Carbon Storage Newsletter

April 2013

## What's Inside?



# Highlights

**"President Requests $638.0 Million for Fossl Energy Programs."**

The FY 2014 budget request seeks $638 million for the Office of Fossil Energy (FE) to advance technologies related to the reliable, efficient, affordable, and environmentally sound use of fossil fuels, as well as managing the Strategic Petroleum Reserve and Northeast Home Heating Oil Reserve. The request includes $420 million for the fossil energy research and development (R&D) portfolio. For the Carbon Capture and Storage (CCS) Demonstrations program, including the Clean Coal Power Initiative and Industrial CCS Demonstrations, the FY 2014 budget does not request any funds because these projects are already fully funded by prior year appropriations and the 2009 American Recovery and Reinvestment Act; the CCS and Power Systems program FY 2014 budget request is $276.6 million, including $35.0 million for National Energy Technology Laboratory (NETL) staff to conduct in-house coal R&D; the carbon capture R&D FY 2014 budget request is $112.0 million to develop post-combustion and pre-combustion $CO_2$ capture and compression technologies for new and existing power plants ($25.0 million is allocated to fund a solicitation to demonstrate a commercial natural gas combined cycle plant to capture and store 75 percent or more of the $CO_2$ emissions); and finally the carbon storage R&D FY 2014 budget request is $61.1 million to develop and validate technologies to ensure safe and permanent geologic storage of captured $CO_2$. The budget request allows FE to fulfill its mission of providing the Nation with the best opportunity to tap the full potential of its fossil energy resources in an environmentally sound and affordable manner, while ensuring America's readiness to respond to short-term energy supply disruptions. For more information, refer to the Fossil Energy Budget-in-Brief. From *Fossil Energy Techline* on April 10, 2013.

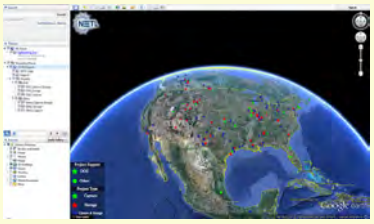
# Announcements

**DOE's Acting Assistant Secretary for Fossil Energy and NETL Director to Speak at 12th Annual CCS Conference.**

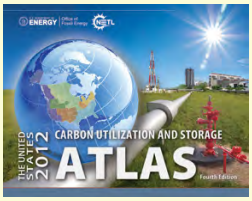
Chris Smith, the U.S. Department of Energy's (DOE) Acting Assistant Secretary for Fossil Energy, and Anthony Cugini, NETL Director, will speak at the 12th Annual CCS Conference scheduled for May 13-16, 2013, in Pittsburgh, Pennsylvania. At the conference, government decision makers and leaders from industry and academia will address the policy, program, and technology needs necessary to allow coal-fired power generation and other industrial processes to continue in a carbon-constrained environment and contribute to energy security. The 2013 Conference theme is advancing science, technology, and policy needed to meet near-term carbon reduction goals. The conference is convened in partnership with DOE's FE and NETL.

# Announcements (Continued)

**NETL's Carbon Capture, Utilization, and Storage Database – Version 4.**



NETL has released the fourth version of the CCS Database, which includes active, proposed, canceled, and terminated CCS projects worldwide. As of November 2012, the database contained 268 CCS projects worldwide. The 268 projects include 68 capture, 61 storage, and 139 for capture and storage in more than 30 countries across 6 continents. Users can download the CCS Database as a Google Earth layer or download a copy in Microsoft Excel file format.




**DOE Releases Carbon Utilization and Storage Atlas.**

DOE's 2012 United States Carbon Utilization and Storage Atlas (Atlas IV) states that the United States has at least 2,400 billion metric tons of potential $CO_2$ storage resource in saline formations, oil and gas reservoirs, and unmineable coal. Atlas IV was created by NETL with input from DOE's Regional Carbon Sequestration Partnerships (RCSPs) and American Recovery and Reinvestment Act (ARRA)-funded site characterization projects. Click here to access the NATCARB Viewer.

**2013 Midwest Carbon Sequestration Science Conference.**

The Midwest Geological Sequestration Consortium (MGSC) will hold their annual Project Advisory Meeting on October 7, 2013, at the I Hotel and Conference Center in Champaign, Illinois. This conference will include a full day of Illinois Basin Decatur Project (IBDP) research presentations covering the MGSC Development Phase research activities. The conference will also include a Sequestration Training and Education Program (STEP)-sponsored workshop and an optional tour of the IBDP site. Full meeting details will be distributed in June, with registration opening in July.

**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).

**CCEMC Grand Challenge: Innovative Carbon Uses: Converting GHGs into Valuable Carbon-Based Products.**

NineSigma, representing the Climate Change and Emissions Management Corporation (CCEMC), invites proposals for technologies that will convert $CO_2$ arising from greenhouse gases (GHGs) into valuable, carbon-based products. The goal of the challenge is to reduce GHG emissions by fostering the development of technologies that create new, carbon-based, value-added products and markets. The challenge is a multi-stage event, with opportunities for additional funding upon advancement to each successive stage. Responses are due by July 15, 2013.

# Carbon Storage in the News

**"Carbon Storage Drilling Project Begins at AA Quarry."**

Work has commenced on a 4,800-foot-deep research well in northeastern Kentucky. The stratigraphic-test well will be designed to collect geologic information about the nature of the deep subsurface formations in the region, without actual $CO_2$ injection; according to the Kentucky Geological Survey (KGS), who is monitoring the wells for changes, there are no plans to store $CO_2$ at the site. KGS will obtain rock cores, geophysical well logs, and water samples, and test properties of several deep formations penetrated in the well. The research will be used to better understand the reservoir rock properties of the region, and the data gathered will help KGS evaluate the potential for future $CO_2$ storage along the Ohio River industrial corridor. Comprehensive geologic and geophysical data will also be acquired in the well, including nearly 300 feet of core samples, native formation fluid samples, advanced downhole well logs, and standard reservoir tests. The project, part of $CO_2$ storage research mandated by the Kentucky General Assembly in 2007, will take place in northeastern Carter County, with Hanson Aggregates providing access to its AA Limestone quarry. From *Journal-Times* on March 27, 2013.

**"$CO_2$ Solutions Announces Agreement with Statoil."**

$CO_2$ Solutions has entered into an agreement to provide certain project data and reports to Statoil, an international energy company headquartered in Norway. $CO_2$ Solutions is developing $CO_2$ capture technology for use in oil sands production. The data and reports to be provided under this agreement relate to the pre-pilot phase of $CO_2$ Solutions' Alberta oil sands project. Previously announced by $CO_2$ Solutions in January 2013, the Alberta oil sands project is partially funded through a $4.7 million investment from the ecoENERGY Innovation Initiative, as well as $500,000 from Alberta's CCEMC. From *$CO_2$ Solutions News Release* on March 12, 2013.

# Carbon Storage in the News (Continued)

**"Update on Elk Petroleum Projects: Grieve $CO_2$ EOR Project."**

Officials from Elk Petroleum announced that $CO_2$ injection started at Grieve in early March and is continuing at a rate of up to 40 million standard cubic feet per day, depending on the availability of $CO_2$ from ExxonMobil's gas plant at Shute Creek, Wyoming. The injection of water to re-pressurize the Grieve Muddy reservoir is expected to begin in April or May. The water will be sourced from the Grieve #62 well that was drilled to the Tensleep and Madison formations to assess down-dip and deeper geological information. The Grieve #62 well is now being completed as a water source well. Elk had previously stated that it expected this re-pressurization/miscibility process to take up to 18 months. During this process, $CO_2$ and water will be injected to raise the average reservoir pressure above the minimum miscible pressure throughout the main oil section in the reservoir. Officials said that oil production will commence once this is completed. The construction of the processing facilities to separate produced oil, gas, $CO_2$, and water (as well as compress and dehydrate $CO_2$ for recycling back into the reservoir) will begin in 2013 to handle the first oil produced. From *Elk Petroleum Ltd News Release* on April 3, 2013.

**"Preferred Bidders Announced in UK's [~$1.5 billion] CCS Competition."**

Following a period of commercial negotiations with four projects shortlisted from an original eight in October 2012, the Peterhead Project in Aberdeenshire, Scotland, and the White Rose Project in Yorkshire, England, were announced as the two preferred bidders in the United Kingdom's (UK) [~$1.5 billion] Carbon Capture and Storage Commercialization Program Competition. The Peterhead Project will capture approximately 90 percent of the $CO_2$ from part of its existing gas-fired power station, and then transport and store it in a depleted gas field beneath the North Sea. The White Rose Project will capture 90 percent of the $CO_2$ from a new, coal-fired power station at the Drax site in North Yorkshire, and then transport and store it in a saline formation beneath the southern North Sea. The two preferred bidders and the UK government will now begin discussions to agree to terms for Front End Engineering Design (FEED) studies. Once the terms are agreed upon (expected by summer), the FEED studies, which are best practices for complex projects in the engineering and construction industry, are expected to last approximately 18 months. From *United Kingdom Department of Energy and Climate Change Press Release* on March 20, 2013.

**"GCEP Will Award $6.6 Million for Novel Energy Research."**

Stanford University's Global Climate and Energy Project (GCEP) has awarded $6.6 million in funding to seven research teams (six from Stanford; one from Carnegie Mellon University [CMU]) to advance research on clean-burning fuels and technologies for capturing $CO_2$ emissions. Three Stanford research teams will utilize the funding to develop carbon-neutral technologies that produce electricity or clean-burning hydrogen fuel. Two Stanford research teams will use the funding to test new electrochemical catalysts that convert $CO_2$ into liquid fuels and chemicals. Lastly, in addition to the previously mentioned lab-oriented projects, two research teams (one from Stanford and one from CMU) will use the funding to develop computer models that evaluate the effectiveness of various technologies for capturing $CO_2$ emissions from power plants. From *GCEP News Release* on March 17, 2013.

# Science

**"Computer Models Show How Deep Carbon Could Return to Earth's Surface."**

Researchers at the University of California, Davis, and John Hopkins University are using computer simulations of water under extreme pressure to gain a better understand how $CO_2$ might be recycled from hundreds of miles below Earth's surface. Replicating the conditions of water in Earth's mantle – pressures up to hundreds of tons per square inch and temperatures higher than 2,500°F – has been difficult according to geochemists, as they have lacked the dielectric constant, which determines how easily minerals dissolve in water. The research, published in the journal "Proceedings of the National Academy of Sciences," used computer simulations to predict how the water behaves under extreme pressures and temperatures, and showed that the dielectric constant changes significantly. Researchers then combined that with existing models, leading to a prediction that magnesium carbonate, which is insoluble at Earth's surface, would at least partially dissolve in water at that depth. From *ScienceDaily* on March 18, 2013.

**"Sea Urchins Cope with Rising $CO_2$ Levels."**

According to a paper published in "Proceedings of the National Academy of Sciences," sea urchins can adapt to high $CO_2$ levels caused by potential climate change. Increasing atmospheric $CO_2$ levels can lead to oceans becoming more acidic, posing a threat to marine organisms with calcium carbonate shells (such as sea urchins) that corrode due to the acid. When exposed to high levels of $CO_2$, however, sea urchins experience changes in genes that affect their survival in an acidic environment. For the study, scientists collected adult purple sea urchins, due to their high levels of genetic variability, from the North American Pacific coast – a region that often experiences $CO_2$-rich water. Scientists then fertilized eggs from the females and raised the produced larvae in conditions of either ambient acidity (atmospheric $CO_2$ levels of 400 parts per million [ppm]) or elevated acidity (atmospheric $CO_2$ levels of 900 ppm, matching expected concentrations in the year 2100). Gene sequencing showed that the high-$CO_2$ group experienced changes in genes related to mineral growth, lipid metabolism, and ion homeostasis, all of which affect the ability to cope with high acid levels. From *PhysOrg* on April 9, 2013.

# Policy

**"Agreement Signed to Reduce Carbon Dioxide Emissions."**

Edinburgh-based Scottish Carbon Capture and Storage (SCCS), the UK's largest group of CCS researchers, and Korea Carbon Capture and Sequestration R&D Center (KCRC), South Korea's leading CCS research institute, have signed a Memorandum of Understanding (MOU) to reduce $CO_2$ emissions. Under the strategic agreement, scientists from both countries will collaborate to develop technologies for reducing $CO_2$ emissions from power generation and industry. In addition to creating a framework for a joint research program, the agreement will also facilitate knowledge sharing between the two institutes and provide training opportunities for researchers in both the UK and South Korea. This MOU, which is the first such agreement to be signed between the UK and South Korean CCS researchers, will run for three years. From *Gas World* on March 24, 2013.

**"Competition and environmental policies in an electricity sector."**

The following is the Abstract of this article: "[The authors] study the impact of competition and environmental policy (feed-in tariff vs. the [European Union Emission Trading Scheme (EU ETS)]) on investment, $CO_2$ emissions and welfare in an electricity sector. [The authors] consider different market structures (a planner who [maximizes] social welfare vs. duopoly) and two types of consumers (those whose [behavior] depends on the weather vs. those whose [behavior] does not). The demand specification is innovative and takes incompressible consumption into account. Given the costs and demand functions, [the authors] find that competition can increase $CO_2$ emissions, as is highlighted by Mansur (2007). In duopoly, the EU ETS seems to be the only efficient policy for reducing $CO_2$ emissions but also to increase the share of production based on renewable energy sources. The retained feed-in tariff policy seems to be the most expensive policy in terms of 'social welfare.' Even if this policy seems to increase 'social welfare,' feed-in tariffs increase the CSPE, which is paid for by consumers in the form of higher electricity prices and only benefits new entrants. It is also less effective in terms of emission reduction." **Corinne Chaton and Marie-Laure Guillerminet**, *Energy Economics*. (Subscription may be required to view article.)

**"Policy options to improve the effectiveness of the EU emissions trading system: A multi-criteria analysis."**

The following is the Abstract of this article: "This paper considers several policy options which have been proposed to improve the functioning of the ETS. These options require an intervention either on the ETS cap (−30 [percent] target, set-aside, carbon central bank, long-term target) or on the carbon price (European and national price floor). [The authors analyze] the impact of each policy on the ETS carbon price and emissions. A multi-criteria evaluation method is applied to compare the policy options against a plurality of environmental, economic and procedural criteria. [The authors] find that the final ranking depends on the goals to be achieved, i.e., the relative weights attributed to the criteria. When policymakers want mainly to support the carbon price both in the short and long-run, while improving ETS flexibility and harmonization, the CCB and the EU price floor are, respectively ranked as first and second-best options. As the preference for environmental and implementation goals gradually increases, the position of the EU price floor and CCB options tend to invert. The −30 [percent] target should be adopted when reducing emissions is the priority goal, while a national price floor is the worst option, in this case. Nevertheless, self-interested States looking for a relatively quick, feasible solution, may find it optimal." **Stefano Clò, Susan Battles, and Pietro Zoppoli**, *Energy Policy*. (Subscription may be required to view article.)

# Geology

**"Liquid $CO_2$ injection for geological storage in deep saline [formations]."**

The following is the Abstract of this article: "[Carbon dioxide] will remain in supercritical (SC) state (i.e. $p > 7.382$ MPa and $T > 31.04$°C) under the pressure (p) and temperature (T) conditions appropriate for geological storage. Thus, it is usually assumed that $CO_2$ will reach the [formation] in SC conditions. However, inflowing $CO_2$ does not need to be in thermal equilibrium with the [formation]. In fact, surface operations are simpler for liquid than for SC $CO_2$, because $CO_2$ is transported in liquid state. Yet, problems might arise because of thermal stresses induced by cold $CO_2$ injection and because of phase changes in the injection tubing or in the formation. Here, [the authors] propose liquid $CO_2$ injection and analyze its evolution and the thermo-hydro-mechanical response of the formation and the caprock. [The authors] find that injecting $CO_2$ in liquid state is energetically more efficient than in SC state because liquid $CO_2$ is denser than SC $CO_2$, leading to a lower overpressure not only at the wellhead, but also in the reservoir because a smaller fluid volume is displaced. Cold $CO_2$ injection cools down the formation around the injection well. Further away, $CO_2$ equilibrates thermally with the medium in an abrupt front. The liquid $CO_2$ region close to the injection well advances far behind the SC $CO_2$ interface. While the SC $CO_2$ region is dominated by gravity override, the liquid $CO_2$ region displays a steeper front because viscous forces dominate (liquid $CO_2$ is not only denser, but also more viscous than SC $CO_2$). The temperature decrease close to the injection well induces a stress reduction due to thermal contraction of the media. This can lead to shear slip of pre-existing fractures in the [formation] for large temperature contrasts in stiff rocks, which could enhance injectivity. In contrast, the mechanical stability of the caprock is improved in stress regimes where the maximum principal stress is the vertical." **Víctor Vilarrasa, Orlando Silva, Jesús Carrera, and Sebastià Olivella**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view this article.)

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

The following is the Abstract of this article: "Stable isotope data can assist in successful monitoring of the movement and the fate of injected $CO_2$ in enhanced oil recovery and geological storage projects. This is demonstrated for the IEA-GHG Weyburn-Midale $CO_2$ Monitoring and Storage Project (Saskatchewan) where fluid and gas samples from multiple wells were collected and analyzed for geochemical and isotopic compositions for more than a decade.

# Geology (Continued)

Carbon isotope ratios of the injected $CO_2$ (−20.4‰) were sufficiently distinct from median δ13C values of background $CO_2$ ($\delta^{13}C = -12.7‰$) and $HCO_3^-$ ($\delta^{13}C = -1.8‰$) in the reservoir to reveal the movement and geochemical trapping of injected $CO_2$ in the reservoir. The presented 10-year data record reveals the movement of injected $CO_2$ from injectors to producers, dissolution of $CO_2$ in the reservoir brines, and ionic trapping of injected $CO_2$ in conjunction with dissolution of carbonate minerals. [The authors] conclude that carbon isotope ratios constitute an excellent and cost effective tool for tracing the fate of injected $CO_2$ at long-term $CO_2$ storage sites with injection rates exceeding 1 million tons per year." **Bernhard Mayer, Maurice Shevalier, Michael Nightingale, Jang-Soon Kwon, Gareth Johnson, Mark Raistrick, Ian Hutcheon, and Ernie Perkins**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

**"Effect of hydraulic fracturing on long-term storage of $CO_2$ in stimulated saline [formations]."**

The following is the Abstract of this article: "Stimulation techniques, primarily as hydraulic fracturing, can contribute to improve practical storage capacity of low-permeable saline [formations] by increasing injectivity. Since the shape of the $CO_2$ plume in the injection period can affect its subsequent migration, impact of hydraulic fracturing on post-injection plume migration should be investigated to assess $CO_2$ long-term trapping in stimulated saline [formations]. Compositional reservoir simulation results, based on a case study of Rose Run sandstone [formation] in Ohio River Valley, show the important role of methods for increasing near wellbore injectivity on $CO_2$ plume dynamics. Significant tradeoff between enhancing injectivity and long-term trapping of [$CO_2$] in hydraulically fractured saline [formations] in normal faulting regime is proven by analysis of parameters controlling $CO_2$ storage in saline [formations] such as gravity number. In addition, [the authors] discuss effects of the [formation] stress regime, fracture properties, and injection of water on immobilization of $CO_2$ by residual and solubility trapping inside the stimulated saline [formations]. Finally, [the authors] show that non-Darcy flow effects inside the fracture could reduce injectivity of the stimulated saline [formation] by causing additional pressure drop inside the fracture." **S. Raziperchikolaee and V. Alvarado**, *Applied Energy*. (Subscription may be required to view article.)

**"The northernmost Adriatic Sea: A potential location for $CO_2$ geological storage?"**

The following is the Abstract of this article: "In 2009, the National Institute of Oceanography and Experimental Geophysics (OGS, Italy) has performed a geophysical survey in the northernmost sector of the Northern Adriatic Sea, between the Tagliamento and Po river deltas, with R/V OGS Explora. About 820 km of 2D multichannel seismic and Chirp profiles, together with multibeam data along the ship tracks, have been acquired, with the aim to reconstructing the Plio-Quaternary stratigraphic and tectonic setting of the study area. Data have been also analyzed to verify whether this region is suitable for $CO_2$ geological storage. Sites eligible for the application of CCS techniques have been already identified in the Adriatic Sea, except in the northernmost sector, due to the scarcity of available data. The analyses of the new OGS seismic dataset highlighted the occurrence of peculiar seismic anomalies, represented by sub-vertical wipe-out zones, that have been interpreted as due to gas [releases] affecting the Plio-Quaternary sequence. They could be possibly related to the formation of rock outcrops interpreted as methane-derived carbonates. It is suggested that gas migrates along sub-vertical chimneys throughout the Plio-Quaternary sequence. The correlation of these sub-vertical features among the seismic profiles reveals that two main alignments could be recognized: a NW–SE trend offshore the Venice Lagoon and a NE–SW in the northernmost part of the investigated area. It leads to hypothesize that the preferential conduits for gas migration are associated to tectonic lineaments. The analysis of the tectonic setting has been then addressed at defining the role of fault/fracture zones, which can affect the integrity of a $CO_2$ storage complex in this area. Tectonic features have been identified in the Mesozoic–Paleogene succession, but their relationship with the shallow faults/fractures representing the paths for gas leakages still need further work and additional data in order to be clearly constrained." **Federica Donda, Dario Civile, Edy Forlin, Valentina Volpi, Massimo Zecchin, Emiliano Gordini, Barbara Merson, and Laura De Santis**, *Marine and Petroleum Geology*. (Subscription may be required to view article.)

# Technology

**"A review of carbon dioxide capture and storage technology using coal fly ash."**

The following is the Abstract of this article: "This work reviews the availability and the potential of the CCS technology using coal fly ash (FA). Because the technology can be effectively applied on-site to coal fired power plants and as FA contains sufficient alkali components, the technology may be another option of CCS technology to a limited extent. The technology can be divided into wet and dry processes. In the former, the available components for CCS in FA are leached into solution by the solvent where they are subsequently consumed for carbonation to store $CO_2$. Particularly, the $CO_2$ storage capacity of [calcium oxide (CaO)]-enriched FA solution mixed with brine under high pressure may be equal to or greater than the true $CO_2$ emission reduction achieved by applying FA as a cement additive. In the dry process, FA can be used as a direct support or as the raw material of the sorbent supports for $CO_2$ capture. The dry process is effectively applied for $CO_2$ capture rather than storage because the sorbents should be regenerated. Another advantage of the technology is the stabilization of the harmful components present in FA, which are mostly co-precipitated with carbonated FA during the process." **Jung-Ho Wee**, *Applied Energy*. (Subscription may be required to view article.)

**"Adsorption of Carbon Dioxide, Methane, and Their Mixtures in Porous Carbons: Effect of Surface Chemistry, Water Content, and Pore Disorder."**

The following is the Abstract of this article: "The adsorption of [$CO_2$], methane, and their mixtures in nanoporous carbons in the presence of water is studied using experiments and molecular simulations. Both the experimental and numerical samples contain polar groups that account for their partially hydrophilicity. For small amounts of adsorbed water, although the shape of the adsorption isotherms remain similar, both the

# TECHNOLOGY (CONTINUED)

molecular simulations and experiments show a slight decrease in the $CO_2$ and $CH_4$ adsorption amounts. For large amounts of adsorbed water, the experimental data suggest the formation of methane or [$CO_2$] clathrates in agreement with previous work. In contrast, the molecular simulations do not account for the formation of such clathrates. Another important difference between the simulated and experimental data concerns the number of water molecules that desorb upon increasing the pressure of [$CO_2$] and methane. Although the experimental data indicate that water remains adsorbed upon [$CO_2$] and methane adsorption, the molecular simulations suggest that 40 to 75 [percent] of the initial amount of adsorbed water desorbs with [$CO_2$] or methane pressure. Such discrepancies show that differences between the simulated and experimental samples are crucial to account for the rich phase behavior of confined water–gas systems. [The authors'] simulations for [$CO_2$]–methane coadsorption in the presence of water suggest that the pore filling is not affected by the presence of water and that adsorbed solution theory can be applied for pressures as high as 15 MPa." **Pierre Billemont, Benoit Coasne, and Guy De Weireld**, *Langmuir*. (Subscription may be required to view article.)

**"Evaluation of Cubic, SAFT, and PC-SAFT Equations of State for the Vapor-Liquid Equilibrium Modeling of $CO_2$ Mixtures with Other Gases."**

The following is from the Abstract of this article: "Accurate thermodynamic models for phase equilibria calculations of [$CO_2$] mixtures with other gases are of high importance for the safe and economic design of CCS technologies. In this work, [the authors] assess the capability of Redlich–Kwong (RK), Soave–Redlich–Kwong (SRK), Peng–Robinson (PR) cubic equations of state (EoS), as well as Statistical Associating Fluid Theory (SAFT) and Perturbed-Chain SAFT (PC-SAFT) in modeling vapor–liquid equilibria for binary mixtures of $CO_2$ with [methane ($CH_4$), nitrogen ($N_2$), oxygen ($O_2$), sulfur dioxide ($SO_2$), argon (Ar), and hydrogen sulfide ($H_2S$)], and for the ternary mixture $CO_2$–$N_2$–$O_2$. Liquid density calculations for some of these mixtures are also performed. Experimental data available are used to assess the accuracy of the models. Two different expressions are used for the calculation of parameter α in PR EoS. PC-SAFT is, on average, more accurate than cubic EoS and SAFT when no binary interaction parameter is used. However, when a binary interaction parameter fitted to the experimental data is used, model correlations from SRK, PR, SAFT, and PC-SAFT are of comparable accuracy." **Nikolaos I. Diamantonis, Georgios C. Boulougouris, Erum Mansoor, Dimitrios M. Tsangaris, and Ioannis G. Economou**, *Ind. Eng. Chem. Res*. (Subscription may be required to view article.)

**"Geochemical tracers applied to reservoir simulation of the Weyburn $CO_2$ EOR field."**

The following is the Abstract of this article: "The results of integrating processes affecting selected geochemical tracers into a model of fluid flow and phase [behavior] at the Weyburn $CO_2$ EOR Field are presented. Flow patterns, and phase [behaviors] are obtained from a reservoir model, which had been history matched to fluid (oil and water) production rates as part of the IEAGHG Weyburn-Midale $CO_2$ Monitoring and Storage Project. The reservoir model was updated by including tracer components with properties similar to those measured in produced fluids as part of the same project. The [modeling] results are compared with field values of chloride in produced water and the carbon isotope ratio of ethane, $\delta^{13}C(C_2H_6)$, in produced gases. An accurate representation of the processes responsible for generating these, relatively simple, signals is a prerequisite for any future simulations incorporating reactive transport, such as would be needed to quantify rates of reactions between the injected $CO_2$ and the host-rock. [Modeling] runs based on the previously developed history-matched single-porosity reservoir model failed to reproduce the variability seen in produced fluids for either a conservative major ion or $\delta^{13}C(C_2H_6)$. Modifications incorporating fracture flow through use of a dual-porosity reservoir description lead to calculated chemical signals that were more compatible with the field observations." **S. Talman, E. Perkins, A. Jafari, and M. Shevalier**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

**"Multiphase compositional [modeling] of $CO_2$ injection under subcritical conditions: The impact of dissolution and phase transitions between liquid and gaseous $CO_2$ on reservoir temperature."**

The following is the Abstract of this article: "[Modeling] of $CO_2$–$H_2O$ mixture flows in a porous media under subcritical conditions remains a challenging issue for carbon [storage] and possible [release] scenarios. Currently, there is no widely used and generally accepted numerical model that can simulate three-phase flows with both gaseous and liquid $CO_2$-rich phases. [The authors] propose a new compositional [modeling] approach for sub- and supercritical three-phase flows of water, liquid $CO_2$ and gaseous $CO_2$. The new approach is based on the calculation of the thermodynamic potential of the mixture as a function of pressure, total enthalpy and mixture composition and storing it values as a spline table, which is then used for the hydrodynamic simulation. A three-parametric [generalization] of the Peng–Robinson equation of state is used to fit the experimental data on $CO_2$–$H_2O$ mixture properties. Using the approach developed in this paper, [the authors] assess several sample problems of $CO_2$ injection in shallow reservoirs for the purpose of testing the model. [The authors] provide the simulation results for a simple 1D problem with a homogeneous reservoir and for a more complicated 2D problem with a highly heterogeneous reservoir using data from the 10th SPE comparative project reservoir. [The authors analyze] the temperature variations in the reservoir due to the dissolution of $CO_2$ in water and the evaporation of liquid $CO_2$. The interplay of these processes results in a complicated non-monotonic temperature distribution. At different distances from the $CO_2$ injection point, the temperature can either decrease or increase with respect to the reservoir temperature before injection. The main phenomenon responsible for the considerable temperature decline around the $CO_2$ injection point is the liquid $CO_2$ evaporation process." **Andrey A. Afanasyev**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

# TERRESTRIAL

**"The response of abyssal organisms to low pH conditions during a series of $CO_2$-release experiments simulating deep-sea carbon sequestration."**

The following is the Abstract of this article: "The effects of low-pH, high-$pCO_2$ conditions on deep-sea organisms were examined during four deep-sea $CO_2$ release experiments simulating deep-ocean [carbon storage] by the direct injection of $CO_2$ into the deep sea. [The authors] examined the survival of common deep-sea, benthic organisms (microbes; macrofauna, dominated by Polychaeta, Nematoda, Crustacea, Mollusca; megafauna, Echinodermata, Mollusca, Pisces) exposed to low-pH waters emanating as a dissolution plume from pools of liquid [$CO_2$] released on the seabed during four abyssal $CO_2$-release experiments. Microbial abundance in deep-sea sediments was unchanged in one experiment, but increased under environmental hypercapnia during another, where the microbial assemblage may have benefited indirectly from the negative impact of low-pH conditions on other taxa. Lower abyssal metazoans exhibited low survival rates near $CO_2$ pools. No urchins or holothurians survived during 30–42 days of exposure to episodic, but severe environmental hypercapnia during one experiment (E1; pH reduced by as much as ca. 1.4 units). These large pH reductions also caused 75 [percent] mortality for the deep-sea amphipod, Haploops lodo, near $CO_2$ pools. Survival under smaller pH reductions ($\Delta pH<0.4$ units) in other experiments (E2, E3, E5) was higher for all taxa, including echinoderms. Cephalopods, gastropods, and fish were more tolerant than most other taxa. The gastropod Mohnia vernalis and octopus Benthoctopus sp. survived exposure to pH reductions that episodically reached −0.3 pH units. Ninety percent of abyssal zoarcids (*Pachycara bulbiceps*) survived exposure to pH changes reaching ca. −0.3 pH units during 30–42 day-long experiments." **J.P. Barry, K.R. Buck, C. Lovera, P.G. Brewer, B.A. Seibel, J.C. Drazen, M.N. Tamburri, P.J. Whaling, L. Kuhnz, and E. Pane**, *Deep Sea Research Part II: Topical Studies in Oceanography*. (Subscription may be required to view article.)

# TRADING

**"[RGGI] Auction Notice for $CO_2$ Allowance Auction 20 on 6/5/13."**

The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2013 auctions released the Auction Notice and application materials for their 20th quarterly $CO_2$ allowance auction scheduled for June 5, 2013. The Auction Notice for $CO_2$ Allowance Auction 20 provides potential auction participants with the information needed to submit a Qualification Application and indicate their intent to bid. As indicated in the Auction Notice for $CO_2$ Allowance Auction 20, the states will offer for sale 38,782,076 $CO_2$ allowances. The states will use a reserve price of $1.98 for the June auction. From *RGGI News Release* on April 8, 2013.

**"A modified GHG intensity indicator: Toward a sustainable global economy based on a carbon border tax emissions trading."**

The following is the Abstract of this article: "It will be difficult to gain the agreement of all the actors on any proposal for climate change management, if universality and fairness are not considered. In this work, a universal measure of emissions to be applied at the international level is proposed, based on a modification of the Greenhouse Gas Intensity (GHG-INT) measure. It is hoped that the generality and low administrative cost of this measure, which [the authors] call the Modified Greenhouse Gas Intensity measure (MGHG-INT), will eliminate any need to classify nations. The core of the MGHG-INT is what [the authors] call the IHDI-adjusted Gross Domestic Product (IDHIGDP), based on the Inequality-adjusted Human Development Index (IHDI). The IDHIGDP makes it possible to propose universal measures, such as MGHG-INT. [The authors] also propose a carbon border tax applicable at national borders, based on MGHG-INT and IDHIGDP. This carbon tax is supported by a proposed global ETS. The proposed carbon tax is analyzed in a short-term scenario, where it is shown that it can result in a significant reduction in global emissions while keeping the economy growing at a positive rate. In addition to annual GHG emissions, cumulative GHG emissions over two decades are considered with almost the same results." **Reza Farrahi Moghaddam, Fereydoun Farrahi Moghaddam, and Mohamed Cheriet**, *Energy Policy*. (Subscription may be required to view article.)

**"Emissions trading and international competition: The impact of labor market rigidity on technology adoption and output."**

The following is the Abstract of this article: "Emission trading systems have been proposed in different regions to reduce polluting emissions and are in use in the European Union for [$CO_2$] emissions. One of the objectives of these systems is to encourage firms to adopt advanced abatement technologies. However, permits also create an incentive to reduce output, which may be seen as negative by policy makers. [The authors] analyze the impact of a rigid [labor] market on these two outcomes, showing the conditions necessary to avoid reductions in production while keeping the incentives to improve abatement technologies. The analysis is done for oligopolistic firms engaged in international rivalry." **Alejandro Caparrós, Jean-Christophe Péreau, and Tarik Tazdaït**, *Energy Policy*. (Subscription may be required to view article.)

**"Emission trading schemes – avenues for unified accounting practices."**

The following is the Abstract of this article: "Emission trading has emerged as a preferred mechanism to address the global challenge of climate change. Crafting an effective [GHG] accounting and disclosure program is fundamental to the design of an emission trading scheme. This paper reviews emission trading schemes that are currently administered under various regulatory and voluntary regimes. In particular, [the authors] look at how these emission trading schemes differ when addressing risk and assurance within their monitoring and disclosure programs. One important finding is that significant variations in terms of assurance engagement, spatial scope and level of compliance exist. It is concluded that harmonization of these approaches is desirable if an effective and functional global emission trading scheme is to be implemented." **Noim Uddin and Pernille Holtedahl**, *Journal of Cleaner Production*. (Subscription may be required to view article.)

# Recent Publications

**"Carbon Capture and Storage (CCS) for Coal-Fired Plants – Opportunity Assessment and Key Country Analysis to 2025."**

The following is a summary of this document: "This report provides the retrofit potential and new market potential for the global CCS market in terms of revenues and capacity. It also discusses the key drivers and restraints impacting the market. The report provides an in depth analysis of key global CCS markets – the [United States], Canada, the UK, Germany, Poland, Australia, China and Japan. It provides the retrofit potential and new market potential for CCS and the regulations in each of these countries. The report also provides an overview of key players in global CCS market."

**"Permitting process: Special report on getting a CCS project permitted."**

The following is a summary of this document: "The ROAD-project is the first of its kind in The Netherlands and applying for all of the necessary permits was one of the most challenging aspects of the project. CCS projects indeed face a complex and time consuming permitting process. The permitting process for the ROAD-project is described and evaluated in this report; with all relevant legislation and regulations described and all permits discussed. Special attention is given to the storage permitting process because this proved the most unprecedented. The EU CCS Directive, providing the legislative framework for the storage permit, and the key issues arising from this Directive was also extensively assessed. This report aims to help similar projects (CCS projects using post-combustion capture technology, transporting $CO_2$ by pipelines and storing $CO_2$ in depleted gas reservoirs) identify the important considerations for a successful permitting process."

**"The Industrial Base for Carbon Dioxide Storage: Status and Prospects."**

The following is a summary of this document: "CCS is the process of capturing $CO_2$ prior to its being emitted into the atmosphere, then either using it in a commercial application or storing it in geological formations for hundreds to thousands of years. If policies aimed at large reductions of $CO_2$ emissions from industrial sources and power plants are enacted, more CCS will be needed. RAND researchers explored the ability of the industrial base supporting the transportation and storage of $CO_2$ to expand, assessing the industrial base for transportation and injection for $CO_2$ for both geologic storage and enhanced oil recovery. They also identified and quantified the activities, equipment, and labor required for transporting $CO_2$ to an injection site, using it in oil recovery, and storing it in a geologic formation. RAND developed four scenarios for future CCS development and determined that under most of them, significant expansion of geologic storage capacity is required after 2025, and that based on current activities, it appears that the industrial base supporting the development of geologic storage has the ability to meet increased needs for $CO_2$ storage."

# Legislative Activity

**"Wash. State Climate Change Bill Signed into Law."**

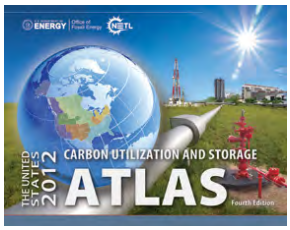
A bill that would study the best ways to reduce GHGs was signed into law by Washington Governor Jay Inslee. Under the measure, a newly created working group of legislators and other leaders would recommend actions based on an independent consultant's evaluation of Washington state's efforts to reduce $CO_2$ emissions. Strategies that are considered most effective, while providing the greatest environmental benefit in relation to the investment would be prioritized. The measure is expected to help the state reach its GHG-reduction target based on a 2008 state law calling for a return to 1990 emissions levels by 2020. From *The Seattle Times* on April 2, 2013.

## About DOE's Carbon Storage Program

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

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

## Carbon Storage Program Resources




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

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

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

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

NETL RSS Feed

NETL on Facebook

NETL on Twitter

NETL on LinkedIn

NETL on YouTube

## About NETL's Carbon Storage Newsletter

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

National Energy Technology Laboratory

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## Disclaimer