mineralization rate and thus the protection of SOC was similar in both macro-aggregates and micro-aggregates." **S.M. Fazle Rabbia, Brian R. Wilsona, Peter V. Lockwooda, Heiko Daniela, and Iain M. Younga**, *Geoderma*. (Subscription may be required.)

# Trading

**"[California's] Carbon Permits Raise $297 Million."**

All of the carbon permits for sale in California's fifth auction under the state's cap-and-trade program were sold for a total of $297 million, according to the California Air Resources Board. The centerpiece of the state's climate change law (AB 32), the cap-and-trade program imposes $CO_2$ emission limits on more than 400 of California's oil refiners, food processors, and other large industries. The permits that can be used immediately sold for $11.48 per ton; future permits, which cannot be used until 2016, sold for $11.10 per ton. Combined, the five auctions have raised $1.4 billion. From *The Sacramento Bee* on November 22, 2013.

**"$CO_2$ Allowances Sold at $3.00 at 22nd RGGI Auction."**

The states participating in RGGI announced that 100 percent of the $CO_2$ allowances offered for sale in their 22nd auction of $CO_2$ allowances sold at a clearing price of $3.00. Bids for the 38,329,378 $CO_2$ allowances ranged from $1.98 to $12.00 per allowance. In total, the auction generated $114.9 million for reinvestment by RGGI in a variety of consumer-benefit initiatives, such as energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. To date, proceeds from all RGGI $CO_2$ allowance auctions have totaled $1.5 billion. According to the "Market Monitor Report for Auction 22," electricity generators and their corporate affiliates have won 81 percent of the $CO_2$ allowances sold in RGGI auctions since 2008. From *RGGI News Release* on December 6, 2013.

**"Quebec Carbon Credits Sell for Lowest Price in First Auction."**

Quebec sold one-third of the $CO_2$ allowances offered in its first cap-and-trade auction. Bidders purchased 1.03 million of the 2.97 million 2013 permits auctioned, according to results released by the province. The allowances sold for the floor price of $10.75 per metric ton of $CO_2$. Quebec plans to sell the remaining 2013 $CO_2$ allowances in future auctions, which will be held every quarter starting March 4, 2014. Emitters will have until November 1, 2015, to buy and submit $CO_2$ allowances for emissions created during 2013 and 2014. From *Bloomberg* on December 6, 2013.

**"An integrated optimization modeling approach for planning emission trading and clean-energy development under uncertainty."**

The following is the Abstract of this article: "The growing concern for global warming caused by the increased atmospheric concentration of $CO_2$ has a significant effect on environmental and energy policies and economic activities, due to the ever-increasing use of fossil fuels such as coal, oil and natural gas throughout the world. A variety of complexities and uncertainties exist in $CO_2$-emission-related processes and various impact factors, such as $CO_2$-emission inventory, mitigation measure, and cost parameter. Decision makers face problems of how many clean-energy resources (or carbon credits) are needed to be replaced (or bought) by measuring electric-power benefits and uncertain economic penalties from random excess $CO_2$ exceeding to given discharge permits. In this study, an integrated optimization modeling approach is developed for planning $CO_2$ abatement through emission trading scheme (ETS) and clean development mechanism (CDM), where uncertainties presented in terms of fuzzy sets, interval values, and random variables can be addressed. The developed model is also applied to a case study of planning $CO_2$-emission mitigation for an electric-power system (EPS) that involves three fossil-fueled power plants (i.e., gas, oil and coal-power plants). Different trading schemes and clean-energy development plans corresponding to different $CO_2$-emission management policies have been analyzed. The results demonstrate that $CO_2$-emission reduction program can be performed cost-effective through emission trading and clean-energy development projects. Violation analyses are also conducted to demonstrate that different violation levels for model's

# Trading (Continued)

objective and constraints have different effects on system benefit and satisfaction degree as well as emission trading and clean-energy development." **Y.P. Li, G.H. Huang, M.W. Li**, *Renewable Energy*. (Subscription may be required.)

**"Deciding between carbon trading and carbon capture and [storage]: An optimization-based case study for methanol synthesis from syngas."**

The following is the Abstract of this article: "The economic and technical feasibility of CCS systems are gaining importance as $CO_2$ emission reduction is becoming a more pressing issue for parties from production sectors. Public and private entities have to comply with national schemes imposing tighter limits on their emission allowances. Often these parties face two options as whether to invest in CCS or buy carbon credits for the excess emissions above their limits. CCS is an expensive system to invest in and to operate. Therefore, its feasibility depends on the carbon credit prices prevailing in the markets now and in the future. In this paper [the authors] consider the problem of installing a CCS unit in order to ensure that the amount of $CO_2$ emissions is within its allowable limits. [The authors] formulate this problem as a non-linear optimization problem where the objective is to maximize the net returns from pursuing an optimal mix of the two options described above. General Algebraic Modelling Systems (GAMS) software was used to solve the model. The results were found to be sensitive to carbon credit prices and the discount rate, which determines the choices with respect to the future and the present. The model was applied to a methanol synthesis plant as an example. However, the formulation can easily be extended to any production process if the $CO_2$ emissions level per unit of physical production is known. The results showed that for CCS to be feasible, carbon credit prices must be above 15 Euros per ton. This value, naturally, depends on the plant-specific data, and the costs [the authors] have employed for CCS. The actual prices (≈5 Euros/ton $CO_2$) at present are far from encouraging the investors into CCS technology." **Fehmi Görkem Üçtuğa, Semra Ağralıb, Yıldız Arıkana, Eray Avcıoğluc**, *Journal of Environmental Management*. (Subscription may be required.)

# Recent Publications

**"Hazard analysis for offshore carbon capture platforms and offshore pipelines."**

The following is from the Foreword of this document: "The intention of this publication is to: [1] Provide a basic guide for the health and safety hazard analysis for offshore management of $CO_2$ pipelines and platforms, where $CO_2$ will be present as a part of CCS installations; communicate existing knowledge on pipeline and offshore facility design and operation; and identify areas of uncertainty where existing knowledge cannot be applied with sufficient confidence, considering the scale and nature of expected CCS operations in the future. [2] Allow engineers and project managers involved in CCS projects to widen their knowledge base to ensure that procurement of equipment and operational guidelines are using current knowledge. [3] Supplement the 'Technical Guidance on hazard analysis for onshore carbon capture installations and onshore pipelines' which has previously been published."

**"$CO_2$ Emissions from Fuel Combustion."**

The following is a summary of this document: "In recognition of fundamental changes in the way governments approach energy-related environmental issues, the [International Energy Agency (IEA)] has prepared this publication on $CO_2$ emissions from fuel combustion. This annual publication was first published in 1997 and has become an essential tool for analysts and policy makers in many international fora such as the Conference of the Parties…The data in this book are designed to assist in understanding the evolution of the emissions of $CO_2$ from 1971 to 2011 for more than 140 countries and regions by sector and by fuel. Emissions were calculated using IEA energy databases and the default methods and emission factors from the Revised 1996 [Intergovernmental Panel on Climate Change (IPCC)] Guidelines for National Greenhouse Gas Inventories." (Subscription may be required.)

**"Social Site Characterization & Stakeholder Management."**

The following is a summary of this document: "The overall objective of this report is to propose a methodology targeted at creating the most [favorable] negotiating environment for all project stakeholders—including the project developer—to agree on project acceptability conditions. This process has been partially applied to a real $CO_2$ Capture and Storage project: the ULCOS project. This report provides four in-depth case studies detailing the critical early steps that a project most go through to first understand, then manage, the social environment in which a project is taking place. The case studies capture the context for each step in the process, as well as examples of the methodologies used, the results achieved and the lessons learned and recommendations for other projects. The case studies cover four stages in two phases, the first three explain the key stages in the social site characterization phase, the fourth the enactment of a stakeholder engagement strategy."

# Legislative Activity

**"Regulating a Pilot Project in the Absence of Legislation Specific to Carbon Storage."**

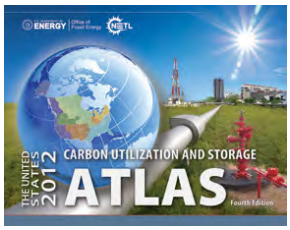
The following is the Abstract of this article: "The CO2CRC Otway Project was initiated in 2004 as a first of a kind pilot project when there was no legislation for regulating CCS activities. After deliberations on how this project was going to be regulated in 2006 and the preparation of documents for regulatory approvals in late 2006 and 2007, the project came into operation in April 2008 with approval from three key authorities. This paper sets out the journey of how the Otway Project, a pilot carbon storage project, was approved in the absence of legislation specific to regulating carbon storage. It covers the challenges of getting a pilot project approved through government including: managing timelines and resources; clarifying the regulatory framework for a pilot project; ensuring that the project approvals are fit for purpose; engaging the right authorities in the project approvals processes; allowing adequate time and resources for land access negotiations; allowing for continuation of pilot projects with the development of new legislation; resolving project responsibilities and long-term liability prior to project commencement; and taking a proactive approach to stakeholder engagement including engaging the media. The Project presented many challenges along the way but these were worked through between the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), the operator of the Project and the Victorian Government. With lateral thinking on the regulators' part and sheer perseverance of project facilitators in Victorian Government, the Project was delivered putting Victoria on the map as a State making an important contribution to advancing research into [GHG] geological storage." **Namiko Ranasinghe**, *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:

NETL RSS Feed

NETL on Facebook

NETL on Twitter

NETL on LinkedIn

NETL on YouTube

## About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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