NETL's Carbon Storage Newsletter: Annual Index

(*Formerly the Carbon Sequestration Newsletter*)

September 2014 – August 2015

This is a compilation of the National Energy Technology Laboratory's monthly Carbon Storage Newsletter published over the last year. The newsletter is produced by the NETL to provide information on activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news. This compilation covers newsletters issued from September 2014 to August 2015. Outdated Information (e.g., conference dates, paper submittals) has been removed.

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For more information on DOE's Carbon Storage Program, click here.

HIGHLIGHTS

September 2014

"NETL Collaborations Advance Carbon Management Strategies." The Carbon Capture Simulation Initiative (CCSI) and the National Risk Assessment Partnership (NRAP) are using predictive computational modeling to help the U.S. Department of Energy (DOE) meet its goal of having carbon capture and storage (CCS) technologies ready for demonstration in the 2020 to 2025 timeframe. This goal requires the development of new approaches to reduce the 20 to 30 years typically required for commercial deployment of new technology concepts. Led by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), the two collaborative efforts use computational modeling, which involves developing mathematical equations and computer code to simulate the real-life behavior of engineered and natural systems. The use of these models allows for more efficient, timely, and cost-effective technology development and deployment. For more information, visit DOE's national lab webpage. From *NETL News Release* on August 27, 2014.

"Projects Selected for Safe and Permanent Geologic Storage of Carbon Dioxide." DOE selected 13 projects to develop technologies and methodologies for geologic carbon dioxide (CO_2) storage. The projects will develop technologies, methodologies, and characterization tools to improve the ability to predict geologic storage capacity, understand geomechanical processes, and enhance geologic storage safety. The total value of the projects is approximately $17.6 million over three years, with $13.8 million of DOE funding and $3.8 million of non-Federal cost sharing. The projects will be managed by NETL and were awarded in two areas of interest: "Geomechanical Research" and "Fractured Reservoir and Seal Behavior." Project details are available via the link. CCS research is focused on developing technologies to capture industrially generated CO_2 and safely and permanently store it in underground geologic formations in order to reduce the amount of CO_2 being released into the atmosphere. From *NETL News Release* on August 6, 2014.

"Construction Begins on DOE-Sponsored Carbon Capture Project at Kentucky Power Plant." Construction started on a DOE-funded carbon capture pilot project at Kentucky Utilities' E.W. Brown Generating Station near Harrodsburg, Kentucky, USA. The unit will test, at slipstream scale, a novel system conceived by the University of Kentucky Center for Applied Energy Research (UKCAER) to capture CO_2 from the flue gas of an operating coal-fired power plant. The 2-megawatt thermal system will be the first megawatt-scale carbon capture pilot unit in the Commonwealth of Kentucky and will be managed by NETL for DOE's Carbon Capture Program. For more information about the UKCAER project, visit NETL's project webpage. From *NETL News Release* on July 21, 2014.

"World's Largest Post-Combustion Carbon Capture Project Begins in Construction." In partnership with NRG Energy Inc. and JX Nippon, DOE announced the beginning of construction on the Petra Nova Project, the first commercial-scale, post-combustion carbon capture retrofit project in the United States. Once completed, the project is expected to capture approximately 1.4 million metric tons of CO_2 per year from an existing coal-fired power plant in Texas, USA; the captured CO_2 will then be used for enhanced oil recovery (EOR) at a depleted oil field approximately 80 miles away. The 240-megawatt project is expected to capture 90 percent of the CO_2 using a process previously deployed in a DOE-sponsored, three-year, pilot-scale test in Alabama in which more than 150,000 metric tons of CO_2 were successfully captured annually from a coal-fired power plant. From *NETL News Release* on July 16, 2014.

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computational modeling to help the U.S. Department of Energy (DOE) meet its goal of having carbon capture and storage (CCS) technologies ready for demonstration in the 2020 to 2025 timeframe. Meeting this goal requires the development of new approaches to reduce the number of years typically required for commercial deployment of new technology concepts. Led by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), the two collaborative efforts use computational modeling, which involves developing mathematical equations and computer code to simulate the real-life behavior of engineered and natural systems. The use of these models allows for more efficient, timely, and cost-effective technology development and deployment. For more information, visit DOE's national lab webpage. From *NETL News Release* on August 27, 2014.

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January 2015

"Energy Department Project Captures and Stores One Million Metric Tons of Carbon." The U.S. Department of Energy (DOE) announced that the Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of carbon

dioxide (CO_2) in a saline formation. The CO_2 is captured from the Archer Daniels Midland Company ethanol-production facility in Decatur, Illinois. It is then compressed and transported by pipeline for injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. Since initiation in November 2011, the injection has sustained pressure increases below regulatory limits. The injected CO_2 is expected to remain hundreds of feet below a 300-foot thick shale formation that acts as a seal. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying carbon capture and storage (CCS) technologies across the United States. MGSC, led by the Illinois State Geological Survey (ISGS), is evaluating CCS options for the 60,000-square-mile Illinois Basin, which underlies most of Illinois, southwestern Indiana, and western Kentucky. From *NETL News Release* on January 8, 2015.

"Oil Operators Gain Powerful, User-Friendly Enhanced Oil Recovery Planning Software." Under a cooperative agreement with DOE's National Energy Technology Laboratory (NETL), NITEC LLC developed new software, called COZView/COZSim, that enables quicker, more affordable technical studies of CO_2-enhanced oil recovery (CO_2-EOR) for small- to mid-sized U.S. oilfield operators. The software has the following features: (1) addresses the physical and chemical factors that impact the flow and recovery of reservoir fluids, such as solubility of CO_2 in water and oil or swelling of oil in the presence of CO_2; (2) allows an integrated feasibility study to be completed within one month, compared to the six or more months required for other approaches; and (3) integrates a friendly, interactive user interface (COZView) for pre- and post-processing of simulation results with a reservoir simulator (COZSim). The COZView/COZSim software can reduce the cost to small- and mid-sized operators for commissioning technically sophisticated studies to assess the feasibility of CO_2-EOR. The NETL-funded version of the software can be downloaded from the NITEC LLC website at no cost. The website also includes a comprehensive user manual and a number of tutorials. As of December 2014, more than 80 copies of the software had been downloaded. By injecting CO_2 into oilfields that are nearing the end of prime oil production, operators can extract a portion of the remaining oil and increase geologic CO_2 storage. From *NETL News Release* on December 15, 2014.

February 2015

"Department of Energy, Shell Canada to Collaborate on CO_2 Storage." The U.S. Department of Energy (DOE) and Shell Canada announced intentions to collaborate in field tests to validate advanced monitoring, verification, accounting (MVA), and assessment technologies for underground carbon dioxide (CO_2) storage at Shell's Quest carbon capture and storage (CCS) project in Alberta, Canada. The technologies under consideration would be tested alongside the state-of-the-art, comprehensive monitoring program Shell has already put in place for the Quest project. The test results are expected to provide additional information that would benefit future large-scale CCS projects around the world. Details of the collaboration are expected to be finalized in early 2015. From *NETL News Release* on February 4, 2015.

"Energy Department Project Captures and Stores One Million Metric Tons of Carbon." DOE announced that the Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of CO_2 and injected it into a saline formation. The CO_2 is captured from Archer Daniels Midland Company's ethanol-production facility in Decatur, Illinois, USA, and is compressed before transport by pipeline and subsequent injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. Since initiation in November 2011, the injection has sustained pressure increases below regulatory limits. The injected CO_2 is projected to remain hundreds of feet below a 300-foot thick shale formation that acts as a seal to inhibit CO_2 migration. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying CCS technologies across the United States. MGSC, led by the Illinois State Geological Survey, is evaluating CCS options for the 60,000-square-mile Illinois Basin, which underlies most of Illinois, southwestern Indiana, and western Kentucky. From *NETL News Release* on January 8, 2015.

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March 2015

"Energy Department Project Captures and Stores One Million Metric Tons of Carbon." The U.S. Department of Energy (DOE) announced that the Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of carbon dioxide (CO_2) and injected it into a saline formation. The CO_2 is captured from the Archer Daniels Midland Company ethanol-production facility in Decatur, Illinois, and is compressed before transport by pipeline and subsequent injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. Since initiation in November 2011, the injection has sustained pressure increases below regulatory limits. The injected CO_2 is projected to remain hundreds of feet below a 300-foot thick shale formation that acts as a seal to inhibit CO_2 migration. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying carbon capture and storage (CCS) technologies across the United States. MGSC, led by the Illinois State Geological Survey, is evaluating CCS options for the 60,000-square-mile Illinois Basin, which underlies most of Illinois, southwestern Indiana, and western Kentucky. From *NETL News Release* on January 8, 2015.

"Department of Energy, Shell Canada to Collaborate on CO_2 Storage." DOE and Shell Canada announced intentions to collaborate in field tests to validate advanced monitoring, verification, accounting (MVA), and assessment technologies for underground CO_2 storage at Shell's Quest CCS project in Alberta, Canada. The technologies under consideration would be tested alongside the state-of-the-art, comprehensive monitoring program Shell has already put in place for the Quest project, which is funded by the Government of Canada and the Canadian Province of Alberta. The test results are expected to provide additional information that would benefit future large-scale CCS projects around the world. DOE is leveraging a Federal investment of approximately $3 million in existing and ongoing projects in their research and development (R&D) program by proposing roughly $500,000 for this collaborative effort. From *NETL News Release* on February 4, 2015.

"NETL-Sponsored Study Confirms Vast Energy Resource in Residual Oil Zones." National Energy Technology Laboratory (NETL)-sponsored researchers confirmed that CO_2-enhanced oil recovery (EOR) can extract oil from largely untapped areas called "residual oil zones" (ROZs). The researchers, led by the University of Texas-Permian Basin (UTPB), analyzed a geologic core taken during a pilot test from a well at the Goldsmith Landreth San Andres Unit in the Permian Basin, Ector County, Texas, USA. The results provide insight into the potential oil displacement efficiency of the CO_2-EOR process. The UTPB researchers are developing a state-of-the-art geologic model to compare past reservoir performance and current CO_2-EOR flood performance. The goal is to optimize the performance of an ROZ CO_2 flood and share the knowledge with other operators. ROZs are areas of relatively immobile oil that are found below the oil-water contact (the first observance of water) within an oil-bearing reservoir. In these zones, natural water flooding has swept away much of the original oil, leaving residual oil behind; recovery of this oil is

not economic using primary or secondary oil recovery, requiring EOR techniques to produce the oil. From *NETL News Release* on February 24, 2015.

April 2015

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May 2015

"Energy Department Projects Reach Milestone to Safely and Permanently Store 10 Million Metric Tons of Carbon Dioxide." A group of carbon capture and storage (CCS) projects supported by the U.S. Department of Energy (DOE) and managed by the National Energy Technology Laboratory (NETL) has reached a milestone to safely and permanently store carbon dioxide (CO_2). The milestone builds upon the goals of providing clean energy, supporting American jobs, and reducing CO_2 emissions. The projects contributing to the milestone are part of DOE's Regional Carbon Sequestration Partnership (RCSP) Initiative and the Industrial Carbon Capture and Storage (ICCS) Major Demonstrations Program. The RCSP Initiative, which consists of seven partnerships focused on determining the best regional approaches to geologic storage of CO_2, includes more than 400 organizations spanning 43 states and four Canadian provinces. The ICCS Program, which represents a $1.4 billion investment under the American Recovery and Reinvestment Act (ARRA), helps industry to demonstrate CCS technologies that can be readily replicated and commercially deployed in industrial facilities. From *Fossil Energy Techline* on April 22, 2015.

"NETL-Sponsored Study Confirms Vast Energy Resource in Residual Oil Zones." NETL-sponsored researchers confirmed that CO_2-enhanced oil recovery (EOR) can extract oil from largely untapped areas called "residual oil zones" (ROZs). The researchers, led by the University of Texas-Permian Basin (UTPB), analyzed a geologic core taken during a pilot test from a well at the Goldsmith Landreth San Andres Unit in the Permian Basin, Ector County, Texas, USA. The results provide insight into the potential oil displacement efficiency of the CO_2-EOR process. The UTPB researchers are developing a

state-of-the-art geologic model to compare past reservoir performance and current CO_2-EOR flood performance. The goal is to optimize the performance of an ROZ CO_2 flood and share the knowledge with other operators. ROZs are areas of relatively immobile oil that are found below the oil-water contact (the first observance of water) within an oil-bearing reservoir. In these zones, natural water flooding has swept away much of the original oil, leaving residual oil behind; recovery of this oil is not economic using primary or secondary oil recovery, requiring EOR techniques to produce the oil. From *NETL News Release* on February 24, 2015.

June 2015

"Texas CO_2 Capture Demonstration Project Hits Two Million Metric Ton Milestone." In a U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL)-sponsored project, Air Products and Chemicals Inc. has captured and stored 2 million metric tons of carbon dioxide (CO_2). The project, located at a hydrogen production facility in Port Arthur, Texas, demonstrates vacuum swing adsorption (VSA) to capture more than 90 percent of the CO_2 from the product streams of two commercial-scale steam methane reformers. In addition, the project looks to help verify CO_2-enhanced oil recovery (EOR) as an effective method for permanent geologic storage of CO_2 by capturing the CO_2 and using it for EOR at the West Hastings oilfield in southeast Texas, USA. It is estimated that the West Hastings oilfield has the potential to produce in the range of 60 to 90 million additional barrels of oil through EOR operations. The VSA project is supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program. To date, DOE-sponsored projects have captured and securely stored more than 10 million metric tons of CO_2. From *NETL News Release* on May 15, 2015.

"DOE-Funded Project Testing Laser CO_2 Monitoring at Carbon Storage Site." A multipoint, laser-based CO_2 monitoring system was installed at an operational carbon storage site in Decatur, Illinois, USA, as part of an NETL-managed project. Developed by Exelis, the system, called GreenLITE, runs autonomously and provides real-time updates of two-dimensional concentrations of CO_2 at the storage site, which is located adjacent to an ethanol production facility where 1 million metric tons of CO_2 have been captured over the past three years and transported for storage. The Midwest Geological Sequestration Consortium (MGSC), one of seven regional partnerships in NETL's Regional Carbon Sequestration Partnership (RCSP) Program, began large-scale CO_2 injection at the Decatur site in 2011. From *Energy.gov* on June 3, 2015.

July 2015

"DOE-Funded Project Testing Laser CO_2 Monitoring at Carbon Storage Site." A multipoint, laser-based carbon dioxide (CO_2) monitoring system was installed at an operational carbon storage site in Decatur, Illinois, USA, as part of a National Energy Technology Laboratory (NETL)-managed project. Developed by Exelis, the system, called GreenLITE, runs autonomously and provides real-time updates of two-dimensional atmospheric CO_2 concentrations over a 0.25 square-kilometer area at the storage site, which is located adjacent to an ethanol production facility where 1 million metric tons of CO_2 have been captured over the past three years and transported for storage. The Midwest Geological Sequestration Consortium (MGSC), one of seven regional partnerships in NETL's Regional Carbon Sequestration Partnership (RCSP) Initiative, began CO_2 injection at the Decatur site in 2011. From *Energy.gov* on June 3, 2015.

August 2015

"DOE Selects Projects to Assess Offshore Carbon Storage." The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has selected four projects to receive funding through NETL's Carbon Storage Program. The research projects will assess the geologic storage potential of offshore subsurface depleted oil and natural gas reservoirs and saline formations on the East

Coast of the United States and the Gulf of Mexico by using existing geologic and geophysical data that will approximate the amount of carbon dioxide (CO_2) that can be safely stored. More information on the four projects, titled, "Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment Project," "Assessment of CO_2 Storage Resources in Depleted Oil and Gas Fields in the Ship Shoal Area, Gulf of Mexico," "Southeast Offshore Storage Resource Assessment," and "Offshore CO_2 Storage Resource Assessment of the Northern Gulf of Mexico (Upper Texas-Western Louisiana Costal Areas)," is available via the above link. From *Energy.gov* on July 15, 2015.

Carbon Storage in the News

September 2014

"Wells In Northern Montana Mark Big Step For MSU Carbon Sequestration Research." Researchers from the Montana State University (MSU)-led BSCSP drilled a pair of wells in Toole County, Montana, USA, to test the underlying sedimentary formation's ability to store CO_2. The Kevin Dome Large-Scale Carbon Storage Project is an eight-year project being run through BSCSP. Kevin Dome has contained naturally occurring CO_2 for 50 million years in the Middle Duperow formation, a deep, porous rock layer, which occurs below the Potlatch Anhydrite formation, a dense layer of rock that acts as a cap. The plan is to extract 1 million metric tons of CO_2 stored in Kevin Dome, bring it approximately 4,000 feet through the first of the two completed wells, transport it six miles via pipeline, and inject it into the down-dip flank of the Middle Duperow formation where CO_2 does not occur. The second well, which was drilled to a depth of nearly 5,000 feet, will be used to monitor the CO_2 and subsurface geochemistry near a yet-to-be-drilled injection well. BSCSP, of DOE's Regional Carbon Sequestration Partnerships (RCSPs), is seeking to develop novel approaches for carbon storage in Montana, Wyoming, Idaho, South Dakota, eastern Washington, and Oregon. From *Fairfield Sun Time* on August 18, 2014.

"Peterhead Power Station Opens Doors for CCS Tours." United Kingdom (UK)-based utility SSE conducted tours at Peterhead power station in order to inform the public about the station and future proposals for a CCS project at Peterhead. Four tour groups, consisting of nearly 100 local people, participated. SSE is supporting Shell, who is developing a full-scale gas CCS project where up to 10 million metric tons of CO_2 emissions could be captured and transported via pipeline offshore to Shell's existing Goldeneye reservoir for long-term storage. The Peterhead project is one of two CCS demonstration projects selected by the UK Government to enter a Front-End Engineering Design (FEED) study as part of their CCS commercialization competition. From *PennEnergy* on August 13, 2014.

"Shell Fits Final Module on Alberta Oil Sands' First Carbon Capture Project." Shell Canada fit the final module for the Quest CCS project in Alberta, Canada. The project is now 70 percent complete and expected to start up in 2015. Once complete, the project will capture more than 1 million metric tons of CO_2 per year from Shell's Scotford upgrader north of Edmonton, Alberta, and inject the CO_2 for storage. The upgrader converts mined bitumen from Shell's Athabasca oil sands project into refinery-ready crude; 35 percent of direct emissions will be captured from the Scotford facility. The project received funding from the Alberta and Canadian Federal government to help mitigate GHG emissions from oil sands. From *Reuters* on August 27, 2014.

October 2014

"Carbon Sequestration Research Continues at Sandia Labs under Energy Department funds." The Center for Frontiers of Subsurface Energy Security (CFSES), a joint carbon storage program undertaken by Sandia and the University of Texas at Austin, was awarded a contract to research long-term geologic CO_2 storage. The work focuses on three technical challenges: (1) sustaining large storage rates over decades; (2) increasing efficient use of pore space in geologic formations/reservoirs where CO_2 would be stored; and (3) making sure CO_2 does not release from the reservoir. The effort will

concentrate on deep saline reservoirs, including issues ranging from the atomic- to full reservoir-scale in a multidisciplinary approach that unites chemistry, microbiology, geomechanics, geophysics, and computer sciences. CFSES also studies how CO_2 dissolves into resident brines over time. In addition, the researchers are working at New Mexico's Bravo Dome (a natural underground CO_2 reservoir) to calculate long-term dissolution rates to understand the importance of solubility to CO_2 trapping. From *Sandia Labs News Release* on September 15, 2014.

"UW Wins DOE Grant for Further Study of Rock Springs Uplift." University of Wyoming (UW) researchers received a grant to study the possible subsurface effects of injecting CO_2 into the Rock Springs Uplift in southwest Wyoming, USA. According to a UW official, the goal of this research is to improve the understanding of the geomechanical effect(s) of CO_2 injection on two types of reservoir rocks (sandstone and limestone/dolomite). An improved understanding would help to increase the accuracy of subsurface models that predict storage reservoir integrity. The researchers will use a variety of tools, such as lab experiments on core samples taken from the Rock Springs Uplift, computer modeling, and seismic data, to predict the underground impacts of CO_2 injection at the site. Previous work on the Rock Springs Uplift included field work and subsurface characterization of lithology, structure, mechanical stratigraphy, fracture systems, and in situ stress. Research has shown that two deep saline formations in Rock Springs Uplift could store 26 billion tons of CO_2 over 50 years. From *University of Wyoming News Release* on September 26, 2014.

"SaskPower Launches World's First Commercial CCS Process." SaskPower opened a commercial-scale CCS process on a coal-fired power plant at Boundary Dam Power Station in Estevan, Saskatchewan, Canada. SaskPower's CCS process will capture up to 1 million metric tons of CO_2 per year when fully optimized. The captured CO_2 will be used for enhanced oil recovery (EOR) and will be continuously monitored for safe and permanent underground storage. From *SaskPower News Release* on October 2, 2014.

"$5 Million Assures Otway Project will be Ongoing." The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) received an additional $5 million in funding from Victoria's Minister for Energy and Resources for researching CO_2 storage at the Otway site. The Otway Project has injected and stored more than 60,000 metric tons of CO_2 in a depleted gas reservoir near Warrnambool in Victoria, Australia, over the last 10 years. A book, titled, "Geologically Storing Carbon: Learning from the Otway Project Experience," was recently released, highlighting the work of more than 100 researchers from Federal and state governments, Australian and international industry, and the global research community. From *CO2CRC News Release* on September 15, 2014.

November 2014

"Wood Group Kenny Awarded Subsea Pipeline FEED Contract for Carbon Capture and Storage Project." Wood Group Kenny was awarded a contract for the front end engineering design (FEED) of the subsea and pipeline element of the Peterhead CCS project in Aberdeenshire, Scotland, United Kingdom (UK). A total of 80 engineers will support the project from Wood Group Kenny offices in Aberdeen and London. The contract includes developing a landfall solution at the Peterhead Power Station; design of a CO_2 pipeline from Peterhead Power Station to a subsea tie-in with the existing Goldeneye pipeline; and a new subsea intervention valve, including controls system and tie-in spools. The project is being developed by Shell, with support from Scottish and Southern Energy. The Peterhead CCS project is part of the UK's CCS roadmap. From *OilVoice* on October 16, 2014.

"UAE's Carbon Capture Project to Remove 800,000 [Metric Tons] of Carbon Dioxide per Year." A CCS project in the iron and steel sector in Abu Dhabi will capture 800,000 [metric tons] of CO_2 emissions annually. The project will start capturing CO_2 and injecting it into oil fields for EOR in 2016. The joint venture between Abu Dhabi National Oil Company (Adnoc) and Masdar will capture CO_2 at Emirates Steel, one of United Arab Emirates' (UAE) largest steelmaking facilities. The Global CCS Institute

(GCCSI) published the information in its "Global Status of CCS: 2014" report, which found that there are currently 22 carbon capture projects in construction or operation worldwide. The report highlights nine CCS projects currently under construction, with eight expected to be operational by 2016. The report also states that there are 14 CCS projects in the advanced planning stage, including nine in the power sector. A summary of the "Global Status of CCS: 2014" report is available in the "Recent Publications" section of this newsletter. From *gulfnews.com* on November 7, 2014.

"Skyonic Opens World's First Commercial-Scale Carbon Capture and Utilization Facility." Skyonic Corporation opened Capitol SkyMine, a commercial-scale carbon capture and utilization facility at Capitol Aggregates' existing cement plant in San Antonio, Texas, USA. According to officials, the Capitol SkyMine will have a total carbon impact of 300,000 tons annually by capturing CO_2 and transforming it into functional products, like baking soda, bleach, and hydrochloric acid, through the use of Skyonic's SkyMine® technology. The process allows industrial facilities or fossil-fuel-fired power plants to capture up to 90 percent of CO_2 emissions from flue gas and transform them into solid products that can be sold. From *Skyonic Press Release* on October 20, 2014.

December 2014

"Magellan Announces Potential Acquisition of CO_2 Source and Poplar Pilot Update." Magellan Petroleum Corporation announced the acquisition of an option to purchase either the Farnham Dome (a CO_2 reservoir located in Carbon County, Utah, USA) or the un-contracted CO_2 at a fixed price. Magellan officials also updated the status of the CO_2 injection into the Charles formation at the Poplar CO_2-enhanced oil recovery (EOR) project in Montana, USA. After beginning injection in August 2014, the downhole pressure remained stable and above the minimum pressure necessary for CO_2-oil miscibility. It is expected that the expanding CO_2 front should aid in the recovery of additional oil. Magellan opened the four pilot producer wells in October 2014 and projects to see increased oil production. Magellan Petroleum Corporation is an oil and gas exploration and production company focused on the development of a CO_2-EOR program at Poplar Dome and the exploration of hydrocarbon resources in the Weald Basin, onshore United Kingdom. From *CNNMoney* on December 3, 2014.

"Shell Cansolv Starts Testing at TCM." Shell Cansolv has initiated testing of its CO_2 capture process using exhaust gas from the combined heat and power (CHP) plant at the CO_2 Technology Centre Mongstad's (TCM) amine test facility in Norway. This phase will study the technology and validate the readiness for deployment at industrial-scale projects. TCM is an advanced facility for testing and improving CO_2 capture. The center is comprised of two CO_2 capture plants, each with a capacity to capture approximately 80,000 tons of CO_2 from the nearby refinery or 20,000 tons from a gas-fired power plant. In addition, the center has available space and infrastructure for future testing. From *Technology Centre Mongstad Press Release* on November 25, 2014.

January 2015

"Drax CCS Well Drilling Design Contract Signed." National Grid awarded the front-end engineering and design (FEED) contract to Applied Drilling Technology International (ADTI) for well drilling in the North Sea to store CO_2 from the White Rose CCS project in the United Kingdom. ADTI will design a shallow water well envelope with features making the wells suitable for storing CO_2. ADTI will also research suitable materials and programming and estimate these costs. The White Rose CCS project is a collaborative effort of Capture Power, a consortium of Drax Power, Alstom, and BOC. The project will capture carbon from a 426-megawatt power plant planned for land next to Drax Power Station in North Yorkshire. The White Rose CCS Project was awarded European Union funding in July 2014 and also won initial FEED funding from the UK government in December 2013. From *The Chemical Engineer* on December 22, 2014.

February 2015

"CCS Collaboration Launched in Teesside, UK." A group of industrial plants in Teesside, United Kingdom (UK), known as the Teesside Collective, has launched a collaboration to set up a CCS-equipped industrial zone. The plan for the project is for industries in the region to capture emissions and transport them via a shared pipeline network for storage under the North Sea. BOC, Lotte Chemical, SSI, and GrowHow's Teesside facilities will form the four "anchor projects" of the Collective's work; the steering group also includes National Grid, Tees Valley Unlimited, and the North East Process Industry Cluster. Tees Valley Unlimited was awarded $1.5 million in funding by the UK's Department of Energy and Climate Change (DECC) to develop a business case for the CCS cluster and recommend a funding mechanism. From *The Chemical Engineer* on January 22, 2015.

"Magellan Provides Update on Poplar CO_2-EOR Pilot." According to Magellan Petroleum Corporation officials, downhole injection pressure has remained stable at above miscibility pressure at the CO_2-EOR pilot at Poplar Dome in Montana, USA. Magellan has been injecting CO_2 into the B-2 zone of the Charles formation through an injector well for approximately 150 days. In addition to the stable injection pressure, the data also shows that injected CO_2 has entered into the target formation matrix. During January 2015, two of the four pilot producer wells exhibited oil production with small volumes of natural gas and injected CO_2 also being produced. From *Magellan Petroleum Press Release* on January 29, 2015.

"[Australian Government] Injects $25m into CCS Research." Australia's Minister for Industry and Science announced that the Australian Government would provide $25 million over five years to the CO2CRC Otway Project and related activities. According to a CO2CRC official, a major focus of the research will be on high resolution monitoring and verification of stored CO_2 and continued research into CO_2 capture technologies. The funding will be provided to CO2CRC under the CCS Flagships Program. The funding will be matched by contributions from CO2CRC members, in particular $10 million from the Australian coal industry's Coal21 Fund and a $5 million Victorian Government grant announced in September 2014. From *CO2CRC News Release* on February 2, 2015.

March 2015

"Federal Government Invests $4.9 Million in Field Research Station." The Canadian government announced that it will invest $4.9 million to fund a Carbon Management Canada (CMC) Research Institute project that aims to accelerate the development and deployment of technologies that monitor and verify CO_2 storage. Expected to be completed in early 2016, the field research station (FRS) will inject small volumes of CO_2 at an intermediate depth, simulating release into a subcritical geologic horizon. It is anticipated that the project will help to lower the cost of CCS projects and aid in the acceleration of commercialization opportunities in international markets. Since 2008, the Government of Canada has committed more than $580 million to CCS research, development, and demonstration (RD&D) initiatives. From *Carbon Management Canada News Release* on February 12, 2015.

"CO_2 Solutions Provides Update on Carbon Capture Project." CO_2 Solutions, Inc. announced that the procurement of components for the pilot plant at Husky Energy's Pikes Peak South site in Saskatchewan is now complete and construction has begun. The pilot unit will be constructed and tested onsite in the Montreal, Canada, area before being transported to Saskatchewan, Canada. The project is currently on schedule and within budget; installation and commissioning at the site is anticipated for the second quarter of 2015, with operation planned through September 2015, representing more than 2,500 hours of field operation. The project is funded, in part, by the Government of Canada's ecoENERGY Innovation Initiative (ecoEII) Program. From *CO_2 Solutions News Release* on February 3, 2015.

"UK Member Joins International CCS Test Centre Network." The U.K. CCS Research Center's (UKCCSRC) Pilot-Scale Advanced Capture Technology (PACT) facilities have joined the Technology

Centre Mongstad (TCM)-founded CCS Test Center Network. The purpose of PACT, which is jointly funded by the U.K. Department of Energy and Climate Change (DECC) and the Engineering and Physical Sciences Research Council (EPSRC), is to support industrial and academic R&D by providing testing facilities to accelerate the development and commercialization of technologies for carbon capture and clean power generation. Initiated by TCM in 2012, the International Test Center Network provides a platform for carbon capture test facilities around the world to progress technologies and share knowledge. From *Carbon Capture Journal* on February 24, 2015.

"CCS Performance Data Exceeding Expectations at World-First Boundary Dam Power Station Unit #3." SaskPower released the preliminary performance numbers for the operation of Unit #3 at the Boundary Dam Power Station (BD3). The coal-fired, CCS technology-equipped commercial power plant now has more than 130 days of commercial operating experience. SaskPower has invested approximately $1.2 billion in the BD3 CCS project, with the Canadian government contributing an additional $240 million. Since its official launch on October 2, 2014, the plant has captured approximately 135,000 metric tons of CO_2; the plant has the capacity to capture up to 1 million metric tons of CO_2 in 2015, and is currently on pace to meet that goal. From *SaskPower CCS News Release* on February 11, 2015.

April 2015

"Grangemouth CCS Project Gets State Funding." The Caledonia Clean Energy Project, a new 570-megawatt CCS coal gasification power station in Grangemouth, Scotland, will receive $6.2 million in funding for industrial research and feasibility studies from the United Kingdom (UK) and Scottish governments. The power station will emit 90 percent less CO_2 than a coal-fired plant without CCS and 75 percent less than a comparable gas-fired plant without CCS. The project's research and feasibility studies are expected to be completed over the next 18 months. According to the UK Department of Energy and Climate Change (DECC), the findings will increase understanding of how to develop and deploy CCS at commercial scale. The facility marks the third major project to receive UK government backing, joining the White Rose 426-MW oxyfuel coal-fired CCS plant at Drax and the Peterhead project in Aberdeenshire. From *The Chemical Engineer* on March 30, 2015.

"Interactive Maps of Potential CO_2 Storage Sites." The Norwegian Petroleum Directorate (NPD) produced two interactive versions of an atlas of potential CO_2 storage sites in the sea along the Norwegian coast. One version, integrated with NPD's ordinary "fact map," provides access to more information than the printed version, enabling users to compare storage data with available information from active and terminated wells on the Norwegian shelf. The second interactive version, called the "CO_2 StoryMap," presents the storage possibilities for a broader audience. Since 2011, NPD has published three atlases for the southern part of the North Sea, as well as the Norwegian Sea and Barents Sea, plus a compilation atlas for all sea areas. The atlases can be found on the NPD website. From *Norwegian Petroleum Directorate News Release* on February 12, 2015.

"Magellan Concludes Poplar CO_2-EOR Pilot a Technical Success and Provides Update on Utah CO_2 Option." Magellan Petroleum Corporation has concluded that the CO_2-EOR pilot project at Poplar has demonstrated a technically viable CO_2-EOR technique as a tertiary recovery method in the Charles formation at Poplar Dome. The injection of CO_2 into the single injector well at Poplar was initiated in August 2014, with the four producer wells opening for production in October; since then, oil production has increased in three of the four, with a current run-rate in the range of 50 to 75 barrels of oil per day. Magellan expects the rate to increase through the summer and that the fourth producer well will soon produce oil. From *Magellan Petroleum Press Release* on April 7, 2015.

May 2015

"UNDEERC Enters Into $2.5 Million Cooperative Agreement with the U.S. Department of Energy." DOE signed a cooperative agreement with the University of North Dakota's Energy & Environmental Research Center (UNDEERC) to research and develop technologies to reduce CO_2 emissions from fossil fuels. Through the Office of Fossil Energy (FE)-funded and NETL-administered collaboration, EERC will conduct research to assist industry in deploying and commercializing low-carbon technologies. Work will be performed in five task areas: (1) carbon storage R&D, (2) carbon capture R&D, (3) oil and gas R&D, (4) strategic studies, and (5) support of FE. From *U.S. Senator John Hoeven News Release* on May 11, 2015.

"Enhanced Oil Recovery Institute to be Centered in Casper." The Wyoming Enhanced Oil Recovery Commission announced that the University of Wyoming's Enhanced Oil Recovery Institute (EORI) will center its efforts in Casper, Wyoming, USA, in order to build closer relationships with companies working to improve oil recovery within the state. EORI is part of the University of Wyoming's School of Energy Resources (SER), which focuses on solving potential energy challenges. From *University of Wyoming News Release* on April 21, 2015.

"CO_2 Injection Begins at Aquistore." The Aquistore Project, an independent research and monitoring project focusing on demonstrating the safe underground storage of CO_2, has begun underground injection into the Deadwood and Winnipeg formations, which underlie the majority of western Canada. During the initial six-month injection period, the project is expected to inject up to 1,000 tons of CO_2 per day. Managed by the Petroleum Technology Research Center (PTRC), Aquistore is the second CO_2 project in Saskatchewan, Canada; the first was the International Energy Agency Greenhouse Gas Research and Development Program's (IEAGHG) Weyburn-Midale CO_2 Monitoring and Storage Project. The $45 million Aquistore Project was founded in 2009 and includes research institutions and industry partners who will gather, analyze, and interpret data through 2017. From *Aquistore News Release* on April 27, 2015.

"CO_2 Solutions Announces Results of Pilot Testing." CO_2 Solutions announced the results of the pilot testing of their carbon capture process, confirming the technology can provide reduced operating costs and reduced parasitic load relative to conventional CO_2 capture processes. The testing, which was conducted at UNDEERC, was completed in January 2015. EERC led the performance evaluation of the process, and the test data were used as input for models to simulate CO_2 capture from typical coal- and gas-fired power generation plants. In order to provide a baseline, the models were based on methodology established by DOE. From *CO_2 Solutions News Release* on April 23, 2015.

"Seismos Inc. Secures $4M Funding for Flow Monitoring." Seismos Inc. has secured $4 million in funding to track underground CO_2 flow during EOR operations. The Seismos method of fluid monitoring consists of field-installed low-impact emitters and seismic sensors connected to a cloud-based data processing platform that generates maps of CO_2 movement over time. From *Seismos, Inc. News Release* on April 8, 2015.

June 2015

"ETI Appoints Consortium to Deliver New CCS Storage Appraisal Project." The Energy Technologies Institute (ETI) has appointed a consortium to identify the next phase of sites under the North Sea to store CO_2. The 12-month project, through funding from the United Kingdom (UK) Department for Energy and Climate Change (DECC), will aim to identify new sites in UK waters to store CO_2 emissions from power stations and other industry plants. The project will make use of the publically available UK CO_2 storage atlas, "CO_2 Stored," developed by The Crown Estate and the British

Geological Survey. The results will be shared with the CCS community at the end of the project. From *Gas World* on May 21, 2015.

"CO_2 Solutions Announces Successful Start-Up of Demonstration Plant." CO_2 Solutions announced the commencement of its CO_2 capture demonstration project at Salaberry-de-Valleyfield, Québec, Canada. The 10-ton-per-day (tpd) demonstration unit's first commissioning was successful, with all controls and equipment responding according to design parameters. The facility has been adapted to produce its own heat and flue gas from a natural gas-fired boiler; the CO_2 is captured from the flue gas and stripped from the solvent using the hot water generated by the boiler. The operation is scheduled to run for at least 1,000 hours, and all test results will be independently reviewed by third parties. From *CO_2 Solutions Press Release* on May 19, 2015.

"Wood Group to Provide Technical Support on Carbon Capture and Storage." Wood Group entered into an agreement with DECC to provide technical support on CCS. Wood Group subsidiary Wood Group Kenny (WGK) will act as one of six DECC-appointed technical specialists to provide independent advice on the technical understanding and review of CCS developments. Under the technical specialist framework, Wood Group will also provide support as required. The scope of the contract will include carbon capture, transport and storage, power and generations solutions and novel technology, and process and materials for CCS projects. From *Daily Record* on May 27, 2015.

"Large-Scale Experimental Data Released to Enhance CO_2 Pipeline Design Safety." The DNV GL-led CO2PIPETRANS joint industry project (JIP) has released experimental data focused on assisting the design process of CO_2 pipelines. The data can be used to validate computer models used in CO_2 pipeline design. The data, which marks the third batch of experimental material publically shared by the JIP, was gathered by using computer models for gas dispersion to assess CO_2 release. For more information, visit the CO2PIPELINES JIP website. From *DNV GL Press Release* on June 4, 2015.

July 2015

"Green Light for Peterhead Carbon Capture and Storage Proposal." Aberdeenshire council approved plans for the Peterhead CCS project being developed by Shell and Scottish and Southern Energy (SSE). According to Shell, up to 10 million metric tons of CO_2 emissions could be captured over a 10- to 15-year lifecycle from the Peterhead Power Station and transported offshore, via pipeline, for long-term storage in depleted gas wells under the North Sea. The Peterhead CCS Project was chosen as one of two CCS demonstration projects to progress to the next stage of the UK Government's CCS Commercialization Competition funding. From *Daily Record* on June 18, 2015.

"Royal Dutch Shell Seeks Funding for Carbon Capture Project." According to a report from the Financial Times, Royal Dutch Shell is seeking funds to develop a CCS project at an abandoned offshore natural gas power station. Shell officials believe that if successful, the project, located at Goldeneye, an abandoned offshore natural gas production platform connected to the Scottish coast via a 100-kilometer pipeline, can serve as an example for other similar projects. From *Bidness Etc* on June 29, 2015.

"Canada's SaskPower Opens Carbon Capture Test Facility." SaskPower opened its Carbon Capture Test Facility (CCTF) in Estevan, Saskatchewan, Canada. Built in partnership with Mitsubishi Hitachi Power Systems, Ltd., CCTF is a laboratory that uses flue gas from the neighboring Shand Power Station and allows researchers to test equipment, chemical innovation, and engineering designs. Individual parts can be isolated, modified, and operated to test carbon capture technologies at CCTF, allowing companies to track how they react under commercial operating conditions. The launch was attended by member countries of the Carbon Sequestration Leadership Forum (CSLF). From *POWER Magazine* on June 18, 2015.

August 2015

"NRG Expects 2016 Startup for Texas Carbon Capture Coal Plan." Operations are expected to commence at a new carbon capture project at NRG Energy's WA Parish Texas coal facility in late 2016. The WA Parish CO_2 Capture Project, which will receive funding from DOE's Clean Coal Power Initiative (CCPI) Program, is being developed jointly by NRG and JX Nippon Oil & Gas Exploration. The facility is expected to capture approximately 90 percent of the CO_2 from a 240-mewawatt (MW) slipstream of flue gas, and will use or store approximately 1.6 million tons of CO_2 a year. From *Utility Dive* on August 7, 2015.

"S. Arabia's SABIC Starts Up CO_2 [Utilization] Plant in End-'15." According to SABIC officials, operations at the CO_2 utilization plant located at SABIC's chemical complex in Jubail, Saudi Arabia, are set to begin by the end of 2015. Plant construction has been completed and commissioning work is currently underway at the unit, which will capture CO_2 emitted from SABIC's 500,000 metric tons/year ethylene glycol (EG) plant in Jubail, which is set to begin operations around the same timeframe. From *ICIS News* on July 15, 2015.

"Launching the [Kingdom of Saudi Arabia's] First Carbon Capture Project." A CO_2-enhanced oil recovery (EOR) pilot project led by Saudi Aramco's EXPEC-Advanced Research Center is expected to capture approximately 40 million standard cubic feet per day of CO_2 at the Hawiyah gas recovery plant. The CO_2 will then be transported, via pipeline, approximately 50 miles to the 'Uthmaniyah field where it will be used for EOR. The project, which will inject 800,000 tons of CO_2 a year, includes a monitoring and surveillance program that consists of seismic monitoring, electromagnetic surveys, borehole and surface gravity, and tracer tests. From *Saudi Aramco* on July 29, 2015.

Science

September 2014

"N.J. Announces Climate Change Mapping Website." Scientists from Rutgers University announced the launch of NJADAPT.org, a climate change mapping website that allows New Jersey community planners to see how infrastructure, population, and the environment are affected by storm surges, coastal flooding, and sea level rise. In addition to interactive maps, the website also contains a self-assessment tool for towns and cities, and plans are in place to add inland flooding and local temperature maps. Interactive map users are able to see evacuation routes, emergency medical services, schools, and other energy facilities on maps, then add layers to see how areas could be affected by potential climate change. From *NewsWorks* on August 14, 2014.

"Climate Change Reflected in Altered Missouri River Flow, Report Says." According to a recently released U.S. Geological Survey (USGS) report, the Missouri River's stream flow has experienced change over the last 50 years, leading to water shortages in Montana and Wyoming and flooding in the Dakotas. Beginning in the Rocky Mountains of western Montana, the Missouri River flows east and south for more than 2,300 miles before entering the Mississippi River north of St. Louis, Missouri. According to the USGS report, potential climate shifts may be causing changes in the Missouri River Basin. Scientists note that higher stream flow in the Dakotas occurred even as water use increased; in addition, it was also noted that lower stream flow in some areas could also be related in part to groundwater pumping. From *Los Angeles Times* on August 17, 2014.

October 2014

"Global Warming Changes the Way Sharks Swim." According to new research published in the journal "Biology Letters," sharks exposed to ocean water acidified by CO_2 swim for longer time frames

than sharks in typical ocean water. The altered behavior happens during nighttime and has the potential to affect the species. By studying two sets of small-spotted catsharks (half in tanks with typical ocean water and half in tanks with acidified ocean water), researchers found that those in the more acidified water had more sodium and bicarbonate ions in their blood, and swam more continuously during nighttime hours than those in typical ocean water, signifying a potential inability to acclimate. From *Discovery* on September 17, 2014.

November 2014

"Climate Change Alters Cast of Winter Birds." According to biologists from the University of Wisconsin-Madison, wintering bird species that were once rare in the American Northeast have become more common. The research, which was published in the journal "Global Change Biology," used more than two decades of data on 38 species of birds. The data showed that birds typically found in more southerly regions are pushing north and changing the communities of birds that spend their winters in northern latitudes. The researchers found that the shifts in the mix of overwintering bird species is occurring in areas of milder winters with less snow, more variable and strong precipitation events, and a shorter snow season. From *Science Daily* on October 17, 2014.

"Fish Moving Poleward at Rate of 26 Kilometers (~16.2 Miles) per Decade." According to a University of British Columbia study examining the impacts of potential climate change on fish stocks, large numbers of fish could disappear from the tropics by 2050 as changing temperatures may drive them into Arctic and Antarctic waters. The study, which appears in the "ICES Journal of Marine Science," used modeling to predict how 802 commercially important species of fish and invertebrates react to warming water temperatures, other changing ocean properties, and new habitats opening up at the poles. Using an Intergovernmental Panel on Climate Change (IPCC) scenario that has the Earth's oceans warming by 3°C by 2100, the researchers found that fish could potentially move away from their current habitats at a rate of approximately 16 miles per decade. Under another IPCC scenario that has the Earth's oceans warming by 1°C by 2100, the fish would move approximately 9 miles per decade. From *Science Daily* on October 10, 2014.

"Penguins Use Their Personalities to Prepare for Climate Change." A researcher from the Institute of Veterinary, Animal, and Biomedical Sciences at Massey University in New Zealand suggests a bird's individual personality may be a factor in improving its chances of coping with environmental stressors. Studying the differences in the level of a stress hormone called corticosterone that native little penguins secreted when exposed to stressful stimulus, the study found a variation in corticosterone responses, which was determined by personality. The study found that "[b]irds with low corticosterone responses and proactive personalities are likely to be more successful (have greater fitness) in constant or predictable conditions, while birds with reactive personalities and high corticosterone responses will be more successful in changing or unpredictable conditions." From *Science Daily* on October 8, 2014.

December 2014

"Research Confirms How Global Warming Links to Carbon Emissions." A team of researchers from the universities of Southampton, Bristol, and Liverpool have developed a theoretical equation to establish a link between CO_2 emissions and potential climate change. The results of the theoretical equation, which reveals the relationship between CO_2 and the ocean system, show that every million-million metric tons of CO_2 emitted could potentially warm the climate by one degree Celsius. In addition, the results, which are published in the journal "Nature Geoscience," also claim that surface warming is related to the total amount of CO_2 emissions from fossil fuels, with little change over time as ocean carbon and changes in heat uptake nearly cancel out. From *Science Daily* on December 1, 2014.

"Warmest Oceans Ever Recorded." According to analysis of ocean temperature datasets, this past summer resulted in the highest global mean sea surface temperatures ever recorded, surpassing the

temperatures recorded during the then record-breaking 1998 El Niño year. A researcher from the International Research Center at the University of Hawaii at Manoa found that, due to quick-rising sea-surface temperatures in the extratropical North Pacific, westerly winds pushed warm water that was usually stored in the western Pacific along the equator to the eastern Pacific. As the warm water spread across the North American Pacific coast, heat that had been contained in the Western tropical Pacific for nearly a decade was released into the atmosphere. From *Science Daily* on November 14, 2015.

"Carbon Dioxide Warming Effects Felt Just a Decade After Being Emitted." According to Carnegie Institute of Science researchers, a single CO_2 emission could have its maximum warming effects on the Earth in as little as 10 years, while the potential warming can persist for more than a century. The researchers' study also claims that it is possible the benefits from emission reductions, such as the avoidance of weather events like droughts, heatwaves, and flooding, will be felt by current and future generations. The study says that potential climate impacts, such as a rise in sea level and melting ice sheets, will have a longer time outlook. Published in IOP Publishing's journal "Environmental Research Letters," the study combined information taken from a group of climate models used in the latest Intergovernmental Panel on Climate Change (IPCC) assessment, finding that that median time between a single CO_2 emission and maximum warming was 10.1 years. From *Science Daily* on December 3, 2014.

January 2015

"Wall Brown Butterfly 'May Be a Victim of Climate Change.'" According to Belgian scientists, the population decline of the wall brown butterfly from areas of southern England may be the result of potentially warming weather patterns. Recent research claims that warming conditions are causing the butterfly to hatch too late in the year to survive, falling into a "development trap." Instead of spending the entire winter as a caterpillar, the wall butterfly offspring are turning into butterflies later in the year (September and October), when it is too cold and there is insufficient food supply. Since 1976, the wall butterfly has decreased by 86 percent in England. The butterfly has nearly disappeared from most of central and southern England, but continues to survive at coastal sites. The research, published in the online journal "Oikos," showed that the micro-climate at the inland sites was an average of 1.2°C warmer than the coastal sites, leading scientists to suggest that the butterfly can maintain its traditional life cycle at coastal sites due to cooler conditions by the sea. From *The Guardian* on December 24, 2014.

"Mussel Shells Being Affected Due to Climate Change." According to researchers from the University of Glasgow in Scotland, the mussel population may be affected by potential climate change, as their shells have become more brittle as water becomes more acidic. The more acidic oceanic water may also be affecting the yields of mussels available for the fishing industry. According to the study, mussels growing in the wild may be more prone to attacks by predators and may also be affected by other ocean forces. The researchers came to their conclusions by studying common blue mussels in laboratory tanks and changing the water temperature and pH levels to simulate different types of ocean waters. Some experts' projections claim the world's oceans may become more acidic in the coming decades. From *Austrian Tribune* on December 29, 2014.

"Top Weather Conditions that Amplify Lake Erie Algal Blooms Revealed." A study conducted by researchers at Ohio State University claims that wind is the most important weather-related factor contributing to harmful algal blooms (HABs) in Lake Erie, suggesting that potential climate change may have to be incorporated into HAB prevention efforts by environmental agencies. The researchers analyzed nine environmental factors in Lake Erie from 2002 to 2012, using data from the sensor onboard the European Space Agency's Envisat satellite Medium Resolution Imaging Spectrometer (MERIS) to examine how the lake water changed colors (an indication of the concentration of the toxic blue-green algae present in HABs). The study found that spanning the 10-year period, wind speed contributed to HABs more consistently than other environmental factors, such as sunshine, precipitation, water temperature, and water quality. From *Science Daily* on December 17, 2014.

February 2015

"NASA, NOAA Find 2014 Warmest Year in Modern Record." According to two separate analyses conducted by NASA and the National Oceanic and Atmospheric Administration (NOAA), the Earth's 10 warmest years in the instrumental record (with the exception of 1998) have occurred since 2000, with 2014 ranking as the warmest since 1880. Scientists at NASA's Goddard Institute of Space Studies (GISS) analyzed surface temperature measurement data, which was also independently analyzed by NOAA scientists. The data showed that since 1880, the Earth's average surface temperature has warmed by approximately 1.4°F, with the majority of the increase occurring over the past three decades. The GISS analysis incorporated surface temperature measurements from 6,300 weather stations, observations of sea surface temperatures, and temperature measurements from Antarctic research stations, while the raw data analyzed by NOAA scientists was analyzed using an algorithm that took into account varied spacing of temperature stations and urban heating effects that could affect the calculations. From *ScienceDaily* on January 16, 2015.

March 2015

"Global Warming Could Increase Risk of U.S. Megadroughts." According to a new study, droughts in the southwest and Central Plains of the United States during the second half of the 21st century could be longer and drier than those in the same regions during the last millennium. A team of scientists from the NASA Goddard Institute for Space Studies and the Lamont-Doherty Earth Observatory claim that the severity of the drought would surpass any of the decades-long "megadroughts" that occurred much earlier during the past millennium. The research article, titled "Unprecedented 21st century drought risk in the American Southwest and Central Plains" and published in the journal "Science Advances," is based on projections from several climate models and is the first to state that such drying could exceed conditions of the past. Researchers used data from the North American Drought Atlas to represent past climates, applying three different measures for droughts – two soil measurements at various depths and a measurement that gauges the net input of water into the land. They also compared two different potential climate change scenarios: a business-as-usual scenario (projecting a continued rise in greenhouse gas [GHG] emissions) and a scenario in which emissions are moderated. From *Sci-News.com* on February 13, 2015.

April 2015

"97 [Percent] of Northwest Alaska Bird, Mammal Species Could Experience Habitat Change from Warming Climate." The habitat of 195 of the 201 bird and mammal species (approximately 97 percent) in northwest Alaska's arctic and subarctic region could be affected by potential climate change, according to a study conducted by the U.S. Forest Service. The study projected the effects of climate-related changes on the habitats of 162 species of birds and 39 species of mammals within 403,000 acres of the arctic by relating recent and projected vegetation changes. The findings, which were published in the journal "Climatic Change," revealed that up to 52 percent of the 201 species would experience habitat expansion under the models, 45 percent would experience habitat contraction, and 3 percent would experience no change at all. In addition, researchers found that mammal species would experience habitat declines at a higher proportion than bird species. From *ScienceDaily* on April 3, 2015.

"Western Canada to Lose 70 Percent of Glaciers by 2100." According to University of British Columbia Researchers, British Columbia and Alberta could lose 70 percent of their glacier ice by the end of the 21st century due to potential climate change. Using observational data, computer models, and climate simulations, researchers found that warming temperatures are affecting the glaciers in western Canada, in particular freshwater ecosystems, as summer glacier melt provides cool water to many of the region's headwaters. The more than 17,000 glaciers in British Columbia and Alberta contribute to energy

production through hydroelectric power, contribute to the water supply, and are vital to mining and agriculture operations. From *ScienceDaily* on April 6, 2015.

May 2015

"Arctic Beetles May be Ideal Marker of Climate Change." According to a team of researchers from McGill University, the feeding habits of Arctic beetles may offer a basis for the future monitoring of potential climate change. While studying more than 460 different species of Arctic beetles, the researchers found that the ecological roles the beetles fulfilled differed depending on the latitude and temperature in which they lived. Published in the journal "PLOS ONE," the study was a large-scale survey of the Artic beetle population and spanned locations ranging from the edge of the boreal forest in Northern Ontario to Ellesmere Island in the far north of Canada. From *ScienceDaily* on April 22, 2015.

"Farmland Management Changes Can Boost Carbon Sequestration Rates." Well-maintained pastures may boost carbon storage rates more quickly than previously thought, according to researchers from the University of Georgia and the University of Florida. Soil contains a large terrestrial reservoir of carbon, and tilling the fields every year to plant crops releases the soil carbon into the atmosphere. The study, titled, "Emerging land use practices rapidly increase soil organic matter," found that converting the cropland to pastureland replenishes the soil's carbon at a rate high enough that the carbon in the soil could eventually help offset a potential rise in atmospheric CO_2. The study was funded by the National Institute of Food and Agriculture and published in the journal "Nature Communications." From *UGA Today* on May 11, 2015.

June 2015

"Study Backs Seaweed's Carbon Capture Potential." According to a new study, coastal plants and seaweeds have the potential to contribute to long-term carbon storage. The study, conducted by scientists from the University of Technology, Sydney (UTS), and Deakin University, investigated how a diverse range of macroalgae can contribute to "blue carbon" stocks – the carbon in leaves, sediments, and roots that is naturally captured by plants in coastal habitats. Published in the journal "Ecology," the results show that some seaweed species have the capacity to make a contribution to coastal capture, with their cell wall structure and composition central to their long-term carbon storage potential. In addition, the study claims that some species of seaweed contain compounds that degraded at high temperatures, leading to the potential for a contribution to long-term carbon storage. From *R&D Magazine* on May 19, 2015.

"Diverse Soil Communities Can Help Offset Impacts of [Potential Climate Change]." In a study led by researchers at Yale, it was discovered that small soil animals can limit the effect of potential climate change by helping to control changes in carbon cycling. The study was conducted by an international collaboration at the Harvard Forest long-term climate change research site. As part of the experiment, researchers examined how atmospheric warming and nitrogen deposition could alter natural ecosystems under future climate change scenarios. The soil communities were manipulated to four levels of complexity to see which types of community would be most affected by global change factors, such as warming temperatures. The results of the study, titled, "Biotic interactions mediate soil microbial feedbacks to climate change," were published in the "Proceedings of the National Academy of Sciences." From *Yale School of Forestry & Environmental Studies* on May 19, 2015.

July 2015

"New Calculations to Improve Carbon Dioxide Monitoring From Space." A team of climate scientists have developed calculations that predict how light of different colors is absorbed by CO_2, helping to interpret GHG emissions data collected from satellites and ground stations. Published in the journal

"Physical Review Letters," the scientists' study shows how the fundamental laws of quantum mechanics can be used to make the predictions, how it will aid in learning how CO_2 evolves in the atmosphere, and where CO_2 is being produced. By improving the understanding of how much light the CO_2 absorbs, the group of researchers, led by the University College London (UCL), believe that uncertainties in some models can be reduced. According the study, the new calculations give an accuracy of 0.3 percent, while previous methods were accurate to approximately 5 percent. From *R&D Magazine* on June 15, 2015.

"Enhancing North Sea Oil Recovery Can Store More CO_2 Much Faster," and "Carbon Capture Could Provide Lifeline to North Sea Oil, Report Says." According to a new report, synergy between CO_2-EOR and CCS could aid in the development of both technologies in the UK continental shelf. The study, conducted by researchers from Edinburgh University, states that storing CO_2 from industry in spaces left by oil extraction under the North Sea has the potential to stimulate exploration in the area, while also helping the UK meet its international targets for reducing CO_2 emissions. According to the report, projects that combined carbon capture with subsea exploration could extend the life of North Sea oil fields. From *Gas World* on June 16, 12015, and *Chronicle Live* on June 16, 2015.

"Increased Carbon Dioxide Levels in Air Restrict Plants' Ability to Absorb Nutrients." According to a study conducted by researchers from the University of Gothenburg, potentially rising levels of atmospheric CO_2 may affect plants' ability to absorb nutrients. Published in the journal "Global Change Biology," the study examined various ecosystems using large-scale field experiments conducted in eight countries on four continents. The data revealed that the concentration of nitrogen (a nutrient that impacts crop growth in terrestrial ecosystems) in plants' tissue was lower in air with high levels of CO_2. As a result, a potential rise in CO_2 levels in the atmosphere could result in crops having a reduced nitrogen content. An abstract of the study, titled, "Constraints to nitrogen acquisition of terrestrial plants under elevated CO_2," is available in the "Terrestrial" section of this newsletter. From *Scicasts* on June 15, 2015.

August 2015

"Rapid Decline in Bumblebee Species Caused by Climate Change, Study Finds." According to a study published in "Science," declines in bumblebee species across North America and Europe could be linked to potential climate change. Researchers from the University of Ottawa's Department of Biology used long-term observations of 67 bumblebee species collected over a 110-year period across Europe and North America. Previous smaller-scale studies have shown that other species expand to the North Pole as the climate warms; however, the new study found that bumblebee species are not relocating, and are instead disappearing over large areas. From *University of Ottawa, Canada* on July 9, 2015.

"'Carbon Sink' Detected Underneath World's Deserts." New research conducted by the University Corporation for Atmospheric Research has found that large formations underneath deserts may have the potential to store more CO_2 than plants on land. By examining the flow of water through a Chinese desert, scientists found that carbon from the atmosphere is being absorbed by crops, released into the soil, and transported underground. The study found that underground formations store the dissolved carbon deep below the desert, where it cannot enter the atmosphere. According to their data, the researchers estimate that due to agriculture, approximately 14 times more carbon than previously thought could be entering the underground desert formations every year. The Abstract of the study, titled "Hidden carbon sink beneath the desert," is available in the "Terrestrial" section of this newsletter. From *ScienceDaily* on July 28, 2015.

Policy

September 2014

"U.S. EPA Approves Carbon Sequestration Permits in Central Illinois." The U.S. Environmental Protection Agency (EPA) approved four identical permits allowing the FutureGen Industrial Alliance Inc. to inject CO_2 in Illinois. FutureGen plans to capture the CO_2 from a retrofitted coal-fired power plant in Meredosia, Illinois, and then transport it for injection in the proposed wells in Morgan County, Illinois. The FutureGen project goal is to capture and inject 1.1 million metric tons of CO_2 per year for 20 years. EPA completed a technical review of the permits, which were the Nation's first Class VI underground injection permits for carbon storage, before approving them. Before injecting CO_2, the integrity of the wells must be demonstrated. More information is available on the EPA website. From *U.S. EPA News Release* on September 2, 2014.

"Chile Set to Pass Latin America's Second Carbon Tax." Chile is set to become the second country in Latin America to approve a carbon tax. If approved, Chile will start charging $5 per metric ton of CO_2 in 2017; Mexico, the other Latin American country to price carbon emissions, charges approximately $2 less per metric ton of CO_2. Chile has voluntarily committed to reduce its GHG emissions 20 percent by 2020 based on 2007 levels. The carbon tax is part of a broader package of tax reforms that included other environmental taxes intended to reduce GHG emissions and address potential climate change. From *Responding to Climate Change* on September 3, 2014.

"Public perception of carbon capture and storage (CCS): A review." The following is the Abstract of this article: "CCS is regarded as an important bridging technology to a sustainable energy production. Whether it will be deployed on a large scale depends on both technological advances and social processes. Public perception of CCS can be crucial, and research interest in this topic has been growing. This review analyzes the public perception research thus far (42 articles were identified). Laypeople's concerns and spontaneous reactions to the technology have been thoroughly analyzed, and the results form a good basis for risk communication about CCS. What deserves more research is the role of the context (particularly the social context) in which CCS would be deployed. More case studies are also needed to gain a clearer picture of what matters for CCS acceptance at the project level, as opposed to societal acceptability of CCS." **Selma L'Orange Seigo, Simone Dohle, and Michael Siegrist**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

"An overview of current status of carbon dioxide capture and storage technologies." The following is the Abstract of this article: "Global warming and climate change concerns have triggered global efforts to reduce the concentration of atmospheric CO_2. CCS is considered a crucial strategy for meeting CO_2 emission reduction targets. In this paper, various aspects of CCS are reviewed and discussed including the state of the art technologies for CO_2 capture, separation, transport, storage, [release], monitoring, and life cycle analysis. The selection of specific CO_2 capture technology heavily depends on the type of CO_2 generating plant and fuel used. Among those CO_2 separation processes, absorption is the most mature and commonly adopted due to its higher efficiency and lower cost. Pipeline is considered to be the most viable solution for large volume of CO_2 transport. Among those geological formations for CO_2 storage, [EOR] is mature and has been practiced for many years but its economical viability for anthropogenic sources needs to be demonstrated. There are growing interests in CO_2 storage in saline [formations] due to their enormous potential storage capacity and several projects are in the pipeline for demonstration of its viability. There are multiple hurdles to CCS deployment including the absence of a clear business case for CCS investment and the absence of robust economic incentives to support the additional high capital and operating costs of the whole CCS process." **Dennis Y.C. Leunga, Giorgio Caramannab, and M. Mercedes Maroto-Valerb**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

October 2014

"U.S. EPA Approves Carbon Sequestration Permit in Decatur, Illinois." The U.S. Environmental Protection Agency (EPA) approved a permit allowing the Archer Daniels Midland Company (ADM) to store CO_2 underground in Decatur, Illinois. Before approving the permit, EPA completed a technical review of the Class VI permit and responded to more than 100 public comments. ADM plans to capture and inject underground approximately 1.1 million metric tons of CO_2 annually from an ethanol manufacturing facility. This is the second facility in the United States to receive a Class VI underground injection permit for carbon storage and ADM can begin drilling the well in November. Before injecting CO_2, ADM must demonstrate the integrity of the well, as well as conduct extensive monitoring at the location. Click here for more information. From *U.S. EPA News Release* on September 26, 2014.

"New Experimental Data Released to Enhance CO_2 Pipeline Design." The CO2PIPETRANS joint industry project (JIP) is releasing data related to the depressurization of CO_2 pipelines. The data is intended to fill knowledge gaps associated with the safe and reliable pipeline transport of CO_2 and result in cost efficiencies and improved design basis for the pipelines. In addition to making datasets for model validation publicly available, The DNV GL-led CO2PIPETRANS JIP also involves work to improve the understanding of CO_2 pipeline propagating cracks and corrosion rates with various CO_2 stream impurities. Click here for more information on CO2PIPETRANS. From *DNV GL New Release* on October 7, 2014.

"CCS (carbon capture and storage) investment possibility in South East Europe: A case study for Croatia." The following is the Abstract of this article: "In order to reduce carbon emissions, great efforts are required to [optimize] the processes and solve the main technical and economic problems which currently limit a large-scale diffusion of CCS technologies. In this paper, the main results of a techno-economic comparison between USCPC or USC plants (ultra supercritical [pulverized] coal combustion) with and without CCS are presented. In this study, a few related questions about the development of CCS and power generation technologies in SEE (South East Europe) are answered. The main questions considered are: (1) what are the current cost estimates for building a new entrant power plant with an installed CCS system compared to a typical USC power plant (2) what is the breakeven [CO_2] price to justify CCS investment for USCPC power plants. To answer these questions, a LCOE ([levelized] cost of electricity) model is built for the power plants in study, with assumptions best representing the current costs and technologies in the EU (European Union). Then, a sensitivity analysis of some of the key parameters of the LCOE to reveal their impact on the financial viability of the project is done. The technical model of the plant is implemented in the database of the SEE REM (South East Europe Regional Electricity Market) in order to evaluate its performance on the electricity market and results gained are [analyzed]." **Alfredo Višković, Vladimir Franki, and Vladimir Valentić**, *Energy*. (Subscription may be required.)

November 2014

"U.S.-China Joint Announcement on Climate Change." The United States of America and the People's Republic of China announced bilateral cooperation on climate change and will collaborate with other countries to adopt a protocol, another legal instrument, or an agreed outcome at the United Nations (UN) Climate Conference in Paris, France, in 2015. Under the agreement, the United States would cut its 2005 level of carbon emissions by 26 to 28 percent before the year 2025. China would peak its carbon emissions by 2030 and will also aim to increase the share of non-fossil fuels in primary energy consumption to approximately 20 percent by 2030. Both sides intend to work toward higher targets over time. The United States and China believe that technological innovation is essential for reducing the cost of current mitigation technologies. Energy technology cooperation between the two nations is shown from past efforts, such as establishing the U.S.-China Climate Change Working Group (CCWG), agreeing to work together towards the global phase down of hydrofluorocarbons (HFCs), creating the

U.S.-China Clean Energy Research Center (CERC), and agreeing on a joint peer review of inefficient fossil fuel subsidies under the G-20. Finally, the United States and China announced additional measures to strengthen and expand their cooperation by using the existing entities such as the CCWG, the CERC, and the U.S.-China Strategic and Economic Dialogue. The measures include expanding joint clean energy research and development (R&D); advancing major carbon capture, utilization and storage demonstrations; enhancing cooperation on HFCs; launching a climate-smart/low-carbon cities initiative; promoting trade in green goods; and demonstrating clean energy. From *White House Press Release* on November 11, 2014.

"EU Strikes Compromise to Set New Climate Target" and **"European Leaders Agree on Targets to Fight Climate Change."** European Union (EU) leaders agreed to a new overall target to reduce EU CO_2 emissions in 2030 by at least 40 percent from levels in the benchmark year of 1990. The EU has nearly achieved an existing goal of a 20 percent cut by 2020. The agreement makes the EU the first global emitter to reach agreement ahead of a UN climate summit scheduled for December 2015 in Paris, France. According to officials, the EU pledge to cut emissions by 40 percent would eventually require legally binding targets for each of the EU's member countries to meet the target in a reasonable manner. From *Reuters* on October 23, 2014, and from *New York Times* on October 23, 2014.

"Siting Is a Constraint to Realize Environmental Benefits from Carbon Capture and Storage." The following is the Abstract of this article: "CCS for coal power plants reduces onsite [CO_2] emissions, but affects other air emissions on and offsite. This research assesses the net societal benefits and costs of Monoethanolamine (MEA) CCS, valuing changes in emissions of CO_2, [sulfur dioxide (SO_2), nitrogen oxide (NO_X), ammonia (NH_3)] and particulate matter (PM), including those in the supply chain. Geographical variability and stochastic uncertainty for 407 coal power plant locations in the U.S. are analyzed. The results show that the net environmental benefits and costs of MEA CCS depend critically on location. For a few favorable sites of both power plant and upstream processes, CCS realizes a net benefit (benefit–cost ratio >1) if the social cost of carbon exceeds $51/ton. For much of the U.S. however, the social cost of carbon must be much higher to realize net benefits from CCS, up to a maximum of $910/ton. While the social costs of carbon are uncertain, typical estimates are in the range of $32-220 per ton, much lower than the breakeven value for many potential CCS locations. Increased impacts upstream from the power plant can dramatically change the social acceptability of CCS and needs further consideration and analysis." **Ashok Sekar, Eric Williams, and Mikhail Chester**, *Environ. Sci. Technol*. (Subscription may be required.)

"Communication science and technology while engaging the public at the Illinois Basin – Decatur Project." The following is the Abstract of this article: "The Midwest Geological Sequestration Consortium communication initiative at the Illinois Basin – Decatur Project (IBDP) draws on multiple CCS best practices, guidelines, and international project experiences to be both proactive and responsive toward the engagement of multiple stakeholders. The IBDP communications strategy was developed early in the project to actively reduce associated risks by creating and implementing a communication plan, training communicators, and providing a structure for the communications team. Formalized approaches to knowledge sharing and capacity building have generated additional opportunities to further outreach and impact from IBDP experiences. The initial challenge for the communications team was to provide easy-to-understand, scientifically accurate, and consistent information for stakeholders to carry throughout the project. Consistent, factual information was developed and incorporated into project planning, and provides the basis of public communications through the alignment of goals across communications, risk mitigation, and project management. The refinement of the communication strategy and plan is ongoing due to the changing communication needs that are encountered throughout the lifetime of the project." **Sallie E. Greenberg and Lori M. Gauvreau**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

December 2014

"U.S.-China Joint Announcement on Climate Change." The United States of America and the People's Republic of China announced bilateral cooperation on climate change and will collaborate with other countries to adopt a protocol, another legal instrument, or an agreed outcome at the United Nations (UN) Climate Conference in Paris, France, in 2015. Under the agreement, the United States would cut its 2005 level of carbon emissions by 26 to 28 percent before the year 2025. China would peak its carbon emissions by 2030 and will also aim to increase the share of non-fossil fuels in primary energy consumption to approximately 20 percent by 2030. Both sides intend to work toward higher targets over time. The United States and China believe that technological innovation is essential for reducing the cost of current mitigation technologies. Energy technology cooperation between the two nations is shown from past efforts, such as establishing the U.S.-China Climate Change Working Group (CCWG), agreeing to work together towards the global phase-down of hydrofluorocarbons (HFCs), creating the U.S.-China Clean Energy Research Center (CERC), and agreeing on a joint peer review of inefficient fossil fuel subsidies under the G-20. The United States and China also announced additional measures to strengthen and expand their cooperation by using the existing entities such as the CCWG, the CERC, and the U.S.-China Strategic and Economic Dialogue. The measures include expanding joint clean energy research and development (R&D); advancing major carbon capture, utilization, and storage demonstrations; enhancing cooperation on HFCs; launching a climate-smart/low-carbon cities initiative; promoting trade in green goods; and demonstrating clean energy. From *White House Press Release* on November 11, 2014.

"UK, Canada Sign Joint Research Agreement for Carbon Capture and Storage." The United Kingdom (UK) Department of Energy and Climate Change (DECC) and Department of Natural Resources of Canada (NRCan) signed an agreement to collaborate on CCS research, innovation, and knowledge sharing. The UK and Canada will: (1) build on existing R&D partnerships between the research centers; (2) develop joint research projects, reciprocal visits, and access to testing; and (3) pursue joint CCS-themed academic programs. Among other knowledge sharing objectives, the countries will share experience in CCS regulation. More information on the agreement is available via the "Joint Statement from the Department of Natural Resources of Canada and the Department of Energy and Climate Change of the United Kingdom concerning Carbon Capture and Storage." From *Energy Business Review* on November 19, 2014.

"EPA Finalizes Greenhouse Gas Permit for Carbon Capture Facility." The U.S. Environmental Protection Agency (EPA) issued a final GHG Prevention of Significant Deterioration (PSD) construction permit to Nuevo Midstream, LLC, to build three gas-processing plants in Orla, Texas. The facility is expected to "help increase processing of natural gas in Texas and New Mexico," according to EPA officials. The project, which is the first GHG PSD construction permit in Texas for CO_2 capture and storage, will involve the expansion of three cryogenic plants and two 1,000-gpm amine plants, in addition to selling GHGs for EOR operations. For more information on GHG permits in Texas, click here. From *U.S. EPA News Release* on November 25, 2014.

"The prospects for coal-fired power plants with carbon capture and storage: A UK perspective." The following is the Abstract of this article: "CCS facilities coupled to coal-fired power plants provide a climate change mitigation strategy that potentially permits the continued use of fossil fuels whilst reducing the CO_2 emissions. Potential design routes for the capture, transport and storage of CO_2 from United Kingdom (UK) power plants are examined. Energy and carbon analyses were performed on coal-fired power stations with and without CCS. Both currently available and novel CCS technologies are evaluated. Due to lower operating efficiencies, the CCS plants showed a longer energy payback period and a lower energy gain ratio than conventional plant. Cost estimates are reported in the context of recent UK industry-led attempts to determine opportunities for cost reductions across the whole CCS chain, alongside international [endeavors] to devise common CCS cost estimation methods. These cost figures should be viewed as 'indicative' or suggestive. They are nevertheless helpful to various CCS

stakeholder groups [such as those in industry, policy makers (civil servants and the staff of various government agencies), and civil society and environmental 'non-governmental organisations' (NGOs)] in order to enable them to assess the role of this technology in national energy strategies and its impact on local communities." **Geoffrey P. Hammond and Jack Spargo**, *Energy Conversion and Management*. (Subscription may be required.)

January 2015

"Alberta's Climate Change Regulations Extended." The Government of Alberta announced the extension of four climate change regulations through the end of June 2015 to allow for the continued analysis of new approaches and partnership opportunities discussed at the UN climate change conference in Peru in early December 2014. The four regulations are the Specified Gas Emitters Regulation (SGER), the Specified Gas Reporting Regulation (SGRR), the Administrative Penalty Regulation, and the Climate Change and Emissions Management Fund Administration Regulation. The SGER outlines compliance options and sets Alberta's greenhouse gas (GHG) emissions reduction target from business as usual at 12 percent for facilities emitting more than 100,000 metric tons of GHGs. The SGRR requires facilities emitting more than 50,000 metric tons of GHGs annually to report emission levels. The Administrative Penalty Regulation provides authority to issue a penalty for compliance breaches under SGER and SGRR. Finally, the Climate Change and Emissions Management Fund Administration Regulation enables the Climate Change Emissions Management Corporation to decide how to administer money paid to the corporation. The regulations were set to expire on December 21, 2014. The new climate change framework will be introduced in 2015. From *Government of Alberta News Release* on December 19, 2014.

"In silico science for climate policy: How policy-makers process and use carbon storage simulation data." The following is the Abstract of this article: "Knowledge gained from computer simulations in new earth-related technologies is not limited to the scientific community itself but impacts other domains of society such as politics, business and industry, and the public at large. In general business and industry in the oil and gas business are using computer simulations on a daily basis. In this case it is using computer simulations to gain understanding of the risk of a new technology which would affect the subsurface on a large scale and hence in Europe a substantial amount of people. So far, research did not consider in depth patterns of *in silico* science for policy. This paper [analyzes] how policymakers process and use simulation data based on a case-study of geo-scientific [CO_2] capture modeling. The empirical results are based on 19 qualitative interviews with decision-makers from politics, business and industry, and society. The empirical results reveal a great variety of co-existing perception, evaluation and use patterns of how decision-makers deal with simulations. The field work reveals that the current state-of-the-art in research literature which emphasizes an overall misperception, misunderstanding and misuse of simulation data by policy-makers is, in general, not backed by the case-study results. However, scientific simulations do leave considerable room for misunderstandings for experts not disposing on specific geo-scientific and simulation expertise." **Dirk Scheer**, *Environmental Science & Policy*. (Subscription may be required.)

February 2015

"UK Increases CFD Funding for [Low-Carbon] Projects." The UK government increased funding available for low-carbon projects under the Contract for Difference (CfD) scheme, allocating approximately $38 million starting in 2017-2018 for "Pot 2" funding, which focuses on offshore wind and biomass projects. Total funding available for the CfD scheme has now increased to approximately $495 million, with the projects receiving 15-year contracts after winning the auction. Additional funding is expected to be made available for CfDs for renewables and CCS in future years, increasing to more than approximately $1.5 billion in 2020-2021. From *Clean Technology Business Review* on January 29, 2015.

"Transferring responsibility of CO_2 storage sites to the competent authority following site closure." The following is the Abstract of this article: "The requirements for pre-qualifying a site for CO_2 storage are well developed. Less attention has been paid to rehearsing and preparing for the transfer of responsibility of the storage site from the operator to a governmental authority following closure of the site at the end of the injection period. This is not surprising because the industry is in its infancy and most effort has been focused on working towards the early stages of the various projects. A procedure for complying to the regulatory requirements for the transport of responsibility in the CCS Directive has been proposed, which consists of a chart with Site Closure Milestones and a traffic light system for treating irregularities in observed behavior of the storage site, and accompanying criteria. The procedure was successfully tested on the K12-B CO_2 injection pilot. Conclusions have been drawn on the basis of several dry runs for reporting the requirements for transfer of responsibility including feedback from operators and regulators." **Ton Wildenborg, Geert de Bruin, Alexander Kronimus, Filip Neele, Jens Wollenweber, and Andy Chadwick**, *Energy Procedia*. (Subscription may be required.)

March 2015

"Nations Agree Draft Text for Deal to Fight Climate Change." Government delegates from nearly 200 countries have agreed to a draft text for a deal to address potential climate change. The draft will be used as the basis for negotiations later in 2015. The United Nations required negotiators to agree on official text six months prior to the December 2015 United National Climate Change Conference in Paris, France. From *Reuters* on February 13, 2015.

"Swiss to Reduce Greenhouse Gas Emissions." Switzerland's environment ministry unveiled plans to reduce GHG emissions by 50 percent by 2030 in relation to 1990 levels, with a minimum of 30 percent being achieved domestically. Originally approved by the Federal Council in November 2014, Switzerland will officially announce its commitment at the United Nations Framework Convention on Climate Change (UNFCCC), ahead of the December 2015 United Nations Climate Change Conference in Paris, France. According to a statement released by the environment ministry, Switzerland was responsible for 0.1 percent of global GHG emissions. From *swissinfo.ch* on February 27, 2015.

"Host community compensation in a carbon dioxide capture and storage (CCS) context: Comparing the preferences of Dutch citizens and local government authorities." The following is the Abstract of this article: "The prospect of negative local impacts in combination with the absence of local benefits can be a reason for people to oppose plans for the siting of a CCS project in their community. Local public opposition may be reduced by implementing compensation measures that redress the balance between perceived local costs and benefits. Here, [the authors] examine evaluations and relative preferences of Dutch citizens and local government authorities (LGAs) concerning five different types of compensation measures. The results of a survey experiment show that citizens and LGAs were equally (and most) positive about the establishment of a fund for the compensation of damage or other negative local impacts associated with nearby CCS activities. They differed in how they judged the other measures though: Citizens were more positive about compensation in the form of measures to improve the local economy, monetary payments to individual households, and improvements to local recreational amenities; LGAs were more positive about a grant to local government. Citizens assumed that LGAs would be more positive about four of the five compensation measures than they actually were, whereas LGAs performed well in estimating the judgments of citizens. Implications for compensation policy are discussed." **Bart W. Terwel and Emma ter Mors**, *Environmental Science & Policy*. (Subscription may be required.)

April 2015

"Mexico Unveils National Strategy for Paris Climate Talks." Mexico's Foreign and Environment Ministries unveiled a national climate plan to begin reducing greenhouse gas (GHG) emissions by 2026,

leading to a 22 percent reduction in GHGs below business-as-usual levels by 2030. According to the plan, GHGs would become independent of economic growth after 2026, leading to a 40 percent reduction in emissions intensity per unit of gross domestic product from 2013 to 2030. Mexico, which submitted its plan to the United Nations ahead of the December 2015 climate summit in Paris, France, and without financial support from developed countries, said it could potentially raise its 2030 GHG target to 36 percent under some scenarios and conditions. From *Reuters* on March 27, 2015.

"Carbon Emissions Abatement (CEA) allocation and compensation schemes based on DEA." The following is the Abstract of this article: "As environment constraints on economic growth are strengthening, Carbon Emissions Abatement (CEA) allocation becomes a significant issue that draws academia's attention. In the literature, the Data Envelopment Analysis (DEA) technique has been applied to obtain CEA allocation with centralized models. Nevertheless, a centralized allocation plan suffers from an implementation difficulty in persuading decision-making units (DMUs) into an agreement. In this paper, [the authors] propose a new two-step method to mitigate this side effect. In the first step, [the authors] provide improved DEA-based centralized allocation models under the assumptions of constant returns-to-scale (CRS) and variable returns-to-scale (VRS) respectively and in the second step, two compensation schemes are developed for centralized allocation plans. An empirical application to the countries in Organization for Economic Co-operation and Development (OECD) is presented to elaborate the main idea." **Chenpeng Feng, Feng Chu, Jingjing Ding, Gongbing Bi, and Liang Liang**, *Omega*. (Subscription may be required.)

"Quantitative risk assessment in the early stages of a CO_2 geological storage project: implementation of a practical approach in an uncertain context." The following is the Abstract of this article: "Methodologies for quantitative risk assessment regarding CO_2 storage operations are currently scarce, mostly because of the lack of experience in this field and the relatively significant degree of uncertainty regarding the subsurface intrinsic properties and the processes occurring after the injection starts. This paper presents a practical approach designed to perform a quantitative risk assessment in an uncertain context. [The authors'] approach is illustrated by a realistic case study (Paris Basin, France), conceived to be representative of the level of information available in the early stages of a project. It follows the risk assessment principles from the international standards (ISO 31000:2009), which are adapted to account for the specificities and challenges of subsurface operations. After the establishment of the context of the specific case study, the main risks are identified and [the authors] analyze two different risk scenarios: risk of brine [release] from an abandoned well and risk of subsurface use conflict. These scenarios were selected to give a comprehensive overview of different types of analysis in terms of available data, modeling tools and uncertainty management methodologies. The main benefit of this paper is to propose an approach, based on existing risk assessment standards, best practices, and analysis tools, which allows an objective quantitative risk analysis taking into account the uncertainties, and therefore enabling fully informed decision-making while evaluating risk acceptability." **Louis de Lary, Jean-Charles Manceau, Annick Loschetter, Jeremy Rohmer, Olivier Bouc, Isaline Gravaud, Christophe Chiaberge, Pierre Willaume, and Thierry Yalamas**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Expert involvement in science development: (re-)evaluation of an early screening tool for carbon storage site characterization." The following is the Abstract of this article: "CCS science development takes place in a highly contested and politicized environment and cannot be seen isolated from the public debate on energy policies. Early expert and decision-maker involvement in CCS science development thus is necessary for assessing the accountability and reliability of scientific methods and decision-tools. Relying on a participatory Group Delphi exercise with 14 experts involved, [the authors] carried out early expert involvement in science development with the evaluation of the so-called gravitational number (Gr) approach – an early screening tool for carbon storage site characterization. The aim was to elicit expert evaluations and judgments on the Gr approach and feeding back these judgments to method developers. Experts hinted to several Gr constraints, specifications and recommendations that served the method developers for re-designing and re-evaluating the screening

tool. The expert assessment indicate an overall good understanding of the Gr approach with all but two items (far) beyond the scale midpoint of 3.5 on a seven point Likert scale. Evaluating reservoir characterization criteria, experts ranked safety related criteria more important than capacity related criteria. In a final evaluation of the Gr method, experts agreed unanimously to a very high degree that the Gr number approach alone is not meaningful and a review of Gr results by earth scientist is necessary. Oversimplification, therefore, seems to be the overarching downside aspect of the method that leads to the conclusion not to use the Gr results as a sole basis for decision making on site selection." **D. Scheer, W. Konrad, H. Class, A. Kissinger, S. Knopf, V. Noack**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

May 2015

"Norway and Czech Republic Establish Cooperation on CCS." Norway and the Czech Republic have agreed to a cooperation program, titled, "Pilot Studies and Surveys on CCS Technology," that focuses on raising awareness of CCS and examining the technical and financial possibilities of deploying the technology in the Czech Republic. The program, which will receive funding from Norway, will be composed of four different projects: (1) a pilot project on CO_2 geologic storage in the Czech Republic; (2) a feasibility study of CCS pilot technologies for coal-fired power plants; (3) a project aimed at furthering research on the potential for the application of CCS under existing conditions in the Czech Republic; and (4) a project focused on knowledge sharing and awareness raising on the role of CCS as a climate mitigation tool. From *Bellona* on April 15, 2015.

"European Parliament Committee Supports Energy Security Report." Members of the European Parliament (MEPs) from the Committee on Industry, Research, and Energy (ITRE) voted in favor of a draft report on the European Energy Security Strategy (EESS). The draft report on EESS, which addresses issues surrounding Europe's energy supply and use, climate action, and economic growth, includes two amendments concerning CCS. The first calls on the Commission to improve deployment conditions of CCS and for funding to be provided for the continued development of CCS. The second calls for funding for the Horizon 2020 Framework Program for Research and Innovation to be protected from any future cuts in order to ensure the improvement of existing CCS technologies, as well as the development of new technologies. From *Bellona* on May 11, 2015.

"An examination of geologic carbon [storage] policies in the context of [release] potential." The following is the Abstract of this article: "Carbon dioxide (CO_2) injected into geologic reservoirs for long-term [storage], or the brine it displaces, may [release] through natural or manmade pathways. Using a [release] estimation model, [the authors] simulated fluid [release] from a storage reservoir and its migration into overlying formations. The results are discussed in the context of policies that seek to assure long-term [storage] and protect groundwater. This work is based on a case study of CO_2 injection into the Mt. Simon sandstone in the Michigan sedimentary basin, for which [the authors] constructed a simplified hydrologic representation of the geologic formations. The simulation results show that (1) CO_2 [release] can reach [a formation] containing potable water, but numerous intervening stratigraphic traps limit the rate to be orders of magnitude less than the rate of [release] from the storage reservoir; (2) [DOE] guidelines for storage permanence allow for more [release] from larger injection projects than for smaller ones; (3) well [release] permeability is the most important variable in determining [release] processes and substantial [release] requires that numerous wells [releasing] with the anomalously high permeability of 10−10 m^2; and (4) [release] can reduce the U.S. Environmental Protection Agency's Area of Review." **Jeffrey M. Bielicki, Catherine A. Peters, Jeffrey P. Fitts, and Elizabeth J. Wilson**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Long-term scenarios for reaching climate targets and energy security in UK." The following is the Abstract of this article: "The construction and subsequent analysis of scenarios using energy systems models is an essential tool in energy policy making. This paper presents two descriptive scenarios for the development of the UK energy system to 2050, using four subsequent decadal time-slices. The two

scenarios, K_Scenario and Z_Scenario, were modelled with the use of the Department of Energy and Climate Change (DECC) 2050 Pathways Calculator. K_Scenario is a scenario in which the use fossil fuels with CCS are prominent in the power sector, while Z_Scenario focuses on the development of renewables with energy storage and nuclear power. Both scenarios seek to achieve the UK's legally binding target of an 80 [percent] reduction in GHG emissions from 1990 levels by 2050. Abatement is achieved through numerous developments in each of the scenarios, including the development and use of shale gas, hydrogen, additional wind and solar deployment, the expansion of bioenergy and use of CCS. These developments must be driven by policies designed to pursue dramatic decarbonisation." **Catalina Spataru, Paul Drummond, Eleni Zafeiratou, and Mark Barrett**, *Sustainable Cities and Society*. (Subscription may be required.)

June 2015

"North American Energy Ministers Establish a Working Group on Climate Change and Energy." The North American Energy Ministers established a new working group called the North American Energy Ministers' Working Group on Climate Change and Energy. The trilateral working group, which was announced at the Energy and Climate Partnership of the Americas (ECPA) and Clean Energy Ministerial (CEM) meetings in Merida, Mexico, supports implementation of clean energy and climate change goals of the U.S., Mexican, and Canadian governments. The working group, which expands on the 2014 North American Energy Ministers Dialogue, includes collaboration in areas such as modeling and deployment of clean energy technologies; carbon capture, use, and storage; and emissions from the oil and gas sector. From *Energy.Gov* on May 25, 2015.

"Government of Canada Announces 2030 Emissions Target." Canada announced plans to reduce its GHG emissions by 30 percent below 2005 levels by 2030. Canada formally submitted its target, referred to as an intended Nationally Determined Contribution, to the United National Framework Convention on Climate Change (UNFCCC). In addition, Canada's announcement included new regulatory measures that build upon their existing coal-fired electricity regulations. From *Government of Canada News Release* on May 15, 2015.

"Proposed Clean Power Plan Rule Cuts Power Sector CO_2 Emissions to Lowest Level Since 1980s." According U.S. Energy Information Administration (EIA) analysis of the U.S. Environmental Protection Agency's (EPA) proposed Clean Power Plan rule, power sector CO_2 emissions may be reduced approximately 1,500 million metric tons per year by 2025 – a level experienced in the early 1980s. EIA's analysis uses the "Annual Energy Outlook 2015" (AEO2015) as a baseline, and aggregates the targets in EPA's proposed rule to the 22 regions represented in its model. A summary of EIA's analysis, titled, "Analysis of the Impacts of the Clean Power Plan," is available in the "Recent Publications" section of this newsletter. From *U.S. Energy Information Administration* on May 26, 2015.

"Impacts of Potential CO_2-Reduction Policies on Air Quality in the United States." The following is the Abstract of this article: "Impacts of emissions changes from four potential U.S. CO_2 emission reduction policies on 2050 air quality are analyzed using the community multiscale air quality model (CMAQ). Future meteorology was downscaled from the Goddard Institute for Space Studies (GISS) ModelE General Circulation Model (GCM) to the regional scale using the Weather Research Forecasting (WRF) model. [The authors] use emissions growth factors from the EPAUS9r MARKAL model to project emissions inventories for two climate tax scenarios, a combined transportation and energy scenario, a biomass energy scenario and a reference case. Implementation of a relatively aggressive carbon tax leads to improved $PM_{2.5}$ air quality compared to the reference case as incentives increase for facilities to install flue-gas desulfurization (FGD) and CCS technologies. However, less capital is available to install NO_X reduction technologies, resulting in an O_3 increase. A policy aimed at reducing CO_2 from the transportation sector and electricity production sectors leads to reduced emissions of mobile source NO_X, thus reducing O_3. Over most of the U.S., this scenario leads to reduced $PM_{2.5}$ concentrations. However, increased primary $PM_{2.5}$ emissions associated with fuel switching in the residential and industrial sectors

leads to increased organic matter (OM) and $PM_{2.5}$ in some cities." **Marcus A. Trail, Alexandra P. Tsimpidi, Peng Liu, Kostas Tsigaridis, Yongtao Hu, Jason R. Rudokas, Paul J. Miller, Athanasios Nenes, and Armistead G. Russell**, *Environ. Sci. Technol.* (Subscription may be required.)

July 2015

"Administration Announces More Than $4 Billion in Private-Sector Commitments and Executive Actions to Scale-Up Investment in Clean Energy Innovation." The White House announced a series of executive actions to encourage clean energy innovation. Under one of the executive actions, DOE will launch a Clean Energy Impact Investment Center. Among other purposes, the center will share relevant research and analysis by DOE and its National Laboratories, and collect and make available existing, public information on entities currently engaged in partnerships with DOE, as well as information about energy and climate programs at other government agencies. From *The White House Press Release* on June 16, 2015.

"United Stated and China Strengthen Climate Change." Government officials from the United States and China announced cooperation on potential climate change and clean energy through the U.S.-China Climate Change Working Group at the seventh U.S.-China Strategic and Economic Dialogue (S&ED). The cooperation builds upon the November 2014 Joint Announcement on Climate Change in which the two countries pledged to commit to work together to achieve a global climate agreement and transition to low-carbon economies. The Working Group highlighted, among other outcomes of the meeting, the announcement of a "Climate-Smart/Low-Carbon Cities Summit," to be held later this year; a bilateral, industry-led working group to develop pilot projects demonstrating energy efficiency in industrial and commercial buildings; an industrial boiler emission control program; and two joint carbon capture, utilization, and storage pilot projects. From *The U.S. Department of State* on June 24, 2015.

"**U.S.-Brazil Joint Statement on Climate Change**." The United States and Brazil have launched a Joint Initiative on Climate Change, to be implemented through a high-level U.S.-Brazil Climate Change Working Group. The new Working Group will look to enhance bilateral cooperation on issues relating to land use, clean energy, and adaption, as well as policy dialogues on domestic and international climate issues. The first meeting of the Working Group will occur in October. From *The White House Press Release* on June 30, 2015.

"Carbon dioxide emission standards for U.S. power plants: An efficiency analysis perspective." The following is the Abstract of this article: "On June 25, 2013, [the United States] announced [a] plan to introduce [CO_2] emission standards for electricity generation. This paper proposes an efficiency analysis approach that addresses which emission rates (and standards) would be feasible if the existing generating units adopt best practices. A new efficiency measure is introduced and further decomposed to identify different sources' contributions to emission rate improvements. Estimating two Data Envelopment Analysis (DEA) models – the well-known joint production model and the new materials balance model – on a dataset consisting of 160 bituminous-fired generating units, [the authors] find that the average generating unit's electricity-to-[CO_2] ratio is 15.3 [percent] below the corresponding best-practice ratio. Further examinations reveal that this discrepancy can largely be attributed to non-discretionary factors and not to managerial inefficiency. Moreover, even if the best practice ratios could be implemented, the generating units would not be able to comply with the U.S. Environmental Protection Agency's (EPA) recently proposed [CO_2] standard." **Benjamin Hampf and Kenneth Løvold Rødseth**, *Energy Economics*. (Subscription may be required.)

August 2015

"Clean Power Plan to Protect Public Health, Spur Clean Energy Investments, and Strengthen U.S. Leadership." The White House and the U.S. Environment Protection Agency (EPA) announced the

Clean Power Plan, which aims to reduce U.S. carbon emissions from the power sector by 870 million tons (32 percent below 2005 levels) in 2030. The plan reflects public input, with more than 4 million public comments on the proposal. The final rule establishes guidelines for states to follow in developing and implementing their plans. EPA is proposing a model rule states can adopt, as well as a Federal plan that EPA can put in place. Both the proposed model rule and the Federal plan focus on emissions trading mechanisms to make sure carbon-reduction goals are met. More information on the Clean Power Plan is available in a White House Fact Sheet. From *U.S. Environmental Protection Agency News Release* on August 3, 2015.

"Inslee Directing Ecology to Develop Regulatory Cap on Carbon Emissions." The Washington State Department of Ecology has been directed to develop a regulatory cap on CO_2 emissions. The process of developing the emissions reductions by using existing authority, as well as allowing stakeholders the opportunity to provide input, is expected to take approximately a year. Similar legislation was previously proposed in late-2014; this regulatory cap differs in that it would not charge emitters. From *Governor Jay Inslee News Release* on July 28, 2015.

"[New York City] Announces New Greenhouse Gas Emissions Cuts." New York City announced new GHG emissions targets, committing to reduce their emissions by 40 percent by 2030. New York City is currently a member of an alliance of cities around the world committed to reducing emissions by 80 percent by 2050. The announcement was made at a meeting of mayors on addressing climate change. From *Yahoo! Finance* on July 21, 2015.

"A carbon market sensitive optimization model for integrated forward-reverse logistics." The following is the Abstract of this article: "Globalized supply chains, volatile energy and material prices, increased carbon regulations and competitive marketing pressure for environmental sustainability are driving supply chain decision makers to reduce carbon emissions. Enterprises face the necessity and the challenge of implementing strategies to reduce their supply chain environmental impact in order to remain competitive. One of the most important strategic issues in this context is the configuration of the logistics network. The decision concerning the design of an optimal network of the supply chain plays a vital role in determining the total carbon footprint across the supply chain and also the total cost. Therefore, the logistics network should be designed in a way that it could reduce both the cost and the carbon footprint across the supply chain. In this context, this research proposes a quantitative optimization model for integrated forward–reverse logistics with carbon-footprint considerations, by integrating the carbon emission into a quantitative operational decision-making model with regard to facility layout decisions. The proposed research incorporates carbon emission parameters with various decision variables and modifies traditional integrated forward/reverse logistics model into decision-making quantitative operational model, minimizing both the total cost and the carbon footprint. The proposed model investigates the extent to which carbon reduction requirements can be addressed under a particular set of parameters such as customer demand, rate of return of products etc., by selecting proper policy as an alternative to the costly investment in carbon-reducing technologies. To solve the quantitative model, this research implements a modified and efficient forest data structure to derive the optimal network configuration, minimizing both the cost and the total carbon footprint of the network. A comparative analysis shows the outperformance of the proposed approach over the conventional Genetic Algorithm (GA) for large problem sizes." **Alok Choudhary, Sagar Sarkar, Srikar Settur, and M.K. Tiwari**, *International Journal of Production Economics*. (Subscription may be required.)

Geology

September 2014

"Modeling and measurement of CO_2 solubility in salty aqueous solutions and application in the Erdos Basin." The following is the Abstract of this article: "Geological carbon storage (GCS) is

recognized as an effective method for mitigating the greenhouse effect. Deep saline [formations] hold the highest potential capacity for CO_2 storage. [Carbon dioxide] solubility in salty aqueous solutions under geological [storage] conditions plays a key role in GCS. However, most CO_2 solubility studies focus mainly on single-salt solutions ([sodium chloride (NaCl) and calcium chloride ($CaCl_2$)]), and extrapolation of these studies to aqueous solutions with mixed ions is unavailable. To fill the research gap, based on the collection of CO_2 solubility data, a semi-empirical thermodynamic model is proposed in this paper to calculate CO_2 solubility in aqueous solutions containing K^+, Na^+, Ca^{2+} and Mg^{2+} in the temperature and pressure ranges from 313 K to 378 K and from 50 bar to 220 bar. To describe the CO_2–liquid phase equilibrium, the Peng–Robinson equation of state (PR EoS) and the Setschenov equation are applied. The former has been modified to improve its performance in the studied T–P range, and the latter shows excellent accuracy with only three optimized parameters. Before modeling was done, experimental studies were conducted. Brine sampling from five reservoirs potentially chosen for CO_2 [storage] in the Erdos Basin was carried out using a monitoring well in the support of the Shenhua Group CCS site project. The chemical composition of the samples was determined, and experiments measuring CO_2 solubility were carried out in synthetic brine with 64 valid data points reported. An analytical method with a simplified sampling technique was chosen. In the range studied, the average absolute deviation of CO_2 solubility between the model and experimental results was 2.01 [percent], and the maximum absolute deviation in this study was less than 4.79 [percent]. The proposed model and experimental data therefore possess broad adaptability to GCS with satisfactory accuracy." **Lu Wang, Zhaoli Shen, Lisha Hu, and Qingchun Yu**, *Fluid Phase Equilibria*. (Subscription may be required.)

"Simulating Geologic Co-sequestration of Carbon Dioxide and Hydrogen Sulfide in a Basalt Formation." The following is the Abstract of this article: "Co-[stored] CO_2 with [hydrogen sulfide (H_2S)] impurities could affect geologic storage, causing changes in pH and oxidation state that affect mineral dissolution and precipitation reactions and the mobility of metals present in the reservoir rocks. [The authors] have developed a variable component, non-isothermal simulator, STOMP-COMP (Water, Multiple Components, Salt and Energy), which simulates multiphase flow gas mixtures in deep saline reservoirs, and the resulting reactions with reservoir minerals. [The authors] use this simulator to model the co-injection of CO_2 and H_2S into brecciated basalt flow top. A 1000 metric ton injection of these supercritical fluids, with 99 [percent] CO_2 and 1 [percent] H_2S, is [stored] rapidly by solubility and mineral trapping. [Carbon dioxide] is trapped mainly as calcite within a few decades and H_2S is trapped as pyrite within several years." **Bacon DH, R Ramanathan, HT Schaef, and BP McGrail**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

October 2014

"Environmental considerations for subseabed geological storage of CO_2: A review." The following is the Abstract of this article: "Many countries are now using or investigating offshore geological storage of CO_2 as a means to reduce atmospheric CO_2 emissions. Although associated research often focuses on deep-basin geology (e.g. seismic, geomagnetics), environmental data on the seabed and shallow subseabed is also crucial to (1) detect and [characterize] potential indicators of fluid seeps and their potential connectivity to targeted storage reserves, (2) obtain baseline environmental data for use in future monitoring, and (3) acquire information to facilitate an improved understanding of ecosystem processes for use in impact prediction. This study reviews the environmental considerations, including potential ecological impacts, associated with subseabed geological storage of CO_2. Due to natural variations in CO_2 levels in seafloor sediments, baseline CO_2 measurements and knowledge of physical–chemical processes affecting the regional distribution of CO_2 and pH are critical for the design of appropriate monitoring strategies to assess potential impacts of CO_2 seepage from subseabed storage reservoirs. Surficial geological and geophysical information, such as that acquired from multibeam sonar and sub-bottom profiling, can be used to investigate the connectivity between the deep reservoirs and the surface, which is essential in establishing the reservoir containment properties. [Carbon dioxide release] can have a pronounced effect on sediments and rocks which in turn can have carryover effects to biogeochemical cycles. The effects of elevated CO_2 on marine organisms are variable and species-

specific but can also have cascading effects on communities and ecosystems, with marine benthic communities at some natural analogue sites (e.g. volcanic vents) showing decreased diversity, biomass, and trophic complexity. Despite their potential applications, environmental surveys and data are still not a standard and integral part of subseabed CO_2 storage projects. However, the habitat mapping and seabed [characterization] methodology that underpins such surveys is well developed and has a strong record of providing information to industry and decision makers. This review provides recommendations for an integrated and interdisciplinary approach to offshore geological storage of CO_2, which will benefit national programs and industry and will be valuable to researchers in a broad range of disciplines." **A.G. Carroll, R. Przeslawski, L.C. Radke, J.R. Black, K. Picard, J.W. Moreau, R.R. Haese, and S. Nichol**, *Continental Shelf Research*. (Subscription may be required.)

"A preliminary assessment of geological CO_2 storage in Cambodia." The following is the Abstract of this article: "This study screens and rank Cambodian sedimentary basins in terms of their containment, capacity, and feasibility for the geological storage of CO_2. The results of the screening and ranking procedure indicate that the Khmer Basin is the most suitable basin, followed by the Kampong Saom and Tonle Sap basins. A quantitative volumetric assessment-based evaluation of CO_2 storage capacity is performed on these three suitable basins. The evaluation yields a range in the national CO_2 storage capacity of 90 Mt (in structural traps) to 45 Gt (in hydrodynamic traps), representing low- and high-case estimates, respectively. The saline [formations] associated with this storage capacity should be considered prospective storage options as hydrodynamic traps because of containment and capacity issues associated with the structural traps. Eight major point sources of CO_2 are identified that have a combined output (estimated for 2008–2024) of 43.1 Mt annually and 82 billion m^3 in place, and the potentially prospective matched storage capacity is assumed. Overall, a combination of the initial suitabilities of the basins and estimates of prospective matched storage capacity shows that the Khmer, Kampong Saom, and Tonle Sap basins may provide a solution to the problem of reducing future atmospheric emissions. The present results should assist both exploration geologists and experts in [CCS] to gain a better understanding of the CO_2 storage resources of Cambodia. However, the results should be regarded as preliminary because of the limited available data on which the assessments were based; future geological and geophysical data should improve the reliability of the estimates of carbon storage capacity reported here." **Chanrithyrouth Mao, Yasuhiro Yamada, and Toshifumi Matsuoka**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

November 2014

"CO_2 geological storage: hydro-chemo-mechanical analyses and implications." The following is the Abstract of this article: "The injectivity of CO_2 and the integrity of the reservoir-caprock system are affected by CO_2 invasion, water-CO_2-mineral reactions, and ensuing mineral dissolution and precipitation. [The authors] identify different zones around an injection well and investigate the effects of these hydro-chemo-mechanical interactions. Geochemical analyses combine a comprehensive mass balance formulation with chemical calculations using published equations and PHREEQC. This analysis framework is used to assess near-well, pool, and far-field conditions, and to determine species concentrations, pH, changes in brine density, and changes in mineral and fluid volume in the reservoir. Results show that the brine density may increase by as much as 1.2 [percent] and can sustain convective flow of CO_2 dissolved brine; the characteristic time scale for convection can be as short as a few years in some permeable formations currently being considered for storage. The precipitation of secondary minerals near the injection well increases the mineral volume by a maximum of [five percent], yet, only a minor decrease in CO_2 permeability is anticipated. Dissolution may result in unsupported caprock (the span should not exceed 20 [percent] of the caprock thickness to prevent failure), and may cause compaction-driven shear failure of the reservoir. Finally, the analysis of lateral capillary trapping shows that the CO_2 pool is only a few meters thick in leveled caprock interfaces and in the absence of geometric traps." **Seunghee Kim and J. Carlos Santamarina**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Transport of Organic Contaminants Mobilized from Coal through Sandstone Overlying a Geological Sequestration Reservoir." The following is the Abstract of this article: "Column experiments were conducted using a wetted sandstone rock installed in a tri-axial core holder to study the flow and transport of organic compounds mobilized by $scCO_2$ under simulated geologic carbon storage (GCS) conditions. The sandstone rock was collected from a formation overlying a deep saline reservoir at a GCS demonstration site. Rock core effluent pressures were set at 0, 500, or 1000 [pounds per square inch (psig)] and the core temperature was set at 20 or 50°C to simulate the transport to different subsurface depths. The concentrations of the organic compounds in the column effluent and their distribution within the sandstone core were monitored. Results indicate that the mobility though the core sample was much higher for [benzene, toluene, ethylbenzene, and xylenes (BTEX)] compounds than for naphthalene. Retention of organic compounds from the vapor phase to the core appeared to be primarily controlled by partitioning from the vapor phase to the aqueous phase. Adsorption to the surfaces of the wetted sandstone was also significant for naphthalene. Reduced temperature and elevated pressure resulted in greater partitioning of the mobilized organic contaminants into the water phase." **Zhong L, KJ Cantrell, DH Bacon, and JL Shewell**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Mineral Carbonation of Red Gypsum for CO_2 Sequestration." The following is the Abstract of this article: "Reduction of CO_2 emissions into the atmosphere is a key challenge to mitigate the anthropogenic greenhouse effect. [Carbon dioxide] emissions cause lots of problems for the health of humans and increase [climate change], in which CO_2 uptake decreases these environmental issues. The mineral carbonation process is an alternative method during which industrial wastes rich in calcium (Ca) or magnesium (Mg) react with CO_2 to form a stable carbonate mineral. In this research, the feasibility of CO_2 mineral carbonation by the use of red gypsum, as a Ca-rich source, was evaluated using an autoclave mini reactor. Wide-range conditions of procedure variables, such as reaction temperature, reaction time, CO_2 pressure, and liquid/solid ratio, on the rate of mineral carbonation were studied. The results showed that the maximum conversion of Ca (98.8 [percent]) is obtained at the condition that has an optimum amount of these variables. Moreover, the results confirmed that red gypsum has high potential to form calcium carbonate ($CaCO_3$) during the process of CO_2 mineral carbonation. It was concluded that the mineral carbonation process using red gypsum can be considered to be an interesting, applicable, and low-cost method in industry to mitigate a considerable amount of CO_2 from the atmosphere, which is the main issue in the current and coming years." **Omeid Rahmani, Radzuan Junin, Mark Tyrer, and Rahmat Mohsin**, *Energy Fuels*. (Subscription may be required.)

December 2014

"Constraints on the magnitude and rate of CO_2 dissolution at Bravo Dome natural gas field." The following is the Abstract of this article: "The injection of CO_2 captured at large point sources into deep saline [formations] can significantly reduce anthropogenic CO_2 emissions from fossil fuels. Dissolution of the injected CO_2 into the formation brine is a trapping mechanism that helps to ensure the long-term security of geological CO_2 storage. [The authors] use thermochronology to estimate the timing of CO_2 emplacement at Bravo Dome, a large natural CO_2 field at a depth of 700 m in New Mexico. Together with estimates of the total mass loss from the field [the authors] present, to [their] knowledge, the first constraints on the magnitude, mechanisms, and rates of CO_2 dissolution on millennial timescales. Apatite (U-Th)/He thermochronology records heating of the Bravo Dome reservoir due to the emplacement of hot volcanic gases 1.2–1.5 Ma. The CO_2 accumulation is therefore significantly older than previous estimates of 10 ka, which demonstrates that safe long-term geological CO_2 storage is possible. Integrating geophysical and geochemical data, [the authors] estimate that 1.3 Gt CO_2 are currently stored at Bravo Dome, but that only 22 [percent] of the emplaced CO_2 has dissolved into the brine over 1.2 My. Roughly 40 [percent] of the dissolution occurred during the emplacement. The CO_2 dissolved after emplacement exceeds the amount expected from diffusion and provides field evidence for convective dissolution with a rate of 0.1 g/(m^2y). The similarity between Bravo Dome and major US saline [formations] suggests that significant amounts of CO_2 are likely to dissolve during injection at US

storage sites, but that convective dissolution is unlikely to trap all injected CO_2 on the 10-ky timescale typically considered for storage projects." **Kiran J. Sathaye, Marc A. Hesse, Martin Cassidy, and Daniel F. Stockli**, *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required.)

"Reactive and Pore Structure Changes in Carbon Dioxide Sequestration." The following is the Abstract of this article: "The importance of reactions involving CO_2, brine and rock formations into which CO_2 is injected for CO_2 [storage] in saline [formations] is understood. However, the pore-level changes that occur due to these reactions under flow conditions and their impact on the ultimate fate of CO_2 in the repository have not received the same level of attention due to the perceived slowness of the carbonation reactions. In this paper [the authors] examine these reactive changes and their impact on the pore structure in sandstones and limestones at realistic [formation] pressure and temperatures, and under reactive flow conditions. The changes observed at the pore-level by direct porosity and micro-computer tomography measurements were complemented by the measurements of time-dependent effluent concentrations of target cations. It is observed that iron chemistry plays an important role in the dissolution and precipitation reactions in Berea sandstone. Illite dissolution leads to a peak in iron concentration in effluent brines. Higher level of dissolution and porosity increase is observed near the inlet of the core. In limestones, consistent dissolution is observed throughout the experiment. Wormholes are also generated for experiments with a larger total flow rates. Results show that reactive changes can cause significant pore-level changes over a short injection span during CO_2 [storage] in saline [formations] with profound implications on injectivity and possibly major mechanical changes." **Hyukmin Kweon, Christian Payne, and Milind D. Deo**, *Ind. Eng. Chem. Res*. (Subscription may be required.)

"Influence of Porous Texture and Surface Chemistry on the CO_2 Adsorption Capacity of Porous Carbons: Acidic and Basic Site Interactions." The following is the Abstract of this article: "Doped porous carbons exhibiting highly developed porosity and rich surface chemistry have been prepared and subsequently applied to clarify the influence of both factors on [CO_2] capture. Nanocasting was selected as synthetic route, in which a polyaramide precursor (3-aminobenzoic acid) was thermally polymerized inside the porosity of an SBA-15 template in the presence of different H_3PO_4 concentrations. The surface chemistry and the porous texture of the carbons could be easily modulated by varying the H_3PO_4 concentration and carbonization temperature. Porous texture was found to be the determinant factor on [CO_2] adsorption at 0°C, while surface chemistry played an important role at higher adsorption temperatures. [The authors] proved that nitrogen functionalities acted as basic sites and oxygen and phosphorus groups as acidic ones toward adsorption of CO_2 molecules. Among the nitrogen functional groups, pyrrolic groups exhibited the highest influence, while the positive effect of pyridinic and quaternary functionalities was smaller. Finally, some of these N-doped carbons exhibit CO_2 heats of adsorption higher than 42 kJ/mol, which make them excellent candidates for CO_2 capture." **Ángela Sánchez-Sánchez, Fabián Suárez-García, Amelia Martínez-Alonso, and Juan M. D. Tascón**, *ACS Appl. Mater. Interfaces*. (Subscription may be required.)

"Influence of Maximum Pressure on the Path of CO_2 Desorption Isotherm on Coal." The following is the Abstract of this article: "Coal seams with a high CO_2 content may have outburst risk, and degasification of CO_2 has to be conducted before these coal seams can be safely extracted. For [geo-storage] of CO_2 in unmineable coal seams, injected CO_2 may desorb with the reduction of CO_2 pressure. Desorption of CO_2 dominates these processes, while adsorption isotherms are widely used assuming that the adsorption–desorption process is fully reversible. To understand the difference between CO_2 adsorption and desorption isotherms, i.e., sorption hysteresis, as well as the dependence of CO_2 sorption hysteresis on maximum pressure, four cycles of CO_2 adsorption–desorption experiments are conducted continuously with increasing maximum pressure (1, 2, 3, and 4 MPa). The difference of CO_2 emission volume between adsorption and desorption isotherms is compared, and a significant deviation (0.059 and 0.032 mol/g) has been observed. The adsorption isotherms show a good repeatability, indicating that the gas holding capacity does not change during a long-term contact with CO_2. However, a distinct difference between the desorption isotherms is observed. The path of desorption isotherm depends upon

the maximum pressure, and higher maximum pressures can reduce the proneness of CO_2 desorption in the pressure range of this study (0–4 MPa). [The authors] suggest that desorption isotherms should be used to predict the CO_2 emission volume and long-term storage stability, and the maximum pressure of the laboratory sorption test should be decided according to the in situ coal seam pressure." **Gongda Wang, Ting Ren, Kai Wang, and Yaqin Wu**, *Energy Fuels*. (Subscription may be required.)

"Intrinsic Kinetics of Platy Hydrated Magnesium Silicate (Talc) for Geological CO_2 Sequestration: Determination of Activation Barrier." The following is the Abstract of this article: "Hydrated magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$), commonly known as talc, is a direct carbonation agent. In this study, [the authors] investigated the utility of the carbonation reaction for CO_2 adsorption. To gain insight into talc carbonation, [the authors] performed CO_2 temperature-programmed-desorption and dynamic flow system experiments. Structural modifications proved that CO_2 adsorption occurred on the surface of the talc adsorbents to form carbonates. [The authors] achieved stable carbonation activities of talc by varying the temperature. In addition, the reaction kinetic model of talc carbonation based on the changes of CO_2 concentration was developed. From the observation that the activation energy of talc-based carbonation using the Arrhenius equation is 51.4 ± 4.8 kJ/mol, it is inferred that the chemical reaction is a rate-determining step for talc sequestration, based on relatively high activation energy." **Soonchul Kwon, Min Cho, and Seung Geol Lee**, *Ind. Eng. Chem. Res.* (Subscription may be required.)

January 2015

"Fractal analysis in pore structure of coal under conditions of CO_2 sequestration process." The following is the Abstract of this article: "A high pressure supercritical CO_2 (HP-$ScCO_2$) geochemical reactor was used to simulate CO_2 [storage] into deep coal seam under around 40 °C and 9.8 MPa for 72 h and fractal analysis were employed to study the mercury intrusion data of 4 different coal rank samples before and after the $ScCO_2$–H_2O treatment, focusing on the pore structure. It is revealed from the mercury porosimetry data that after exposure to the $ScCO_2$–H_2O fluid, the true density of coal samples are changed as well as total pore volume and porosity most importantly in the increase of micro-pore range. Fractal analysis is introduced to distinguish inter- and intraparticle pores at lower mercury intrusion pressure and to identify the initial pressure associated with the coal compressibility. Three values of fractal dimension (D_1, D_2, and D_3) are obtained under different pressure ranges, which can be classified corresponding to three different mercury intrusion processes. Varied D_1 values are mainly due to the accumulation mode of samples in the penetrometer and can be used to distinguish the interpore and intrapore intrusion process at lower pressure range of mercury intrusion. D_2 values represent the mercury intrusion into intrapores. D_3 value is decreasing as coal rank increased and can be used to describe the initial pressure when coal samples begin to be compressed or deformed at higher pressure of mercury intrusion. The experiments revealed that CO_2 [storage] process changed the physical properties of coal samples, especially in compression resistance. Coal rank and ash content in coal are important factors which will affect the variation of coal structure during CO_2 [storage]." **C.J. Liu, G.X. Wang, S.X. Sang, W. Gilani, and V. Rudolph**, *Fuel*. (Subscription may be required.)

"Mineral carbon storage in pre-treated ultramafic ores." The following is the Abstract of this article: "Mineral carbon [storage] (MCS) is a type of carbon storage based on natural rock weathering processes where CO_2, dissolved in rainwater, reacts with alkaline minerals to form solid carbonates. Although MCS has advantages over other carbon storage techniques, an economic MCS process has not yet been developed. Two approaches were taken in this work to attempt to reduce the cost of MCS. The first approach was to use a waste material, serpentine waste from ultramafic nickel ore processing, as a feedstock. The second approach was to develop pre-treatments to increase the carbon storage capacity of the feedstock. Two pre-treatments were investigated in this work, including microwave pre-treatment and leaching with ligands at neutral to alkaline pH. The carbon uptake of ultramafic ores was found to increase with increasing microwave pre-treatment after a threshold heating time of 4 min was surpassed. A maximum carbon uptake of 18.3 g CO_2/100 g ore (corresponding to a carbonate conversion of 36.6 [percent]) was observed for microwave pre-treated ore. The increase in carbon uptake was attributed

primarily to the conversion of serpentine to olivine in ultramafic ores that occurs as result of microwave pre-treatment. The effect of five different ligands (catechol, citrate, EDTA, oxalate and tiron) on the carbon uptake of ultramafic ores was investigated. Of the ligands tested, only catechol and tiron were found to both improve the leaching of magnesium from the ores and the quantity of CO_2 stored. A maximum carbon uptake of 9.7 g/100 g ore (corresponding to a carbonate conversion of 19.3 [percent]) was observed for ultramafic ore pre-leached and carbonated in tiron solution at pH 10. This is the first time ligands have been reported to improve the carbon uptake of mineral carbon [storage] feedstock. Although process optimization work was not conducted, both microwave pre-treatment and leaching with ligands at neutral to alkaline pH show promise as ways to lower the cost of MCS." **Erin R. Bobicki, Qingxia Liu, and Zhenghe Xu**, *Minerals Engineering*. (Subscription may be required.)

"APTES grafted ordered mesoporous silica KIT-6 for CO_2 adsorption." The following is the Abstract of this article: "Pure KIT-6 was synthesized using pluronic P123 ($PEO_{20}PPO_{70}PEO_{20}$, mw ~ 5800 Da) surfactant in mild acidic condition. It was functionalized with (3-aminopropyl) triethoxysilane (APTES) by grafting in dry and aqueous solvent at 80 °C. Cubic (Ia3d) structure and uniformity of the adsorbents were analyzed by small angle powder X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM). Physical properties of the adsorbents were characterized by nitrogen adsorption/desorption behavior, infrared spectroscopy (IR) and thermo gravimetric (TG) analysis. CO_2 adsorption/desorption behavior of the adsorbents was studied in a gravimetric analyzer. Optimum amine loading was substantially increased from 1.74 mmol N g^{-1} in dry grafting to 2.75 mmol N g^{-1} in aqueous grafting. The adsorption capacity was also remarkably increased from 0.90 mmol CO_2 g^{-1} (An_K_9.0A) to 1.56 mmol CO_2 g^{-1} (Aq_K_0.20W_9.0A) at 30 °C. The heat of adsorption of the process was in the range of 20–32 kJ mol^{-1}. The adsorbent showed its stability with the adsorption capacity remaining constant over 10 adsorption/desorption cycles." **Rupak Kishor and Aloke Kumar Ghoshal**, *Chemical Engineering Journal*. (Subscription may be required.)

"Molecular dynamics simulation on volume swelling of CO_2–alkane system." The following is the Abstract of this article: "The microscopic mechanism of the volume swelling of CO_2–alkane (decane, octane, hexane and cyclohexane) systems and the effects of temperature, pressure and alkane structure on the volume swelling of CO_2–alkane systems are investigated by performing molecular dynamics simulation. It is shown that the increase in pressure, the reduction in temperature and the straight-chain structure of the alkane are of benefit to the volume swelling of CO_2–alkane systems by calculating the volume swelling coefficient; CO_2 in supercritical state plays a dominant role in the volume swelling of CO_2–alkane systems. The microscopic process of the volume swelling of CO_2–decane system shows that the increase in the average separation distance between decane molecules and the stretch of decane molecules result in the volume swelling of decane as CO_2 dissolve into decane. The calculations of interaction energies in CO_2–decane system indicate that the interaction between CO_2 and decane molecules is responsible for the volume swelling of CO_2–alkane system. Further study on the interaction between CO_2 and decane molecules shows that the dispersion interaction, resulting in the different solubility of CO_2 in alkanes, is the essence of the volume swelling for CO_2–alkane system. This work is a good start on understanding the mechanism of alkane swelling influenced by CO_2 at the molecular level and provides useful information for guiding CO_2 enhancing oil recovery." **Bing Liu, Junqin Shi, Baojiang Sun, Yue Shen, Jun Zhang, Xu Chen, and Muhan Wang**, *Fuel*. (Subscription may be required.)

February 2015

"Carbon dioxide storage in olivine basalts: Effect of ball milling process." The following is the Abstract of this article: "The goal of this study is to propose a cost-effective method for the optimization of the ex situ carbonation of basaltic rocks. The ball milling process was applied to a sample of olivine basalt from the Troodos ophiolite complex (Cyprus) for the first time, in order to fabricate novel nanomaterials for CO_2 storage. The purpose was to accelerate the kinetics of rock–fluid reactions during the carbonation procedure. Various methodologies were used for the characterization of the starting rock

material and the ball-milled samples. Preliminary results reveal that only a few hours of wet ball milling with ethanol as process control agent can induce significant changes to olivine basalt towards improvement of its performance for CO_2 storage. Specifically, CO_2 uptake measurements via the use of the temperature-programmed desorption (TPD) technique indicate that 4 h of ball milling with 50 wt.% ethanol can lead to an enhancement of the carbonation of olivine basalt by 295 [percent]. The experimental results strongly suggest that (i) olivine basalts have important CO_2-storage capacity and are very promising lithotypes for ex situ carbonation, and (ii) the ball milling process provides hopes for its use at an industrial scale as a preparation technique for the safe and permanent ex situ storage of CO_2." **Ioannis Rigopoulos, Klito C. Petallidou, Michalis A. Vasiliades, Andreas Delimitis, Ioannis Ioannou, Angelos M. Efstathiou, and Theodora Kyratsi**, *Powder Technology*. (Subscription may be required.)

"Screening considerations for caprock properties in regards to commercial-scale carbon-sequestration operations." The following is the Abstract of this article: "Risk management of commercial-scale [storage] operations involves comprehensive site characterization of reservoirs, especially with the long-term integrity of low-permeability seals. Even though storage costs are significantly less than those of carbon capture, the variable costs of pipeline transport can have a significant impact in the overall deployment budget for CCS technologies. This is especially valid with existing electrical generating units (EGUs) where CO_2 source–geologic sink matching may not have been considered in siting. It is therefore important to understand all options with source–sink matching, including storage reservoirs nearby EGUs with potentially sub-optimal confining zones. As such, a finely tuned comprehension of the effects of the most relevant caprock characteristics on its integrity during injection and storage will be paramount to ensuring the safety of future operations. This study supports an understanding toward this end first by summarizing the current regulatory framework and industry practices for assessing caprock integrity. After which it defines how pertinent caprock parameters, most notably the thickness of the primary seal layer, affect the principal sealing and [release] mechanisms involved in typical CO_2 injection and storage scenarios. Lastly, all of these analyses are synthesized into a back-of-the-envelope initial screening protocol." **Michael J. Hannon, Jr. and Richard A. Esposito**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

March 2015

"Experimental investigation of trace element dissolution in formation water in the presence of supercritical CO_2 fluid for a potential geological storage site of CO_2 in Taiwan." The following is the Abstract of this article: "The Pliocene Yutengping Sandstone (depth 1642–1882 m) and its overlying caprock shale (depth 1395–1642 m) in Hsinchu City, central Taiwan, were intended for a storage site of CO_2. Formation water was collected from a gas well located at a depth of 1827–1846 m. This study investigated changes in water chemistry and dissolution of trace elements from the sandstone and shale at 25 MPa and 90°C in the presence and absence of supercritical CO_2 ($scCO_2$) over [seven] days. The results showed substantial dissolution of V, Cr, Co, Cu, and Rb from the sandstone and shale into formation water in the presence of $scCO_2$ fluid, while the release of Zn, Se, Mo, and Cd from the sandstone and shale was minimal. Desorption of V, Cr, Mn, Fe, Sr, and Ba was more pronounced from the sandstone than from shale, whereas Co, Ni, Cu, As, and Mo desorbed more from the shale. The concentration of As in formation water increased from 1.4 μg/L to 130 μg/L after in contact with $scCO_2$. Such a high As concentration may present a significant threat to shallow groundwater quality in this region, particularly if [release] along faults and rock fractures in the region occurred." **Jiin-Shuh Jean, Chien-Lih Wang, Hsing-I. Hsiang, Zhaohui Li, Huai-Jen Yang, Wei-Teh Jiang, Kenn-Ming Yang, and Jochen Bundschuh**, *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

"Efficiently Engineering Pore-Scale Processes: The Role of Force Dominance and Topology during Nonwetting Phase Trapping in Porous Media." The following is the Abstract of this article: "[The authors] investigate trapping of a nonwetting (NW) phase, air, within Bentheimer sandstone cores

during drainage-imbibition flow experiments, as quantified on a three dimensional (3D) pore-scale basis via x-ray computed microtomography (x-ray CMT). The wetting (W) fluid in these experiments was deionized water doped with potassium iodide (1:6 by weight). [The authors] interpret these experiments based on the capillary-viscosity-gravity force dominance exhibited by the Bentheimer-air-brine system and compare to a wide range of previous drainage-imbibition experiments in different media and with different fluids. From this analysis, [the authors] conclude that viscous and capillary forces dominate in the Bentheimer-air-brine system as well as in the Bentheimer-supercritical CO_2-brine system. In addition, [the authors] further develop the relationship between initial (post-drainage) NW phase connectivity and residual (post-imbibition) trapped NW phase saturation, while also taking into account initial NW phase saturation and imbibition capillary number. [The authors] quantify NW phase connectivity via a topological measure as well as by a statistical percolation metric. These metrics are evaluated for their utility and appropriateness in quantifying NW phase connectivity within porous media. Here, [the authors] find that there is a linear relationship between initial NW phase connectivity (as quantified by the normalized Euler number) and capillary trapping efficiency; for a given imbibition capillary number, capillary trapping efficiency (residual NW phase saturation normalized by initial NW phase saturation) can decrease by up to 60 [percent] as initial NW phase connectivity increases from low connectivity to high connectivity. [The authors] propose that multiphase fluid-porous medium systems can be *efficiently* engineered to achieve a desired residual state (optimal NW phase saturation) by considering the dominant forces at play in the system along with the impacts of NW phase topology within the porous media, and [the authors] illustrate these concepts by considering supercritical CO_2 [storage] scenarios." **Anna L. Herring, Linnéa Andersson, Steffen Schlüter, Adrian Sheppard, and Dorthe Wildenschild**, *Advances in Water Resources*. (Subscription may be required.)

"Sedimentary reservoir oxidation during geologic CO_2 sequestration." The following is the Abstract of this article: "Injection of [CO_2] into subsurface geologic reservoirs during geologic carbon [storage] (GCS) introduces an oxidizing supercritical CO_2 phase into a subsurface geologic environment that is typically reducing. The resulting redox disequilibrium provides the chemical potential for the reduction of CO_2 to lower free energy organic species. However, redox reactions involving carbon typically require the presence of a catalyst. Iron oxide minerals, including magnetite, are known to catalyze oxidation and reduction reactions of C-bearing species. If the redox conditions in the reservoir are modified by redox transformations involving CO_2, such changes could also affect mineral stability, leading to dissolution and precipitation reactions and alteration of the long-term fate of CO_2 in GCS reservoirs. [The authors] present experimental evidence that reservoirs with reducing redox conditions are favorable environments for the relatively rapid abiotic reduction of CO_2 to organic molecules. In these experiments, an aqueous suspension of magnetite nanoparticles was reacted with supercritical CO_2 under pressure and temperature conditions relevant to GCS in sedimentary reservoirs (95-210°C and ~100 bars of CO_2). Hydrogen production was observed in several experiments, likely caused by Fe(II) oxidation either at the surface of magnetite or in the aqueous phase. Heating of the Fe(II)-rich system resulted in elevated P_{H2} and conditions favorable for the reduction of CO_2 to acetic acid. Implications of these results for the long-term fate of CO_2 in field-scale systems were explored using reaction path modeling of CO_2 injection into reservoirs containing Fe(II)-bearing primary silicate minerals, with kinetic parameters for CO_2 reduction obtained experimentally. The results of these calculations suggest that the reaction of CO_2 with reservoir constituents will occur in two primary stages (1) equilibration of CO_2 with organic acids resulting in mineral-fluid disequilibrium, and (2) gradual dissolution of primary minerals promoting significant CO_2 reduction through the release of Fe(II). The reduction of CO_2 is identified as a new trapping mechanism that could significantly enhance the long-term stability of GCS reservoirs. Identification of reservoir characteristics that promote CO_2 redox transformations could be used as an additional factor in screening geologic reservoirs for GCS." **Laura N. Lammers, Gordon E. Brown, Dennis K. Bird, Randal B. Thomas, Natalie C. Johnson, Robert J. Rosenbauer, and Katherine Maher**, *Geochemica et Cosmochimica Acta*. (Subscription may be required.)

"CO_2 geological storage in olivine rich basaltic aquifers: New insights from reactive-percolation experiments." The following is the Abstract of this article: "To test the impact of fluid flow on the

reactivity of porous (ultra-)mafic rocks, reactive percolation experiments were realized during which CO_2-enriched water was injected at two different injection rates (Q = 0.1 and 1 mL h^{-1}) through sintered analogues of olivine-accumulation zones in basaltic flows at temperature and fluid composition conditions (T = 180°C; $NaHCO_3$ buffered solution) favorable for CO_2-mineralization (carbonation). All experiments resulted in silicate dissolution, carbonate precipitation upstream and (proto-)serpentine formation downstream indicating a decrease in the fluid reactivity along flow paths. The measured bulk carbonation rates ranged from 4 to 7 × 10^{-8} s^{-1}; these values were significantly lower than previously published values of olivine carbonation rate obtained on powders in closed batch and flow-through reactors. [The authors'] study show complex couplings, at pore scale, between fluid flow, localization of reaction zones, and chemical reaction kinetics which in turn control hydrodynamic properties, carbonation rate and efficiency and fluid reactivity. This results in carbonation rates being higher when injection rates are high and permeability ultimately controlling carbonation reactions by limiting fluid input. During experiments, notable changes in permeability occurred for only minor changes in porosity indicating a control by the geometry of the porous network: heterogeneities in the distribution of flow paths favored the localization of precipitated minerals which in turn resulted in the closure of flow paths. This mechanism was particularly efficient at low injection rates. These results imply that controlling the injection rate could allow enhancing/limiting the efficiency of in situ carbonation." **Steve Peuble, Marguerite Godard, Linda Luquot, Muriel Andreani, Isabelle Martinez, and Philippe Gouze**, *Applied Geochemistry*. (Subscription may be required.)

April 2015

"Numerical simulation of porosity and permeability evolution of Mount Simon sandstone under geological carbon sequestration conditions." The following is the Abstract of this article: "A numerical model was developed with the use of reactive transport code CrunchFlow to estimate porosity, permeability and mineral composition changes of Mount Simon sandstone under typical geological carbon [storage] conditions (P = 23.8 MPa and T = 85 °C). The model predicted a permeability decrease from 1.60 mD to 1.02 mD for the Mount Simon sandstone sample in a static batch reactor after 180 days of exposure to CO_2-saturated brine, which is consistent with measured permeability results. Model-predicted solution chemistry results were also consistent with laboratory-measured solution chemistry data. SiO_2 (am) was the primary mineral that causes permeability decrease, followed by kaolinite. Both SiO_2 (am) formation and kaolinite formation were attributed to the dissolution of quartz and feldspar. This study shows that the formation of SiO_2 (am) and kaolinite in the pore space of host rock is possible under typical CO_2 [storage] conditions. SiO_2 (am) and kaolinite precipitation at the CO_2 plume extent could reduce the permeability of host rock and improve lateral containment of free-phase CO_2, contributing to overall security of CO_2 storage." **Liwei Zhang, Yee Soong, Robert Dilmore, and Christina Lopano**, *Chemical Geology*. (Subscription may be required.)

"Fracture permeability and relative permeability of coal and their dependence on stress conditions." The following is the Abstract of this article: "Determination of petro-physical properties of coal bed methane (CBM) reservoirs is essential in evaluating a potential prospect for commercial exploitation. In particular, permeability of coal and relative permeability of coal to gas and water directly impact the amount of hydrocarbons that can be ultimately recovered. Due to the complex and heterogeneous nature of coal seams, proper relative permeability relationships are needed to accurately describe the transport characteristics of coal for reservoir modeling and production forecasting. In this work, absolute and relative permeability of different coal samples were determined experimentally under steady-state flowing conditions. Multiphase flow tests were conducted using brine, helium and [CO_2] as the flowing phases under different magnitudes of confining and pore pressures. Results indicate that effective stress (confining pressure – average pore pressure) has a significant effect on both absolute and relative permeability of coal. With increases in effective stresses, the absolute permeability decreases. Effective permeability and relative permeability, as well as the cross over point and the width of the mobile two-phase region decrease as the effective stress increases. In addition, the mobile range of gas and water in the coal samples investigated corresponds with water saturations above 50 [percent],

irrespective of the base absolute permeability of the sample. In brine–[CO_2] two-phase flow experiments, the effect of [CO_2] adsorption was observed as effective permeabilities decreased in comparison to the helium–brine permeabilities at the same flowing ratios. As a result, relative permeability characteristics of CBM systems were found to be insufficiently represented as sole functions of fluid saturation. Field scale simulations of primary recovery from CBM systems using variable, stress-dependent relative permeabilities, showed a significant decrease in cumulative gas recovered. A multi-dimensional correlation between relative permeability, fluid saturation and specific surface area of the cleat network is proposed as a continuation from this work in order to account for stress-related changes in cleat network connectivity." **Dennis Arun Alexisa, Zuleima T. Karpyn, Turgay Ertekin, and Dustin Crandall**, *Journal of Unconventional Oil and Gas Resources*. (Subscription may be required.)

"Chemical effects of sulfur dioxide co-injection with carbon dioxide on the reservoir and caprock mineralogy and permeability in depleted gas fields." The following is the Abstract of this article: "The most suitable candidates for subsurface storage of CO_2 are depleted gas fields. Their ability to retain CO_2 can however be influenced by the effect which impurities in the CO_2 stream (e.g., H_2S and SO_2) have on the mineralogy of reservoir and seal. In order to investigate the effects of SO_2 [the authors] carried out laboratory experiments on reservoir and cap rock core samples from gas fields in the northeast of the Netherlands. The rock samples were contained in reactor vessels for 30 days in contact with CO_2 and 100 ppm SO_2 under in-situ conditions (300 bar, 100°C). The vessels also contained brine with the same composition as in the actual reservoir. Furthermore equilibrium modeling was carried out using PHREEQC software in order to model the experiments on caprock samples. After the experiments the permeability of the reservoir samples had increased by a factor of 1.2–2.2 as a result of dissolution of primary reservoir minerals. Analysis of the associated brine samples before and after the experiments showed that concentrations of K, Si, and Al had increased, indicative of silicate mineral dissolution. In the caprock samples, composed of carbonate and anhydrite minerals, permeability changed by a factor of 0.79–23. The increase in permeability is proportional to the amount of carbonate in the caprock. With higher carbonate content in comparison with anhydrite the permeability increase is higher due to the additional carbonate dissolution. This dependency of permeability variations was verified by the modeling study. Hence, caprock with a higher anhydrite content in comparison with carbonate minerals has a lower risk of [release] after co-injection of 100 ppmv SO_2 with CO_2." **Panteha Bolourinejad and Rien Herber**, *Applied Geochemistry*. (Subscription may be required.)

May 2015

"Determination of effective stress parameters for effective CO_2 permeability in deep saline [formations]: An experimental study." The following is the Abstract of this article: "[Potential climate change] has been a major threat to the world for many decades, and CO_2 geo-[storage] in deep saline [formations] has recently been identified as an effective solution due to its ability to greatly mitigate anthropogenic CO_2 emissions to the atmosphere. However, CO_2 [storage]-induced chemical and mineralogical reactions affect the hydro-mechanical characteristics of natural formations, resulting in limited injectability to [formations]. A detailed knowledge of the hydro-mechanical [behavior] of natural formations is therefore important to enhance the safety and effectiveness of the CO_2 storage process. Such understanding can only be gained on the basis of in-depth knowledge of the applied effective stresses on the formations. The aim of this study was therefore to understand the effect of reservoir salinity level on the effective stress parameters of deep saline [formation] rock under various in-situ conditions, including salinity levels ranging from 0 to 30 [percent] (NaCl concentration by weight) and confining pressures ranging 20–35 MPa. Tri-axial permeability tests were conducted for a range of injection pressures (1–12 MPa) under different confining pressures (20, 25, 30 and 35 MPa) at 35°C constant temperature. Comprehensive SEM (scanning electron microscopy) and acoustic emission analyses were also conducted to clarify the observed results. According to the results, the effective stress coefficient (α) for CO_2 permeability decreases with increasing [formation] salinity level, and increasing salinity level from 0 to 30 [percent] causes the effective stress coefficient to be reduced by 31 [percent]. Moreover, the Skempton coefficient (B) increases with increasing salinity level from 0 to 30

[percent] and the increment is about 18 [percent]. Interestingly, the poro-elastic coupling parameter (αB) decreases from 0.89 to 0.72 as the salinity level increases from 0 to 30 [percent] and the reduction is about 19 [percent]. The SEM analysis conducted on tested samples confirmed the deposition of NaCl crystals in rock pore space during the saturation period of one year, and these observed variations in effective stress parameters are probably due to the NaCl crystal deposition in the rock pore space. This significantly alters the rock porosity and pore geometry, causing the simple effective stress law for CO_2 permeability to be inapplicable to saline [formations]." **T.D. Rathnaweera, P.G. Ranjith, M.S.A. Perera, and S.Q. Yang**, *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

"Co-[storage] of SO_2 with supercritical CO_2 in carbonates: An experimental study of capillary trapping, relative permeability, and capillary pressure." The following is the Abstract of this article: "In this study [the authors] performed three categories of steady- and unsteady-state core-flooding experiments to investigate capillary trapping, relative permeability, and capillary pressure, in a $scCO_2$ + SO_2/brine/limestone system at elevated temperature and pressure conditions, i.e., 60°C and 19.16 MPa. [The authors] used a Madison limestone core sample acquired from the Rock Springs Uplift in southwest Wyoming. [The authors] carried out two sets of steady-state drainage-imbibition relative permeability experiments with different initial brine saturations to study hysteresis. [The authors] found that the final $scCO_2$ + SO_2 drainage relative permeability was very low, i.e., 0.04. [The authors] also observed a rapid reduction in the $scCO_2$-rich phase imbibition relative permeability curve, which resulted in a high residual trapping. The results showed that between 62.8 [percent] and more than 76 [percent] of the initial $scCO_2$ + SO_2 at the end of drainage was trapped by capillary trapping mechanism (trapping efficiency). [The authors] found that at higher initial brine saturations, the trapping efficiency was higher. The maximum initial and residual $scCO_2$-rich phase saturations at the end of primary drainage and imbibition were 0.525 and 0.329, respectively. Each drainage-imbibition cycle was followed by a dissolution process to re-establish Sw = 1. The dissolution brine relative permeabilities for both cycles were also obtained. [The authors] characterized the $scCO_2$ + SO_2/brine capillary pressure hysteresis behavior through unsteady-state primary drainage, imbibition, and secondary drainage experiments. [The authors] observed negative imbibition capillary pressure curve indicative of possible wettability alteration throughout the experiments due to contact with $scCO_2$ + SO_2/brine fluid system. The trapping results were compared to those reported in literature for other carbonate core samples. [The authors] noticed slightly more residual trapping in [their] sample, which might be attributed to heterogeneity, different viscosity ratio, and pore-space topologies. The impact of dynamic effects, i.e., high brine flow rate imbibition tests, on trapping of the $scCO_2$-rich phase was also explored. [The authors] performed two imbibition experiments with relatively high brine flow rates. The residual $scCO_2$ saturation dropped to 0.291 and 0.262 at the end of the first and second imbibition tests, i.e., 11.5 [percent] and 20.4 [percent], respectively, compared to 0.329 under capillary-dominated regime." **Morteza Akbarabadi and Mohammed Piri**, *Advances in Water Resources*. (Subscription may be required.)

"Salt precipitation and CO_2/brine flow distribution under different injection well completions." The following is the Abstract of this article: "[CCS] is a viable technology to reduce the concentration of CO_2 emitted to the atmosphere. Salt precipitation due to dry-supercritical CO_2 causes a reduction of permeability, having adverse effects on well injectivity and pressure build-up. This study evaluated the salt precipitation, brine flux patterns, and pressure build-up for two well constructions, (1) partially perforated (4 injection intervals) and (2) fully perforated throughout the target formation. Both well designs showed non-localized salt precipitation in low-k formations (5×10^{-15} and 50×10^{-15} m^2) and localized precipitation in high-k (250×10^{-15} and 500×10^{-15} m^2). It was also found that two distinct brine flux patterns occurred; under low-k conditions the brine flux was outward and parallel to CO_2 migration and precipitation became limited. While under high-k conditions there developed back-flow of the brine which amplified salt precipitation. When this process occurred, the permeability reduction was orders of magnitude greater than when non-localized salt precipitation occurred. This reduction resulted in pressure build-up near the well in regions of the reservoir in which it occurred. Optimal injection conditions were found to be in reservoirs of mid-range permeability; which allowed for adequate pressure dissipation and minimized salt precipitation." **Ethan Guyant, Weon Shik Han, Kue-Young Kim, Myong-**

Ho Park, and Byoung-Yeop Kim, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Factors controlling permeability of cataclastic deformation bands and faults in porous sandstone reservoirs." The following is the Abstract of this article: "Improving the prediction of sub-seismic structures and their petrophysical properties is essential for realistic characterization of deformed sandstone reservoirs. In the present paper, [the authors] describe permeability contrasts induced by cataclastic deformation bands and faults in porous sandstones (766 data synthesized from field examples and the literature). [The authors] also discuss the influence of several factors, including tectonic regime, presence of a fault, burial depth, host sandstone porosity, and grain size and sorting for their initiation and permeability. This analysis confirms that permeability decrease is as a function of grain-crushing intensity in bands. Permeability reduction ranges from very limited in crush-microbreccia of compaction bands to high permeability reduction in cataclasites and ultracataclasites of shear-dominated bands, band clusters and faults. Tectonic regime, and especially normal-fault regime, with its tendency to localize strain and generate faults, is identified as the most important factor, leading to the formation of cataclastic bands with high permeability contrasts. Moreover, moderate burial depth (1 – 3 km) favors cataclastic bands with high permeability contrasts with respect to the host sandstone. High porosity, coarse-grain size and good grain sorting can slightly amplify the permeability reductions recorded in bands." **Gregory Ballas, Haakon Fossen, and Roger Soliva**, *Journal of Structural Geology*. (Subscription may be required.)

June 2015

"Rates of mineral dissolution under CO_2 storage conditions." The following is the Abstract of this article: "Evaluating the potential of a sedimentary basin reservoir to securely store CO_2 benefits from a comprehensive understanding of the geochemical reactions that take place once CO_2 is injected into a formation. In particular, models that predict the transport and reaction of CO_2 within a reservoir require a definition of the types of reactions affected by enhanced levels of CO_2 and how the kinetics of these reactions will affect a heterogeneous mineralogy and formation waters within a reservoir over time. In this review [the authors] evaluate rate models used to describe mineral dissolution kinetics and compare the range in values reported for the kinetic parameters used to describe the reactivity of various minerals relevant to mainly siliciclastic reservoirs. Parameters that have a significant impact on model results include the reactive surface area of a mineral, the apparent activation energies used to extrapolate reaction rates to the temperatures of potential storage reservoirs (c. 50–125°C) and the in-situ pH of formation waters with elevated concentrations of dissolved CO_2. The variation in reported values for these parameters can lead to predicted rates that span many orders of magnitude for a given mineral. Despite these uncertainties recent success with geochemical models has been made by applying a Monte Carlo approach to [optimize] the kinetic parameters for minerals where robust thermodynamic and kinetic data do not exist." **Jay R. Black, Susan A. Carrol, and Ralf R. Haese**, *Chemical Geology*. (Subscription may be required.)

"The Pretty Hill Formation as a natural analogue for CO_2 storage: An investigation of mineralogical and isotopic changes associated with sandstones exposed to low, intermediate and high CO_2 concentrations over geological time." The following is the Abstract of this article: "The Pretty Hill Formation of the Otway Basin (Australia) has been studied as a natural analogue for geological storage of anthropogenic CO_2 in order to examine the effects that CO_2 concentration and reservoir heterogeneity have on CO_2-related reactions. New petrographic data are presented, which validate the use of Hylogger™ as a tool to investigate high-resolution vertical changes in reservoir mineralogy. The integrated data set confirms earlier interpretations, showing that chlorite has been altered to kaolinite and siderite/ankerite in reservoir facies exposed to moderate and high CO_2 concentrations, while chlorite remains the dominant clay mineral in all parts of the formation where CO_2 content is low. Differences have been observed in the degree of CO_2-related reaction relative to CO_2 concentration and reservoir heterogeneity. Where CO_2 content is very high (c. 98 mol%) and associated

with high water saturations, both chlorite and detrital feldspars have undergone complete reaction in the reservoir facies, resulting in quartzose sandstones with a kaolinite matrix, and with siderite as the dominant carbonate precipitate. Conversely, where CO_2 content is moderate (c. 29–57 mol%) and within the gas leg of the reservoir, chlorite has undergone significant reaction, but much of the original feldspar is preserved, suggesting relatively minor reaction. Carbonate cements from the moderate CO_2 gas-leg comprise calcite, siderite and ankerite, occurring as cemented zones associated with rock heterogeneities and the present-day gas–water contact. Heterogeneities within the gas-leg are likely to have associated pore fluid contacts, whereby relatively high water saturations will be present in the fine-grained baffles and seals. The most advanced feldspar reaction occurs locally at the contact between baffles and reservoir rock, while reactions have been significantly impeded in the finer grained units due to their low permeabilities. Stable isotope data presented for carbonate cements [analyzed] from wells with low and moderate CO_2 levels show no clear distinction. Relatively early formed calcite has $\delta^{13}C$ values that require an organic carbon source, suggesting precipitation unrelated to the reservoir CO_2 in the Otway Basin. In contrast, diagenetically late calcite and siderite samples display two distinct $\delta^{13}C$ groups (dependent on carbonate type), where the calculated fluid carbon isotope compositions are similar to documented magmatic CO_2 reservoired in the nearby Caroline Field. This suggests that magma-derived CO_2 may have been more prevalent through the Pretty Hill Formation than previously thought. Although the CO_2 has not been contained over the long term in the low CO_2 sites, it may have caused the local dissolution of carbonate and laumontite cement, and also contributed a source of carbon for late-stage calcite cements. These studies illustrate the importance of understanding both the reservoir composition and vertical heterogeneity of potential storage systems. Fluid–mineral reactions are likely to be advanced within stacked reservoir facies and impeded within siltstone layers, while the distribution of carbonate cement may increase the reservoir heterogeneity by the formation of cemented siltstone/sandstone layers, thereby creating impermeable barriers or baffles to CO_2." **K.E. Higgs, R.R. Haese, S.D. Golding, U. Schacht, and M.N. Watson**, *Chemical Geology*. (Subscription may be required.)

July 2015

"Permeability characteristics of mudstone cap rock and interlayers in bedded salt formations and tightness assessment for underground gas storage caverns." The following is the Abstract of this article: "Permeability of nonsaline cap rock and interlayers is a key parameter for the assessment of the tightness of gas storage caverns in bedded salt formations. X-ray Diffraction, permeability tests, Scanning Electron Microscope studies and theoretical analyses have been performed for the mudstone cap rock and interlayers of a potential cavern in a bedded salt formation. The results show that the permeability of cap rock and interlayers is in the range of 10^{-18}–10^{-20} m^2, whereas the interface in between salt and interlayer behaves as if impervious. Applied confinement conditions significantly affect the permeability. The higher the applied hydrostatic pressure, the lower the permeability. Permeability decreases more than one order of magnitude with hydrostatic pressure increases, up to a certain 'compression threshold pressure'. Permeability remains virtually constant, at an extremely low magnitude, once the hydrostatic pressure exceeds this 'compression threshold pressure'. The intrinsic reasons for the low permeability have been revealed by SEM studies, and are as follows: (1) the grains making up the bulk of the mudstone are very small and extremely tightly cemented; secondary minute clay minerals completely fill the pores and fissures between grains of quarts and feldspar, etc., resulting in very little residual void space and reducing connectivity for fluid penetration; and (2) the boundaries between quartz, feldspar and other grains are mainly plate-shape cracks that are poorly interconnected while the finer matrix is very tight and crack-free. The mechanical compaction investigation shows that the plate-shape cracks are much easier to be compacted than sphere-shape pores, which contributes significantly to the decrease in permeability. A capillary tube model suggests that permeability decreases very rapidly in the initial stages of compaction, but decreases extremely slowly in subsequent stages. So the permeability obviously behaves differently before and after the 'compression threshold pressure'. By comparison with previous studies, the research [the authors] launched demonstrates that the cap rock and interlayers are characterized by extremely low permeability in compression regions. Hence the

requirements of tightness (except for the possible presence of Excavation Disturbed Zones) are basically guaranteed. Also, a recommendation is expressed as: to ensure higher tightness and safety, reasonable design and operating programs should be adopted to reduce the EDZs as much as possible." **Wei Liu, Yinping Li, Chunhe Yang, Jaak J.K. Daemen, Yun Yang, and Guimin Zhang**, *Engineering Geology*. (Subscription may be required.)

"Pore network quantification of sandstones under experimental CO_2 injection using image analysis." The following is the Abstract of this article: "Automated-image identification and quantification of minerals, pores and textures together with petrographic analysis can be applied to improve pore system characterization in sedimentary rocks. [The authors'] case study is focused on the application of these techniques to study the evolution of rock pore network subjected to super critical CO_2-injection. [The authors] have proposed a Digital Image Analysis (DIA) protocol that guarantees measurement reproducibility and reliability. This can be summarized in the following stages: (i) detailed description of mineralogy and texture (before and after CO_2-injection) by optical and scanning electron microscopy (SEM) techniques using thin sections; (ii) adjustment and calibration of DIA tools; (iii) data acquisition protocol based on image capture with different polarization conditions (synchronized movement of polarizers); (iv) study and quantification by DIA that allow (a) identification and isolation of pixels that belong to the same category: minerals vs. pores in each sample and (b) measurement of changes in pore network, after the samples have been exposed to new conditions (in [the authors'] case: SC–CO_2-injection). Finally, interpretation of the petrography and the measured data by an automated approach were done. In [the authors'] applied study, the DIA results highlight the changes observed by SEM and microscopic techniques, which consisted in a porosity increase when CO_2 treatment occurs. Other additional changes were minor: variations in the roughness and roundness of pore edges, and pore aspect ratio, shown in the bigger pore population. Additionally, statistic tests of pore parameters measured were applied to verify that the differences observed between samples before and after CO_2-injection were significant." **Edgar Berrezueta, Luís González-Menéndez, Berta Ordóñez-Casado, and Peter Olaya**, *Computers & Geosciences*. (Subscription may be required.)

August 2015

"Kinetics of CO_2-fluid-rock reactions in a basalt [formation], Soda Springs, Idaho." The following is the Abstract of this article: "The dissolution of silicate minerals by CO_2-rich fluids and the subsequent precipitation of CO_2 as carbonate minerals represent a means of permanently storing anthropogenic CO_2 waste products in a solid and secure form. Modelling the progression of these reactions is hindered by poor understanding of the rates of mineral dissolution–precipitation reactions and mineral surface properties in natural systems. This study evaluates the chemical evolution of groundwater flowing through a basalt [formation], which forms part of the [releasing] CO_2-charged system of the Blackfoot Volcanic Field in south-eastern Idaho, USA. Reaction progress is modelled using changes in groundwater chemistry by inverse mass balance techniques. The CO_2-promoted fluid–mineral reactions include the dissolution of primary plagioclase, orthoclase, pyroxene and gypsum which is balanced by the precipitation of secondary albite, calcite, zeolite, kaolinite and silica. Mineral mole transfers and groundwater flow rates estimated from hydraulic head data are used to determine the kinetics of plagioclase and orthoclase feldspar dissolution. Plagioclase surface area measurements were determined using the evolution of the U-series isotope ratios in the groundwater and are compared to published surface area measurements. Calculated rates of dissolution for plagioclase range from 2.4×10^{-12} to 4.6×10^{-16} mol/m^2/s and orthoclase from 2.0×10^{-13} to 6.8×10^{-16} mol/m^2/s respectively. These feldspar reaction rates, correlate with the degree of mineral–fluid disequilibrium and are similar to the dissolution rates for these mineral measured in other natural CO_2-charged groundwater systems." **Alexandra Maskell, Niko Kampman, Hazel Chapman, Daniel J. Condon, and Mike Bickle**, *Applied Geochemistry*. (Subscription may be required.)

"Environmental considerations for subseabed geological storage of CO_2: A review." The following is the Abstract of this article: "Many countries are now using or investigating offshore geological storage

of CO_2 as a means to reduce atmospheric CO_2 emissions. Although associated research often focuses on deep-basin geology (e.g. seismic, geomagnetics), environmental data on the seabed and shallow subseabed is also crucial to (1) detect and [characterize] potential indicators of fluid seeps and their potential connectivity to targeted storage reserves, (2) obtain baseline environmental data for use in future monitoring, and (3) acquire information to facilitate an improved understanding of ecosystem processes for use in impact prediction. This study reviews the environmental considerations, including potential ecological impacts, associated with subseabed geological storage of CO_2. Due to natural variations in CO_2 levels in seafloor sediments, baseline CO_2 measurements and knowledge of physical–chemical processes affecting the regional distribution of CO_2 and pH are critical for the design of appropriate monitoring strategies to assess potential impacts of CO_2 seepage from subseabed storage reservoirs. Surficial geological and geophysical information, such as that acquired from multibeam sonar and sub-bottom profiling, can be used to investigate the connectivity between the deep reservoirs and the surface, which is essential in establishing the reservoir containment properties. [Carbon dioxide release] can have a pronounced effect on sediments and rocks which in turn can have carryover effects to biogeochemical cycles. The effects of elevated CO_2 on marine organisms are variable and species-specific but can also have cascading effects on communities and ecosystems, with marine benthic communities at some natural analogue sites (e.g. volcanic vents) showing decreased diversity, biomass, and trophic complexity. Despite their potential applications, environmental surveys and data are still not a standard and integral part of subseabed CO_2 storage projects. However, the habitat mapping and seabed [characterization] methodology that underpins such surveys is well developed and has a strong record of providing information to industry and decision makers. This review provides recommendations for an integrated and interdisciplinary approach to offshore geological storage of CO_2, which will benefit national programs and industry and will be valuable to researchers in a broad range of disciplines." **A.G. Carroll, R. Przeslawski, L.C. Radke, J.R. Black, K. Picard, J.W. Moreau, R.R. Haese, and S. Nichol**, *Continental Shelf Research*. (Subscription may be required.)

Technology

September 2014

"Passive injection: A strategy for mitigating reservoir pressurization, induced seismicity and brine migration in geologic CO_2 storage." The following is the Abstract of this article: "Many technical, regulatory and public perception challenges remain to be addressed before large-scale deployment of CO_2 geologic storage becomes a reality. Two major risks associated with injection of CO_2 into the subsurface are the possibility of induced earthquakes compromising long-term seal integrity, and the displacement of saline brines resulting in contamination of shallow groundwater. Both induced seismicity and brine migration are caused by elevated pressures in the storage formation owing to the relative incompressibility of water. Here, [the authors] describe a strategy, termed passive injection that can be used to inject large amounts of CO_2 in a storage formation with no increase, temporary or long-term, in reservoir pressure. Passive injection relies on the strategic placement of brine production wells to create negative pressure gradients that result in CO_2 entering the formation at ambient pressure. Injection occurs at the intersection of pressure-depth profiles for a surface-pressurized, low-density CO_2 column and a hydrostatic column of formation fluid. A multi-stage, square-ring well configuration is envisaged, in which brine production wells are repurposed for CO_2 injection upon CO_2 breakthrough, and the next concentric ring of production wells installed at a greater distance. Numerical simulations of passive injection are presented using the coupled thermo-hydro-mechanical (THM), multi-fluid, multi-phase numerical simulator FEHM. [The authors] consider CO_2 injection into a 3 km-deep, closed reservoir over a period of 50 years, with up to four stages of injection and production depending on well-spacing and production pressures. Storage rates as high as 4 Mt yr^{-1} at 70 [percent] utilization of the reservoir pore volume are achieved under optimum conditions. Long-term mass production of brine is approximately 1.7 times that of CO_2 [stored]. Geomechanical effects due to reservoir drawdown, cooling near injection wells, and surface subsidence are modeled. The risk of induced seismicity is quantified in terms of the

Coulomb Failure Stress (CFS) for an optimally oriented fault in an extensional tectonic regime. Injection and production-induced changes in pressure and CFS confirm that, both during and at the conclusion of injection, (i) reservoir pressure is everywhere less than or equal to its initial value; and (ii) the risk of induced seismicity is everywhere reduced or unchanged. Thus, the primary risks of brine migration outside the primary reservoir and induced seismicity compromising seal integrity are neutralized. Passive injection produces large quantities of brine, the treatment and disposal of which represents an additional economic burden to CO_2 geologic storage operations. Unless additional revenue streams or economies of scale can be leveraged, these costs are likely to limit the viability of the proposed scheme to only the most economically favorable sites." **David Dempsey, Sharad Kelkar, and Rajesh Pawar**, *International Journal of Green Gas Control*. (Subscription may be required.)

"Modeling of the pressure propagation due to CO_2 injection and the effect of fault permeability in a case study of the Vedsted structure, Northern Denmark." The following is the Abstract of this article: "Assessing the pressure buildup in CO_2 storage sites and especially the vertical propagation is vital for evaluation of site behavior and security. Vedsted structure in the Northern part of Jylland in Denmark consists of 290 m thick Gassum Formation at 2100 m depth forming the primary reservoir and is sealed by the 530 m thick Fjerritslev Formation which is mainly shale lithology with very low permeability. Overlying the caprock is a number of formations forming secondary reservoirs and seals including a 420 m thick Chalk Group which is overlain by 20–50 m Quaternary deposits. Seismic profiling of the structure shows the presence of northwest-southeast trending faults of which some originate in the upper layer of the Gassum reservoir and some reach the base Chalk Group layer. Two faults in the upper Gassum reservoir have been interpreted to be connected to the base Chalk Group. In order to evaluate potential risks associated with vertical pressure transmission via the faults through the caprock, a number of simulation cases have been run with various fault permeabilities spanning orders of magnitude to represent both the worst and best case scenarios. Fault rock permeability data were obtained from a literature study and range from 1000 mD (maximum value reported from sedimentary rock environment) for the worst case scenario down to 0.001 mD (sealing faults in sedimentary rock environment) for the best case scenario. The results show that after injecting 60 million tons (Mt) of CO_2 at a rate of 1.5 Mt/year for 40 years, overpressure is developed in the reservoir and about 5 bar is transmitted to the base Chalk Group for the 1000 mD fault permeability (open fault) case, while for the 0.001 mD (sealing fault) case the pressure buildup is confined within the primary caprock. The results also show that, approximately 0.3–5.0 bar overpressure can be transmitted to the base Chalk Group when the fault permeability is above 1.0 mD." **Ernest N. Mbia, Peter Frykman, Carsten M. Nielsen, Ida L. Fabricius, Gillian E. Pickup, and Ann T. Sørensen**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Uncertainty quantification for the impact of injection rate fluctuation on the geomechanical response of geologic carbon sequestration." The following is the Abstract of this article: "[The authors] present an analysis of the geomechanical effects of injection rate fluctuations for geological [storage] of CO_2. Initially, [the authors] present analytical solutions for the effects of injection rate fluctuations on CO_2 fluid pressure spatial distribution and temporal evolution for a typical injection scenario. Numerical calculations are performed using a finite element method to investigate the effects of injection rate fluctuations on geomechanical deformation, stresses, and potential failure of the [formation] and caprock layers. The numerical method was first validated by the fluid pressure distribution's good agreement with the analytical solution…The proportional constants are identified, and the fluctuations have the most pronounced effect on the geomechanical stresses, and, therefore, on the potential failure of the [formation] and caprock layers. Instead of expensive computational simulation, this study provides an efficient tool to estimate the geomechanical response variance to injection rate fluctuation. A failure analysis was presented based on the numerical results, where probability of failure was estimated for fluctuating injection rates with different mean and variance during the entire injection period. It was found that with increasing injection rate fluctuation, the failure probability increases significantly. Therefore, the risk associated with injection rate fluctuations should be carefully evaluated." **Bao J, Y Chu, Z Xu, AM**

Tartakovsky, and Y Fang, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

October 2014

"Regional Assessment of CO_2-Solubility Trapping Potential: A Case Study of the Coastal and Offshore Texas Miocene Interval." The following is the Abstract of this article: "This study presents a regional assessment of CO_2-solubility trapping potential (CSTP) in the Texas coastal and offshore Miocene interval, comprising lower, middle, and upper Miocene sandstone. Duan's solubility model was applied to estimate carbon content in brine saturated with CO_2 at reservoir conditions. Three approaches (simple, coarse, and fine) were used to calculate the CSTP. The estimate of CSTP in the study area varies from 30 Gt to 167 Gt. Sensitivity analysis indicated that the CSTP in the study area is most sensitive to storage efficiency, porosity, and thickness and is least sensitive to background carbon content in brine. Comparison of CSTP in [the authors'] study area with CSTP values for seven other saline [formations] reported in the literature showed that the theoretical estimate of CO_2-solubility trapping potential (TECSTP) has a linear relationship with brine volume, regardless of brine salinity, temperature, and pressure. Although more validation is needed, this linear relationship may provide a quick estimate of CSTP in a saline [formation]. Results of laboratory experiments of brine-rock–CO_2 interactions and the geochemical model suggest that, in the study area, enhancement of CSTP caused by interactions between brine and rocks is minor and the storage capacity of mineral trapping owing to mineral precipitation is relatively trivial." **Changbing Yang, Ramón H. Treviño, Tongwei Zhang, Katherine D. Romanak, Kerstan Wallace, Jiemin Lu, Patrick J. Mickler, and Susan D. Hovorka**, *Environ. Sci. Technol.* (Subscription may be required.)

"Coal bed reservoir simulation with geostatistical property realizations for simultaneous multi-well production history matching: A case study from Illinois Basin, Indiana, USA." The following is the Abstract of this article: "Coal seam degasification is a means to recover energy from the methane gas retained in coal, and is also a supplementary measure to ventilation, which is proven to be one of the most effective ways to reduce methane emissions to a safe level in coal mines. Reservoir simulation is probably the most effective way to assess the coal seam as a 'gas reservoir' and thereby its fluid-storage and flow-related properties. This objective is achieved by taking advantage of history matching of wellbore production. Reservoir simulation with multi-well history matching is a tedious process as important coal properties that affect wells' production characteristics are spatially variable across the seam. The common practice is to change various properties at the well blocks during the history matching process, and assume that they are uniform across the domain of interest. This process, however, often does not produce realistic and effective results for well or coal reservoir management. In this work, a multi-level approach to coal bed reservoir simulation is demonstrated for a group of coalbed methane wells in the Illinois Basin producing from the Seelyville Coal Member of the Linton Formation of the Carbondale Group (Pennsylvanian) in Indiana. This approach includes, in order, gas and water deliverability analyses of wells, geostatistical simulation and co-simulation, and coal bed reservoir simulation. It is shown that a reservoir model, which utilizes the geostatistical maps of important coal properties, is effective for simultaneous history matching of all wells, and eliminates the need for guessing and changing values of coal properties at and around individual well blocks. This methodology also provides realistic distributions of reservoir parameters and how they change during gas depletion, and thus aids in coal seam and coal gas management." **C. Özgen Karacan, Agnieszka Drobniak, and Maria Mastalerz**, *International Journal of Coal Geology*. (Subscription may be required.)

"Comparative life cycle assessment of biomass co-firing plants with carbon capture and storage." The following is the Abstract of this article: "Combining co-firing biomass and CCS in power plants offers attractive potential for net removal of CO_2 from the atmosphere. In this study, the impact of co-firing biomass (wood pellets and straw pellets) on the emission profile of power plants with [CCS] has been assessed for two types of coal-fired power plants: a supercritical [pulverized] coal power plant (SCPC) and an integrated gasification combined cycle plant (IGCC). Besides, comparative life cycle

assessments have been performed to examine the environmental impacts of the combination of co-firing biomass and CCS. Detailed calculations on mass balances of the inputs and outputs of the power plants illustrate the effect of the different content of pollutants in biomass on the capture unit. Life cycle assessment results reveal that 30 [percent] co-firing biomass and applying CCS net negative CO_2 emissions in the order of 67–85 g/kWh are obtained. The impact in all other environmental categories is increased by 20–200 [percent]. However, aggregation into endpoint levels shows that the decrease in CO_2 emissions more than offsets the increase in the other categories. Sensitivity analyses illustrate that results are most sensitive to parameters that affect the amount of fuel required, such as the efficiency of the power plant and assumptions regarding the supply chains of coal and biomass. Especially, assumptions regarding land use allocation and carbon debt of biomass significantly influence the environmental performance of BioCCS." **Wouter Schakel, Hans Meerman, Alireza Talaei, Andrea Ramírez, and André Faaij**, *Applied Energy*. (Subscription may be required.)

"Probabilistic electrical resistivity tomography of a CO_2 sequestration analog." The following is the Abstract of this article: "Electrical resistivity tomography (ERT) is a well-established method for geophysical characterization and has shown potential for monitoring geologic CO_2 [storage], due to its sensitivity to electrical resistivity contrasts generated by liquid/gas saturation variability. In contrast to deterministic inversion approaches, probabilistic inversion provides the full posterior probability density function of the saturation field and accounts for the uncertainties inherent in the petrophysical parameters relating the resistivity to saturation. In this study, the data are from benchtop ERT experiments conducted during gas injection into a quasi-2-D brine-saturated sand chamber with a packing that mimics a simple anticlinal geological reservoir. The saturation fields are estimated by Markov chain Monte Carlo inversion of the measured data and compared to independent saturation measurements from light transmission through the chamber. Different model parameterizations are evaluated in terms of the recovered saturation and petrophysical parameter values. The saturation field is parameterized (1) in Cartesian coordinates, (2) by means of its discrete cosine transform coefficients, and (3) by fixed saturation values in structural elements whose shape and location is assumed known or represented by an arbitrary Gaussian Bell structure. Results show that the estimated saturation fields are in overall agreement with saturations measured by light transmission, but differ strongly in terms of parameter estimates, parameter uncertainties and computational intensity. Discretization in the frequency domain (as in the discrete cosine transform parameterization) provides more accurate models at a lower computational cost compared to spatially discretized (Cartesian) models. *A priori* knowledge about the expected geologic structures allows for non-discretized model descriptions with markedly reduced degrees of freedom. Constraining the solutions to the known injected gas volume improved estimates of saturation and parameter values of the petrophysical relationship." **Tobias Lochbühler, Stephen J. Breen, Russell L. Detwiler, Jasper A. Vrugt,and Niklas Lindea**, *Journal of Applied Geophysics*. (Subscription may be required.)

"Mobilization and Transport of Organic Compounds from Reservoir Rock and Caprock in Geological Carbon Sequestration Sites." The following is the Abstract of this article: "Supercritical CO_2 ($scCO_2$) is an excellent solvent for organic compounds, including benzene, toluene, ethyl-benzene, and xylene (BTEX), phenols, and polycyclic aromatic hydrocarbons (PAHs). Monitoring results from geological carbon sequestration (GCS) field tests has shown that organic compounds are mobilized following CO_2 injection. Such results have raised concerns regarding the potential for groundwater contamination by toxic organic compounds mobilized during GCS. Knowledge of the mobilization mechanism of organic compounds and their transport and fate in the subsurface is essential for assessing risks associated with GCS. Extraction tests using $scCO_2$ and methylene chloride (CH_2Cl_2) were conducted to study the mobilization of volatile organic compounds (VOCs, including BTEX), the PAH naphthalene, and n-alkanes (n-C20 – n-C30) by $scCO_2$ from representative reservoir rock and caprock obtained from depleted oil reservoirs and coal from an enhanced coal-bed methane recovery site. More VOCs and naphthalene were extractable by $scCO_2$ compared to the CH2Cl2 extractions, while $scCO_2$ extractable alkane concentrations were much lower than concentrations extractable by CH2Cl2. In addition, dry $scCO_2$ was found to extract more VOCs than water saturated $scCO_2$, but water saturated

$scCO_2$ mobilized more naphthalene than dry $scCO_2$. In sand column experiments, moisture content was found to have an important influence on the transport of the organic compounds. In dry sand columns the majority of the compounds were retained in the column except benzene and toluene. In wet sand columns the mobility of the BTEX was much higher than that of naphthalene. Based upon results determined for the reservoir rock, caprock, and coal samples studied here, the risk to [formations] from contamination by organic compounds appears to be relatively low; however, further work is necessary to fully evaluate risks from depleted oil reservoirs." **Zhong L, KJ Cantrell, AV Mitroshkov, and JL Shewell**, *Environmental Earth Sciences.* (Subscription may be required.)

November 2014

"Conceptual Process Design of CO_2 Recovery Plants for Enhanced Oil Recovery Applications." The following is the Abstract of this article: "Processes for recovering CO_2 from CO_2-rich gas are important in the CO_2 EOR field. From an environmental point of view EOR through the injection of CO_2 is very beneficial because it allows for the storage of part of the CO_2 injected while increasing oil recovery. To make this process even more environmentally friendly, the fraction of CO_2 which exits (is produced from) the oil well can be captured and recycled for reinjection giving a more efficient CO_2 storage strategy. The mixture of gases produced from an oil well contains light hydrocarbons, heavy hydrocarbons, water, and CO_2. Dehydration units and numerous other separation units for separating CO_2 and hydrocarbons can be used to recover CO_2, so various potential configurations should be investigated to find the one which is most appropriate. In this study, the TEG (triethylene glycol) and adsorption dehydration processes are used for gas dehydration and a combination of amine, Selexol and distillation processes are used for CO_2 separation. Unisim is used to simulate the processes and they are evaluated economically in terms of plant installation costs and energy consumption. A case study is presented to demonstrate the feasibility of various design configurations." **Dong-Hun Kwak, Donghyun Yun, Michael Binns, Yeong-Koo Yeo, and Jin-Kuk Kim**, *Ind. Eng. Chem. Res.* (Subscription may be required.)

"In Situ ^{13}C and ^{23}Na Magic Angle Spinning NMR Investigation of Supercritical CO_2 Incorporation in Smectite-Natural Organic Matter Composites." The following is the Abstract of this article: "This paper presents an in situ NMR study of clay-natural organic polymer systems (a hectoritehumic acid [HA] composite) under CO_2 storage reservoir conditions (90 bars CO_2 pressure, 50°C). The ^{13}C and ^{23}Na NMR data show that supercritical CO_2 interacts more strongly with the composite than with the base clay and does not react to form other C-containing species over several days at elevated CO_2. With and without organic matter, the data suggest that CO_2 enters the interlayer space of Na-hectorite equilibrated at 43 [percent] relative humidity. The presence of supercritical CO_2 also leads to increased ^{23}Na signal intensity, reduced line width at half height, increased basal width, more rapid ^{23}Na T_1 relaxation rates, and a shift to more positive resonance frequencies. Larger changes are observed for the hectorite-HA composite than for the base clay. In light of recently reported MD simulations of other polymer-Na-smectite composites, [the authors] interpret the observed changes as an increase in the rate of Na^+ site hopping in the presence of supercritical CO_2, the presence of potential new Na^+ sorption sites when the humic acid is present, and perhaps an accompanying increase in the number of Na^+ ions actively involved in site hopping. The results suggest that the presence of organic material either in clay interlayers or on external particle surfaces can significantly affect the behavior of supercritical CO_2 and the mobility of metal ions in reservoir rocks." **Bowers GM, DW Hoyt, SD Burton, BO Ferguson, T Varga, and RJ Kirkpatrick**, *Journal of Physical Chemistry*. (Subscription may be required.)

"CO_2 Deserts: Implications of Existing CO_2 Supply Limitations for Carbon Management." The following is the Abstract of this article: "Efforts to mitigate the impacts of climate change will require deep reductions in anthropogenic CO_2 emissions on the scale of Gigatons per year. [Carbon dioxide] capture and utilization and/or storage technologies are a class of approaches that can substantially reduce CO_2 emissions. Even though examples of this approach, such as CO_2-EOR, are already being practiced on a scale >0.05 Gt/year, little attention has been focused on the supply of CO_2 for these projects. Here,

facility-scale data newly collected by the U.S. Environmental Protection Agency was processed to produce the first comprehensive map of CO_2 sources from industrial sectors currently supplying CO_2 in the United States. Collectively these sources produce 0.16 Gt/year, but the data reveal the presence of large areas without access to CO_2 at an industrially relevant scale (>25 kt/year). Even though some facilities with the capability to capture CO_2 are not doing so and in some regions pipeline networks are being built to link CO_2 sources and [storage formations], much of the country exists in 'CO_2 deserts'. A life cycle analysis of the sources reveals that the predominant source of CO_2, dedicated wells, has the largest carbon footprint further confounding prospects for rational carbon management strategies." **Richard S. Middleton, Andres F. Clarens, Xiaowei Liu, Jeffrey M. Bielicki, and Jonathan S. Levine**, *Environ. Sci. Technol*. (Subscription may be required.)

"Exploring the effects of data quality, data worth, and redundancy of CO_2 gas pressure and saturation data on reservoir characterization through PEST Inversion." The following is the Abstract of this article: "This study examined the impacts of reservoir properties on CO_2 migration after subsurface injection and evaluated the possibility of characterizing reservoir properties using CO_2 monitoring data such as saturation distribution. The injection reservoir was assumed to be located 1,400-1,500 m below the ground surface such that CO_2 remained in the supercritical state. The reservoir was assumed to contain layers with alternating conductive and resistive properties, which is analogous to actual geological formations such as the Mount Simon Sandstone unit. The CO_2 injection simulation used a cylindrical grid setting in which the injection well was situated at the center of the domain, which extended up to 8,000 m from the injection well. The CO_2 migration was simulated using the [Pacific Northwest National Laboratory (PNNL)]-developed simulator STOMP-CO_2e (the water-salt-CO_2 module). [The authors] adopted a nonlinear parameter estimation and optimization modeling software package, PEST, for automated reservoir parameter estimation. [The authors] explored the effects of data quality, data worth, and data redundancy on the detectability of reservoir parameters using CO_2 saturation monitoring data, by comparing PEST inversion results using data with different levels of noises, various numbers of monitoring wells and locations, and different data collection spacing and temporal sampling intervals. This study yielded insight into the use of CO_2 saturation monitoring data for reservoir characterization and how to design the monitoring system to optimize data worth and reduce data redundancy." **Z Fang, Z Hou, G Lin, DW Engel, Y Fang, and PW Eslinger**, *Environmental Earth Sciences*. (Subscription may be required.)

December 2014

"Experimental and Computational Study of CO_2 Storage and Sequestration with Aqueous 2-Amino-2-hydroxymethyl-1, 3-propanediol (TRIS) Solutions." The following is the Abstract of this article: "Experimental solubility data of CO_2 in (5 and 10) mass% TRIS aqueous solutions were measured at (318.15 and 333.15) K and up to 10 MPa. The solubility data were well correlated with the modified Kent-Eisenberg model. The reaction mechanism, reaction energies, and equilibrium constants for the formation of bicarbonate and carbamate from CO_2, H_2O, and TRIS were studied using the quantum-chemical approach COSMO-RS (conductor-like screening model for real solvents) at the BP/TZVP level. The bicarbonate and carbamate formations were confirmed by using Fourier transform infrared (FTIR) spectroscopy. The results demonstrate that the formation of the bicarbonate anion is the main product formed by the direct reaction of CO_2 with water and TRIS, and reveal that the carbamate anion was formed by a proton transfer from TRIS−CO_2 zwitterion to TRIS. Density functional theory (DFT) calculations with transition-state optimization and intrinsic reaction coordinate (IRC) in water using IEF-PCM solvation model at the B3LYP/6-311++G(d,p) levels of theory were employed to support the reaction pathway for the bicarbonate and carbamate formations. The conversion of the absorption product to stable carbonate ($CaCO_3$) was also investigated experimentally by adding various Ca^{2+} sources, $CaCl_2 \cdot 2H_2O$ aqueous solution, and artificial sea water." **Rama Oktavian, Mohamed Taha, and Ming-Jer Lee**, *J. Phys. Chem. A.* (Subscription may be required.)

"Field Demonstration of CO_2 Leakage Detection in Potable Aquifers with a Pulselike CO_2-Release Test." The following is the Abstract of this article: "This study presents two field pulselike CO_2-release tests to demonstrate CO_2 [release] detection in a shallow [formation] by monitoring groundwater pH, alkalinity, and dissolved inorganic carbon (DIC) using the periodic groundwater sampling method and a fiber-optic CO_2 sensor for real-time in situ monitoring of dissolved CO_2 in groundwater. Measurements of groundwater pH, alkalinity, DIC, and dissolved CO_2 clearly deviated from their background values, showing responses to CO_2 [release]. Dissolved CO_2 observed in the tests was highly sensitive in comparison to groundwater pH, DIC, and alkalinity. Comparison of the pulselike CO_2-release tests to other field tests suggests that pulselike CO_2-release tests can provide reliable assessment of geochemical parameters indicative of CO_2 [release]. Measurements by the fiber-optic CO_2 sensor, showing obvious [release] signals, demonstrated the potential of real-time in situ monitoring of dissolved CO_2 for [release] detection at a geologic carbon [storage] (GCS) site. Results of a two-dimensional reactive transport model reproduced the geochemical measurements and confirmed that the decrease in groundwater pH and the increases in DIC and dissolved CO_2 observed in the pulselike CO_2-release tests were caused by dissolution of CO_2 whereas alkalinity was likely affected by carbonate dissolution." **Changbing Yang, Susan D. Hovorka, Jesus Delgado-Alonso, Patrick J. Mickler, Ramón H. Treviño, and Straun Phillips**, *Environ. Sci. Technol.* (Subscription may be required.)

"Field based stable isotope analysis of CO_2 by mid-infrared laser spectroscopy for CCS monitoring." The following is the Abstract of this article: "A newly developed isotope ratio laser spectrometer for CO_2 analyses has been tested during a tracer experiment at the Ketzin pilot site (northern Germany) for CO_2 storage. For the experiment, 500 t of CO_2 from a natural CO_2 reservoir was injected in supercritical state into the reservoir. The carbon stable isotope value (δ13C) of injected CO_2 was significantly different from background values. In order to observe the breakthrough of the isotope tracer continuously, the new instruments were connected to a stainless steel riser tube that was installed in an observation well. The laser instrument is based on tunable laser direct absorption in the mid-infrared. The instrument recorded a continuous 10-day carbon stable isotope data set with 30 minutes resolution directly [onsite] in a field-based laboratory container during a tracer experiment. To test the instruments performance and accuracy the monitoring campaign was accompanied by daily CO_2 sampling for laboratory analyses with isotope ratio mass spectrometry (IRMS). The carbon stable isotope ratios measured by conventional IRMS technique and by the new mid-infrared laser spectrometer agree remarkably well within analytical precision. This proves the capability of the new mid-infrared direct absorption technique to measure high precision and accurate real-time stable isotope data directly in the field. The laser spectroscopy data revealed for the first time a prior to this experiment unknown, intensive dynamic with fast changing δ13C values. The arrival pattern of the tracer suggest that the observed fluctuations were probably caused by migration along separate and distinct preferential flow paths between injection well and observation well. The short-term variances as observed in this study might have been missed during previous works that applied laboratory based IRMS analysis. The new technique could contribute to a better tracing of the migration of the underground CO_2 plume and help to ensure the long-term integrity of the reservoir." **Robert van Geldern, Martin E Nowak, Martin Zimmer, Alexandra Szizybalski, Anssi Myrttinen, Johannes A. C. Barth, and Hans-Jürg Jost**, *Anal. Chem*. (Subscription may be required.)

January 2015

"Assessment of the recovery and front contrast of CO_2-EOR and sequestration in a new gas condensate reservoir by compositional simulation and seismic modeling." The following is the Abstract of this article: "While mature oil reservoirs and [formations] are considered to be good potential candidates for CO_2 [storage], [the authors] proposed and investigated an alternative which combines CO_2 [storage] and CO_2-EOR at the start of production in a gas condensate reservoir. First, [the authors] established a co-simulation workflow with a combination of compositional reservoir simulation and synthetic seismic simulation. Next, [the authors] conducted compositional reservoir simulation and synthetic seismic simulation in a five-spot well pattern to investigate whether seismic data can monitor

the CO_2 front and gas condensate bank with CO_2 injected from the beginning of well production. Then, [the authors] compared the compositional simulation results with the seismic simulation results. Although the density contrast among reservoir gas, injected CO_2, and condensate is lower than the density contrast in the case of CO_2 [storage] in [formations], the seismic signal may have the potential to capture this smaller difference, monitor the CO_2 injection front, and locate the condensate zone, depending on the temperature, pressure and phase properties. When no adequate data are available for reservoir characterization at an early period of production, the seismic data is the only direct measurement of inter-well properties. It may be valuable for reservoir characterization and for the evaluation of the condensate block. It can serve as the basis for time-lapse monitoring. [The authors] compare production by natural depletion with production by CO_2-EOR and [storage] started at the beginning of well production. It shows that the latter will speed up the recovery process and increase the recovery rate while simultaneously storing a large amount of CO_2 in the reservoir." **Chengwu Yuana, Zhong Zhang, and Kaijian Liu**, *Fuel*, (Subscription may be required.)

"Fully coupled wellbore-reservoir modeling of geothermal heat extraction using CO_2 as the working fluid." The following is the Abstract of this article: "[The authors] consider using CO_2 as an alternative to water as a working fluid to produce geothermal electricity through the application of a coupled reservoir, wellbore, and surface power-plant model. [The authors'] approach has relaxed some of the simplifying assumptions others have made in previous work, through the application of a subsurface reservoir model fully coupled with a detailed wellbore simulator. [The authors] also include a simplified representation of CO_2 turbomachinery for a surface plant optimized for direct use of supercritical CO_2. The wellbore model includes heat transfer between the fluid in the well and the surrounding formation, in addition to frictional, inertial, and gravitational forces. [The authors'] results show that thermophysical operating conditions and the amount of power production are greatly influenced by wellbore flow processes and by wellbore/caprock heat transfer. [The authors] investigate competing effects that control development of a thermosiphon, which enables production of geothermal electricity without the need for a continuously operating external pump." **Lehua Pan, Barry Freifeld, Christine Doughty, Steven Zakem, Ming Sheu, Bruce Cutright, and Tracy Terrall**, *Geothermics*. (Subscription may be required.)

"Ground Gas Monitoring: Implications for Hydraulic Fracturing and CO_2 Storage." The following is the Abstract of this article: "Understanding the exchange of CO_2 and methane (CH_4) between the geosphere and atmosphere is essential for the management of anthropogenic emissions. Human activities such as CCS and hydraulic fracturing ('fracking') affect the natural system and pose risks to future global warming and to human health and safety if not engineered to a high standard. In this paper an innovative approach of expressing ground gas compositions is presented, using data derived from regulatory monitoring of boreholes in the unsaturated zone at infrequent intervals (typically 3 months) with data from a high frequency monitoring instrument deployed over periods of weeks. Similar highly variable trends are observed for time scales ranging from decades to hourly for boreholes located close to sanitary landfill sites. Additionally, high frequency monitoring data confirm the effect of meteorological controls on ground gas emissions; the maximum observed CH_4 and CO_2 concentrations in a borehole monitored over two weeks were 40.1 [percent] v/v and 8.5 [percent] v/v respectively, but for 70 [percent] of the monitoring period only air was present. There is a clear weakness in current point monitoring strategies that may miss emission events and this needs to be considered along with obtaining baseline data prior to starting any engineering activity." **Christopher J. Teasdale, Jean A. Hall, John P. Martin, and David A. C. Manning**, *Environ. Sci. Technol*. (Subscription may be required.)

February 2015

"Benchmark modeling of the Sleipner CO_2 plume: Calibration to seismic data for the uppermost layer and model sensitivity analysis." The following is the Abstract of this article: "…The Sleipner project in the Norwegian North Sea provides more time-lapse seismic monitoring data than any other sites for tracking CO_2 plume development, but significant uncertainties still exist for some reservoir

parameters. In order to simulate CO_2 plume migration and assess model uncertainties, [the authors] applied two multi-phase compositional simulators to the Sleipner Benchmark model for the uppermost layer (Layer 9) of the Utsira Sand and calibrated [the] model against the time-lapsed seismic monitoring data at the site from 1999 to 2010. Approximate match with the observed plume was achieved by introducing lateral permeability anisotropy, CH_4 in the CO_2 stream, and adjusting reservoir temperatures. Model-predicted gas saturation, thickness of the CO_2 accumulation, and CO_2 solubility in brine – none of them used as calibration metrics – were all comparable with interpretations of the seismic data in the literature. Hundreds of simulations of parameter sensitivity (pressure, temperature, feeders, spill rates, relative permeability curves, and CH_4) showed that simulated plume extents are sensitive to permeability anisotropy, temperature, and CH_4 but not sensitive to the other analyzed parameters. However, adjusting a single parameter within the reported range of values would not reproduce the north–south trending CO_2 plume. It took a combination of permeability, CH_4, and temperature adjustments to match simulated CO_2 plume with seismic monitoring data. On the other hand, even with a range of uncertain modeling parameters, the predicted fate of CO_2 fell within a narrow band, ~93 ± 2 [percent] structural/hydrodynamic trapping and ~7 ± 2 [percent] solubility trapping. The calibrated model is not unique. Other possibilities for reproducing the elongated plume such as a slight tilting of the caprock surface to the south and subtle geological features in the Layer 9 were not experimented with in this study, but are worthy of exploration for future studies. While it appears that [the authors] were able to reproduce the north–south elongated CO_2 plume, which is a modest improvement over previous models, the adjustments of parameters need to be verified with new observations." **Chen Zhu, Guanru Zhang, Peng Lu, Lifeng Meng, and Xiaoyan Ji**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Measurement and Modeling of CO_2 Solubility in Natural and Synthetic Formation Brines for CO_2 Sequestration." The following is the Abstract of this article: "[Carbon dioxide] solubility data in the natural formation brine, synthetic formation brine, and synthetic NaCl+$CaCl_2$ brine were collected at the pressures from 100 to 200 bar, temperatures from 323 to 423 K. Experimental results demonstrate that the CO_2 solubility in the synthetic formation brines can be reliably represented by that in the synthetic NaCl+$CaCl_2$ brines. [The authors] extended [their] previously developed model (PSUCO2) to calculate CO_2 solubility in aqueous mixed-salt solution by using the additivity rule of the Setschenow coefficients of the individual ions (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, and SO_4^{2-}). Comparisons with previously published models against the experimental data reveal a clear improvement of the proposed PSUCO2 model. Additionally, the path of the maximum gradient of the CO_2 solubility contours divides the P-T diagram into two distinct regions: in Region I, the CO_2 solubility in the aqueous phase decreases monotonically in response to increased temperature; in region II, the behavior of the CO_2 solubility is the opposite of that in Region I as the temperature increases." **Haining Zhao, Robert Dilmore, Douglas E. Allen, Sheila W. Hedges, Yee Soong, and Serguei N. Lvov**, *Environ. Sci. Technol*. (Subscription may be required.)

"Quantifying the Benefit of Wellbore Leakage Potential Estimated for Prioritizing Long-Term MVA Sampling at a CO_2 Storage Site." The following is the Abstract of this article: "This work uses probabilistic methods to simulate a hypothetical geologic CO_2 storage site in a depleted oil and gas field, where the large number of legacy wells would make it cost-prohibitive to sample all wells for all measurements as part of the post injection site care. Deep well [release] potential scores were assigned to the wells using a random subsample of 100 wells from a detailed study of 826 legacy wells that penetrate the basal Cambrian formation on the U.S. side of the U.S./Canadian border. Analytical solutions and Monte Carlo simulations were used to quantify the statistical power of selecting a [release] well. Power curves were developed as a function of (1) the number of leaking wells within the Area of Review; (2) the sampling design (random or judgmental, choosing first the wells with the highest deep [release] potential scores); (3) the number of wells included in the monitoring sampling plan; and (4) the relationship between a well's [release] potential score and its relative probability of [release]. Cases where the deep well [release] potential scores are fully or partially informative of the relative [release] probability are compared to a non-informative base case in which [release] is equi-probable across all wells in the Area of Review. The results show that accurate prior knowledge about the probability of well

[release] adds measurable value to the ability to detect a [releasing] well during the monitoring program, and that the loss in detection ability due to imperfect knowledge of the [release] probability can be quantified. This work underscores the importance of a data-driven, risk-based monitoring program that incorporates uncertainty quantification into long-term monitoring sampling plans at geologic CO_2 storage sites." **Nicholas A. Azzolina, Mitchell J. Small, David V. Nakles, Kyle A. Glazewski, Wesley D. Peck, Charles D. Gorecki, Grant S. Bromhal, and Robert M. Dilmore**, *Environ. Sci. Technol.* (Subscription may be required.)

"Design of foam-assisted carbon dioxide storage in a North Sea aquifer using streamline-based simulation." The following is the Abstract of this article: "CCS – the collection of CO_2 from industrial sources and its injection underground – could potentially contribute to the reduction of atmospheric emissions of GHGs. In this paper, [the authors] investigate the [storage] of CO_2 in [formations] with the co-injection of surfactants for foam generation. This is equivalent to the use of foam for conformance control in [EOR] applications. To study foam-assisted [storage], [the authors] extend an in-house streamline-based simulator to model foam flow. [The authors] use two foam models that have been previously suggested in the literature. In both models foam hinders gas mobility through increasing its apparent viscosity. The modified simulator is validated by comparison to analytical solutions. [The authors] then investigate the performance of CO_2 [storage] with the co-injection of surfactants. [The authors] look at CO_2 [storage] in a North Sea [formation]. [The authors] study both simultaneous and alternating surfactant-gas injection at different fractional flows (i.e. water:gas ratios). For cases where a seal provides a reliable trapping mechanism, the simulation results suggest that the use of surfactants to generate foam significantly improves the storage efficiency at a marginal increase in water consumption. In this setting, CO_2/surfactant simultaneous injection at a 0.5 CO_2 fractional flow was found to be the optimum injection strategy for the case investigated. To the contrary, if the seal is unreliable or not present at the first place, CO_2/brine simultaneous injection at a 0.85 CO_2 fractional flow was found to be the optimum injection strategy. Although foam-assisted [storage] in this case further improves the storage efficiency, it does that at a significant increase in water consumption. This is since, although foam generation improves the sweep during the [storage] phase, it significantly hinders the sweep during the chase-brine injection phase. Based on that, having a design where the surfactant will degrade just before or during the chase-brine injection phase would provide the optimum [storage] strategy—without reliance on the presence or integrity of the seal." **Siriwat Vitoonkijvanich, Abdulkareem M. AlSofia, and Martin J. Blunt**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"The microseismic response at the In Salah Carbon Capture and Storage (CCS) site." The following is the Abstract of this article: "In 2004, injection of CO_2 to be stored at depth began at the In Salah CCS site and a pilot microseismic monitoring array was installed in 2009. The In Salah project presents an unusual dataset since it is the first major non-EOR CCS project to be monitored for microseismicity. This paper outlines an extensive seismological study using a range of techniques, relying mainly on data from a single three-component geophone. Important information is derived from the data, such as event locations, event magnitudes, and fracture characteristics, which could be used in real-time to regulate the geomechanical response of a site to CO_2 injection. The event rate closely follows the CO_2 injection rate, with a total of 9506 seismic events detected. The locations for a carefully selected subset of events are estimated to occur at or below the injection interval, thereby ruling out fault or fracture activation caused by CO_2 migration at shallow depths. A very small number of events (11) with less well-constrained locations may have occurred above the injection interval. However, there is no microseismic evidence that these events are correlated with CO_2 injection and [the authors] suggest they are caused by stress transfer rather than CO_2 migration into the caprock. The observed maximum moment magnitude, Mw=1.7, is consistent with estimated fracture dimensions at the injection depth. Fracture orientation estimated using shear-wave splitting analysis is approximately NW-SE, in agreement with fracture orientations inferred from logging data. During periods of high injection rates the degree of anisotropy increases slightly and then falls back to original values when injection rates fall. This implies the CO_2 is opening pre-existing fractures which then close as pressure decreases. This an important proof-of-concept study that proves the value of microseismic monitoring of CCS projects, even with a

limited array. [The authors] thus recommend that microseismic monitoring arrays are installed prior to CO_2 injection at future CCS sites to enhance understanding by making baseline and comparative studies possible. This would also provide real-time monitoring of the geomechanical response to injection, allowing operators to modify injection parameters and to help ensure the safe operation of a project." **Anna L. Stork, James P. Verdon, and J.-Michael Kendall**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"CO_2 EOR and storage in Jilin oilfield China: Monitoring program and preliminary results." The following is the Abstract of this article: "Jilin oilfield is conducting the first large scale demonstration project on CO_2 EOR and storage in the northeast China. [Carbon dioxide] with high purity is produced from a nearby natural gas reservoir and injected into the tight oil reservoir of H-59 block. Up to early in 2012, more than 20×104 tons of CO_2 has been injected into the reservoir through a miscible flooding scheme. In order to track the migration of CO_2 in the reservoir and ensure a long-term storage safety, a monitoring program has been deployed in the field. The used monitoring techniques include wellbore integrity detecting, produced fluid sampling, CO_2 gas tracer, electric spontaneous potential measurement, micro-seismic and cross-well seismic. An environmental monitoring program is also implemented for verifying CO_2 [release]. Preliminary results indicate that it is effective to detect the movement of CO_2 in the oil reservoir by jointly applying various monitoring techniques based on wellbores. After more than four years of operation since 2008, nearly 80 [percent] of injected CO_2 has been stored in the reservoir with the rest of injected CO_2 breakthrough in the production wells. [Carbon dioxide] storage safety needs more detailed and comprehensive monitoring data for further verification. The obtained preliminary monitoring experience can provide valuable guidance for the future enlarged Jilin project and other CO_2 EOR and storage operations." **Liang Zhang, Bo Ren, Haidong Huang, Yongzhao Li, Shaoran Ren, Guoli Chen, and Hua Zhang**, *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

"CO_2 sequestration by indirect carbonation of artificial gypsum generated in the manufacture of titanium dioxide pigments." The following is the Abstract of this article: "In this paper, the use of red gypsum (RG), waste from the naturally occurring radioactive materials industry that is devoted to the production of the TiO_2 pigment, was evaluated as a source of calcium for CO_2 [storage] by an indirect carbonation process. The main objective was to valorise this waste and, at the same time, [analyze] the reduction of [GHG] emissions (CO_2) emitted by industrial sources that use this process. In order to induce the carbonation process, the extraction of calcium from the sample was required beforehand. For this, two different extraction routes were applied (the NaOH and NH_4OH pathways). The obtained results demonstrate that RG has high carbonation reactivity, depending on the extraction agent used at room temperature and pressure. The conversion of RG to calcium carbonate was 92 [percent] when using sodium hydroxide, whereas 64 [percent] was obtained with ammonium hydroxide extracting. The [behavior] and fluxes of the radionuclides and trace elements, initially contained in the RG, were also evaluated during the full carbonation process. In general, the levels of pollutants in the final calcite (calcium carbonate) were comparable to the ones found for typical unperturbed soils." **S.M. Perez-Moreno, M.J. Gazquez, and J.P. Bolivar**, *Chemical Engineering Journal*. (Subscription may be required.)

"Thin-film versus slurry-phase carbonation of steel slag: CO_2 uptake and effects on mineralogy." The following is the Abstract of this article: "The results of direct aqueous accelerated carbonation of three types of steel manufacturing residues, including an electric arc furnace (EAF) slag and two basic oxygen furnace (BOF) slags, are reported. Batch accelerated carbonation tests were conducted at different temperatures and CO_2 pressures applying the thin-film route (liquid to solid, *L/S*, ratio = 0.3 L/kg) or the slurry-phase route (*L/S* ratio = 5 L/kg). The CO_2 uptake strongly depended on both the slag characteristics and the process route; maximum yields of 280 (EAF), 325 (BOF1) and 403 (BOF2) g CO_2/kg slag were achieved in slurry phase at T = 100°C and p_{CO2} = 10 bar. Differently from previous studies, additional carbonates (other than Ca-based phases) were retrieved in the carbonated BOF slags, indicating that also Mg-, Fe- and Mn-containing phases partially reacted with CO_2 under the tested

conditions. The results hence show that the effects of accelerated carbonation in terms of CO_2 uptake capacity, yield of mineral conversion into carbonates and mineralogy of the treated product, strongly rely on several factors. These include, above all, the mineralogy of the original material and the operating conditions adopted, which thus need specific case-by-case optimization to maximize the CO_2 [storage] yield." **R. Baciocchi, G. Costa, M. Di Gianfilippo, A. Polettini, R. Pomi, and A. Stramazzo**, *Journal of Hazardous Materials*. (Subscription may be required.)

March 2015

"Recent developments in carbon dioxide capture technologies for gas turbine power generation." The following is the Abstract of this article: "This paper describes the status of various carbon capture technologies investigated and outlines challenges and opportunities of carbon capture in gas turbine power generation for EOR. Technical achievements, maturity, drivers, barriers and gaps in knowledge are described for four technologies: novel chemical solvents and processes, low temperature separation, membranes and exhaust gas recirculation (EGR) in gas turbines. As a near-term application, carbon capture in gas turbine power generation for EOR is analyzed and drivers, requirements and challenges are outlined. The paper is structured as follows: the first section describes the current global status of CCS, second section explains the approach followed in the paper, third section presents a literature review, fourth section provides a technical analysis of the focus technologies, fifth section describes challenges and opportunities of carbon capture from gas turbines for CO_2-EOR applications and finally sixth section provides conclusions." **Miguel Angel González-Salazar**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Seismicity characterization around the Farnsworth field site for combined large-scale CO_2 storage and EOR." The following is the Abstract of this article: "Induced seismicity at levels noticeable to the public or higher is a concern for long-term, large-scale geologic carbon storage. To lower the risk of induced seismicity, it is desirable to [store] CO_2 within a region where earthquakes are rare. [The authors] characterize the natural seismicity around the Farnsworth field site for the Phase III project of the U.S. Southwest Regional Partnership on Carbon Sequestration. [The authors] study all available catalog earthquake information within a region of approximately 180 km × 220 km (2 × 2 degrees) centered at the Farnsworth field. [The authors] find that there is no recorded catalog earthquake within a region of approximately 30 km in radius from planned CO_2 injection well No. 13-10A. The earliest earthquake recorded within [the] study region occurred in 1907, and the maximum magnitude of all recorded earthquakes since then is 4.8. Out of all the earthquakes recorded in this region, only four of them have magnitudes larger than 4. [The authors'] seismicity study indicates that the seismic risk for large-scale geologic carbon storage combined with [EOR] at the Farnsworth field may be relatively low. This characterization of natural seismicity around the Farnsworth field also benefits the ongoing monitoring of induced seismicity at the site." **Ting Chen and Lianjie Huang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"TOUGH2Biot – A simulator for coupled thermal-hydrodynamic-mechanical processes in subsurface flow systems: Application to CO_2 geological storage and geothermal development." The following is the Abstract of this article: "Coupled thermal–hydrodynamic–mechanical processes have become increasingly important in studying the issues affecting subsurface flow systems, such as CO_2 [storage] in deep saline [formations] and geothermal development. In this study, a mechanical module based on the extended Biot consolidation model was developed and incorporated into the well-established thermal–hydrodynamic simulator TOUGH2, resulting in an integrated numerical THM simulation program TOUGH2Biot. A finite element method was employed to discretize space for rock mechanical calculation and the Mohr-Coulomb failure criterion was used to determine if the rock undergoes shear-slip failure. Mechanics is partly coupled with the thermal–hydrodynamic processes and gives feedback to flow through stress-dependent porosity and permeability. TOUGH2Biot was verified against analytical solutions for the 1D Terzaghi consolidation and cooling-induced subsidence. TOUGH2Biot was applied to evaluate the thermal, hydrodynamic, and mechanical responses of CO_2

geological [storage] at the Ordos CCS Demonstration Project, China and geothermal exploitation at the Geysers geothermal field, California. The results demonstrate that TOUGH2Biot is capable of analyzing change in pressure and temperature, displacement, stress, and potential shear-slip failure caused by large scale underground man-made activity in subsurface flow systems. TOUGH2Biot can also be easily extended for complex coupled process problems in fractured media and be conveniently updated to parallel versions on different platforms to take advantage of high-performance computing." **Hongwu Lei, Tianfu Xu, and Guangrong Jin**, *Computers & Geosciences*. (Subscription may be required.)

"Key techniques of reservoir engineering and injection-production process for CO_2 flooding in China's SINOPEC Shengli Oilfield." The following is the Abstract of this article: "This paper addresses the geological problems and engineering hot points of the CO_2 flooding, such as the big vertical span of the beach-bar sand, the strong reservoir heterogeneity, the distribution of residual oil, and the problem of gas channeling. The core identification, log analysis, seismic interpretation, laboratory test and numerical simulation of reservoir engineering are integrated to investigate the geological characteristics of the reservoir in the demonstration zone of SINOPEC Shengli Oilfield. It demonstrates the reservoir is large but it has thin thickness, low porosity and super-low permeability. Due to some great differences between the beach sand and the bar sand, the oil reservoirs of demonstration zone are divided into 2 sand groups, 8 small layers, and 17 sand bodies in total. Then, a 3D geological model and qualitative evaluation system of safety of vertical faults are built. The optimal evaluation method of CO_2 flooding and [storage] is established. According to the engineering optimization of the CO_2 flooding, the results of a recommendation scheme indicate that the [EOR] can increase by 6.7 [percent], the total injection volume is expected to reach to 563 × 104 t, and CO_2 [storage] rate is 60.5 [percent]. Finally, the multi-level umbrella downhole gas separator is designed, and the high gas–oil ratio (GOR) production string and free kill gas injection string are also successfully developed for the CO_2-EOR." **Guangzhong Lv, Qi Li, Shijie Wang, and Xiaying Li**, *Journal of CO_2 Utilization*. (Subscription may be required.)

"Application of tracers to measure, monitor and verify breakthrough of sequestered CO_2 at the CO2CRC Otway Project, Victoria, Australia." The following is the Abstract of this article: "At the Cooperative Research Centre for Greenhouse Gas Technology's (CO2CRC) field site in the Otway Basin of Victoria, Australia, investigations into the storage of CO_2-rich gas in a depleted hydrocarbon gas field have been conducted in the Waarre C reservoir. The injected gas from the nearby Buttress field contained 75 mol% CO_2, 21 mol% CH_4 with the remaining balance being a mixture of wet hydrocarbons, condensate and nitrogen. Chemical tracers (sulphur hexafluoride, SF_6; krypton, Kr; perdeuterated methane, CD_4) were added on the basis of literature surveys and small volume trials at the Frio II Brine experiment in Texas. The aim of the project was to measure, monitor and verify the presence of injected CO_2 in a depleted gas field and that the arrival of tracers was a major component of demonstrating breakthrough of CO_2 at the monitoring well, Naylor-1. The paper focuses on methods developed for the injection, recovery and analysis of samples collected at the Naylor-1 well. Results of tracer analysis compare well with other data collected (including pH and density measurements) to demonstrate breakthrough. A slip-stream injection system was designed to deliver the tracers mixed with the CO_2-rich gas into the subsurface at the CRC-1 well. The tracers were added to the gas stream 17 days after the start of injection (CO_2 injection commenced March 18, 2008) into the depleted natural gas field at Naylor. A U-tube system was used to retrieve the samples from the Naylor-1 monitoring well. Collected gas and formation water samples were [analyzed] in detail for gas composition, tracers, isotopes (^{13}C CO_2 mainly) and inorganic geochemistry for the broader project. The tracer results confirm that CO_2 breakthrough at the monitoring well occurred within the predicted times. However the interval between samples taken from the U-tubes was too coarse to resolve detailed differences in arrival times between the CO_2 and tracers. Of the three tracers used, SF_6 provided the clearest evidence of breakthrough at U-tube 2. Kr, because of its abundance in air, and its potential to be present in the subsurface, was more prone to contamination and had higher background levels prior to breakthrough. CD_4 was expected to provide some more unique data based on the presence of abundant CH_4 in the reservoir interval. With hindsight, larger volumes should have been injected to facilitate comparisons with the other tracers and add value to the data set. The test of CD_4 however acted as a suitable proof of concept that CD_4 could be used in

such a high background of CH_4. Further work is ongoing to generate data for partition coefficients between supercritical CO_2, CH_4 and water under the injection conditions." **Linda Stalker, Chris Boreham, Jim Underschultz, Barry Freifeld, Ernie Perkins, Ulrike Schacht, and Sandeep Sharma**, *Chemical Geology*. (Subscription may be required.)

"Bioinspired Silica Nanocomposite with Autoencapsulated Carbonic Anhydrase as a Robust Biocatalyst for CO_2 Sequestration." The following is the Abstract of this article: "Here, [the authors] report on the development and characterization of a carbonic anhydrase (CA)-based biocatalyst encapsulated in a biosilica matrix for use in environmental CO_2 [storage]. Encapsulation occurred simultaneously with autonomous silica synthesis by silica-condensing R5 peptide that was fused to recombinant CA. The encapsulation efficiency was greater than 95 [percent], and the encapsulated CA was not leached from the silica matrix, demonstrating the highly efficient R5-mediated autoencapsulation process. The catalytic efficiencies for both esterase and CO_2 hydratase activities tended to increase with increasing pH; however, the catalytic efficiency for CO_2 hydration was much more pH dependent, suggesting that proton transfer from silica to water is a rate limiting step, especially for CO_2 hydration. In addition to good reusability, the encapsulated CA exhibited outstanding thermostability, even retaining 80 [percent] activity after 5 days at 50°C. The thermoactivity was also remarkable, showing ~10-fold higher activity at 60°C compared to that at 25°C. The physical structure was observed to be highly compact with a low surface area, stressing the importance of the outermost surface for catalytic performance. [The authors] also demonstrated the applicability of the silica nanoparticle to the [storage] of CO_2 in carbonate minerals. The rate of $CaCO_3$ precipitation was remarkably accelerated by the encapsulated biocatalyst. The biosilica nanocomposite exhibited ~60 [percent] of the CO_2 [storing] power of the free enzyme, which is expected to be the maximal ability of the encapsulated CA. Thus, this silica-CA nanocomposite, efficiently synthesized via a biomimetic green route, can be successfully used as a robust biocatalyst for biomimetic [storage] of the [GHG] CO_2." **Byung Hoon Jo, Jeong Hyun Seo, Yun Jung Yang, Kyungjoon Baek, Yoo Seong Choi, Seung Pil Pack, Sang Ho Oh, and Hyung Joon Cha**, *ACS Catal.* (Subscription may be required.)

"Potassium salt-assisted synthesis of highly microporous carbon spheres for CO_2 adsorption." The following is the Abstract of this article: "Highly microporous carbon spheres for CO_2 adsorption were prepared by using a slightly modified one-pot Stöber synthesis in the presence of potassium oxalate. Formaldehyde and resorcinol were used as carbon precursors, ammonia as a catalyst, and potassium oxalate as an activating agent. The resulting potassium salt-containing phenolic resin spheres were simultaneously carbonized and activated at 800°C in flowing nitrogen. Carbonization of the aforementioned polymeric spheres was accompanied by their activation, which resulted in almost five-time higher specific surface area and total pore volume, and almost four-time higher micropore volume as compared to analogous properties of the carbon sample prepared without the salt. The proposed synthesis resulted in microporous carbon spheres having the surface area of 2130 $m^2\ g^{-1}$, total pore volume of 1.10 $cm^3\ g^{-1}$, and the micropore volume of 0.78 $cm^3\ g^{-1}$, and led to the substantial enlargement of microporosity in these spheres, especially in relation to fine micropores (pores below 1 nm), which enhance CO_2 adsorption. These carbon spheres showed three-time higher volume of fine micropores, which resulted in the CO_2 adsorption of 6.6 mmol g^{-1} at 0°C and 1 atm." **Jowita Ludwinowicz and Mietek Jaroniec**, *Carbon*. (Subscription may be required.)

April 2015

"Multiphase Modeling of Geologic Carbon Sequestration in Saline Aquifers." The following is the Abstract of this article: "Geologic carbon [storage] (GCS) is being considered as a climate change mitigation option in many future energy scenarios. Mathematical modeling is routinely used to predict subsurface CO_2 and resident brine migration for the design of injection operations, to demonstrate the permanence of CO_2 storage, and to show that other subsurface resources will not be degraded. Many processes impact the migration of CO_2 and brine, including multiphase flow dynamics, geochemistry, and geomechanics, along with the spatial distribution of parameters such as porosity and permeability. In this

article, [the authors] review a set of multiphase modeling approaches with different levels of conceptual complexity that have been used to model GCS. Model complexity ranges from coupled multiprocess models to simplified vertical equilibrium (VE) models and macroscopic invasion percolation models. The goal of this article is to give a framework of conceptual model complexity, and to show the types of modeling approaches that have been used to address specific GCS questions. Application of the modeling approaches is shown using five ongoing or proposed CO_2 injection sites. For the selected sites, the majority of GCS models follow a simplified multiphase approach, especially for questions related to injection and local-scale heterogeneity. Coupled multiprocess models are only applied in one case where geomechanics have a strong impact on the flow. Owing to their computational efficiency, VE models tend to be applied at large scales. A macroscopic invasion percolation approach was used to predict the CO_2 migration at one site to examine details of CO_2 migration under the caprock." **Karl W. Bandilla, Michael A. Celia, Jens T. Birkholzer, Abdullah Cihan, and Evan C. Leister**, *Groundwater*. (Subscription may be required.)

"N_2+CO_2+NaCl brine interfacial tensions and contact angles on quartz at CO_2 storage site conditions in the Gippsland basin, Victoria/Australia." The following is the Abstract of this article: "Carbon geo-[storage] (CGS) has been identified as an important method to reduce CO_2 emissions to the atmosphere thus mitigating global warming. In CGS, the CO_2 captured from large point source emitters is injected into hydrocarbon reservoirs for enhanced oil and gas recovery or into deep saline [formations] for storage. In this context the State of Victoria (southeast Australia) is reviewing the suitability of Victorian sedimentary basins as CO_2 [storage formations]. The main focus is on the Gippsland basin, which has been positively evaluated from a geological point of view. Now it is necessary to assess the storage capacity of the formation and thus the intimately related fluid–fluid–rock properties. [The authors] therefore conducted interfacial tension and contact angle measurements at the prevailing storage conditions (13 MPa, 333 K); as a result, [the authors] show that CO_2 has a relatively high water contact angle (θ=47°), while lower θ values were measured for N_2 (θ=40.6°=47°) and for a 50 mol% CO_2+50 mol% N_2 mixture (θ=33.9°). Consequently all systems were weakly water-wet. This implies that residual and structural trapping capacities are reduced; however, both mechanisms should work adequately. Specifically, [the authors] predict that a CO_2 column height of ~698 m can be permanently immobilized beneath the caprock." **Ahmed Al-Yaseri, Mohammad Sarmadivaleh, Ali Saeedi, Maxim Lebedev, Ahmed Barifcani, and Stefan Iglauer**, *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

"Optimized Carbonation of Magnesium Silicate Mineral for CO_2 Storage." The following is the Abstract of this article: "The global ambition of reducing the [CO_2] emission makes [storage] reactions attractive as an option of storing CO_2. One promising environmentally benign technology is based on forming thermodynamically stable carbonated minerals, with the drawback that these reactions usually have low conversion rates. In this work, the carbonation reaction of Mg rich olivine, Mg_2SiO_4, under supercritical conditions has been studied. The reaction produces $MgCO_3$ at elevated temperature and pressure, with the addition of $NaHCO_3$ and NaCl to improve the reaction rates. A [storage] rate of 70 [percent] was achieved within 2 h, using olivine particles of sub-10 μm, whereas 100 [percent] conversion was achieved in 4 h. This is one of the fastest complete conversions for this reaction reported to date. The CO_2 [storage] rate is found to be highly dependent on the applied temperature and pressure, as well as the addition of $NaHCO_3$. In contrast, adding NaCl was found to have limited effect on the reaction rate. The roles of $NaHCO_3$ and NaCl as catalysts are discussed and especially how their effect changes with increased olivine particle size. The products have been characterized by Rietveld refinement of powder X-ray diffraction, scanning electron microscopy (SEM), and energy-dispersive X-ray (EDX) spectroscopy revealing the formation of amorphous silica and micrometer-sized magnesium carbonate crystals." **Espen Eikeland, Anders Bank Blichfeld, Christoffer Tyrsted, Anca Jensen, and Bo Brummerstedt Iversen**, *ACS Appl. Mater. Interfaces*. (Subscription may be required.)

"Monitoring CO_2 sequestration into deep saline aquifer and associated salt intrusion using coupled multiphase flow modeling and time-lapse electrical resistivity tomography." The following

is the Abstract of this article: “Successful geological storage of CO_2 [requires] efficient monitoring of the migration of CO_2 plume during and after large-scale injection in order to verify the containment of the injected CO_2 within the target formation and to evaluate risk. Field studies have shown that surface and cross-borehole electrical resistivity tomography (ERT) can be a useful tool in imaging and characterizing solute transport in heterogeneous subsurface. In this synthetic study, [the authors] have coupled a 3-D multiphase flow model with a parallel 3-D time-lapse ERT inversion code to explore the feasibility of using time-lapse ERT for simultaneously monitoring the migration of CO_2 plume in deep saline formation and potential brine intrusion into shallow fresh water [formation]. Direct comparisons of the inverted CO_2 plumes resulting from ERT with multiphase flow simulation results indicate the ERT could be used to delineate the migration of CO_2 plume. Detailed comparisons on the locations, sizes and shapes of CO_2 plume and intruded brine plumes suggest that ERT inversion tends to underestimate the area review of the CO_2 plume, but overestimate the thickness and total volume of the CO_2 plume. The total volume of intruded brine plumes is overestimated as well. However, all discrepancies remain within reasonable ranges. [The authors’] study suggests that time-lapse ERT is a useful monitoring tool in characterizing the movement of injected CO_2 into deep saline [formation] and detecting potential brine intrusion under large-scale field injection conditions.” **Chuan Lu, Chi Zhang, Hai Hunag, and Timothy C. Johnson**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

“Experimental CO_2 injection: Study of physical changes in sandstone porous media using Hg porosimetry and 3-D pore network models.” The following is the Abstract of this article: “Variations in the pore system of sandstones from the so-called Utrillas Formation (Lower Cretaceous, Iberian Peninsula) after CO_2 injection have been investigated in a laboratory on a micro scale. In this study, [the authors] present results regarding variations in the pore spaces of sandstones caused by the injection of CO_2 and its permanence in supercritical conditions in contact with a rock sample for two months. The modifications produced in the porosity and pore size distribution have been evaluated on two geological samples, using a 3-D modelling of the results obtained by Hg intrusion porosimetry. Reconstructions of the pore structure of the rock before and after CO_2 injection from mercury intrusion–extrusion curves, generating virtual models of pores that reproduce the experimental porosity. By analyzing the results, a drastic modification in the mesoporosity of the rock is confirmed, which may have a paramount influence not only on the total storage capacity but also on the percolation of fluid through the rock.” **Rocío Camposa, Icíar Barriosa, and Javier Lillo**, *Energy Reports*. (Subscription may be required.)

May 2015

“SECARB CO_2 Injection Test in Mature Coalbed Methane Reservoirs of the Black Warrior Basin, Blue Creek Field, Alabama.” The following is the Abstract of this article: “The [Southeast Regional Carbon Sequestration Partnership (SECARB)] Black Warrior field verification test employed a diverse suite of well testing and monitoring procedures designed to determine the injectivity, capacity, heterogeneity, and performance of mature coalbed methane reservoirs. A total of 3,250 bbl of water and 252 t of CO_2 were injected into coal in a battery of slug tests. These tests demonstrate that significant injectivity exists in Black Warrior coalbed methane reservoirs and that reservoir heterogeneity is a critical factor to consider when implementing CO_2 [storage] and CO_2-enhanced recovery programs. The primary test well produces coalbed methane at wellhead pressures just above atmospheric, and yet desorption testing indicates that less than 20 [percent] of the original gas in place has been recovered by primary production. Injection of CO_2 was conducted at sustained rates of about 90 t/d of CO_2. Reservoir pressure declined exponentially following the emplacement of each CO_2 slug. Slug and pressure-buildup tests verify that permeability decreases exponentially with depth and also decreased during injection. Monitoring operations included multi-zone pressure logging and gas sampling in deep observation wells and groundwater sampling in a shallow observation well. Results indicate that significant permeability anisotropy exists in each coal group. In the Black Creek coal, pressure response was greatest in the dominant natural fracture direction. In the Pratt coal group, pressure response was dominated by hydrofractures. [Carbon dioxide] broke through to the observation wells only in the Pratt coal group and only along the major fracture directions. No significant flow of CO_2 out of zone was detected, and no

impact on shallow groundwater resources was identified." **Jack C. Pashin, Peter E. Clark, Marcella R. McIntyre-Redden, Richard E. Carroll, Richard A. Esposito, Anne Y. Oudinot, and George J. Koperna, Jr.**, *International Journal of Coal Geology*. (Subscription may be required.)

"Quantification of CO_2 masses trapped through free convection process in isothermal brine saturated reservoir." The following is the Abstract of this article: "Dissolution trapping of supercritical CO_2 into formation brine has been investigated as a potential mechanism for reducing buoyancy force in carbon storage formations. This study attempts to quantify how much CO_2 can be stored through dissolution trapping assuming the free-phase CO_2 will be dissolved continuously on the top of perturbed brine phase. Most former investigations focused on physical explanations of density-driven free convection instability. [The authors'] aim is to compute the amount of CO_2 (by mass) captured by dissolution trapping until the model reservoir reaches steady state. The numerical experimentation is done using dimensionless mass and momentum conservation laws. The major problem parameter here is the Rayleigh number, for which [the authors] carry out an extensive survey to find out its low and high ends based on field and observed data from the literature and in-house database. Because density difference is the main driving force, [the authors] also investigate the effects of impurities retained in CO_2 stream on density contrast. [The authors] study both homogeneous and heterogeneous reservoirs. Also, different boundary conditions (Neumann, Dirichlet, and periodic) are compared to understand their effects. The simulations are run until nearly complete saturation (~99 [percent]) is reached. For a test case (T = 40°C, P = 50 bar) of geologic and thermophysical conditions, [the authors] have found that on average 0.33–15 g CO_2 will dissolve per year until a heterogeneous unit reservoir volume of 1 m^3 reaches complete saturations. For the case of homogeneous reservoir this amount is 0.28–6 g." **Akand Islam and Alexander Y. Sun**, *International Journal of Heat and Mass Transfer*. (Subscription may be required.)

"Monitoring CO_2 gas-phase migration in a shallow sand aquifer using cross-borehole ground penetrating radar." The following is the Abstract of this article: "Understanding potential pathways of gaseous CO_2 into and through the shallow subsurface from deep geological storage is one of many requirements related to risk assessment of a CCS site. In this study, a series of field experiments were carried out at a site located in Vrøgum in western Denmark. Up to 45 kg of gaseous CO_2 was injected into a shallow [formation] approximately 8 m below the groundwater table. In the upper 6 m, the [formation] consisted of fine Aeolian sand underlain by coarser glacial sand. The migration of the gaseous CO_2 was tracked using cross-borehole ground penetrating radar (GPR). A total of six GPR-boreholes were installed around the injection well and in the dominant flow direction of the groundwater. The GPR measurements were collected before, during, and after the CO_2-injection. The GPR method proved to be very sensitive to desaturation of the [formation] when gaseous CO_2 evolved and the method was thus useful for mapping the migration of the CO_2 gas plume. The experimental results demonstrated that the migration of the gas plume was highly irregular. Initially, the gaseous CO_2 migrated upwards due to buoyancy effects and subsequently it moved laterally and transversely to the groundwater flow direction. As the injection continued, the main flow direction of the gaseous CO_2 shifted and CO_2 gas pockets with a gas saturation of up to 0.3 formed below lower-permeable sand layers. [Carbon dioxide] gas was detected in a GPR-panel 5 m away from the injection point after 21 h. The GPR measurements showed that CO_2 gas never penetrated the fine Aeolian sand at 6 m depth and that the gas saturation appeared to become constant in the survey area after less than 24 h of CO_2 injection. The results of the experiments have emphasized that lateral spreading is of significance in case of [release] from a CCS site, and that even small changes in the formation texture can create barriers for the CO_2 migration." **R.N. Lassen, T.O. Sonnenborg, K.H. Jensen, and M.C. Looms**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"An investigation into the integrity of wellbore cement in CO_2 storage wells: Core flooding experiments and simulations." The following is the Abstract of this article: "An important issue for geological storage of CO_2 is the potential for wellbore cements to degrade in contact with the acidic formation waters resulting from CO_2 dissolution. Cement degradation is a two stage process; cement

carbonation occurs as various cement phases react to form calcium carbonate. The key second stage is the potential for erosion of the cement as this calcium carbonate dissolves into the formation water. For significant erosion to occur there would need to be a flow of water, under-saturated in calcium and carbonate ions, across the cement to remove dissolved calcium carbonate. This paper, presents a program of work that investigates cement degradation at the cement-formation interface. Two core flooding experiments were conducted at pressures and temperatures representative of storage conditions using composite cement–sandstone core plugs using CO_2 saturated waters with chemistries representative of formation waters. The relatively high permeability of the sandstone allowed sufficient water flow rates for regular water samples to be collected and the chemistry [analyzed]. As the sandstone simply provided a flow path for water, and did not impart any substantial chemical effect, the observations are applicable to a range of situations involving water flow in contact with cement. As the experiments, were structured such that the inflow water flowed across the cement plug surface before passing through the sandstone, each experiment provided two sets of observations with significantly different water flow velocities and chemistries. The measurements of water chemistry were combined with the flow rate observations to calculate the cumulative dissolution of the calcium carbonate and thus estimate the erosion of the cement. This compared well with direct estimates of the volume eroded by the flow across the cement plug surface. Using μXRD it was found that where the cement came into contact with the water it reacted to form calcium carbonate with none of the original cement phases detected. The erosion rate of the cement, when normalized by the water flow rate, had a clear relationship with respect to the difference between the inflow and outflow calcium concentrations. An empirical relationship was used to fit this data, thus providing a mathematical description of the cement erosion rate with respect to water flow velocity and the calcium solubility deficit. This was applied in a simulation model to a series of hypothetical case studies to investigate cement erosion at the cement-formation interface of a well, where there was an initial flow channel, across the geological seal in a CO_2 storage formation." **L. Connell, David Down, Meng Lu, David Hay, and Deasy Heryanto**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

June 2015

"CO_2 migration and pressure evolution in deep saline [formations]." The following is the Abstract of this article: "In 2005, the [Intergovernmental Panel on Climate Change (IPCC)] special report on carbon dioxide capture and storage (SRCCS) summarized the state of knowledge about CCS as an emerging technology for reducing CO_2 emissions to the atmosphere. At the time of writing, the emphasis of the SRCCS was on understanding the fate of injected CO_2 whereas less attention was paid to effects of pressure buildup associated with CO_2 injection. Since then, the CCS community has significantly improved the knowledge base and addressed many of the technical gaps mentioned in 2005. A large body of research has been devoted to identify and verify the main processes that control CO_2 migration, trapping, and containment in deep saline [formations]. Much work has also been conducted to better understand the magnitude and implications of reservoir pressure buildup in response to large CO_2 storage projects. The aim of this paper is to provide a summary and overview of the most relevant recent (since publication of the IPCC SRCCS) literature and findings in the areas of CO_2 migration and pressure evolution. The paper first summarizes recent findings related to CO_2 plume migration and trapping, based on analytical and numerical modeling studies as well as several field injection tests conducted to examine the fate of injected CO_2 in various subsurface settings. The paper then discusses pressure effects as a function of space and time, including the effects of confinement (boundary conditions), highlights possible unwanted pressure impacts such as pressure-driven [release] and geomechanical damage, analyzes potential capacity constraints, reviews current concepts for pressure management, and closes with a discussion about use of pressure signals for advanced monitoring." **Jens T. Birkholzer, Curtis M. Oldenburg, and Quanlin Zhou**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Molecular Dynamics Characterizations of the Supercritical CO_2-Mediated Hexane-Brine Interface." The following is the Abstract of this article: "In the CO_2 EOR process and subsequent

geological CO_2 [storage], a ternary system consisting of CO_2, crude oil, and brine exists in the reservoir due to the common practice of injecting CO_2 together with brine. In this paper, [the authors] carried out molecular dynamics simulations to study the interfacial properties of the ternary CO_2, hexane, and 1.52 mol/L sodium chloride (NaCl) solution system under 330 K and 20 MPa with different CO_2 compositions at the supercritical state, which are very important for the efficiency of the EOR and CO_2 [storage] processes. [The authors] observed that CO_2 mixes well with hexane and a clear interface separates the CO_2–hexane mixture with the NaCl solution. The interfacial roughness increases with the CO_2 composition, indicating deeper molecular penetrations and shorter capillary wavelengths, which leads to the reduced interfacial tension. Interestingly, the surface excess of CO_2 reaches maximum at a CO_2 molar fraction of 62.5 [percent] (or a weight fraction of 46 [percent]), which implies the amphiphilic feature of CO_2, acting like surfactants, toward the hexane–brine interface. The orientational preferences of CO_2, hexane, and water molecules at the interface are more random at higher CO_2 compositions, as a result of the increased absolute amount of CO_2 and the absence of hexane at the interface." **Lingling Zhao, Lu Tao, and Shangchao Lin**, *Ind. Eng. Chem. Res.* (Subscription may be required.)

"Impacts of Organic Ligands on Forsterite Reactivity in Supercritical CO_2 Fluids." The following is the Abstract of this article: "Subsurface injection of CO_2 for enhanced hydrocarbon recovery, hydraulic fracturing of unconventional reservoirs, and geologic carbon [storage] produces a complex geochemical setting in which CO_2-dominated fluids containing dissolved water and organic compounds interact with rocks and minerals. The details of these reactions are relatively unknown and benefit from additional experimentally derived data. In this study, [the authors] utilized an in situ X-ray diffraction technique to examine the carbonation reactions of forsterite (Mg_2SiO_4) during exposure to supercritical CO_2 ($scCO_2$) that had been equilibrated with aqueous solutions of acetate, oxalate, malonate, or citrate at 50°C and 90 bar. The organics affected the relative abundances of the crystalline reaction products, nesquehonite ($MgCO_3 \cdot 3H_2O$) and magnesite ($MgCO_3$), likely due to enhanced dehydration of the Mg^{2+} cations by the organic ligands. These results also indicate that the $scCO_2$ solvated and transported the organic ligands to the forsterite surface. This phenomenon has profound implications for mineral transformations and mass transfer in the upper crust." **Quin R. S. Miller, John P. Kaszuba, Herbert T. Schaef, Mark E. Bowden, and Bernard P. McGrail**, *Environ. Sci. Technol.* (Subscription may be required.)

July 2015

"CO_2 foam flooding for improved oil recovery: Reservoir simulation models and influencing factors." The following is the Abstract of this article: "A mechanistic model of CO_2 foam that allows for direct simulation of foam generation, propagation, coalescence and collapse was described in this study. The controlling parameters, such as reaction rate factors for foam generation, coalescence and collapse in presence of oil, the viscosity of foaming components and surfactant adsorption, were adjusted to match the experimental results of CO_2 foam coreflooding. A three dimensional heterogeneous conceptual reservoir model was then built to study the mechanisms of CO_2 foam flooding based the foam model. The simulation results show that CO_2 foam flooding can improve oil recovery through a combination of various mechanisms, including selective blocking and conformance control, gas up-flow effect, reservoir energy support, and the improvement of displacement efficiency. The sensitivity and the effect of different influencing factors on the performance of CO_2 foam flooding were investigated via the simulation models on various scenarios. [Carbon dioxide] foam flooding can achieve a better oil recovery in comparison with water flooding, CO_2 flooding and WAG (water alternating gas) processes. Early CO_2 foam injection is conducive to the improvement of oil recovery and the success of the project. [Carbon dioxide] foam flooding technique can be applied in a wide range of complex reservoirs, especially for highly heterogeneous reservoirs with high permeability channels, and reservoirs with different sedimentary sequences." **Yang Zhang, Yuting Wang, Fangfang Xue, Yanqing Wang, Bo Ren, Liang Zhang, and Shaoran Ren**, *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

"Well completion and integrity evaluation for CO_2 injection wells." The following is the Abstract of this article: "[Storage] of CO_2 in depleted oil and gas reservoirs, coal seams and saline [formations] is one important means of mitigating greenhouse effect on the environment and enhancing oil and gas recovery. The collected CO_2 is injected via injection wells into the underground space. Due to the characteristics of supercritical CO_2, e.g., corrosive, low temperature, the well design and completion for CO_2 injection purposes requires more considerations. This paper introduces the basic challenges of designing a CO_2 injection well, reviews the famous CO_2 injection cases around the world, and proposes well completion criteria, including completion scheme design, materials selection and so on. Well integrity tests in use are reviewed and evaluated in terms of their pros and cons. Well integrity evaluation using numerical simulation is conducted as well to study the influences of CO_2 injection on well integrity in a pilot area in Germany. The results show that the materials selected for CO_2 injection well shall adapt to the low-temperature environment, and the cement should have a high tensile strength and resist corrosion. Under the impact of salt rock creep, the cement cracks resulting from temperature decrease during injection tend to heal. At the end of the paper for the wells with loss of integrity, a remedial work needs to be done, e.g., cement repair, and for this a thorough review of cement repair experiences is performed." **Mingxing Bai, Jianpeng Sun, Kaoping Song, Lili Li, and Zhi Qiao**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

"Field measurement of residual carbon dioxide saturation using reactive ester tracers." The following is the Abstract of this article: "As part of the CO2CRC Otway Residual Saturation and Dissolution Test, a series of field tests were conducted at their project site in Victoria, Australia, with the primary goal of developing and assessing methods for quantifying residual CO_2 saturation in a saline [formation]. This paper reports the outcome of one of these tests, a single-well 'push–pull' tracer test that uses novel reactive esters (i.e., propylene glycol diacetate, triacetin and tripropionin). For this tracer test, the ester is injected (pushed) into the reservoir where residual saturation has been established using CO_2, and maintained by pushing with CO_2 saturated water (to prevent changes in saturation due to CO_2 dissolution). The ester is partially [hydrolyzed] by the formation water to yield multiple compounds (i.e., the corresponding alcohol and acid generated from the ester). During water production (pull) from the same well, these compounds will partition differentially between the residual supercritical CO_2 phase and water phase, leading to chromatographic separation. By modelling the concentration profiles of these tracers in production water samples and using the experimentally determined partition coefficients, [the authors] generate two consistent residual saturation estimates using two separate modelling techniques, one a simple finite difference simulation of the tracer velocity field and the other a standard multiphase simulation code." **Matthew Myers, Linda Stalker, Tara La Force, Bobby Pejcic, Christopher Dyt, Koon-Bay Ho, and Jonathon Ennis-King**, *Chemical Geology*. (Subscription may be required.)

August 2015

"Model Predictions via History Matching of CO_2 Plume Migration at the Sleipner Project, Norwegian North Sea." The following is the Abstract of this article: "The Sleipner Project in Norway is the world's first industrial-scale geological carbon storage project. Seismic surveys have produced high fidelity 4D seismic data that delineated the CO_2 plume migration history. Therefore, the Sleipner Project provides a somewhat unique opportunity to simulate the dynamics of CO_2 plume migration in a real geological system. [The authors] simulated CO_2 plume migration in the uppermost layer (Layer 9) in the Utsira Sand, Sleipner field and calibrated the model against the time-lapsed seismic monitoring data from 1999 to 2008. Instead of using ideal geometry and homogenous geological properties, [the authors] adopted the grid mesh from the Sleipner Benchmark model to represent the complexity of real geological systems. Approximate match with the observed plume was achieved by introducing lateral permeability anisotropy coupled with either an increased reservoir temperature with CH_4 impurities in the CO_2 stream or a second feeder. Predicted gas saturation, thickness of the CO_2 accumulation and CO_2 solubility in brine–none of them has been used as calibration metrics–are comparable with interpretations of the seismic data in the literature. [The authors'] simulation results illustrate that the actual behaviors of the injected CO_2 plume conform to the modeled behaviors. The Sleipner project is on-going. The good match

of plume history provides a calibrated model for making predictions of CO_2 plume migration into the future. By comparing the model prediction and monitoring data that are not used in the calibration, [the authors] will have a well-grounded assessment of modeling uncertainties." **Guanru Zhang, Peng Lu, and Chen Zhu**, *Energy Procedia*. (Subscription may be required.)

"CO_2 retention values in enhanced oil recovery." The following is the Abstract of this article: "Carbon dioxide retention is the fraction of the injected volume trapped in the subsurface as a result of EOR. [Carbon dioxide] retention is determined by multiple factors acting generally in combinations varying according to the geology of the reservoir and the implementation of the recovery. Primarily, the factors are the amount of CO_2 remaining in the pore space connected to injection wells but not to the producer; dissolution into the formation water, subjacent [formation], or both; accumulation in the pore space vacated by produced oil; chemical reaction with the minerals in the matrix; and loss to a thief zone. Accurate modeling of retention is important in the evaluation of the economics of reservoir development and in the assessment of potential CO_2 [storage]. This contribution deals with 23 units containing information relating retention rates to the amount of CO_2 injected in EOR operations. For all but two units, the flooding is miscible and all but two units are in the United States. Compilation of values reported in the literature shows a tendency for higher values of retention for carbonate than for siliciclastic reservoirs." **Ricardo A. Olea**, *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

"Hydromechanical modelling of shaft sealing for CO_2 storage." The following is the Abstract of this article: "The geological [storage] of CO_2 in abandoned coal mines is a promising option to mitigate climate changes while providing sustainable use of the underground cavities. In order to certify the efficiency of the storage, it is essential to understand the [behavior] of the shaft sealing system. The paper presents a numerical analysis of CO_2 transfer mechanisms through a mine shaft and its sealing system. Different mechanisms for CO_2 [release] are considered, namely multiphase flow through the different materials and flow along the interfaces between the lining and the host rock. The study focuses on the abandoned coal mine of Anderlues, Belgium, which was used for seasonal storage of natural gas. A two-dimensional hydromechanical modelling of the storage site is performed and CO_2 injection into the coal mine is simulated. Model predictions for a period of 500 years are presented and discussed with attention. The role and influence of the interface between the host rock and the concrete lining are examined. In addition the impact of some uncertain model parameters on the overall performance of the sealing system is [analyzed] through a sensitivity analysis." **A.C. Dieudonne, B. Cerfontaine, F. Collin, and R. Charlier**, *Engineering Geology*. (Subscription may be required.)

Terrestrial

September 2014

"The fate of soil organic carbon upon erosion, transport and deposition in agricultural landscapes – A review of different concepts." The following is the Abstract of this article: "Erosion and deposition redistribute large quantities of sediment and soil organic carbon (SOC) in agricultural landscapes. In the perspective of global carbon cycling, the coupling between erosion processes and the fate of SOC is of particular interest. However, different concepts have been proposed to assess the impact by erosion-induced lateral and vertical carbon fluxes. On landscape scale, this resulted in contrasting conclusions if agricultural soils represent either a carbon sink or source. The large global area of arable soil and generally high erosion rates, make these insights important. In this review, [the authors] aim to give an overview of the different conceptual relations described governing C dynamics at sites of erosion, along the transport pathway and at depositional sites and the current state of knowledge on the fate of SOC upon erosion, transport and deposition in agricultural landscapes. The impact of erosion on SOC dynamics differs for sites of erosion, deposition and during transport, with further influences by agricultural practices (e.g. tillage and [fertilization]). Controlling processes are the

detachment of sediment and SOC, net primary production resulting in dynamic replacement and changes in [mineralization] upon transport and deposition due to aggregate breakdown and deep burial, respectively. However, the exact magnitude and dominance of these processes are debated, resulting in a controversy whether arable land functions as a sink or source for atmospheric CO_2. Global estimations range between a net sink strength of 0.06–1 versus a source of 0.27–1.14 Gt C yr^{-1} for agricultural soils. An eco-geomorphologic approach, which encompasses physical- and biological-driven factors (e.g. spatio-temporal variation in biological, geomorphological and biological processes, environmental conditions, [mineralization], and net primary production) is of importance to balance the carbon budget and ascertain sink or source formation at landscape scale. High spatio-temporal variability on process-scale imposes constrains, to measure and model the fate of SOC upon erosion, with limited quantitative data available. Prospective research across the landscape (eroding sites, transport pathway, and depositional sites) should include all relevant processes at broad temporal and spatial scales. Definitive resolution of the sink/source controversy lies in further eco-geomorphologic research on the fate of SOC, [focusing] on long-term and spatial extensive monitoring studies, combined with advanced measuring, modelling and extrapolation techniques to cover broad spatio-temporal SOC dynamics. Ascertainment of carbon dynamics in agricultural landscapes provides important insights to balance the carbon budget and finally holds the answer on sink/source formation." **F.M.S.A. Kirkels, L.H. Cammeraat, and N.J. Kuhn**, *Geomorphology*. (Subscription may be required.)

October 2014

"Reduced global warming potential after wood ash application in drained Northern peatland forests." The following is the Abstract of this article: "Past land use change has converted vast areas of Northern peatland by drainage to agricultural or forested land. This change often reduces the [greenhouse gas (GHG)] sink strength of peatlands or turns them even from sinks to sources, which affects the global climate. Therefore, there is a need for suitable mitigation options for GHG emissions from drained peatlands. Addition of wood ash to peatland forests has been suggested as such a measure, but the overall effect on the global warming potential (GWP) of these ecosystems is still unclear. In order to fill this knowledge gap, [the authors] investigated three drained peatland forests in Sweden that had been fertilized with wood ash and monitored stand growth as well as the GHG emissions from soil, i.e. net effluxes of CO_2, methane (CH_4) and nitrous oxide (N_2O). [The authors'] results show that over the first five to eight years after wood ash application, tree growth was enhanced at all sites. This was accompanied by generally little changes in the GHG emissions. Overall, [the authors] found that wood ash application reduced the GWP of drained peatland forests. Even though that [the authors'] study was limited to eight years after wood ash application, [the authors] can conclude that in the short term wood ash application may be a suitable mitigation option for GHG emissions from Northern drained peatland forests." **Tobias Rütting, Robert G. Björk, Astrid Meyer, Leif Klemedtsson, and Ulf Sikström**, *Forest Ecology and Management*. (Subscription may be required.)

November 2014

"Laboratory Investigations of Weathering of Soils from Mammoth Mountain, CA, a Naturally CO_2-Impacted Field Site." The following is the Abstract of this article: "The potential impacts of CO_2 [release] from a natural subsurface reservoir on soil and water quality were studied. Field measurements of soil pore CO_2 concentrations and visual inspection of plants at Mammoth Mountain, CA, allowed the demarcation of tree-kill and non-tree-kill zones, with CO_2 concentrations >100,000 ppm and ~1,000 ppm, respectively. Soils collected from six sites along a transect stretching from the center of the tree-kill zone to an equidistant point into the non-tree-kill zone were analyzed for surface area and organic carbon content. Batch and column leaching tests were conducted to determine the extent of weathering induced by the presence of CO_2 in the aqueous solution. Soils deep into the tree-kill area exhibited significantly higher surface areas (10.67 m^2/g vs 2.53 m^2/g) and lower organic carbon content (9,550 mg/kg vs 35,550 mg/kg). Batch results indicated that lower pH values (~2) released higher concentrations of Mg, Si, Fe,

and As, while, for soils in the tree-kill zone, longer-term batch results indicated higher releases at the higher pH of 5.5. Column experiments were used to compare the effects of pH adjusted using HCl vs CO_2. For pore volumes (PV) < 100, CO_2 enhanced trace element release. For 100 < PV < 10,000 concentrations of elements in the two systems were equivalent and steady. At PV > 10,000, after a drop in pH in the CO_2 system, larger amounts of Fe and As were released, suggesting a CO_2-induced dissolution of Fe-silicates/clays and/or reductive dissolution of Fe^{3+} that releases Fe-bound arsenic. The specific role of pore water-dissolved CO_2 on the release of trace elements is hitherto unknown. However, interactions of pore-water CO_2 and the minerals in the Mammoth Mountain soils can cause the release of environmental pollutants." **Helen Sanchez, Gustavo Menezes, Andre Ellis, Claudia Espinosa-Villegas, and Crist Khachikian**, *Environ. Sci. Technol.* (Subscription may be required.)

December 2014

"Threshold Dynamics in Soil Carbon Storage for Bioenergy Crops." The following is the Abstract of this article: "Because of increasing demands for bioenergy, a considerable amount of land in the midwestern United States could be devoted to the cultivation of second-generation bioenergy crops, such as switchgrass and miscanthus. The foliar carbon/nitrogen ratio (C/N) in these bioenergy crops at harvest is significantly higher than the ratios in replaced crops, such as corn or soybean. [The authors] show that there is a critical soil organic matter C/N ratio, where microbial biomass can be impaired as microorganisms become dependent upon net immobilization. The simulation results show that there is a threshold effect in the amount of aboveground litter input in the soil after harvest that will reach a critical organic matter C/N ratio in the soil, triggering a reduction of the soil microbial population, with significant consequences in other microbe-related processes, such as decomposition and mineralization. These thresholds are approximately 25 and 15 [percent] of aboveground biomass for switchgrass and miscanthus, respectively. These results suggest that values above these thresholds could result in a significant reduction of decomposition and mineralization, which, in turn, would enhance the [storage] of atmospheric [CO_2] in the topsoil and reduce inorganic nitrogen losses when compared to a corn–corn–soybean rotation." **Dong K. Woo, Juan C. Quijano, Praveen Kumar, Sayo Chaoka, and Carl J. Bernacchi**, *Environ. Sci. Technol.* (Subscription may be required.)

January 2015

"The importance of soil sampling depth for accurate account of soil organic carbon sequestration, storage, retention and loss." The following is the Abstract of this article: "Soil organic carbon distribution within soil profile is highly influenced by management practices, especially tillage systems where soil environment is altered. Such changes in soil environment will affect soil carbon retention or accumulation in different layers of the soil profile. However, much published research in the area of soil organic carbon (SOC) sequestration focuses on shallow sampling depths within the 0–30 cm tillage zone when determining SOC stocks and sequestration. The objectives of this study are to quantify the SOC stock differences with depth between tillage treatments after 20 years and to determine the appropriate sampling depth when assessing SOC stocks as influenced by management practices. A 20-year moldboard plow (MP), chisel plow (CP) and no-tillage (NT) study was established with a maize–soybean rotation. The 75-cm root zone was sampled in 5-cm intervals to measure SOC stocks. The SOC sequestration, storage, retention and loss were determined for the 0–5 cm, 0–15 cm, 15–75 cm and 0–75 cm layers. The NT treatment did retain more SOC stock than the MP treatment to a 20 cm depth but the SOC stock of the 20–35 cm layer NT system was lower than the MP system. It is recommended that the depth of soil sampling has to include the entire root zone to accurately report SOC stock and the effect of tillage system on change in SOC." **K.R. Olson and M.M. Al-Kaisi**, *CATENA*. (Subscription may be required.)

"Short-term carbon dioxide emission under contrasting soil disturbance levels and organic amendments." The following is the Abstract of this article: "Agriculture can be either a source or sink of

atmospheric CO_2 depending on soil management. The application of swine slurry in conventional tilled soils could enhance soil CO_2 emission depleting soil organic C stocks. However, the use of recalcitrant C-rich organic fertilizers in no-till soils can offset soil CO_2 emission promoting soil C [storage]. This hypothesis was tested by evaluating short-term CO_2-C emissions from a Rhodic Nitisol under contrasting soil disturbance levels (disturbed (DS) and undisturbed soil (US)) top-dressed with mineral or organic fertilizers (urea (UR), raw swine slurry (RS), anaerobically digested swine slurry (ADS), and composted swine slurry (CS)). Soil CO_2 emission was evaluated for 64 days using static chambers where gas samples were collected and [analyzed] by photoacoustic infrared spectroscopy. Soil water-filled pore space (WFPS), temperature and meteorological data were concomitantly registered and a first-order exponential decay model was used to assess the decomposition of organic fertilizers and CO_2 emissions induced by soil disturbance. Soil CO_2-C emission was correlated with soil temperature, while limiting soil aeration impaired CO_2-C efflux when WFPS >0.6 cm^3 cm^{-3}. Disturbance increased soil CO_2-C efflux (36.3 ± 2.2 kg CO_2-C ha^{-1} day^{-1}) in relation to US (33.3 ± 1.6 kg CO_2-C ha^{-1} day^{-1}). Extra labile C input through RS amendment induced an increased soil CO_2-C efflux for a longer period ($t_{1/2}$ = 16.9 and 9.6 days in DS and US treatments, respectively), resulting in higher CO_2-C emissions than soil amended with other fertilizers. The recalcitrant C input by ADS and CS had limited effect on soil CO_2-C emissions. CS presented a genuine potential for substantial soil organic C accumulation while offsetting increased CO_2-C emissions in comparison to RS amended soils." **Roberto André Grave, Rodrigo da Silveira Nicoloso, Paulo Cezar Cassol, Celso Aita, Juliano Corulli Corrêa, Morgana Dalla Costa, and Diego Daniel Fritz**, *Soil and Tillage Research*. (Subscription may be required.)

February 2015

"Optimizing carbon sequestration in arid and semiarid rangelands." The following is the Abstract of this article: "Destocking degraded rangeland can potentially help climate change mitigation by re-[storing] emitted carbon. Broad-scale implementation has been limited by uncertainties in the magnitude, duration and location of [storage] and the profitability relative to the existing grazing land use. This paper employs a novel methodology to assess potential rangeland [storage] and its profitability, using 31 Mha of rangeland in New South Wales, Australia as a case-study. This approach combines remotely sensed data and modelled estimates of various components. Remotely sensed, synthetic aperture radar data were used to determine woody biomass of minimally degraded forest (benchmarks) and [neighboring] more-degraded forest, followed by [storage] modelling using non-linear growth rates based on woody thickening and slow-growing plantations, scaled to the benchmarks. Livestock concentration and livestock-based farm profits were modelled. [The authors] compared [storage] and grazing net profits, for a carbon price of AUD$10 Mg^{-1} CO_2-e, at different growth stages for different levels of forest attrition. [The authors] found that broad-scale destocking with subsequent C re-[storage] was initially unprofitable compared with grazing. However, after 50 years, with full costing of C emissions, the returns were similar for the two alternatives of continued grazing or re-[storage], for areas with biomass below benchmark levels. Reforestation of recently deforested land represents the most profitable option with profitability increasing with growth rate. Emissions of soil organic carbon, set in motion by climate change over the next century, were calculated to be the largest of all sources. Emissions from biomass, induced by climate change, will be higher where vegetation cannot adapt. The secondary effects of climate change will reduce re-[storage] and grazing profits, possibly limiting the carbon stored by re-[storage] projects." **Christopher Dean, Jamie B. Kirkpatrick, Richard J. Harper and David J. Eldridge**, *Ecological Engineering*. (Subscription may be required.)

"Long term carbon storage potential and CO_2 sink strength of a restores salt marsh in New Jersey." The following is the Abstract of this article: "The study compares the amounts of carbon fixed via photosynthesis of a restored tidal marsh to the total organic carbon remaining in sediments of a natural tidal marsh and arrives at preliminary baselines for [carbon… storage] over time. The Eddy-covariance method (indirect method) was used to estimate marsh canopy net ecosystem exchange (NEE) and measured an annual gross primary production of 979 g C m^{-2}, while the loss through respiration was 766 g C m^{-2}, resulting in a net uptake of 213 g C m^{-2} yr^{-1}. Time of the day, solar

irradiation, air temperature, humidity and wind direction all together explained 66 [percent] of the variation in NEE. The high marsh community of Spartina patens showed NEE to be significantly higher than the low marsh community. The net ecosystem carbon balance (NECB) over long time scales was estimated by measuring the actual amount of total organic carbon contained in dated sediment cores from a natural marsh (direct method), which resulted in a carbon accumulation rate of 192.2 g m^{-2} yr^{-1}. Changes in total organic carbon content over time in the core sample showed that 78 [percent] of organic carbon remained stored in the sediments after 130 years and only the most recalcitrant carbon (50 [percent]) remained under storage beyond 645 years. Overall the study showed that temperate macrotidal salt marshes are net [releases] of carbon with potential for long term carbon storage. The marsh turned into a carbon [release] at the beginning of May and switched back to being a source in late November. The average sedimentation rate estimated from the 137 CS dating (1950s to present) was 1.4 mm yr^{-1} which is similar to accretion rates of comparable S. patens patches in the east coast. Accretion rates derived from [the authors'] study are slightly lower than the 60+ year rate of sea level rise (2.6 mm yr^{-1}) recorded by tide gauge measurements in the Northeast." **Francisco Artigas, Jin Young Shin, Christine Hobble, Alejandro Marti-Donati, Karina V.R. Schäfer, and Ildiko Pechmann**, *Agricultural and Forest Meteorology*. (Subscription may be required.)

March 2015

"Evaluation of atmospheric CO_2 sequestration by alkaline soils through simultaneous enhanced carbonation and biomass production." The following is the Abstract of this article: "A series of microcosm experiments were conducted. The objectives were to evaluate the effects of Ca/Mg-bearing materials on CO_2 [storage] in highly alkaline sodic soils (Sodosol) through carbonation and biomass production. Application of gypsum resulted in an increase in inorganic carbon and a decrease in organic carbon. The addition of talc did not significantly enhance carbonate formation. Soluble $CaCl_2$ and $MgCl_2$ did not have significantly better effects on soil carbonation, as compared to gypsum. The one-year growth experiment using five widely cultivated pasture grasses revealed that accumulation of carbonates following gypsum application could be inhibited by plant growth; the organic acids secreted from plant roots were likely to facilitate soil carbonate dissolution. In comparison with pedogenic carbonation, carbon [storage] by biomass production was much more evident. However, the biomass carbon gain varied markedly among the five species with *Digitaria eriantha* showing the highest biomass carbon gain. This further enhanced the accumulation of soil organic carbon. At the end of the experiment, an estimated CO_2 [storage] capacity of 93 t/ha was achieved. The research findings have implications for cost–benefit analysis of alkaline soil reclamation projects." **Emohamed Maryol and Chuxia Lin**, *Geoderma*. (Subscription may be required.)

"Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis." The following is the Abstract of this article: "A promising option to [store] carbon in agricultural soils is the inclusion of cover crops in cropping systems. The advantage of cover crops as compared to other management practices that increase soil organic carbon (SOC) is that they neither cause a decline in yields, like extensification, nor carbon losses in other systems, like organic manure applications may do. However, the effect of cover crop green manuring on SOC stocks is widely overlooked. [The authors] therefore conducted a meta-analysis to derive a carbon response function describing SOC stock changes as a function of time. Data from 139 plots at 37 different sites were compiled. In total, the cover crop treatments had a significantly higher SOC stock than the reference croplands. The time since introduction of cover crops in crop rotations was linearly correlated with SOC stock change (R^2 = 0.19) with an annual change rate of 0.32 ± 0.08 Mg ha^{-1} yr^{-1} in a mean soil depth of 22 cm and during the observed period of up to 54 years. Elevation above sea level of the plot and sampling depth could be used as explanatory variables to improve the model fit. Assuming that the observed linear SOC accumulation would not proceed indefinitely, [the authors] modeled the average SOC stock change with the carbon turnover model RothC. The predicted new steady state was reached after 155 years of cover crop cultivation with a total mean SOC stock accumulation of 16.7 ± 1.5 Mg ha^{-1} for a soil depth of 22 cm. Thus, the C input driven SOC [storage] with the introduction of cover crops proved to be highly

efficient. [The authors] estimated a potential global SOC [storage] of 0.12 ± 0.03 Pg C yr^{-1}, which would compensate for 8 [percent] of the direct annual [GHG] emissions from agriculture. However, altered N_2O emissions and albedo due to cover crop cultivation have not been taken into account here. Data on those processes, which are most likely species-specific, would be needed for reliable [GHG] budgets." **Christopher Poeplau and Axel Don**, *Agriculture, Ecosystems & Environment*. (Subscription may be required.)

April 2015

"Accelerated foliar litter humification in forest gaps: Dual feedbacks of carbon sequestration during winter and the growing season in an alpine forest." The following is the Abstract of this article: "Can forest gaps lead to constrained litter decomposability by redistributing heat and moisture conditions, thereby increasing carbon [storage] from plant to soil via litter humification in alpine forests? [The authors] studied mass losses, humic substances, humic acid, fulvic acids, as well humification degrees and humification ratios in six foliar litters with a field litterbag experiment from the gap center, canopy gap and expanded gap to the closed canopy in winter and the growing season in an alpine forest of the east Tibetan Plateau. Humification degrees of [18 to 45 percent] for birch, [15 to 40 percent] for fir, [8 to 30 percent] for willow, [14 to 26 percent] for cypress, [9 to 25 percent] for larch and [7 to 19 percent] for azalea foliar litter were observed in forest gaps and the closed canopy over one year of incubation. Small amounts of humic substances accumulated in winter, whereas considerable humic acid accumulated, but fulvic acid mineralized during the growing season. Compared with the closed canopy, foliar litter humification in forest gaps was lower in winter but greater in the growing season, implying a dual role of forest gaps in carbon [storage] between winter and the growing season. Carbon [storage] could be accelerated in forest gaps. Reduced snow cover under a scenario of winter warming would stimulate soil carbon storage in these alpine forests." **Xiangyin Ni, Wanqin Yang, Bo Tan, Jie He, Liya Xu, Han Li, and Fuzhong Wu**, *Geoderma*. (Subscription may be required.)

May 2015

"CO_2 emissions from a forest soil as influenced by amendments of different crop straws: Implications for priming effects." The following is the Abstract of this article: "In this study, the effects of crop straw amendments on CO_2 emissions from a forest soil were investigated by using a 22-day incubation experiment. Five types of crop straw (winter wheat, rice, maize, soybean, and peanut) were used in the experiment and the soil without straw added was control (CK). There were three levels (0.6, 1.2, and 2.4 g) for each straw type. Soil CO_2 emission rates were measured 1, 2, 4, 6, 8, 11, 15, 18, and 22 days after the crop straw amendments by using an infra-red gas analyzer. Results showed that the basal soil CO_2 emission, i.e. soil organic carbon (SOC) mineralization in CK, was significantly ($P < 0.01$) lower than the CO_2 emission from straw-amended soils. Given a specific straw type, soil CO_2 emission was significantly and positively correlated with the amount of straw inputs, yielding the coefficient of determination (R^2) ranging from 0.9988 ($P = 0.022$) to 1.0000 ($P < 0.001$). The decomposition coefficients, i.e. the slopes of the linear function, of winter wheat, rice, maize, soybean, and peanut straws, were 0.275 ± 0.003, 0.593 ± 0.018, 0.895 ± 0.031, 0.890 ± 0.000, and 1.344 ± 0.039 mg g^{-1} per gram straw, respectively. Winter wheat straw amendment induced an about [two]-fold increase of basal soil CO_2 emission, showing a positive net priming effect (PE). Further investigation indicated that a semi-empirical model based on urease activity, DOC content, and pH could explain 94.5 [percent] ($R^2 = 0.945$) variations in soil CO_2 emissions. This study supports strong vulnerability of SOC in forest in particular under the scenario of changes in land use and agricultural straw management practice." **Shutao Chen, Yuanyuan Wang, Zhenghua Hu, and Hui Gao**, *CATENA*. (Subscription may be required.)

June 2015

"Changes in soil aggregation and microbial community structure control carbon [storage] after afforestation of semiarid shrublands." The following is the Abstract of this article: "Changes in plant cover after afforestation induce variations in litter inputs and soil microbial community structure and activity, which may promote the accrual and physical-chemical protection of soil organic carbon (SOC) within soil aggregates. In a long-term experiment (20 years) [the authors] have studied the effects, on soil aggregation and SOC stabilization, of two afforestation techniques: a) amended terraces with organic refuse (AT), and b) terraces without organic amendment (T). [The authors] used the adjacent shrubland (S) as control. Twenty years after stand establishment, aggregate distribution (including microaggregates within larger aggregates), sensitive and slow organic carbon (OC) fractions, basal respiration in macroaggregates, and microbial community structure were measured. The main changes occurred in the top layer (0–5 cm), where: i) both the sensitive and slow OC fractions were increased in AT compared to S and T, ii) the percentage and OC content of microaggregates within macroaggregates (Mm) were higher in AT than in S and T, iii) basal respiration in macroaggregates was also higher in AT, and iv) significant changes in the fungal (rather than bacterial) community structure were observed in the afforested soils (AT and T) – compared to the shrubland soil. These results suggest that the increase in OC pools linked to the changes in microbial activity and fungal community structure, after afforestation, promoted the formation of macroaggregates – which acted as the nucleus for the formation and stabilization of OC-enriched microaggregates." **N. Garcia-Franco, M. Martinez-Mena, M. Goberna, and J. Albaladejo**, *Soil Biology and Biochemistry*. (Subscription may be required.)

July 2015

"Constraints to nitrogen acquisition of terrestrial plants under elevated CO_2." The following is the Abstract of this article: "A key part of the uncertainty in terrestrial feedbacks on climate change is related to how and to what extent nitrogen (N) availability constrains the stimulation of terrestrial productivity by elevated CO_2 (eCO_2), and whether or not this constraint will become stronger over time. [The authors] explored the ecosystem-scale relationship between responses of plant productivity and N acquisition to eCO_2 in free-air CO_2 enrichment (FACE) experiments in grassland, cropland and forest ecosystems and found that: (i) in all three ecosystem types, this relationship was positive, linear and strong ($r^2 = 0.68$), but exhibited a negative intercept such that plant N acquisition was decreased by 10 [percent] when eCO_2 caused neutral or modest changes in productivity. As the ecosystems were markedly N limited, plants with minimal productivity responses to eCO_2 likely acquired less N than ambient CO_2-grown counterparts because access was decreased, and not because demand was lower. (ii) Plant N concentration was lower under eCO_2, and this decrease was independent of the presence or magnitude of eCO_2-induced productivity enhancement, refuting the long-held hypothesis that this effect results from growth dilution. (iii) Effects of eCO_2 on productivity and N acquisition did not diminish over time, while the typical eCO_2-induced decrease in plant N concentration did. [The authors'] results suggest that, at the decennial timescale covered by FACE studies, N limitation of eCO_2-induced terrestrial productivity enhancement is associated with negative effects of eCO_2 on plant N acquisition rather than with growth dilution of plant N or processes leading to progressive N limitation." **Zhaozhong Feng, Tobias Rütting, Håkan Pleijel, Göran Wallin, Peter B. Reich, Claudia I. Kammann, Paul C.D. Newton, Kazuhiko Kobayashi, Yunjian Luo, and Johan Uddling**, *Global Change Biology*. (Subscriptions may be required.)

August 2015

"Hidden carbon sink beneath desert." The following is the Abstract of this article: "For decades, global carbon budget accounting has identified a 'missing' or 'residual' terrestrial sink; i.e., CO_2 released by anthropogenic activities does not match changes observed in the atmosphere and ocean. [The authors] discovered a potentially large carbon sink in the most unlikely place on earth, irrigated saline/alkaline arid land. When cultivating and irrigating arid/saline lands in arid zones, salts are leached downward.

Simultaneously, dissolved inorganic carbon is washed down into the huge saline [formations] underneath vast deserts, forming a large carbon sink or pool. This finding points to a direct, rapid link between the biological and geochemical carbon cycles in arid lands which may alter the overall spatial pattern of the global carbon budget." **Yan Li, Yu-Gang Wang, R.A. Houghton, and Li-Song Tang**, *Geophysical Research Letters*. (Subscription may be required.)

"Impacts of CO_2 concentration and climate change on the terrestrial carbon flux using six global climate-carbon coupled models." The following is the Abstract of this article: "Based on the simulations of the fifth phase of the Coupled Model Intercomparison Project (CMIP5), [the authors] estimated the response of net primary production (NPP) and net ecosystem production (NEP) to rising atmospheric CO_2 concentration and climate change on global and regional scales. The modeled NPP and NEP significantly increased by about 0.4 Pg C yr^{-2} and 0.09 Pg C yr^{-2}, respectively, in response to the rising atmospheric CO_2 concentration. However, adverse trends of the two variables were driven by climate change on a global scale. Regarding the spatial pattern, the decreases were mainly located in tropical and temperate regions. Thus, the terrestrial carbon sink was accelerated not only by a rising atmospheric CO_2 concentration, but also by global warming at high latitude and altitude regions, e.g. Tibet and Alaska. Although the simulations indicated increases of NPP and NEP owing to the CO_2 fertilization effect, the strength of the trends significantly differed from the CMIP5 models. The enhanced trend in the terrestrial carbon sink simulated by MPI-ESM-LR was about 47 times larger than that simulated by CESM-BGC considering the CO_2 fertilization effect. Differences in the modeled responses of NPP and NEP resulted from the various processes of the land surface component accounting for the nitrogen limitation effect and plant functional types (PFTs). [The authors] also found that the difference in the accelerating terrestrial carbon loss forced by global warming between CMIP5 models, ranged between 6.0 Tg C yr^{-2} in CESM-BGC and 52.7 Tg C yr^{-2} in MPI-ESM-LR. Such a divergence was partially responsible for the difference in the simulated climate between the CMIP5 models: the difference in increasing temperature was about 1.4 K." **Jing Peng and Li Dan**, *Ecological Modelling*. (Subscription may be required.)

Trading

September 2014

"CO_2 Allowances Sold for $4.88 in 25th RGGI Auction." The states participating in RGGI announced that 100 percent of the CO_2 allowances offered for sale at their 25th auction (17,998,687 total CO_2 allowances) were sold at a clearing price of $4.88. The auction generated $87.8 million for reinvestment by the RGGI states in consumer-benefit initiatives, such as energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. Cumulative proceeds from all RGGI CO_2 allowance auctions total approximately $1.8 billion. According to the independent market monitor's report, titled, "Market Monitor Report for Auction 25," electricity generators and their corporate affiliates have won 78 percent of the CO_2 allowances sold in RGGI auctions since 2008. From *RGGI News Release* on September 5, 2014.

"California's Latest Carbon Auction Raises $331.8 Million." According to California state officials, industrial companies and other businesses paid a combined $331.8 million for carbon credits in California's latest cap-and-trade auction. The California Air Resources Board (CARB) reported that companies paid $11.50 a ton for carbon credits that can be used this year and all of the 22.5 million credits available were sold. Carbon credits to be used in 2017 sold for $11.34 a ton, with approximately two-thirds of the 9.3 million available credits being purchased. The market is the centerpiece of AB 32, California's law that placed a ceiling on the total amount of carbon that can be emitted each year by more than 400 manufacturers, food processors, and others. For more information on CARB Quarterly Auction 8, view the Summary Results Report. From *The Sacramento Bee* on September 9, 2014.

"A real option-based model to valuate CDM projects under uncertain energy policies for emission trading." The following is the Abstract of this article: "Emission trading has been considered a primary policy tool for emission reduction. Governments establish national targets for emission reduction and assign emission reduction goals to private entities to accomplish the targets. To attain the goal, private entities should perform offset projects that can produce emission credits or buy emission credits from the market. However, it is not easy for private entities to decide to implement the projects because energy policies associated with emission trading keep changing; thus, the future benefits of the offset projects are quite uncertain. This study presents a real option-based model to investigate how uncertain energy policies affect the financial viability of an offset project. A case study showed that the establishment of a target emission was attractive to the government because it could make the CDM project financially viable with a small amount of government subsidy. In addition, the level of the government subsidy could determine the investment timing for the CDM project. In this context, governments should be cautious in designing energy policies, because even the same energy policies could have different impacts on private entities. Overall, this study is expected to assist private entities in establishing proper investment strategies for CDM projects under uncertain energy policies." **Taeil Park, Changyoon Kim, and Hyoungkwan Kim**, *Applied Energy*. (Subscription may be required.)

October 2014

"RGGI States Initiate Bidding Process for Auction 26." The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their 26th quarterly CO_2 allowance auction scheduled for December 3, 2014. The Auction Notice for CO_2 Allowance Auction 26 provides potential participants with the information needed to indicate their intent to bid on the 18,198,685 CO_2 allowances offered for sale at a reserve price of $2.00. Auction 26 will be the last quarterly auction that states will offer CO_2 allowances for purchase in order to meet CO_2 compliance obligations for the second control period (January 1, 2012, through December 31, 2014). From *RGGI News Release* on October 6, 2014.

"California and Québec Announce First Joint Cap-and-Trade Auction." The California Air Resources Board and the Québec Ministry of Sustainable Development, Environment, and the Fight Against Climate Change will hold their first joint cap-and-trade auction on November 19, 2014. The two jurisdictions officially linked their programs on January 1, 2014, but have been working together for several years to ensure their regulations are equally stringent and can be integrated. The online platform that will hold the joint auction (the same platform both parties used for their individual auctions) was tested by stakeholders during a "practice" joint auction held in August 2014. All participants of the auction must be registered in the Compliance Instrument Tracking System Service (CITSS) and the auction platform; carbon allowances sold in the auction may be used in either the California or Québec cap-and-trade programs. From *California Air Resource Board News Release* on September 18, 2014.

"S. Korea Increases Emissions Cap in Proposed Carbon Trading Scheme." The South Korean government announced that the CO_2 cap expected to be introduced as part of a carbon trading scheme will be approximately three percent larger than previously anticipated. According to the environment ministry, 1.687 billion metric tons of carbon-equivalent emission permits would be distributed from 2015 through 2017 as part of what is projected to be one of the world's largest carbon emissions trading schemes. The environment ministry also stated that 1.598 billion of the total permits will be distributed to the 526 covered emitters before the trading starts, which is more than 1.64 billion than were previously expected. The remaining 89 million permits will be distributed from 2015 to 2017. The South Korean government's goal is reduce CO_2 emissions in 2020 to 30 percent below business-as-usual levels. From *Reuters Africa* on September 11, 2014.

"How will the emissions trading scheme save cost for achieving China's 2020 carbon intensity reduction target?" The following is the Abstract of this article: "Chinese government has committed to reduce its carbon intensity by 40–45 [percent] over the period 2005–2020 at the 2009 Copenhagen

Summit. To achieve the target in a cost-effective way, China is signaling strong intentions to establish emissions trading scheme, and presently seven pilots have been established. This paper focuses on the cost-saving effects of carbon emissions trading in China for the 2020 target. First, an interprovincial emissions trading model is constructed. Then, three kinds of policy scenarios, including no carbon emissions trading among provinces (NETS), the carbon emissions trading only covering the pilots (PETS), and the unified carbon emissions trading market (CETS), have been designed. The results show that China needs to reduce its emissions by 819 $MtCO_2$ for achieving the 42.5 [percent] reduction in carbon intensity over the period 2005–2020. The PETS and the CETS, which may result in a carbon price of 99 yuan/tCO_2 and 53 yuan/tCO_2, could reduce the total abatement costs by 4.50 [percent] and 23.67 [percent], respectively. This paper also finds that the carbon emissions trading could yield different impacts on different provinces, and the cost-saving effects of the eastern and western provinces are more pronounced than the central provinces. Necessary sensitivity analysis is also provided at the end of the research. These findings may be useful for promoting the development of carbon emissions trading in China." **Lian-Biao Cui, Ying Fan, Lei Zhu, and Qing-Hua Bi**, *Applied Energy*. (Subscription may be required.)

November 2014

"Columbia to Launch Voluntary Carbon Credit Trading." Fundacion Natura, a Columbian environmental charity, announced it will launch a carbon trading platform in 2015 to companies seeking to offset carbon emissions. The platform is being developed by the Bolsa Mercantil de Colombia (BMC), a commodities exchange used by physical producers and consumers of farm produce. Columbia does not currently have any legally binding GHG emission limits. From *Reuters* on October 31, 2013.

"On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme." The following is the Abstract of this article: "The EU Emissions Trading Scheme continues to exempt industries deemed at risk of carbon [release] from permit auctions. Carbon [release] risk is established based on the carbon intensity and trade exposure of each [four]-digit industry. Using a novel measure of carbon [release] risk obtained in interviews with almost 400 managers at regulated firms in six countries, [the authors] show that carbon intensity is strongly correlated with [release] risk whereas overall trade exposure is not. In spite of this, most exemptions from auctioning are granted to industries with high trade exposure to developed and less developed countries. [The authors'] analysis suggests two ways of tightening the exemption criteria without increasing relocation risk among non-exempt industries. The first one is to exempt trade exposed industries only if they are also carbon intensive. The second one is to consider exposure to trade only with less developed countries. By modifying the carbon [release] criteria along these lines, European governments could raise additional revenue from permit auctions of up to €3 billion per year [approximately $3.73 billion], based on a permit price of €30 [approximately $37]." **Ralf Martin, Mirabelle Muûls, Laure B. de Preux, and Ulrich J. Wagner**, *Ecological Economics*.

"Endogenous market power in an emissions trading scheme with auctioning." The following is the Abstract of this article: "This paper contributes to the literature on market power in emissions permits markets, modeling an emissions trading scheme in which [emitters] differ with respect to their marginal abatement costs at the business-as-usual emissions. The [emitters] play a two-stage static complete information game in which their market power arises endogenously from their characteristics. In the first stage all [emitters] bid in an auction for the distribution of the fixed supply of permits issued by the regulator, and in the second stage they trade these permits in a secondary market. For compliance, they can also engage in abatement activity at a quadratic cost. Under the assumptions of the model, in equilibrium all [emitters] are successful in the auction. In the secondary market the low-cost emitters are net sellers and the high-cost emitters are net buyers. Moreover, the high-cost emitters are worse off as a result of the strategic behavior. In addition, the secondary market price is unambiguously above the auction clearing price. I find that the aggregate compliance cost when [emitters] act strategically increases in the heterogeneity of their marginal abatement costs at the business-as-usual emissions, but there exists a threshold of the fixed supply of permits above which strategic behavior is compliance cost-

saving for the [emitters]. Finally, for a low enough variance of the marginal abatement cost at the business-as-usual emissions, strategic behavior is compliance cost-saving for the [emitters], regardless of the level of the available supply of permits." **Corina Haita**, *Resource and Energy Economics*. (Subscription may be required.)

"An emissions trading scheme design for power industries facing price regulation." The following is the Abstract of this article: "The electricity market, monopolistic in nature, with government price regulation, poses a serious challenge for policy makers with respect to the cost-effectiveness of emissions trading, particularly in Asian countries. This paper argues that a cap-and-trade regulatory system for indirect emissions combined with a rate-based allocation system for direct emissions can achieve market efficiency even in the presence of price and quantity controls in the electricity market. This particular policy mix could provide appropriate incentives for industries to reduce their electricity consumption while inducing power producers to reduce their direct carbon emissions cost-effectively in conditions where there is strict government control of electricity prices. Another advantage of the suggested policy mix is that it allows carbon [release] in cross-border power trades to be effectively eliminated." **Yong-Gun Kim and Jong-Soo Lim**, *Energy Policy*. (Subscription may be required.)

December 2014

"California Says Carbon Permits Sell Out at Auction with Quebec." Officials from the California Air Resources Board (CARB) said that firms spent approximately $407 million in the latest quarterly auction of CO_2 emissions permits. The auction, held on November 25, was the first conducted that included participation from the Canadian province of Quebec. All of the nearly 34 million allowances available were sold. The auctions are part of California's cap-and-trade program, which seeks to limit CO_2 emissions as part of the state's initiative to address climate change. The California cap-and-trade program and Québec cap-and-trade system officially linked in January 2014. This enabled mutual acceptance of compliance instruments issued by each jurisdiction and the jurisdictions to hold joint auctions of GHG allowances. Quebec is the first entity to join the program. Each CO_2 emissions permit gives a firm the right to emit one ton of CO_2. More information on the auction is available via the CARB press release. From *Sacramento Bee* on December 3, 2014.

"CO_2 Allowances Sold for $5.21 in 26th RGGI Auction." The states participating in RGGI announced that 18,198,685 CO_2 allowances were sold at their 26th auction at a clearing price of $5.21. All allowances offered for sale were sold, generating more than $94 million for reinvestment in energy efficiency and renewable energy initiatives, direct bill assistance, and GHG abatement programs. The cumulative proceeds from all RGGI CO_2 allowance auctions currently total $1.9 billion dollars; more information is available via the Market Monitor Report for Auction 26. RGGI's second control period began on January 1, 2012, and ends on December 31, 2014. Regulated power plants in the participating states will be required to demonstrate compliance for the second control period on March 2, 2015. The 2014 RGGI cap is 91 million short tons; the RGGI cap then declines 2.5 percent each year from 2015 to 2020. From *RGGI News Release* on December 5, 2014.

"Futures trading with information asymmetry and OTC predominance: Another look at the volume/volatility relations in the European carbon markets." The following is the Abstract of this article: "This paper constitutes the first exercise of [analyzing] the European carbon market efficiency from a double perspective combining both nature of execution venues (screen vs. OTC trading) and their volatility/liquidity relations. Using a bivariate asymmetric GJR-GARCH model, [the authors] first document that OTC (exchange traded) trading volume shows consistent bi-(uni) directional Granger causality to [the authors'] volatility estimates, consistent with greater responsiveness of the OTC (exchange traded) market to changes in market-wide (idiosyncratic) risks. Second, [the authors] report significant contemporaneous and lagged positive causality of OTC derivatives volume on spot/futures volatility confirming that the Sequential Information Arrival Hypothesis (SIAH) applies. Third, [the authors] find that the one-way causality from OTC to futures volumes is mainly driven by heterogeneous investor

beliefs: trading volume provides an indication on how (private) information is dispersed and held at different levels rather than proxying information signal itself. After rejecting execution venues' substitutability, [the authors] advocate for systematic clearing and netting of OTC positions through a unique clearing house and reporting rules to identify speculation in line with Mifid (Art. 59) proposals." **Yves Rannou and Pascal Barneto**, *Energy Economics*. (Subscription may be required.)

January 2015

"South Korea Launches World's Second-Biggest Carbon Market." South Korea opened its CO_2 cap-and-trade system on January 12, 2015, limiting CO_2 emissions from power generators, petrochemical firms, steel producers, car makers, electro-mechanical firms and airlines. The market covers 525 South Korean companies that will be allotted a fixed amount of permits (totaling 1.687 million metric tons of CO_2 equivalent) to cover emissions for the next three years. Any company that exceeds its allotment must buy credits from another firm. South Korea's goal is to reduce GHG emissions by 30 percent by 2020. South Korea follows Kazakhstan as the second country in Asia to launch a nationwide emissions market; China and Japan operate regional schemes. The South Korean market is considered the second largest cap-and-trade system in the world behind Europe. From *Reuters* on January 12, 2015.

"Carbon pricing versus emissions trading: A supply chain planning perspective." The following is the Abstract of this article: "Carbon pricing (taxes) and carbon emissions trading are two globally practiced carbon regulatory policy schemes. This paper presents an analytical supply chain planning model that can be used to examine the supply chain performance at the tactical/operational planning level under these two policy schemes. Model implementation and analyses are completed using actual data from a company operating in Australia, where these environmental regulatory policies are practiced. Numerical results provide important managerial and practical implications and policy insights. In particular, the results show that there are inflection points where both carbon pricing and trading schemes could influence costs or emissions reductions. An erratic nonlinear emissions reduction trend is observed in a carbon pricing scheme as the carbon price increases steadily; whereas emissions reduction in a carbon trading scheme follows a relatively linear trend with a nonlinear cost increase. Overall, a carbon trading mechanism, although imperfect, appears to result in better supply chain performance in terms of emissions generation, cost, and service level; even though a carbon tax may be more worthwhile from an uncertainty perspective as emissions trading costs depend on numerous uncertain market conditions." **Atefe Zakeri, Farzad Dehghanian, Behnam Fahimnia, and Joseph Sarkis**, *International Journal of Production Economics*. (Subscription may be required.)

"Gains from Emissions Trading Under Multiple Stabilization Targets and Technological Constraints." The following is the Abstract of this article: "This study quantified the effectiveness of emissions trading by considering multiple technological constraints, burden sharing schemes, and climate stabilization targets. [The authors] used a global computable general equilibrium model, and evaluated the effectiveness of emissions trading using welfare losses associated with climate mitigation for scenarios with and without emissions trading, as measured by the Hicksian Equivalent Variation (HEV). [The authors] found that emissions trading contributed to a reduction in the economic losses associated with climate mitigation for all technological assumptions, burden sharing schemes, and stabilization targets. The net global welfare losses in scenarios without emissions trading ranged between 0.7 [percent] and 1.9 [percent], whereas emissions trading reduced the losses by 0.1 [percent] to 0.5 [percent]. The range depended on the assumptions in the burden sharing schemes, technological constraints, and stabilization targets. The percentage change in welfare gain from emissions trading varied regionally, and was relatively high in low-income or middle-income countries (0.2 [percent] to 1.0 [percent] and − 0.1 [percent] to 1.2 [percent], respectively) compared to high-income countries (− 0.1 [percent] to 0.3 [percent]). Some regions displayed negative values with regard to the effectiveness of emissions trading, which might be due to the change in goods and service trades associated with emissions trading. If the usage of [CCS] was constrained, welfare loss became large and the effectiveness of emissions trading ultimately increased. The use of a burden sharing scheme was a

significant factor in changing the effectiveness of emissions trading, and the per capita emissions convergence in 2050 was more effective for emissions trading than a per income convergence." **Shinichiro Fujimoria, Toshihiko Masuia, and Yuzuru Matsuokab**, *Energy Economics*. (Subscription may be required.)

February 2015

"China Opens National Registry for Carbon Offsets, Doubles Supply." China has opened a national register for carbon offsets, known as Chinese Certified Emissions Reductions (CCERs), enabling carbon emission credits to be transferred from the national scheme to regional exchanges. In addition, the National Development and Reform Commission (NDRC) issued 7 million CCERs from 16 projects, adding to the 6.5 million CCERs approved in December 2014. Emitters are permitted to use CCERS to cover a percentage of their annual emissions. Participants in China's seven pilot emissions trading schemes can use a total of approximately 110 million CCERs annually, with demand expected to rise as new regions and sectors are included. From *The Business Times* on January 14, 2015.

"Carbon prices and incentives for technological development." The following is the Abstract of this article: "There is concern that the carbon prices generated through climate policies are too low to create the incentives necessary to stimulate technological development. This paper empirically analyzes how the Swedish CO_2 tax and the European Union emission trading system (EU ETS) have affected productivity development in the Swedish pulp and paper industry 1998−2008. A Luenberger total factor productivity indicator is computed using data envelopment analysis. The results show that climate policy had a modest impact on technological development in the pulp and paper industry, and if significant it was negative. The price of fossil fuels, on the contrary, seems to have created important incentives for technological development. Hence, the results suggest that the carbon prices faced by the industry through EU ETS and the CO_2 tax have been too low. Even though the data for this study is specific for Sweden, the models and results are applicable internationally. When designing policy to mitigate CO_2 emissions, it is vital that the policy creates a carbon price that is high enough – otherwise the pressure on technological development will not be sufficiently strong." **Tommy Lundgren, Per-Olov Marklund, Eva Samakovlis, and Wenchao Zhou**, *Journal of Environmental Management*. (Subscription may be required.)

"Carbon emissions in a multi-echelon production-inventory model with lead time constraints." The following is the Abstract of this article: "[The authors] develop a deterministic optimization model that incorporates carbon emissions in a multi-echelon production-inventory model with lead time constraints. [The authors] impose that each customer order must be delivered within the due date fixed by the customer. The quantity that cannot be delivered on time is a lost sale. [The authors] consider a multi-echelon supply chain with different external suppliers, different manufacturing facilities, and different distribution centers. [The authors] adopt a general inventory policy. Indeed, [the authors] do not impose any constraints on the stock level that must be kept for each product in each facility in each period and on the procurement order quantities in the different facilities. Carbon emissions are associated with the decisions of manufacturing of intermediate and final products, ordering (transportation) from external and internal suppliers, and inventory positioning of the different products in the different stages of the supply chain. [The authors] first deal with the case of carbon emissions tax and then turn to the case of carbon emissions cap. [The authors] use the model to provide a series of insights that would be of interest for firms and policy makers. Such insights would be difficult to obtain with classical production-inventory models. For instance, the integration of lead times permits to show how the amount of carbon emissions is non-monotone with the variation of customer lead time and orders frequency. Also, the consideration of a general inventory policy permits to show how some particular policies (such as the base stock and the fixed order quantity) leads to increasing emissions. In addition, [the authors] capitalize on the multi-echelon aspect of [their] model in order to study the effect of individual emissions caps on each facility with comparison to a global cap on the entire supply chain. For instance, [the authors] demonstrate that individual caps can achieve significant lower emissions but can paradoxically lead to increasing the per

unit emissions. [The authors] also show how a share of emissions can improve per unit emissions without deteriorating total emissions." **Ramzi Hammami, Imen Nouira, and Yannick Frein**, *International Journal of Production Economics*. (Subscription may be required.)

"Tactical supply chain planning under a carbon tax policy scheme: A case study." The following is the Abstract of this article: "[GHG] emissions are receiving greater scrutiny in many countries due to international forces to reduce anthropogenic global climate change. Industry and their supply chains represent a major source of these emissions. This paper presents a tactical supply chain planning model that integrates economic and carbon emission objectives under a carbon tax policy scheme. A modified Cross-Entropy solution method is adopted to solve the proposed nonlinear supply chain planning model. Numerical experiments are completed utilizing data from an actual organization in Australia where a carbon tax is in operation. The analyses of the numerical results provide important organizational and policy insights on (1) the financial and emissions reduction impacts of a carbon tax at the tactical planning level, (2) the use of cost/emission tradeoff analysis for making informed decisions on investments, (3) the way to price carbon for maximum environmental returns per dollar increase in supply chain cost." **Behnam Fahimnia, Joseph Sarkis, Alok Choudhary, and Ali Eshragh**, *International Journal of Production Economics*. (Subscription may be required.)

"Market-Driven Emissions from Recovery of Carbon Dioxide Gas." The following is the Abstract of this article: "This article uses a market-based allocation method in a consequential life cycle assessment (LCA) framework to estimate the environmental emissions created by recovering CO_2. [The authors] find that 1 ton of CO_2 recovered as a coproduct of chemicals manufacturing leads to additional greenhouse gas [GHG] emissions of 147–210 kg CO_2 eq, while consuming 160–248 kWh of electricity, 254–480 MJ of heat, and 1836–4027 kg of water. The ranges depend on the initial and final purity of the CO_2, particularly because higher purity grades require additional processing steps such as distillation, as well as higher temperature and flow rate of regeneration as needed for activated carbon treatment and desiccant beds. Higher purity also reduces process efficiency due to increased yield losses from regeneration gas and distillation reflux. Mass- and revenue-based allocation methods used in attributional LCA estimate that recovering CO_2 leads to 19 and 11 times the global warming impact estimated from a market-based allocation used in consequential LCA." **Sarang D. Supekar and Steven J. Skerlos**, *Environ. Sci. Technol.* (Subscription may be required.)

March 2015

"California Carbon Permits Fetch $12.21 [per Metric Ton] at Auction." All carbon permits offered in California's first cap-and-trade program auction of the year were sold at $12.21 per metric ton, the state announced. It was the first auction held since the program nearly doubled in size in January. All 73.6 million carbon permits offered to cover 2015 emissions and 10.4 allowances offered to cover emissions in 2018 were sold, with the 2018 permits selling at $12.10 per metric ton (the minimum price allowed under auction rules). The auction was the state's 10th overall and the second since partnering with the province of Quebec, Canada. Previous auctions raised more than $969 million, which California plans to invest in, among other things, energy efficiency and clean energy programs. The state's cap-and-trade program is looking to reduce its emissions to 1990 levels by 2020. From *Reuters* on February 25, 2015.

"Quantifying CO_2 abatement costs in the power sector." The following is the Abstract of this article: "[Carbon dioxide] cap-and-trade mechanisms and CO_2 emission taxes are becoming increasingly widespread. To assess the impact of a CO_2 price, marginal abatement cost curves (MACCs) are a commonly used tool by policy makers, providing a direct graphical link between a CO_2 price and the expected abatement. However, such MACCs can suffer from issues related to robustness and granularity. This paper focuses on the relation between a CO_2 emission cost and CO_2 emission reductions in the power sector. The authors present a new methodology that improves the understanding of the relation between a CO_2 cost and CO_2 abatement. The methodology is based on the insight that CO_2 emissions in the power sector are driven by the composition of the conventional power portfolio, the

residual load and the generation costs of the conventional units. The methodology addresses both the robustness issue and the granularity issue related to MACCs. The methodology is based on a bottom-up approach, starting from engineering knowledge of the power sector. It offers policy makers a new tool to assess CO_2 abatement options. The methodology is applied to the Central Western European power system and illustrates possible interaction effects between, e.g., fuel switching and renewables deployment." **Kenneth Van den Bergh and Erik Delarue**, *Energy Policy*. (Subscription may be required.)

April 2015

"California Carbon Revenue Hits $1.6 Billion." According to officials, California's February carbon permit auction raised $629.5 million, bringing the cap-and-trade program's total revenue to nearly $1.6 billion. Revenue generated from the 10 quarterly auctions is used to fund clean energy programs. The program is a component of the state's goal to reduce GHGs to 1990 levels by the end of the decade, with the ultimate goal of reducing GHGs 80 percent below 1990 levels by 2050. California's cap-and-trade program operates in conjunction with the Canadian province of Quebec; the next carbon permit auction will be held in May 2015. From *Reuters* on March 17, 2015.

"CO_2 Allowances Sold for $5.41 in 27th RGGI Auction." The states participating in RGGI announced that all 15,272,670 CO_2 allowances available for sale were sold at the 27th auction at a clearing price of $5.41. Bids for the CO_2 allowances ranged from $2.05 to $12.50 per allowance. Ten million cost containment reserve (CCR) allowances were also available for sale. None of the CCR allowances were sold. The auction generated more than $82 million for reinvestment in energy and consumer benefit programs, including energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. The cumulative proceeds from the RGGI CO_2 allowance auctions now exceed $2 billion. From *RGGI News Release* on March 13, 2015.

"CO_2 Budget Source 2015 Interim Compliance." RGGI's third three-year control period began on January 1, 2015, and extends through December 31, 2017. Starting in 2015, each CO_2 budget source must: (1) hold allowances equal to 50 percent of emissions during each interim control period (the first two calendar years of each three-year control period); and (2) hold allowances equal to 100 percent of their remaining emissions for the three-year control period at the end of the three-year control period. The first interim control period began on January 1, 2015, and each CO_2 budget source must hold allowances available for compliance deduction equal to 50 percent of their emissions by March 1, 2016. Market participants can acquire allowances through the CO_2 allowance auctions and secondary markets. The next CO_2 allowance auction is scheduled for June 3, 2015 (see Announcements section of this newsletter for more information). From *RGGI News Release* on March 16, 2015.

"An optimization decision support approach for risk analysis of carbon emission trading in electric power systems." The following is the Abstract of this article: "Concerns over dramatic increasing electricity demand, exacerbating power shortage and changing climatic condition are emerging associated with municipal electric power systems (EPS). In this study, a risk-explicit mixed-integer full-infinite programming (RMFP) approach is developed for planning carbon emission trading (CET) in EPS. RMFP-CET has advantages in risk reflection and policy analysis, particularly when the input parameters are provided as crisp and functional intervals as well as probabilistic distributions. The developed method is applied to a real case study of CET planning of EPS in Beijing. Various electricity policies are incorporated within the modeling formulation for enhancing the RMFP-CET's capability. The results indicate that reasonable solutions have been generated, which are useful for making decisions of electricity production and supply as well as gaining insight into the tradeoffs among electricity supply risk, system cost, and CO_2 mitigation strategy." **Y. Zhu, Y.P. Li, and G.H. Huang**, *Environmental Modelling & Software*. (Subscription may be required.)

"Carbon capture and storage: Frames and blind spots." The following is the Abstract of this article: "The European Union (EU) CCS demonstration [program] stands out for the speed with which financial support was agreed to, the size of this support, and its unusual format. This paper sets out to examine CCS policymaking in the EU by [analyzing] the way this technology was framed. It draws up a simple model of technology framing with two variants. The first one describes the creation of 'mainstream frames' of technologies in policymaking. The second one explains the effects of a 'hegemonic frame', namely the weakening of evaluation criteria and the increased salience of 'blind spots'. On this basis, this paper explains the global mainstreaming of a CCS frame and its transformation into a hegemonic frame in the EU. Finally, the paper reviews the blind spots in this hegemonic frame and their impact on EU policy." **Alfonso Martínez Arranz**, *Energy Policy*. (Subscription may be required.)

May 2015

"EU Agrees to Overhaul Carbon-Trading System." The European Union (EU) has agreed to create a stabilization mechanism for the EU Emissions Trading System (EUETS) in order to raise the cost of releasing CO_2 into the atmosphere and encourage the investment in low-carbon technologies. Since the world's first carbon market was established in 2005, the cost of emitting CO_2 has dropped from a high of approximately $34 per ton to less than $9 per ton. Analysts estimate that there are approximately 2 billion excess CO_2 allowances in the carbon market. National EU governments and European Parliament will create a "market stability reserve" from 2019 to act as a "central bank" that has the ability to remove the surplus of allowances. From *The Wall Street Journal* on May 5, 2015.

"Ontario to Sign Cap-and-Trade Agreement with Quebec to Cut Carbon Emissions." Officials announced that Ontario will sign an agreement to join Quebec in a cap-and-trade system to reduce GHG emissions, with the long-term plan of joining the largest cap-and-trade market, the Western Climate Initiative (WCI). Proceeds from the carbon market will be reinvested in projects to help reduce GHG emissions. Quebec, which currently operates its cap-and-trade system with California, has auctioned off nearly $190 million worth of credits since it was implemented in early 2015. From *CBC News* on April 10, 2015.

"Estimating the public's value of implementing the CO_2 emissions trading scheme in Korea." The following is the Abstract of this article: "The Korean government set out the CO_2 emissions reduction target as 30 [percent] below business-as-usual by 2020. The CO_2 emissions trading scheme (ETS) was initiated in January 2015 to meet this target. [The authors] attempt to estimate the public's value of implementing the ETS for CO_2 emissions reduction. [The authors] apply the contingent valuation (CV) method using the willingness to pay (WTP) data obtained from a national CV survey of 1000 randomly selected households. The survey was conducted via in-person interviews. Value judgments required of the respondents were within their abilities. The mean WTP to achieve the stated target of CO_2 emissions reduction using ETS is estimated to be KRW 1873 (USD 1.66) per household per month, which is statistically significant at the [one percent] level. The aggregate national value amounts to KRW 409.2 billion (USD 363.4 million) per year. Thus, even though Korea has no obligations to cut emissions under the Kyoto protocol, the public is willing to bear a financial burden to implement the ETS. If its cost is less than this value, implementing the ETS can be socially profitable. The results of this study can serve as a basis for further policy discussions and decisions." **Tae-Ho Song, Kyoung-Min Lim, and Seung-Hoon Yoo**, *Energy Policy*. (Subscription may be required.)

June 2015

"Carbon Pricing Initiatives Valued at Close to $50 Billion." Emissions trading systems have grown in value from $32 billion in 2014 to $34 billion currently, according to a new report from the World Bank Group. In addition, the report also states that existing carbon tax systems are currently valued at approximately $14 billion. The publication, titled, "Carbon Pricing Watch 2015," is a preview of a report to

be launched later this year, titled, "State and Trends of Carbon Pricing 2015." An abstract of "Carbon Pricing Watch 2015" is available in the "Recent Publications" section of this newsletter. From *The World Bank Press Release* on May 26, 2015.

"EEM Buys European Operations of the Carbon Trade Exchange Group." Environmental commodities exchange operator European Environmental Markets (EEM) has acquired Carbon Trade Exchange Ltd (CTX EU), the European operations of the Carbon Trade Exchange Group (CTX Group). Based in Sydney, Australia, the CTX Group operates the global electronic exchange platform in the voluntary carbon market. The transaction includes CTX EU's European Clients and exchange businesses for both voluntary and regulated carbon emissions trading. EEM plans to launch spot trading for the European Union Emissions Trading Scheme (EU ETS) using CTX's infrastructure later this year. From *Commodities Now* on May 21, 2015.

"Statistical regularities of Carbon emission trading market: Evidence from European Union allowances." The following is the Abstract of this article: "As an emerging financial market, the trading value of carbon emission trading market has definitely increased. In recent years, the carbon emission allowances have already become a way of investment. They are bought and sold not only by carbon emitters but also by investors. In this paper, [the authors] analyzed the price fluctuations of the European Union allowances (EUA) futures in European Climate Exchange (ECX) market from 2007 to 2011. The symmetric and power-law probability density function of return time series was displayed. [The authors] found that there are only short-range correlations in price changes (return), while long-range correlations in the absolute of price changes (volatility). Further, detrended fluctuation analysis (DFA) approach was applied with focus on long-range autocorrelations and Hurst exponent. [The authors] observed long-range power-law autocorrelations in the volatility that quantify risk, and found that they decay much more slowly than the autocorrelation of return time series. [The authors'] analysis also showed that the significant cross correlations exist between return time series of EUA and many other returns. These cross correlations exist in a wide range of fields, including stock markets, energy concerned commodities futures, and financial futures. The significant cross-correlations between energy concerned futures and EUA indicate the physical relationship between carbon emission and energy production process. Additionally, the cross-correlations between financial futures and EUA indicate that the speculation behavior may become an important factor that can affect the price of EUA. Finally [the authors] modeled the long-range volatility time series of EUA with a particular version of the GARCH process, and the result also suggests long-range volatility autocorrelations." **Zeyu Zheng, Rui Xiao, Haibo Shi, Guihong Li, and Xiaofeng Zhou**, *Physica A: Statistical Mechanics and its Applications*. (Subscriptions may be required.)

July 2015

"CO_2 Allowances Sold for $5.50 in 28th RGGI Auction." The 28th auction of CO_2 allowances conducted by the nine states participating in the Regional Greenhouse Gas Initiative (RGGI) was completed, with 15,507,571 CO_2 allowances selling at the auction clearing price of $5.50. The auction generated a total of $85 million for reinvestment in strategic programs, including energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. To date, all RGGI CO_2 allowance auctions have generated a total of $2.1 billion. Additional details of the auction are available in the Market Monitor Report for Auction 28. From *RGGI Press Release* on June 5, 2015.

"China Climate Change Plan Unveiled." China officials announced details of its climate action plan, aiming to reduce CO_2 emissions by 60 to 65 percent, based on 2005 levels, by 2030. The carbon intensity target builds upon a previous plan to reduce carbon intensity by 40 to 45 percent by 2020. In addition, the new climate plan calls for an increase in the share of non-fossil fuels in its primary energy consumption to approximately 20 percent by 2030. From *BBC News* on June 30, 2015.

"Carbon pricing versus emissions trading: A supply chain planning perspective." The following is the Abstract of this article: "Carbon pricing (taxes) and carbon emissions trading are two globally practiced carbon regulatory policy schemes. This paper presents an analytical supply chain planning model that can be used to examine the supply chain performance at the tactical/operational planning level under these two policy schemes. Model implementation and analyses are completed using actual data from a company operating in Australia, where these environmental regulatory policies are practiced. Numerical results provide important managerial and practical implications and policy insights. In particular, the results show that there are inflection points where both carbon pricing and trading schemes could influence costs or emissions reductions. An erratic nonlinear emissions reduction trend is observed in a carbon pricing scheme as the carbon price increases steadily; whereas emissions reduction in a carbon trading scheme follows a relatively linear trend with a nonlinear cost increase. Overall, a carbon trading mechanism, although imperfect, appears to result in better supply chain performance in terms of emissions generation, cost, and service level; even though a carbon tax may be more worthwhile from an uncertainty perspective as emissions trading costs depend on numerous uncertain market conditions." **Atefe Zakeri, Farzad Dehghanian, Behnam Fahimniab, and Joseph Sarkis**, *International Journal of Production Economics*. (Subscription may be required.)

August 2015

"Revised Emission Trading System Will Help EU Deliver on Climate Goals." The European Commission presented a legislative proposal to revise the European Union's (EU) Emission Trading Scheme (ETS) for the period after 2020. The proposal is a step toward achieving the EU's target of reducing its GHG emissions by at least 40 percent (domestically) by 2030. Specifically, the sectors covered by the EU ETS will reduce their GHG emissions by 43 percent compared to 2005 levels by proposals such as increasing the rate of GHG emissions cuts after 2020 and creating support mechanisms to aid industry and power sectors in the low-carbon transition. More information is available via the European Commission's press release. From *European Commission* on July 15, 2015.

"Tactical supply chain planning under a carbon tax policy scheme: A case study." The following is the Abstract of this article: "[GHG] emissions are receiving greater scrutiny in many countries due to international forces to reduce anthropogenic global climate change. Industry and their supply chains represent a major source of these emissions. This paper presents a tactical supply chain planning model that integrates economic and carbon emission objectives under a carbon tax policy scheme. A modified Cross-Entropy solution method is adopted to solve the proposed nonlinear supply chain planning model. Numerical experiments are completed utilizing data from an actual organization in Australia where a carbon tax is in operation. The analyses of the numerical results provide important organizational and policy insights on (1) the financial and emissions reduction impacts of a carbon tax at the tactical planning level, (2) the use of cost/emission tradeoff analysis for making informed decisions on investments, (3) the way to price carbon for maximum environmental returns per dollar increase in supply chain cost." **Behnam Fahimnia, Joseph Sarkis, Alok Choudhary, and Ali Eshragh**, *International Journal of Production Economics*. (Subscription may be required.)

"Carbon emissions trading scheme exploration in China: A multi-agent-based model." The following is the Abstract of this article: "To develop a low-carbon economy, China launched seven pilot programs for carbon emissions trading (CET) in 2011 and plans to establish a nationwide CET mechanism in 2015. This paper formulated a multi-agent-based model to investigate the impacts of different CET designs in order to find the most appropriate one for China. The proposed bottom-up model includes all main economic agents in a general equilibrium framework. The simulation results indicate that (1) CET would effectively reduce carbon emissions, with a certain negative impact on the economy, (2) as for allowance allocation, the grandfathering rule is relatively moderate, while the benchmarking rule is more aggressive, (3) as for the carbon price, when the price level in the secondary CET market is regulated to be around RMB 40 per metric ton, a satisfactory emission mitigation effect can be obtained, (4) the penalty rate is suggested to be carefully designed to balance the economy

development and mitigation effect, and (5) subsidy policy for energy technology improvement can effectively reduce carbon emissions without an additional negative impact on the economy. The results also indicate that the proposed novel model is a promising tool for CET policy making and analyses." **Ling Tang, Jiaqian Wu, Lean Yu, and Qin Bao**, *Energy Policy*. (Subscription may be required.)

Recent Publications

September 2014

"CO_2 Emissions from Electricity Generation and Imports in the Regional Greenhouse Gas Initiative: 2012 Monitoring Report." The following is from the Executive Summary of this document: "This report, the fourth report in a series of annual monitoring reports, summarizes data for the period from 2005 through 2012, for electricity generation, electricity imports, and related CO_2 emissions for the nine states that participated in the RGGI second control period. These monitoring reports were called for in the 2005 RGGI Memorandum of Understanding (MOU) in response to expressed concerns about the potential for the RGGI CO_2 Budget Trading Program to result in "emissions leakage". This report for 2012 is the first of the annual monitoring reports to review the data as a [nine]-state program after withdrawal of the New Jersey from the program. A comparative 10-state data set similar to previous iterations of this report can be found in Appendix E [of the full report]. In the Northeast and Mid-Atlantic states, CO_2 emissions from the regional electric power sector are a function of highly dynamic wholesale electricity markets. The cost of compliance with the RGGI CO_2 Budget Trading Program is only one of multiple factors that influence the dispatch of electric generation, and resulting CO_2 emissions, through the operation of these markets. As a result, this report presents data without assigning causality to any one of the factors influencing observed trends. The observed trends in electricity demand, net electricity imports, and electricity generation from multiple categories of generation sources (including electricity imports), show there has been no significant change in CO_2 emissions or the CO_2 emission rate (pounds of CO_2 per megawatt hour or lb CO_2/MWh) from total non-RGGI electric generation serving load in the nine-state RGGI region during the period of the RGGI program, 2010 – 2012."

"Meeting Global Carbon Reduction Goals: A Technology Driven Climate Paradigm." The following is from the Executive Summary of this document: "Policymakers concerned about climate change have expressed frustration regarding continued growth in global anthropogenic GHG emissions, despite calls for dramatic reductions. Equally clear is the world's continued reliance on fossil fuels. Both the United States and the world rely on fossil fuels for about 84 percent of their energy. In the United States, 39 percent of electric power in 2013 was produced from coal, and an additional 28 percent was from natural gas. The federal executive branch has chosen to move forward with GHG regulations, with or without Congressional action…EPA has responded and developed a series of new rules under the CAA. But the cited provisions within the CAA date back to its 1970 amendments, and perhaps because during that era the main climate concern related to planetary cooling, not warming, the CAA is poorly suited to addressing GHG emissions from large stationary sources, such as power plants, factories, refineries, etc. The administration's goal, which lacks legislative support, is to reduce U.S. GHG emissions in 2050 by 83 percent, compared to U.S. emissions in 2005. In January 2014, EPA proposed CO_2 limits for new fossil-fueled electric power plants, and in June 2014, EPA proposed guidelines for states to follow in setting standards for CO_2 emissions from existing fossil fueled power plants. Even though these rules are at only the proposal stage, states and others have already filed legal challenges. History suggests that while these CO_2 standards for new and existing power plants are being finalized and litigated, there may be a period of at least 5-10 years during which the ultimate emissions requirements will remain uncertain. This period of uncertainty will contribute to an absence of private-sector interest as well as underinvestment in further advancing CCS technologies."

October 2014

"Legal Liability and Carbon Capture and Storage: A Comparative Perspective." The following is from the "Context and Purpose of the Report" chapter of this document: "This report addresses the legal issues concerning liability for operations connected with CCS. CCS activities involve three distinct operations – capture of CO_2 at power or industrial plants, transportation of CO_2 in a dense phase by pipe, sea or land transport, and long-term storage deep underground under land or sea. Liability issues connected with capture and transport are unlikely to be significantly different from those associated with any other industrial activity, and though there will be considerable overlap in the applicable law, the focus of this report is with storage because this can raise particular challenges in designing appropriate liability regimes: time-scales for storage are lengthy and the technology remains relatively novel. The report is intended to highlight key themes that have emerged in thinking about the design of appropriate legal liability regimes for CCS, and uses as core examples for comparison three jurisdictions - the State of Victoria, Australia; the Province of Alberta, Canada; and the United Kingdom. It is not intended to provide a comprehensive analysis of the legislation in each of the jurisdictions. Instead it will examine the law in order to highlight the typical legal liability issues that need to be addressed in the design of legal and regulatory models for the technology. The study will consider the CCS liability issues that have emerged, and compare the differences that appear to exist, as well as the uncertainties that remain."

November 2014

"Acid Gas Interactions with Pozzolan-Amended Wellbore Cement Under Geologic Storage Conditions." The following is from the Research Objectives section of this National Risk Assessment Partnership (NRAP) report: "The overall goal of the research was to improve the understanding of the permeability change in pozzolan-amended wellbore cement induced by CO_2 and H_2S attack under co-storage conditions and to develop a model to predict these changes over the lifetime of a typical geologic carbon storage site. Information about the permeability change of pozzolan-amended wellbore cement under geologic carbon storage conditions can be incorporated into integrated risk assessment models. Pozzolan-amended wellbore cement was chosen for this study, because pozzolan amended Portland cement is one of the most common types of cement systems used for well sealing in oil and gas fields. Among the many types of available pozzolanic materials, type F fly ash, the most common pozzolan used in well cement (minimum 70 wt% of SiO_2, Al_2O_3 and Fe_2O_3 and maximum 20 wt% of CaO), was chosen as the pozzolanic material used in Kutchko et al. The overall goal was achieved by addressing the following three objectives: (1) understand the response of pozzolan-amended wellbore cement to CO_2 and H_2S attack; (2) quantify CO_2 and H_2S alteration rates of pozzolan-amended cement with different pozzolan contents; and (3) develop a process-based, reactive transport model capable of describing the interactions of a CO_2-H_2S-brine mixture with pozzolan-amended wellbore cement and predicting changes in effective permeability of wellbore cement over time."

"Characterization of Experimental Fracture Alteration and Fluid Flow in Fractured Natural Seals." The following is from the Executive Summary of this NRAP report: "This report describes a series of experiments designed to examine the effects and flow of CO_2 saturated brine moving through samples from rock formations that are seals for geologic storage of CO_2. The samples were obtained from three sites being considered or used for CCS pilot studies within the continental United States. All samples contain small fractures (some natural, others induced) that make the samples suitable for examining the effects on seal integrity of seepage through small fractures. Experiments were performed over multiple weeks by injecting CO_2-saturated brine through fractured samples while the samples were scanned with a computed tomography (CT) scanner at regular intervals during the course of the experiment. Representative reservoir pressures were maintained on the samples during the experiments. The goal was to evaluate the change in the fracture flow that would result from a CO_2 [release] so that accurate relationships can be described in reduced-order models (ROMs) currently under development in the NRAP project. Of the three formations studied, only one formation had a reaction that was significant.

Reactions within the Tuscaloosa claystone sample appeared to reduce the transmissivity of the fracture slightly during the 39-day experiment. A change in the geometry of the fracture was not observable with the medical CT images that were captured during the experiment. All other tests showed minimal changes in the fractures and fracture flow properties. These results indicate that geochemical reactions may not be significant within fractured seal formations *that contain the types of shale rock matrices used here,* and accounting for these reactions should not be needed in the ROMs being developed for the NRAP project. If a rock matrix contains minerals that are more reactive than the three samples studied, this conclusion may not apply."

"The Global Status of CCS: 2014." The following provides a highlight of this report: "The report provides a detailed overview of the current status of large-scale CCS projects worldwide, finding that 2014 has been a pivotal year for CCS, which is now a reality in the power industry. For the first time, the report introduces and provides links to project descriptions for around 40 lesser scale 'notable' CCS projects. The 2014 report focuses on a number of 'notable' projects in Japan. The Global Status of CCS: 2014 report provides a comprehensive overview of global and regional developments in CCS and what is required to support global climate mitigation efforts. Providing a number of key recommendations for decision makers, the report is an important reference guide for industry, government, research bodies and the broader community." A Supplementary Information presentation package and Summary Report are also available from GCCSI.

"6th International Energy Agency (IEA) International CCS Regulatory Network Meeting: Workshop Report." The following is from the Executive Summary of this report: "The IEA International CCS Regulatory Network held its 6th meeting in Paris, France on 27 and 28 May 2014. The first day of the meeting was a survey of progress in developing and implementing legal and regulatory frameworks in the jurisdictions represented. The second day was focused thematically, exploring a range of issues which have emerged in the development of legal and regulatory frameworks. A number of governments have now implemented CCS legal and regulatory frameworks, particularly to ensure the safe and effective storage of CO_2 underground. Many of these leading jurisdictions are now waiting for the regulations to be tested by early large scale CCS projects. Existing projects in these jurisdictions have often been developed under either existing energy or environmental frameworks or under special frameworks crafted for demonstration projects or R&D, and are now being integrated into new CCS specific regulation. Other governments are in the earlier stages of developing CCS legal and regulatory frameworks. A common first step in these jurisdictions is to survey the application of existing legislation to CCS projects. This review and assessment highlights the gaps in existing legislation and helps to identify legislative vehicles for CCS specific regulation. A number of common themes emerged experiences of governments in developing CCS legal and regulatory frameworks as relayed in the meeting. Legal frameworks are not developed in isolation but rather build on and adapt existing law. Furthermore, the nature of regulation will be greatly impacted by the regulatory context in a given jurisdictions. For both of these reasons, CCS legal and regulatory frameworks will differ greatly between jurisdictions and therefore, there is no 'one size fits all' solution. The meeting also discussed the important balance between flexibility and certainty in regulation. Best practice regulation and standard setting now encourages goal setting, rather than prescriptive requirements in order to remain flexible to technological developments and emergent risks. This is an area where standards can complement regulation, as they are regularly updated to reflect best practice. Counterbalancing this need for flexibility is the regulatory certainty required for projects to secure investment."

December 2014

"Use of Science-Based Prediction to Characterize Reservoir Behavior as a Function of Injection Characteristics, Geological Variables, and Time." The following is from the Executive Summary of this NRAP document: "This report summarizes a detailed study designed to generate a baseline understanding of how pressure plumes and CO_2 plumes behave in CO_2 storage reservoirs as a function of storage-site properties, injection conditions, and time. The goal of the study was to provide quantitative

insight into how operational and geologic factors can impact risk at storage sites both during injection and post injection. The study focused on reservoir performance. Thus, this study does not explore risk directly; calculation of risk requires coupling reservoir behavior to other features and processes at the storage site (such as flow along legacy wells). Nevertheless, the focus on reservoir behavior provides critical insight into how the storage system is expected to evolve relative to risk. Specifically, the evolution of differential pressure and CO_2 plumes in the reservoir are central to two categories of potential impacts of concern: fluid release from the reservoir (which could pose a risk to groundwater resources), and slippage along a critically stressed fault (which could produce a felt seismic event). Hence, this aspect of reservoir behavior is central to assessment of risk at a storage site. Future work will utilize the National Risk Assessment Partnership's (NRAP) integrated assessment models (IAMs) to link reservoir behavior with direct technical risk metrics, such as [release] of CO_2 back to the atmosphere or the nature of potential groundwater impacts. [The authors] identified several simple metrics that facilitate the quantification of reservoir behavior for different injection conditions (e.g., rates or durations) and for various reservoir properties. These metrics were applied to results from detailed simulations of >2,300 different scenarios. The resulting analysis helps to elucidate the expected risk-related behavior for scenarios ranging from small pilot tests to large-scale storage operations, demonstrating how this behavior varies over both space and time. Hence, this analysis can help to inform consideration of questions such as: How large of an area might be impacted for a given size of injection? How much of a pressure increase might a reservoir experience for a given size of injection? How will sites evolve post injection for a given size of injection?" For more information on NRAP, please see the "Highlights" section of this newsletter.

"Scaling the CO_2 storage industry: A study and a tool." The following is from the Executive Summary of this document: "CCS is a critical technology in reducing CO_2 emissions from energy and industry. The Intergovernmental Panel on Climate Change (IPCC) estimates that the cost of the necessary emissions reductions would more than double without CCS. A failure to deploy CCS would thus be a failure to avoid a warming world. The availability of CO_2 storage is the linchpin of CCS deployment. A lack of storage capacity could render CO_2 capture futile, and in the worst case could discourage investments in CCS projects. A CO_2 storage industry that can match the scale of the oil and gas sector will therefore be necessary to enable the necessary scale of CCS deployment. This report takes a look at the practicalities of developing CO_2 storage in Europe and answers three key questions: (1) What is the rate at which CO_2 storage needs to be developed for CCS to be deployed and climate goals met? (2) Is the nascent CO_2 storage industry capable of scaling up quickly? (3) What are the requirements of a CO_2 storage industry? Bellona has built a simple yet robust model to answer these questions and give insight into the broad lines of the future scale of CO_2 storage activities. It examines storage scenarios for onshore and offshore storage in saline [formations], depleted oil and gas fields, and for EOR. The model uses storage data and the anticipated CO_2 captured each year to measure the necessary CO_2 storage capacity to be deployed throughout Europe…"

January 2015

"Imaging Techniques for Analyzing Shale Pores and Minerals." The following is from the Introduction of this NETL-published document: "Shales have long played an important role in acting as seals for oil and gas reservoirs, and more recently have been exploited as reservoirs themselves. Shale gas and oil reserves around the world are now estimated at 7,299 trillion cubic feet of natural gas and 345 billion barrels of oil that are now technically recoverable due to advances in horizontal drilling and hydraulic fracturing. The same properties that allow shale formations to seal hydrocarbon reservoirs may also allow them to act as seals for carbon storage, and unconventional oil and gas shales show that it may be possible to simultaneously exploit shales as seals and reservoirs. Studies have shown that CO_2 can be used as a hydraulic fracturing fluid, and in the future it may prove advantageous to couple hydrocarbon extraction and carbon storage through the injection of waste CO_2 to enhance shale, production during drawdown. In order to take full advantage of shale's potential either as a carbon storage caprock or reservoir, it is important to understand the void spaces within shales that control flow

pathways and potential storage volumes. Various imaging techniques can be applied to the study of this problem. The goal of this report is to ease the learning curve of researchers attempting to examine shale for the first time by presenting various imaging techniques, basic explanations of their operations, their capabilities and limits, and their potential application to the study of shales. Particular focus will be given to visualizing pores and compositional variations, both of which are important to shale's sealing properties. While the descriptions and analyses presented in this report are applicable to the study of all shales, samples presented are mainly Marcellus Shale due to regional availability."

February 2015

"Electricity from Natural Gas with CO_2 Capture for Enhanced Oil Recovery: Emission accounting under Cap-&-Trade and LCFS." The following is from the Summary of this document: "This report evaluates emission accounting under California's existing climate policies for energy systems that integrate CCS with CO_2-EOR. CCS has been identified as potentially important for advancing California's 2050 goal of reducing [GHG] emissions by 90 [percent] below 1990 levels will be very difficult to achieve from a technical perspective alone. Moreover, nearly all technology portfolios identified in the study for achieving the 90 [percent] target require CCS, primarily as a way to overcome challenges from irreducible fuel requirements and limited supplies of low-carbon fuels. Near-term industrial experience is viewed by many to be important for ensuring availability of CCS technologies in time to meet California's 2050 emissions target. Systems that integrated CCS with CO_2-EOR ('CCS-EOR'), one of several approaches referred to as carbon capture utilization and storage ('CCUS'), have been identified as particularly important for early deployments due to their ability to reduce near-term emissions, accelerate development of CCS technologies and infrastructure that can enable deeper future reductions, attract commercial capital. As a result, proximate CCS deployments in California depend in part on resolving regulatory uncertainties regarding emission accounting for CCUS systems that integrate CO_2-EOR. Several companies have processed CCUS projects in California where the economics can be improved by using captured CO_2 for CO_2-EOR…"

"Enhanced Oil Recovery Market by Technology (Thermal, Gas, Chemical, Microbial and Seismic) and by Applications (Onshore and Offshore) – Global Trend & Forecast to 2019." The following is a description of this document: "The increase in demand of [EOR] fluids for revitalization of aging brown fields for oil [and] gas production is expected to be a major driver for the [EOR] market. The [EOR] market is expected to grow at a healthy growth rate of 18.2 [percent] between 2014 and 2019. Chemical EOR is the fastest growing technology within [EOR] market across the globe and are suitable for all the application areas including onshore and offshore. The market was segmented on the basis of application areas, type, and regions in terms of value and volume. The market segments by application areas include onshore and offshore. The market segments for types include thermal EOR, chemical EOR, gas EOR, and other EOR. The geographic segmentation includes market size and market volume of North America, Asia-Pacific, Europe, South America, Africa, and Middle East. The overall market size of EOR has been presented in terms of excess production, that is, on the basis of the barrels of oil produced via EOR method…"

"A CCS future for Europe: Catalyzing North Sea action." The following is from the Executive Summary of this document: "The 2014 SCCS Annual Conference, 'A CCS future for Europe,' brought together international CCS experts from industry, government, research, non-governmental organizations (NGOs), and finance to explore how Europe can regain momentum and deliver CCS. Plenary speakers gave perspectives on the problems and opportunities for CCS in Europe, and the measures needed to secure its future. These were set within the context of the European Council's energy and climate policy objectives for 2030. Delegates welcomed the agreement of a 40 percent emissions reduction target, the proposals to strengthen the [EU ETS], the recognition of the need for Member States to make appropriate decarbonization pathway and technology choices, continuation of Projects of Common Interest (PCIs), and the renewal of the New Entrants' Reserve funding mechanism (NER400) to support the demonstration of low-carbon technologies, including CCS. Following the

plenary, detailed discussions were held in three priority areas: creating the right incentives for CCS, facilitating the development of CCS infrastructures through the 'cluster' approach, and catalyzing R&D activities to support CCS deployment. These discussions fed into the development of a set of recommendations aimed at guiding European policy makers. These are summarized here: the first section describes the broader approach for the European energy and climate policy community; the second describes more detailed actions for the European Commission, Member State governments, industry, and R&D actors."

March 2015

"Experimental Characterization of Marcellus Shale Outcrop Samples, and their Interactions with Carbon Dioxide and Methane." The following is from the Executive Summary of this document: "Organic-rich shale formations that have been depleted of hydrocarbon through a period of primary production have been proposed as candidates for geologic storage of CO_2 and beneficial utilization of CO_2 for enhanced hydrocarbon recovery. To evaluate the potential of such CO_2 utilization and storage scenarios, investigators working at the NETL and partner universities are conducting research through the Industrial Carbon Management Initiative (ICMI), funded by the American Recovery and Reinvestment Act of 2009 (ARRA). The research focuses on developing insights into important attributes of depleted organic shale reservoirs through experimental characterization, simulation of formation performance under CO_2 storage and enhanced gas recovery (EGR) scenarios, and a techno-economic assessment. This report provides a detailed description of results of experimental work completed to date and a preliminary discussion of findings and insights. It fulfills a milestone requirement for the ICMI Carbon Storage in Depleted Shale task to report findings of initial experimental assessment of shale gas formation storage. The set of analyses and experiments being performed are intended to improve the science base with respect to important shale matrix properties that may influence CO_2/shale interaction, measure CO_2 and methane (CO_4) adsorptive capacity on shales to understand storage and EGR potential, and improve understanding of effective permeability/porosity in shales. Samples taken from ten outcrops of the Middle Devonian Marcellus shale formation have been designated as the base sample set for the ICMI and are thought to be representative of the range of rock properties across the Marcellus interval including, but not limited to, the organic- rich "main pay" interval that is a subset. Analyses performed to date include fourier transform infrared spectroscopy (FTIR), shale digestion/total metals analysis, semi-quantitative X-ray diffraction (XRD) mineralogical analysis, total organic and inorganic carbon analysis (TOC and TIC), high resolution computed tomography (CT) imaging of shale cores/plugs, optical petrography, and petrophysical analysis of matrix effective porosity/permeability. It is intended that findings of this work will be applied to refine reservoir simulation of CO_2 storage in and EGR from shale and improve confidence in techno-economic screening that are also being developed in this ICMI task."

April 2015

"CO_2 Capture and Storage in Portugal: A Bridge to a Low Carbon Economy." The following is from the Executive Summary of this document: "Several countries and regions have been setting mitigation targets, and defining GHG reduction policies and measures, mostly linked to their energy supply, transport and industry in their mission to tackle climate change. The EU agreed to cut its GHG emissions by 40 [percent] by 2030 relative to 1990 levels, and by 80 [percent] by 2050, which requires a diverse portfolio of clean technologies, including CCS. This report evaluates the role the CCS technology could play in the Portuguese energy and industry system as a mitigation option to achieve deep GHG emissions reductions. The cost effectiveness of its deployment, and the risks and additional benefits it may provide for economic development are also analyzed. Results show that under a high socio-economic development and -80 [percent] GHG reduction target, CCS technology is deployed as cost-effective technology from 2030, and by 2050 captures more than 20 [percent] of the total GHG emitted in that year compared to a Reference scenario. Power sector and cement production are the only sectors in

which CO_2 capture technology is installed and onshore being the primary option for CO_2 storage. Under all mitigation scenarios modelled, CCS is deployed in significant volumes in the cement sector. Given the availability of renewable generation in Portugal, deployment of CCS in the power sector is relatively low and varies significantly depending on the scenario examined. With high socio-economic development and -80 [percent] GHG reduction target, CCS in the power sector is only deployed in significant volumes by 2050. With more modest emissions reduction targets (i.e., 60 [percent] rather than 80 [percent] of emissions reductions by 2050) and with high fossil fuel prices, there are negligible amounts of CO_2 captured in the power sector."

"Tackling Climate Change: Small-scale deliberative engagement with Taranaki community stakeholders on carbon capture and storage (CCS)." The following is from Chapter 2 (Carbon Capture and Storage – the State of Engagement) of this study: "Public risk perceptions and subsequent protest over the planning of climate change mitigation technologies such as wind farms, hydroelectric power stations and CCS pilot facilities have, at times, hindered their progress and even deployment. With an increased need to understand where these publics were coming from, a series of international studies were undertaken to explore the range of public perceptions about and perceived acceptability of CCS. This chapter briefly explores some of this work, particularly from the perspective of 'how' to engage publics, the role of place, and the potential for deliberative engagement techniques, both to gather data and act as a conduit for effective engagement and decision-making. Whilst the nature of the technology (CCS) did play a limited role in risk perception, this report is framed under the supposition that for diverse publics, there is more to risk assessment than purely a critique of the technology itself. Instead, as Slovic argues, public risk perceptions are mainly judgments about risk, which are colored by individual, social, cultural, political and economic factors. Moreover, there is known to be a significant difference between the way experts 'objectively' perceive risk, and the way lay publics understand it, in context. Furthermore, an increase in information and knowledge about CCS does not necessarily lead to more positive public opinions about the technology, with perceptions taking a much more important role. As 'manifestations of a particular perspective on the technology,' perceptions are neither correct not incorrect, and what counts as a misperception differs between stress the importance of dialogue in exploring and understanding a range of viewpoints and their formation."

"CCS in the Baltic Sea Region – Bastor 2." The following is from the Executive Summary of this document: "The objective of this report is to document current knowledge, hazards, and risks about environmental impacts in the light of a possible future CCS project in the offshore Baltic Sea Area. The objective is also to present a tentative EIA work plan for a future CO_2-injection field trial. The intention is to add new knowledge to what is already known or applicable to CCS activities in the offshore Baltic Sea Area. The Environmental Impact Assessment reports have documented the ecological and environmental status both regionally and locally in the offshore Baltic Sea Area."

May 2015

"CO_2 Capture and Storage in Portugal: A bridge to a low carbon economy." The following is the Executive Summary of this document: "Aiming to tackle climate change, several countries and regions have been setting mitigation targets, and defining GHG reduction policies and measures, mostly linked with their energy supply, transport and industry. EU vowed to cut 40 [percent] its GHG emissions by 2030 relative to 1990 levels, and perspectives to cut 80 [percent] by 2050, which requires a diverse portfolio of clean technologies, including CCS. This report evaluates the role the CCS technology may play in the Portuguese energy and industry system as a mitigation option to achieve deep GHG emissions reduction. The cost-effectiveness conditions for its deployment, and the risks and additional benefits it may provide for economic development are also [analyzed]. Results show that under a high socio-economic development and -80 [percent] GHG reduction target, CCS technology is deployed as cost-effective technology from 2030, and by 2050 captures more than 20 [percent] of the total GHG emitted in that year compared to a Reference scenario. Power sector and cement production are the only sectors in which CO_2 captured technology is installed and onshore being the primary option for CO_2

storage. Under all mitigation scenarios modelled, CCS is deployed in significant volumes in the cement sector. Given the availability of renewables generation in Portugal, deployment of CCS in the power sector is relatively low and varies significantly depending on the scenario examined. With high socio-economic development and -80 [percent] GHG reduction target, CCS in power sector is only deployed in significant volumes by 2050. With more modest emissions reduction targets (i.e. 60 [percent] rather than 80 [percent] of emissions reductions by 2050) and with high fossil fuel prices, there are negligible amounts of CO_2 captured in the power sector. The difference in the total energy system costs (including supply and demand side, such as industry) between the scenarios with and without CCS, indicate that for all the scenarios, in the long term, earnings surpass costs. The higher the need for abatement, the more significant are the economic benefits of CCS, revealing that alternative mitigation technologies can be more expensive. Under the same climate change policy mitigation scenario, for example, the price of electricity production in 2050 without the availability of CCS will be significantly higher (more than three times) than a scenario where the technology is available."

June 2015

"Carbon Pricing Watch 2015." The following is the Abstract of this document: "Significant progress in carbon pricing has been made over the last ten years. In 2015, about 40 national and over 20 subnational jurisdictions, representing almost a quarter of global [GHG emissions], are putting a price on carbon. Together, the carbon pricing instruments in these jurisdictions cover about half of their emissions, which translates into approximately 7 $GtCO_2e$ or about 12 percent of annual global GHG emissions. This figure represents a threefold increase over the past decade. The total value of the emissions trading schemes (ETSs) reported in the State and Trends of Carbon Pricing 2014 report was about $30 billion. Despite the repeal of Australia's Carbon Pricing Mechanism in July 2014, and mainly due to the launch of the Korean ETS and the expansion of GHG emissions coverage in the California and Quebec ETSs, the value of global ETSs as of April 1, 2015, increased slightly to about $34 billion. In addition, carbon taxes around the world, valued for the first time in this report, are about $14 billion. Combined, the value of the carbon pricing mechanism globally in 2015 is estimated to be just under $50 billion."

"Analysis of the Impacts of the Clean Power Plan." The following is from the Background of this document: "This report responds to an August 2014 request to EIA from…the U.S. House of Representatives Committee on Science, Space, and Technology, for an analysis of [EPA's] proposed Clean Power Plan under which states would be required to develop plans to reduce CO_2 emissions rates from existing fossil-fired electricity generating units…The starting point for EIA's analysis of the Clean Power Plan is the Annual Energy Outlook 2015 (AEO2015) Reference case rather than earlier AEO projections that were developed using versions of EIA's National Energy Modeling System (NEMS) that lack the model structure needed to analyze key features of the Clean Power Plan proposal. With EIA's decision, unrelated to this project, to publish shorter and longer editions of the AEO in alternating years, AEO2015 does not include all of the alternative cases presented in earlier AEO editions. However, in the spirit of [the Committee on Science, Space, and Technology's] request, this report analyzes the Clean Power Plan in the context of the AEO2015 High Economic Growth and High Oil and Gas Resource cases as well as the Reference case in order to examine indicators of the proposed rule's impacts on energy markets under varying assumptions regarding economic growth, electricity demand, and fuel prices. To address some of the additional questions raised in [the] request, the report includes additional Clean Power Plan sensitivity cases including: (1) extension of the Clean Power Plan targets beyond 2030 to reduce CO_2 emissions from electric power generation by 45 [percent] relative to the 2005 level by 2040; (2) treatment of future nuclear capacity similar to the treatment of renewable capacity; (3) sensitivities for expenditures and effectiveness of energy efficiency programs; (4) sensitivities for the cost and effectiveness of heat rate improvement measures; (5) no availability of markets for CO_2 captured from electric power plants for EOR; (6) an alternative compliance phase-in trajectory during the 2020-29 period; (7) alternative accounting rules for emissions from biomass generation; (8) national compliance cooperation; and (9) limited interregional trade."

July 2015

"CO_2 storage and Enhanced Oil Recovery in the North Sea: Securing a low-carbon future for the UK." The following is from the Introduction of this document: "Production of oil from a North Sea oilfield typically leaves 55 [percent] of the oil underground. Decreasing North Sea production, combined with consistent oil consumption in the UK, results in increasing quantities of oil being imported from elsewhere in the world. This has a high opportunity cost, due to lost employment in the UK offshore, and in the lost GDP of money paid out. Compared to North Sea oils, the imported oils have a similar carbon emission of [GHG] to the atmosphere when used, but can have 50 [percent] to 100 [percent] greater embedded carbon used in their extraction compared to domestic oil. It is sensible to consider the three questions of: (1) Can additional UK oil be produced profitably with CO_2–EOR? (2) Can the [GHG] emissions of UK CO_2–EOR oil be reconciled with a transition to a low carbon economy? (3) Can a mutually beneficial link between CCS and CO_2–EOR be made? [The authors] conclude that the answer to these three questions is 'yes.' Development of CO_2–EOR creates an additional market pull, to use CO_2 from the CCS projects, and eliminates costs and transport and storage for CCS projects. That can rapidly enable and accelerate the [utilization] of North Sea deep geology as a profitable business for CO_2 storage. That helps to rapidly reduce [GHG] emissions in the UK, and starts a revolution in sustainable offshore employment and offshore technology. The North Sea can become a commercially proven and guaranteed, secure site for storage of CO_2 received from across the European Union."

"Building the UK Carbon capture and storage sector by 2030 – Scenarios and actions." The following is the Introduction of this document: "The ETI's work has shown that a successful UK CCS sector could save tens of billions of pounds ([approximately one percent] of GDP) from the annual costs of low carbon energy by the 2040s: a huge potential saving by any standards. Apart from providing low carbon electricity, CCS can capture industrial emissions, help deliver low carbon gas and deliver 'negative emissions' in combination with Bioenergy. The first two key projects (Peterhead and White Rose) are currently being taken forward under the Government's CCS [Commercialization Program]. But what else is needed to build a substantial CCS sector by 2030? What practical steps are needed on the ground, and how much will it cost? This report [summarizes] work that [has been] done to examine these questions. It extends previous modelling-based analysis, using three ambitious but deliverable scenarios to illustrate how the CCS sector [can be built] by 2030."

"Delivering CCS: Essential infrastructure for a competitive, low-carbon economy." The following is from the Introduction of this document: "Developing a domestic CCS industry promises to be a significant prize for the UK economy. There is clear evidence that CCS will be an essential tool to reduce CO_2 emissions at the lowest cost to the UK economy. For example, the ETI has calculated through its energy systems modelling that without CCS the cost of reaching the UK [decarbonization] goals in 2050 could double, costing the UK economy an additional approximately $50.4 billion per year or [one percent] of GDP in 2050. No other technology has such a dramatic impact on the costs of achieving a low-carbon economy. As well as keeping energy bills as low as possible, the development of CCS can help to maintain the future competitiveness of UK industry e.g. steel, cement and chemicals, as it is the only technology available to [decarbonize] these essential sectors. To deliver the considerable economic benefits of CCS it is necessary to institute a progressive build-out of CCS so that by 2030 the UK has in the region of 10GW of power stations fitted with CCS and between 40 – 10 $MtCO_2$ being captured from energy intensive industries every year. At this scale a total of between 40 – 50 Mtpa of UK CO_2 emissions will be abated by 2030, making a material contribution to meeting UK carbon budgets. Development of enabling transport and storage infrastructure of sufficient capacity is essential to provide early investor confidence that can underpin the required investment in CO_2 capture facilities. In particular early appraisal of multiple storage sites, which have an inherently long lead-time and require significant investment, must be facilitated over the life of this parliament."

August 2015

"Mobilization and Transport of Organic Compounds from Geologic Carbon [Storage] Reservoirs." The following is from the Executive Summary of this NETL document: "This report summarizes results of research conducted during FY2012–FY2013 to support the assessment of environmental risks associated with geologic [CCS]. Several research focus areas are ongoing as part of this project. This includes the quantification of the mobility of organic compounds and metals from representative CO_2 storage reservoir and caprock materials, the fate of organic compounds and metals after release, and the development of a method to measure pH in situ under supercritical CO_2 ($scCO_2$) conditions. This report focuses specifically on results for organic compounds. Experiments have been conducted to evaluate the potential for mobilization of organic compounds from representative reservoir materials and caprock and their fate in porous media (quartz sand). Results with Fruitland coal and Gothic shale indicate that lighter organic compounds were more susceptible to mobilization by $scCO_2$ compared to heavier compounds. Alkanes demonstrated very low extractability by $scCO_2$. No significant differences were observed between the extractability of organic compounds by dry or water saturated $scCO_2$. Reaction equilibrium appears to have been reached by 96 hours. When the $scCO_2$ was released from the reactor, less than 60 [percent] of the injected lighter compounds (benzene, toluene) were transported through the dry sand column by the CO_2, while more than 90 [percent] of the heavier organics were trapped in the sand column. For wet sand columns, most (80–100 [percent]) of the organic compounds injected into the sand column passed through, except for naphthalene which was substantially removed from the CO_2 within the column…"

"NSealR–A User's Guide, Third-Generation." The following is from the Executive Summary of this NETL document: "This report provides a guide to the use of the third-generation of the NSealR computer code. The NSealR code is being developed as part of the effort to quantify the risk of geologic storage of CO_2. NSealR is constructed as a stand-alone code to describe the flow or [release] of [CO_2] through the low permeability rock formation (or seal) overlying the storage reservoir into which [CO_2] is injected. Eventually, the NSealR is intended to be integrated into the CO_2-PENS system as a separate module, and therefore, NSealR incorporates CO_2-PENS assumptions, parameters, formats, and definitions as appropriate for consistency. At present, CO_2-PENS does not incorporate a seal horizon, but includes a possible description of this aspect in code documentation. NSealR is intended to address this gap and adds functionality such as allowing spatially-variable flow properties and adding complexity relative to flow through the seal. For example, to emulate CO_2-PENS flexibility, NSealR allows a number of ways to describe the seal horizon, to correspond to the user's current understanding of the barrier. The NSealR code provides for the simulation of [CO_2] flow through the seal barrier horizon, a rock formation that is assumed to be a thin, relatively impermeable, fractured rock unit, initially saturated with saline groundwater. A two-phase, relative permeability approach and Darcy's law are used for one-dimension (1-D) flow computations of [CO_2] through the horizon in the vertical direction. The code is written using GoldSim's simulation software platform and is structured using seven upper-level containers (or subroutines) for the top level code logic. The logic proceeds from two containers for seal property and simulation input, followed by logic to establish the analysis basis of permeability and seal horizon thickness and fluid properties, which in turn serves as the basis for the computation container and a final container for output control…"

"Quantification Protocol for CO_2 Capture and Permanent Storage in Deel Saline [Formations]." The following is from a description of this Protocol: "Carbon dioxide is emitted as a by-product in many industrial production processes. This CO_2 may be captured for other uses, or vented directly to the atmosphere. Capturing CO_2 emissions, and transferring them to permanent storage in deep saline [formations] results in a permanent reduction in CO_2 emissions. [CCS] projects applicable under this protocol consist of three main components: [1] CO_2 capture infrastructure, which includes a process modification to a facility to capture vented CO_2 emissions. The carbon capture facility is usually separate from the emission source facility, and typically uses a chemical solvent CO_2 capture technology; [2] A CO_2 pipeline to transport CO_2 from the capture facility to the injection well(s); and [3] Disposal of CO_2

through injection wells and into deep saline [formations]. Project developers using this protocol must have familiarity with [CCS] projects and [GHG] quantification methodologies."

"National Security Implications of Climate-Related Risks and a Changing Climate." The following is a description of this DoD report: "This report responds to the Congressional request to [DoD] to identify the most serious and likely climate-related security risks for each Combatant Command, the ways in which the Combatant Commands are integrating mitigation of these risks into their planning processes, and a description of the resources required for an effective response."

Legislative

September 2014

"Senate Bill Would Create Fund for Carbon Capture and Storage." On August 1, 2014, a bill was introduced to establish a CCS Deployment Acceleration Fund. The bill, S. 2776, is intended to promote the establishment of at least 10 commercial-scale CCS units in the United States over the next decade. The bill was referred to the Committee on Energy and Natural Resources. From *Govtrack.us* on August 1, 2014.

"The Dynamics and Global Implications of Subglobal Carbon-Restricting Regimes." The following is the Abstract of this article: "The European Union and Australia have enacted comprehensive carbon-restricting reforms that will affect both domestic and foreign industries. After describing these reforms in detail, the article develops a microeconomic analytical model that explains the impact these regimes have on the dynamics of inter-firm competition in carbon-restricting nations and how they will also influence technology choices by certain industries in carbon-friendly nations. Specifically, exporters and producers operating in vertically-integrated industries in carbon-friendly nations will increasingly elect carbon-efficient technologies to minimize costs as they adjust to a changing international regulatory environment. The article hypothesizes that this shift in the carbon intensity of production will cause these industries to form coalitions with other pro-environment groups to pressure national governments for legislative and global carbon-restricting reforms that reduce carbon [release] and losses from trading with industries in carbon-laggard nations. Because these cumulative developments will eventually lead to a binding global emissions-stabilizing agreement, pursuant to which border measures will be taken, the article offers a few suggestions for reducing potential conflicts between the trade and climate change regimes." **Juscelino F. Colares**, *Georgetown International Environmental Law Review 417 (2013)*. (Subscription may be required.)

October 2014

"Chile Becomes the First South American Country to Tax Carbon." The President of Chile signed legislation that makes Chile the first country in South America to tax CO_2 emissions. The carbon tax targets the power sector, specifically generators operating thermal plants with installed capacity equal to or larger than 50 megawatts (MW). These generators will be charged $5 per metric ton of CO_2 released. Thermal plants that use biomass and other smaller installations will be exempt from the tax. As part of a broad tax reform, the new tax is intended to move power producers to cleaner sources. Chile's government will start measuring CO_2 emissions from thermal power plants in 2017 and the new tax would be charged from 2018; the Chilean government expects to collect approximately $160 million from the carbon tax. Chile has a voluntary target of cutting GHG emissions 20 percent from 2007 levels by 2020. From *Reuters* on September 26, 2014.

November 2014

"Malta Proposes Climate Change Law." Malta has proposed a new climate bill that would create a legal obligation to meet emission-reduction targets. The bill will require the government to create national strategies for low-carbon development and adaptation to climate change impacts. In addition, the bill also establishes an independent Climate Action Fund that would be used to finance domestic climate action and provide donations to developing countries. As a member of the EU, Malta is bound to the regional carbon reduction target of 40 percent by 2030 (see Policy section of this newsletter for more information). Under the EU's current targets, Malta's emissions can increase five percent from 2005 levels by 2020. According to the Malta's latest submission to the UN, emissions increased from 2005 to 2011. The bill is currently in the consultation phase and the government plans to discuss the bill in December 2014. From *The Independent* on November 3, 2014.

December 2014

"Sens. Whitehouse and Schatz Introduce Carbon Free Legislation." U.S. Senator Sheldon Whitehouse introduced legislation that would potentially reduce CO_2 emissions while generating revenue over 10 years, which would be credited to the American Opportunity Fund for uses such tax cuts, economic assistance to low-income families and those in areas with high energy costs, and climate mitigation and adaption. Cosponsored by U.S. Senator Brian Schatz, the "American Opportunity Carbon Free Act" would require emitters to pay a fee for every ton of CO_2 emitted. The fee would start at $42 per ton in 2015 and increase annually. Working with EPA, the U.S. Department of Treasury would assess and collect the fee, which would be assessed on all coal, oil, and natural gas produced in or imported to the United States. From *U.S. Senator Sheldon Whitehouse Press Release* on November 19, 2014.

January 2015

"Inslee Announces Slate of Proposals to Curb Pollution, Transition Washington to Cleaner Sources of Energy." Washington's Governor announced a set of proposals to transition Washington to cleaner sources of energy and meet statewide CO_2 emission limits adopted by the state Legislature in 2008. The proposed "Carbon Pollution Accountability Act" (CPAA) would create a new, market-based program that limits CO_2 emissions and requires major emitters to pay for their emissions. The emissions limit would decrease over time, allowing emitters time to transition to cleaner technologies and/or improved operations. According to the release, the program would generate approximately $1 billion in the first year. The proceeds could be used for transportation, education, tax relief, and other purposes. The proposal is founded upon recommendations provided by the Carbon Emissions Reduction Taskforce, which included representative input from several groups, including business, labor, health care, utilities, at-risk communities, government, and others. The proposals build on an executive order previously issued by the Governor. In addition to the CO_2 emission limits, the proposals aim to promote cleaner transportation options for consumers, growth in the clean energy industry, and lower energy costs through energy efficiency. More information on the proposal is available online. From *Washington Governor Jay Inslee News Release* on December 17, 2014.

"Constructing a Legal Framework for Carbon Capture and Storage in New Zealand: Approaches to Legislative Design." The following is the Abstract of this article: "In 2009 the International Energy Agency called attention to the need for states to regulate [CCS] activities. The New Zealand Government has responded to this call by, among other things, commissioning a report on the regulation of CCS. This report, authored by Professor Barry Barton, Kimberley Jordan and the author of this paper, was launched in December 2013. This paper starts by providing a brief overview and update of the New Zealand legal and regulatory position on CCS. The bulk of the paper then seeks to address in more detail one particular issue - that of legislative design for a fledgling CCS regime." **Greg Severinsen**, *Energy Procedia*. (Subscription may be required.)

"Implementation of the EU CCS Directive in Europe: Results and Development in 2013." The following is the Abstract of this article: "Directive 2009/31/EC of the European Parliament on the geological storage of [CO_2], entered into force on June 25th 2009. By the end 2013 the CCS Directive has been fully transposed into national law to the satisfaction of the EC in 20 out of 28 EU Member States, while six EU countries (Austria, Cyprus, Hungary, Ireland, Sweden and Slovenia) had to complete transposing measures. In July 2014 the European Commission closed infringement procedures against Cyprus, Hungary and Ireland, which have notified the EC that they have taken measures to incorporate the CCS Directive into national law. Among other three countries Sweden has updated its legislation and published a new law in their country in March 2014, permitting CO_2 storage offshore. The evaluation of the national laws in Poland, which were accepted at national level in November 2013, and Croatia, which entered the EU on 7 July 2013 and simultaneously transposed the CCS directive, is still ongoing in 2014. The first storage permit under the Directive (for the ROAD Project in the offshore Netherlands) has been approved by the EC." **Alla Shogenova et al**., *Energy Procedia*. (Subscription may be required.)

February 2015

"Guidance for states and provinces on operational and postoperational liability in the regulation of carbon geologic storage." The following is the Abstract of this article: "The Interstate Oil and Gas Compact Commission (IOGCC) Task Force on Carbon Geologic Storage (CGS) has produced reports that constitute IOGCC guidance to U.S. states and Canadian provinces on the formation of legal and regulatory frameworks for the storage of CO_2 in non-hydrocarbon-bearing geologic formations. This paper describes the latest effort of the Task Force focused on issues of liability in all phases of a CGS project and discusses liability broadly under federal, state or provincial, and common law from the perspective of the state or provincial regulator." **Lisa S. Botnen, Kevin C. Connors, Kevin J. Bliss, Lawrence E. Bengal, John A. Harju**, *Energy Procedia*. (Subscription may be required.)

March 2015

"Heitkamp Reintroduces Key Legislation to Provide a Path Forward for Coal." U.S. Senator Heidi Heitkamp reintroduced legislation, the "Advanced Clean Coal Technology Investment in Our Nation Act," to encourage coal plants to lower emissions through the use of advanced clean coal technologies. The bill aims to provide a path forward for clean coal energy production. Senator Heitkamp has (1) worked with DOE to emphasize the need for clean coal energy R&D; (2) talked with the U.S. Environmental Protection Agency (EPA) about proposed regulations; (3) called for more time to review proposed EPA rules regulating CO_2 emissions from existing power plants; and (4) brought together industry, lawmakers, and academics to discuss a path forward for coal. A summary of the bill is available. From *Senator Heidi Heitkamp Press Release* on February 26, 2015.

"House Advances Bill that Would Certify CO_2 Stored in Wyoming Oil Fields." A Wyoming House of Representatives committee advanced a bill that would create a program for the state to certify the amount of CO_2 stored for use during EOR. Senate File 84 would allow the state to review an oil company's CO_2 storage plan and certify the amount being stored. The committee amended the bill to allow the Wyoming Oil and Gas Conservation Commission and the Wyoming Department of Environmental Quality to establish certification rules. From *Casper Star-Tribune Review* on February 19, 2015.

"Williams Introduces Bill to Protect Underground Water." A California Assembly member introduced Assembly Bill 356, which would require groundwater monitoring near Class II injection wells to protect underground sources of drinking water (USDWs) from oil and gas wastewater and EOR. The bill provides the State Water Resources Control Board with the authority to review groundwater monitoring

plans as part of a permit application or notice of intent for injection wells. From *Assembly Member Das Williams News Room* on February 17, 2015.

"[Illinois] Bill Calls for Cap-and-Invest Program to Meet EPA Carbon Goal." A group of Illinois lawmakers proposed measures (SB 1485 and HB 2607) that would expand the state's energy efficiency and renewable energy requirements and create a carbon market. The carbon market program would cap CO_2 emissions and create an allowance auction with approximately two-thirds of the proceeds contributed toward renewable energy and efficiency. The cap-and-invest proposal would establish a framework for the Illinois EPA to meet carbon reduction targets and be limited to the electricity sector. In addition to no free allowances, carbon offsets would also not be allowed. In addition, the legislation permits Illinois to enter multi-state agreements for compliance purposes. The bills would also require a 20 percent reduction in electricity use by 2025 and expand Illinois' renewable energy standard to 35 percent by 2030. From *EnergyWire* on February 20, 2015.

"California Climate Leadership Package Announced." A package of proposals was introduced in the California Senate that includes benchmarks for emissions reduction, energy efficiency, and petroleum use. SB 32 sets an emissions reduction target of 80 percent below 1990 levels by 2050. SB 350 aims to reduce petroleum use by 50 percent, have 50 percent of electricity from renewable sources, and increase energy efficiency in all existing buildings by 50 percent (all measures by 2030). SB 189 proposes that a committee of experts advise and inform state clean energy and climate actions to ensure job creation and economic benefits. Details of the proposals, including the bills, charts, articles, and statements from a broad coalition of supporters, are available online. From *Senate President pro Tempore Kevin de León Press Release* on February 10, 2015.

April 2015

"Low Carbon Fuel Bill Passed In Oregon Senate." The Oregon State Senate passed Senate Bill 324, which, if passed by the Oregon House of Representatives, would require fuel producers to reduce the amount of carbon in fuels and implement a low-carbon standard in the state. Modeled after California's fuel standard, the measure would require fuel importers to cut the carbon in fuels by 10 percent from 2016 to 2025, resulting in a three percent reduction of emissions across the state. Companies not able to reach the low-carbon standard would be required to buy credits to offset their excess emissions. From *Bergeson & Campbell, P.C.* on March 10, 2015.

May 2015

"Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America." California's Governor issued an executive order to establish a California GHG reduction target of 40 percent below 1990 levels by 2030, making it possible to reach the ultimate goal of reducing emissions 80 percent below 1990 levels by 2050. The state is currently on track to meet or exceed the current target established in California's Global Warming Solutions Act of 2006 (AB 32) of reducing GHG emissions to 1990 levels by 2020. In addition, the executive order also specifically addresses the need for climate adaption and directs the state government to, among other things, incorporate climate change impacts into its infrastructure plan; update the state's climate adaption strategy to identify how potential climate change could affect the state's infrastructure and industry; factor potential climate change into state agencies' planning and investment decisions; and implement measures under existing agency and departmental authority to reduce GHG emissions. From *Office of Governor Edmund G. Brown Press Release* on April 29, 2015.

June 2015

"Manchin Bill Aims to Add Carbon Utilization to DOE R&D Priorities." A West Virginia Senator introduced legislation aimed at prioritizing research and development (R&D) of carbon utilization technologies under DOE's Office of Fossil Energy (FE) Program. The legislation, S. 1282, looks to amend a section of the Energy Policy Act of 2005 by adding an objective to improve the conversion, use, and storage of CO_2 produced from fossil fuels. S. 1282 has been referred to the Committee on Energy and Natural Resources. From *Biomass Magazine* on May 18, 2015.

July 2015

"Proposed Market Stability Reserve to Stabilize European Carbon Trading." The European Parliament and the European Council reached an informal agreement to establish and operate a Market Stability Reserve (MSR) for the European Union Emissions Trading Scheme (EU-ETS). The legislative proposal seeks to address a potential oversupply of CO_2 allowances and stabilize the carbon price. According to the compromise package, the MSR will be established in 2018 and become fully operational on January 1, 2019. The originally proposed auction from 2014 to 2016 has been rescheduled to 2019 to 2020, with "backloaded" allowances placed in the market reserve; unallocated allowances will be included in the MSR in 2020. From *Global CCS Institute* on Jun 19, 2015.

August 2015

"France Passes New Energy Law Quadruples Carbon Price." France passed legislation that will reduce reliance on nuclear reactors and increase the target price of carbon to approximately $61.00 a ton in 2020 and approximately $109.00 a ton in 2030. Currently at approximately $16.00 a ton, the price will increase to approximately $24.00 a ton in 2016. Under the new energy transition law, France will have to lower carbon emissions by 40 percent by 2030 compared to 1990 levels. The law also stipulates reducing "primary" fossil-fuel consumption by 30 percent in 2030 compared to 2012 levels, among other actions. From *Bloomberg Business* on July 23, 2015.

Announcements

September 2014

DOE Project Captures and Stores more than One Million Metric Tons of CO_2. DOE, in partnership with Air Products and Chemicals, Inc., announced that more than 1 million metric tons of CO_2 have been captured at a hydrogen production facility in Port Arthur, Texas, USA. The project captures more than 90 percent of the CO_2 from the product stream of two commercial-scale steam methane reformers using vacuum swing adsorption. In addition to geologic storage, the captured CO_2 will be used for EOR at the depleted West Hastings Field in southeast Texas.

BSCSP Kevin Dome Carbon Storage Project Blog Available. The Big Sky Carbon Sequestration Partnership (BSCSP) has created a "News from the Kevin Dome" blog on the BSCSP website as an effort to update the public about work being done on the Kevin Dome Carbon Storage Project. BSCSP expects to post updates on a weekly basis and as developments occur in the field.

RGGI Q2 2014 Secondary Market Report. According to their recently released report, Potomac Economics, the independent market monitor for the Regional Greenhouse Gas Initiative (RGGI), continues to find no evidence of anti-competitive conduct in the RGGI CO_2 allowance secondary market.

CarbonKids Book Can Help Children Understand CCS. A group of Western Australian primary school students released a book that will help children better understand greenhouse gases (GHGs) and the process of CCS. Titled "A Day in the Life of a Carbon Atom – Starring: Adom," the publication was released at the 2014 National Carbon Capture and Storage Conference in Sydney, Australia, and is part of a $200,000 Australian Government sponsorship.

October 2014

BSCSP Kevin Dome Carbon Storage Project Blog Available. The Big Sky Carbon Sequestration Partnership (BSCSP) has created a "News from the Kevin Dome" blog on the BSCSP website as an effort to regularly update the public about work being done on the Kevin Dome Carbon Storage Project. BSCSP expects to post updates on a weekly basis and as developments occur in the field.

November 2014

CSU Launches Degree in GHG Management and Accounting. Colorado State University (CSU) launched a new Master's of Greenhouse Gas Management and Accounting (MGMA) degree that combines environmental knowledge with quantitative and technical skills. The MGMA program is offered by CSU's Department of Ecosystem Science and Sustainability and enables students from a wide variety of backgrounds, such as environmental studies, business, engineering, and agriculture, to develop skills needed for greenhouse gas (GHG) management and accounting. The MGMA program will start in Fall 2015 and applications are being accepted through February 2015.

University of Strathclyde Joins SCCS Partnership. Scientists from the University of Strathclyde have joined the Scottish Carbon Capture & Storage (SCCS) partnership, which includes the British Geological Survey, Heriot-Watt University, the University of Aberdeen, and the University of Edinburgh. The University of Strathclyde offers expertise in areas such as CO_2 transport and environmental impact analysis.

PSE Releases gCCS – Whole Cain CCS Systems Modeling. The "gCCS" is a system modeling tool for design and operating decisions across the CCS chain. The system contains steady-state and dynamic models of all major CCS operations, from power generation through capture, compression, transmission, and injection. Details on model application, major features, and scope are available via the link.

Texas A&M Establishes New CO_2-EOR Center. The Chaparral-Fischer CO_2 Enhanced Oil Recovery (EOR) Center will be used to study and improve the use of CO_2-EOR in both conventional and unconventional reservoirs. Researchers will investigate the potential to increase oil recovery and identify the recovery mechanisms and their impact in unconventional reservoirs. In conventional reservoirs, researchers will focus on understanding sweep efficiency issues related to CO_2 flooding in heterogeneous and fractured rocks, in addition to studying continuous CO_2 injection, water-alternating-gas (WAG), chemically aided WAG, direct CO_2 thickening, and the use of nanoparticles.

December 2014

5th Version of NETL's CCS Database Now Available. NETL's CCS Database includes active, proposed, and terminated CCS projects worldwide. The information is sourced from publically available information to provide the public with information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. As of November 2014, the database contained 274 CCS projects worldwide. The 274 projects include 69 capture, 60 storage, and 145 for capture and storage in more than 30 countries across 6 continents. While several of the projects are still in the planning and development stage, 128 are actively capturing and injecting

carbon dioxide (CO_2). NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth©.

White House Announces Launch of New Initiative. The White House Office of Science & Technology Policy (OSTP) is launching a new Climate Education and Literacy Initiative to help connect American students and citizens with information about climate change. Following a call for information in October, more than 150 activities, projects, and ideas were submitted from more than 30 states. The submissions included approaches being implemented in K-12 classrooms, on college and university campuses, and in zoos, parks, aquariums, and museums to educate and engage the public.

RGGI Releases Q3 2014 Secondary Market Report. Potomac Economics, the independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) market, continues to find no evidence of anti-competitive conduct in the RGGI CO_2 allowance secondary market. The report found that the average transfer price of RGGI's CO_2 allowances in the CO_2 Allowance Tracking System (COATS) during the third quarter of 2014 was $4.87, approximately 8 percent higher than in the second quarter of 2014 and 61 percent higher than the third quarter of 2013. According to the report, the clearing price of $4.88 in Auction 25 (held on September 3, 2014) is consistent with secondary market prices leading up to the auction.

January 2015

U.S.-China Joint Announcement on Climate Change. The United States of America and the People's Republic of China announced bilateral cooperation on climate change and will collaborate with other countries to adopt a protocol, another legal instrument, or an agreed outcome at the United Nations (UN) Climate Conference in Paris, France, in 2015. Under the agreement, the United States would cut its 2005 level of carbon emissions by 26 to 28 percent before the year 2025. China would peak its carbon emissions by 2030 and will also aim to increase the share of non-fossil fuels in primary energy consumption to approximately 20 percent by 2030.

NETL Collaborations Advance Carbon Management Strategies. The Carbon Capture Simulation Initiative (CCSI) and the National Risk Assessment Partnership (NRAP) are using predictive computational modeling to help DOE meet its goal of having CCS technologies ready for demonstration in the 2020 to 2025 timeframe. For more information, visit DOE's national laboratories webpage.

ETI Seeks Partners for New CCS Storage Project. The United Kingdom's (UK) Department for Energy and Climate Change (DECC) made approximately 3 million dollars available through the Energy Technologies Institute (ETI) for the further evaluation of CO_2 storage sites beneath the North Sea. The project will identify the next phase of storage sites that are suitable for secure, long-term storage of CO_2 captured from coal or gas power stations and heavy industry, such as steel and cement factories.

February 2015

Novel Carbon Capture Solvent Begins Pilot-Scale Testing for Emissions Control. Pilot-scale testing of an advanced technology for capturing CO_2 from flue gas has begun at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama, USA. Under a cooperative agreement with the DOE/NETL, Linde LLC is operating a nominal 1-megawatt-electric pilot plant expected to capture 30 tons of CO_2 per day. The testing will validate performance of the Linde-BASF CO_2 capture technology on actual coal-derived flue gas. The test program consists of three phases: initial start-up and operation with flue gas and solvent recirculation, parametric testing, and long-duration testing for a minimum of 60 days. Following pilot testing, Linde and BASF will pursue opportunities for larger-scale testing.

New Membrane Technology for Post-Combustion Carbon Capture Begins Pilot-Scale Test. A new, DOE-sponsored technology for capturing 90 percent of the CO_2 emitted from a coal-burning power plant has begun pilot-scale testing. The Polaris™ membrane system, developed by Membrane Technology and Research, Inc. (MTR) uses a specially designed CO_2-selective membrane (a microporous film that acts as a semi-permeable barrier) to separate CO_2 from other gases in a coal-burning plant's flue gas. The data from this pilot test will provide DOE, MTR, and project partners with insights into the next steps required for scale-up and field tests.

March 2015

Technical Session on Engineering Geologic CO_2 Storage Systems. The American Institute of Chemical Engineers' (AIChE) Annual Meeting, scheduled for November 8-13, 2015, in Salt Lake City, Utah, USA, will include a technical session titled "Engineering Geologic Carbon Dioxide Storage Systems." Research presentations covering the science and technology of carbon storage, as well as field demonstrations of CO_2 injection, are encouraged. Conference details, abstract submission, and more information are available via the above link.

NETL Enhanced Oil Recovery Planning Software NITEC LLC developed new software under a cooperative agreement with NETL, called COZView/COZSim, that enables quicker, more affordable technical studies of CO_2-EOR for small- to mid-sized U.S. oilfield operators. The NETL-funded version of the software can be downloaded from the NITEC LLC website free of charge.

April 2015

NETL Releases Updated Carbon Storage Website. DOE's NETL released a new, user-friendly version of the Carbon Storage Program website. The site contains both introductory and in-depth information about the fundamentals of geologic carbon storage, supporting technologies, program developed publications and best practice manuals (BPMs), the status of the latest program-supported R&D activities, and more.

Technical Session on Engineering Geologic CO_2 Storage Systems. The American Institute of Chemical Engineers' (AIChE) Annual Meeting, scheduled for November 8-13, 2015, in Salt Lake City, Utah, USA, will include a technical session, titled, "Engineering Geologic Carbon Dioxide Storage Systems." Research presentations covering the science and technology of carbon storage, as well as field demonstrations of CO_2 injection, are encouraged. Conference details, abstract submission, and more information are available via the above link.

MGSC Captures and Stores 1 Million Metric Tons of CO_2." The Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin-Decatur Project successfully captured and stored 1 million metric tons of CO_2 and injected it into a saline formation. The CO_2 is captured from the Archer Daniels Midland Company ethanol-production facility in Decatur, Illinois, USA, and is compressed before transport by pipeline and subsequent injection approximately 7,000 feet below the surface into the Mount Simon Sandstone formation. The project is part of DOE's Regional Carbon Sequestration Partnerships (RCSP) Initiative, which is developing and deploying CCS technologies across the United States.

Report on the Secondary Market for RGGI CO_2 Allowances: Fourth Quarter 2014. Potomac Economics, the independent market monitor for RGGI, continues to find no evidence of anti-competitive conduct in the RGGI CO_2 allowance secondary market. The report found that the average transfer price of RGGI's CO_2 allowances during the fourth quarter of 2014 was $5.22, approximately 7 percent higher than in the prior quarter and 69 percent higher than the fourth quarter of 2013. Prices increased throughout the quarter, rising from approximately $4.95 at the start of October 2014 to a daily high of $5.32 in mid-December 2014.

May 2015

DOE, Shell Canada to Collaborate on CO_2 Storage. DOE and Shell Canada announced intentions to collaborate in field tests to validate advanced monitoring, verification, accounting (MVA), and assessment technologies for underground CO_2 storage at Shell's Quest CCS project in Alberta, Canada. The test results are expected to provide additional information that would benefit future large-scale CCS projects around the world.

RGGI Report: Investments Provide $2.9 Billion in Energy Bill Savings. The nine states of the Regional Greenhouse Gas Initiative (RGGI) released a report, titled, "Investment of RGGI Proceeds Through 2013," that tracks cumulative investments made through 2013 using proceeds from RGGI's CO_2 allowance auctions. The report estimates a return of more than $2.9 billion in lifetime energy bill savings to more than 3.7 million participating households and 17,800 businesses.

June 2015

NETL Releases Carbon Storage Project Portfolio. DOE/NETL released the 2015 Carbon Storage Portfolio, which provides a comprehensive overview of the NETL Carbon Storage Program's current and recently completed work. The portfolio includes Storage Division personnel contact information, technology area introductions, project communication products, papers and technical reports, Best Practices Manuals (BPMs), and access to all archived projects.

DOE Projects Safely and Permanently Store 10 Million Metric Tons of CO_2. A group of DOE-supported and NETL-managed carbon capture and storage (CCS) projects reached a milestone by safely capturing and storing 10 million metric tons of CO_2. The milestone builds upon the goals of providing clean energy, supporting American jobs, and reducing CO_2 emissions.

Global News Organizations Agree to Share Climate Change Content. More than two dozen global news organizations have agreed to create a global pool of potential climate change content leading up to the United Nations Climate Change Conference (COP 21), held in Paris, France. Under the initiative, called the Climate Publishers Network, participating publishers will waive licensing fees for related content until December 11, 2015.

Student Training Program for Carbon Capture. The University of Calgary, through a grant from the Natural Sciences and Engineering Research Council of Canada (NSERC), is offering a training opportunity for students looking to work in the carbon capture industry. The six-year program will focus on training students to develop various carbon capture technologies.

July 2015

NETL-Sponsored Demonstration Project Reaches Milestone. In a DOE/NETL-sponsored project at a hydrogen production facility in Port Arthur, Texas, USA, Air Products and Chemicals Inc. captured and stored 2 million metric tons of CO_2. The project, supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program, demonstrates vacuum swing adsorption (VSA) to capture the CO_2, and also looks to help verify CO_2-enhanced oil recovery (EOR) as an effective method for permanent geologic CO_2 storage.

Magellan Provides Project Updates. Magellan Petroleum Corporation announced the completion of a reservoir engineering study using data from the Poplar CO_2-EOR pilot project. The results of the study estimated that approximately 80 to 100 million barrels of oil equivalent (MMboe) may be recoverable from the Charles formation at Poplar using CO_2-EOR over approximately 40 years.

Dutch Government to Speed Up GHG Reductions. The Dutch government will work to reduce their GHG emissions by at least 25 percent compared to 1990 levels by 2020, per a district court order. Current government policy has the Netherlands on pace for an approximate 17 percent reduction by 2020.

August 2015

DOE Selects Projects for Crosscutting Technology Research. DOE's NETL selected 12 projects to receive funding through its Crosscutting Research Program. Among the projects is General Electric's (GE) "Model-Based Extracted Water Desalination System for Carbon Sequestration," in which GE will partner with Pennsylvania State University to develop a water recovery process from high-salinity extracted formation water that can increase the capacity of saline formations for CO_2 storage.

DOE Selects Project to Advance SCO_2-Based Power Cycles. DOE's NETL selected a project to develop new recuperator technologies leading to more efficient supercritical carbon dioxide (SCO_2)-based power cycles. The project will apply focused research and development (R&D) to produce recuperator technologies suitable for future deployment in large-scale SCO_2 power cycle applications.

DoD Releases Report on Climate Change. The U.S. Department of Defense (DoD) released a report in response to a Senate request to identify potential climate-related risks and provide mitigation strategies. A description of the report, titled, "National Security Implications of Climate-Related Risks and a Changing Climate," is available in the "Recent Publications" section of this newsletter.

Alberta Government Publishes CCS Protocol. The Alberta Environment and Parks (Canada) published the "Carbon Offset Quantification Protocol for CO_2 Capture and Permanent Storage in Deep Saline [Formations]." The document covers carbon capture and storage (CCS) from capture through compression, transport, injection, and storage. The "Summary of Feedback to Draft Protocol and Responses" from the public comment period is also available. A description of the protocol is available in the "Recent Publications" section of this newsletter.

RGGI Releases Report. The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "CO_2 Emissions from Electricity Generation and Imports in the Regional Greenhouse Gas Initiative: 2013 Monitoring Report," summarizing data for electricity generation, electricity imports, and related CO_2 emissions for the RGGI states. The report, as well past monitoring reports, are available on the RGGI documents website.

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DOE's Carbon Storage Program