NETL's Carbon Storage Newsletter: Annual Index

(*FORMERLY THE CARBON SEQUESTRATION NEWSLETTER*)

September 2013 – August 2014

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 2013 to August 2014. Outdated Information (e.g., conference dates, paper submittals, etc.) has been removed.

To navigate this document please use the Bookmarks tab or the Acrobat search tool (Ctrl+F).

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

HIGHLIGHTS

September 2013

"MSU and Partners Send Carbon Dioxide Deep Underground in Regional Experiment" and **"Ancient Lava Flows Trap CO_2 for Long-Term Storage in Big Sky Injection."** ABig Sky Carbon Sequestration Partnership-managed (BSCSP) project injected 1,000 tons of carbon dioxide (CO_2) into geological formations that consist of ancient basalt flows. Scientists will examine fluid samples from the injection well to look for changes in chemical composition and compare results to predictions that were made using Pacific Northwest National Laboratory's (PNNL) supercomputer. More information is available via YouTube and the BSCSP project website. From *Montana State University News Release* on July 26, 2013, and *Fossil Energy Techline* on August 13, 2013.

"MRCSP Begins Field Tests in Michigan." The Midwest Regional Carbon Sequestration Partnership (MRCSP) has begun a large-scale CO_2 field project. The project is designed to inject and monitor at least 1 million metric tons of CO_2 into a series of oil fields that are in different stages of their production life cycles. The CO_2 will be injected into the geologic structures known as the northern Niagaran pinnacle reef trend. From *Battelle News Release* on July 9, 2013.

October 2013

"MSU and Partners Send Carbon Dioxide Deep Underground in Regional Experiment" and **"Ancient Lava Flows Trap CO_2 for Long-Term Storage in Big Sky Injection."** A Big Sky Carbon Sequestration Partnership-managed (BSCSP) project injected 1,000 tons of carbon dioxide (CO_2) into geological formations that consist of ancient basalt flows. Scientists will examine fluid samples from the injection well to look for changes in chemical composition and compare results to predictions that were made using Pacific Northwest National Laboratory's (PNNL) supercomputer. More information is available via YouTube and the BSCSP project website. From *Montana State University News Release* on July 26, 2013, and *Fossil Energy Techline* on August 13, 2013.

"MRCSP Begins Field Tests in Michigan." The Midwest Regional Carbon Sequestration Partnership (MRCSP) has begun a large-scale CO_2 field project. The project is designed to inject and monitor at least 1 million metric tons of CO_2 into a series of oil fields that are in different stages of their production life cycles. The CO_2 will be injected into the geologic structures known as the northern Niagaran pinnacle reef trend. From *Battelle News Release* on July 9, 2013.

November 2013

"Energy Ministers Endorse CCS as Key to Combating Climate Change." On November 7, the Carbon Sequestration Leadership Forum (CSLF) member nations endorsed carbon capture and storage (CCS) technologies as a key component of international plans to combat climate change. The CSLF Ministers stated that they are convinced that the demonstration and global deployment of CCS must be accelerated and they are committed to taking individual and collaborative actions. The Ministers' common goal is to ensure that the conditions are right for completing CCS projects currently under construction or in advanced stages of planning. The Ministers also expressed interest in increasing the number of new large CCS demonstrations by 2020 to enable future commercial deployment in the early 2020s. The CSLF Ministers outlined the following actions for CCS deployment: (1) develop predictable financial frameworks and incentives to drive near-term CCS deployment; (2) develop CCS demonstration and deployment strategies in both the power and industrial sectors; (3) stress the importance of global coordinated efforts on CCS research, development, and demonstrations, and actively seek and support such opportunities through bilateral and multilateral collaboration with other key bodies including the International Energy

Agency (IEA) and the Global Carbon Capture and Storage Institute (GCCSI); (4) continue establishing permitting frameworks that will ensure the safety and integrity of integrated CCS systems and eliminate deployment obstacles; (5) recognize the need for pre-commercial storage validation and encourage cooperation between countries to identify and assess shared geologic storage resources and develop plans for their orderly development, including development of associated transport systems; (6) strengthen national, regional, and international efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment; and (7) support efforts to grow capacity in CCS and foster appropriate steps in knowledge-sharing and technology transfer. CSLF is a Ministerial-level international climate change initiative organizing worldwide resources to develop technologies for the separation, capture, transport, and long-term storage of carbon dioxide (CO_2) from power plants and industrial facilities. CSLF includes 22 developed and developing nations. From *CSLF News Release* on November 7, 2013.

"Energy Department Invests to Drive Down Costs of Carbon Capture, Support Reductions in Greenhouse Gas [Emissions]." As part of the Climate Action Plan, the U.S. Department of Energy (DOE) announced the selection of 18 projects to research technologies that will help improve the efficiency and drive down costs of carbon capture processes for new and existing coal-fired power plants. The DOE investment and additional cost-share from industry, universities, and other research institutions will support projects that conduct carbon capture research for two different fossil power generation processes: (1) traditional, combustion-based power plants research will focus on post-combustion carbon capture; and (2) more advanced, gasification-based, electric power plants will work to improve the efficiency and cost-effectiveness of pre-combustion carbon capture. A full list of the projects and accompanying descriptions is available online. From *U.S. Department of Energy News Release* on November 7, 2013.

December 2013

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

"Energy Ministers Endorse CCS as Key to Combating Climate Change." The Carbon Sequestration Leadership Forum (CSLF) member nations endorsed carbon capture and storage technologies (CCS) as a key component of international plans to combat climate change. The CSLF Ministers stated that they are convinced that the demonstration and global deployment of CCS must be accelerated and they are committed to taking individual and collaborative actions. The Ministers' common goal is to ensure that the conditions are right for completing CCS projects currently under construction or in advanced stages of planning. The Ministers also expressed interest in increasing the number of new large CCS demonstrations

by 2020 to enable future commercial deployment in the early 2020s. The CSLF Ministers outlined the following actions for CCS deployment: (1) develop predictable financial frameworks and incentive mechanisms to drive near-term CCS deployment; (2) develop workable CCS demonstration and deployment strategies in both the power and industrial sectors; (3) stress the importance of global coordinated efforts on CCS research, development, and demonstrations, and actively seek and support such opportunities through bilateral and multilateral collaboration with other key bodies including the International Energy Agency (IEA) and the Global Carbon Capture and Storage Institute (GCCSI); (4) continue establishing permitting frameworks that will ensure the safety and integrity of integrated CCS systems, and eliminate deployment obstacles; (5) recognize the need for pre-commercial storage validation and encourage cooperation between countries to identify and assess shared geological storage resources and develop plans for their orderly development, including development of associated transport systems; (6) strengthen national, regional and international efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment; and (7) support efforts to grow capacity in CCS and foster appropriate steps in knowledge sharing and technology transfer. The CSLF is a Ministerial-Level international climate change initiative organizing worldwide resources to develop improved, cost-effective technologies for the separation, capture, transport, and long-term storage of CO_2 from power plants and industrial facilities. CSLF membership includes 22 developed and developing nations. From *CSLF News Release* on November 7, 2013.

January 2014

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

"Department of Energy Releases $8 Billion Solicitation for Advanced Fossil Energy Projects." DOE published a solicitation on December 12, 2013, making up to $8 billion in loan guarantee authority available to support innovative advanced fossil energy projects that avoid, reduce, or store greenhouse gases (GHGs). The loan guarantees under this new solicitation will help provide financing to support new or significantly improved advanced fossil energy projects, such as advanced resource development, carbon capture, low-carbon power systems, and efficiency improvements, which reduce emissions of CO_2, methane (CH_4), and other GHGs. DOE published a draft solicitation on July 9, 2013, which opened a 60-day comment period. During this time, DOE listened to potential applicants and other stakeholders and incorporated their feedback into the solicitation, which includes new provisions intended to facilitate applications, ensure quick review, and foster successful public-private partnerships. Currently, DOE's Loan Programs Office (LPO) supports a portfolio of more than $30 billion for more than 30 closed and committed projects. With the publication of the Advanced Fossil Energy Projects solicitation, the Department is accepting applications through the LPO web portal at apply.loanprograms.energy.gov, and

expects to receive the initial applications by the end of February 2014. A copy of the solicitation, which includes application deadlines and eligibility requirements, and a fact sheet can be found at lpo.energy.gov. The solicitation is part of the Climate Action Plan. The loan guarantees are authorized by Title XVII of the Energy Policy Act of 2005. From *U.S. Department of Energy News Release* on December 12, 2013.

February 2014

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

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

March 2014

"President Requests $711.0 Million for Fossil Energy Programs." The President's Fiscal Year (FY) 2015 budget seeks $711.0 million for the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) to advance technologies related to the reliable, efficient, affordable and environmentally sound use of fossil fuels (as well as manage the Strategic Petroleum Reserve and Northeast Home Heating Oil Reserve). The request includes $475.5 million for FE Research and Development (R&D). FE leads the government's research, development, and demonstration (RD&D) efforts on advanced carbon capture and storage (CCS) technologies. In FY 2015, FE R&D will continue to focus on CCS activities that increase the efficiency and availability of systems integrated with CCS. Under CCS Demonstrations, FE manages the Clean Coal Power Initiative (CCPI) Program, along with two American Recovery and Reinvestment Act (ARRA) CCS demonstration programs. In FY 2015, FE will establish the Natural Gas Carbon Capture and Storage (NG-CCS) Program to support projects that capture and store carbon dioxide (CO_2) emissions from natural gas power systems. The CCS and Power Systems Program conducts research to reduce CO_2 emissions by improving the performance and efficiency of fossil energy systems and CCS technologies. The FY 2015 budget request for the program is $277.4 million, including $34.0 million for the National Energy Technology Laboratory (NETL) to conduct in-house coal R&D. The FY 2015 budget requests $77.0 million for carbon capture R&D. The FY 2015 budget requests $80.1 million for carbon storage R&D under the Carbon Storage Program. The overall goal of the Carbon Storage Program is to develop and validate technologies that ensure safe, permanent geologic CO_2 storage. From *DOE Fossil Energy Techline* on March 4, 2014.

April 2014

"DOE Marks Major Milestone with Startup of Recovery Act Demonstration Project." The U.S. Department of Energy (DOE) and Tampa Electric Company (TECO) announced the startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida. The Polk Power Station is the first coal integrated gasification combined cycle (IGCC) plant in the United States. IGCC technology has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, while increasing reliability and reducing the overall cost of capturing carbon dioxide (CO_2) and other contaminant emissions from power plants. The technology increases the possibility that the captured CO_2 can be turned into a new revenue stream for operators by converting it for other uses, like fertilizer or enhanced oil recovery (EOR). From *U.S. Department of Energy Press Release* on April 9, 2014.

May 2014

"DOE Marks Major Milestone with Startup of Recovery Act Demonstration Project." The U.S. Department of Energy (DOE) and Tampa Electric Company (TECO) announced the startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida. The Polk Power Station is the first coal integrated gasification combined cycle (IGCC) plant in the United States. IGCC technology has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, while increasing reliability and reducing the overall cost of capturing carbon dioxide (CO_2) and other contaminant emissions from power plants. The technology increases the possibility that the captured CO_2 can be turned into a new revenue stream for operators by converting it for other uses, like fertilizer or enhanced oil recovery (EOR). From *U.S. Department of Energy Press Release* on April 9, 2014.

June 2014

"DOE-Sponsored Project Shows Huge Potential for Carbon Storage in Wyoming." A U.S. Department of Energy (DOE)-sponsored study revealed that the Wyoming Rock Springs Uplift (a geologic feature in southwestern Wyoming) could potentially store 14 to 17 billion metric tons of carbon dioxide (CO_2). The project team, led by the University of Wyoming's Carbon Management Institute and sponsored by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), gathered geologic, hydrologic, and geochemical data from a test well. The Rock Springs Uplift was found to have ideal geological characteristics for carbon storage and proximity to CO_2 emission sources. The team performed digital imaging of a core sample to learn about the formation's grain size, mineralogy, facies distribution, and porosity. The team also studied geophysical data from the test well and the overlying formations that would trap the CO_2. The researchers found that the Rock Springs Uplift contains high, commercially viable concentrations of lithium; for every 1 million metric tons of CO_2 stored, approximately 250 metric tons of lithium carbonate could be recovered from processed brine. Lithium, which is used in batteries and other electronics applications, could generate revenue to offset the cost of CO_2 storage and help to reduce the need for lithium import. In addition to testing the characterization well and removing samples, the project team performed a 3-D seismic survey around the test site, allowing researchers to extrapolate the geologic properties measured in the well (e.g., porosity, permeability, and fluid saturation). The Wyoming Rock Springs Uplift storage potential is equal to 250 to 300 years' worth of CO_2 emissions produced by Wyoming's coal-fired power plants and other large, anthropogenic CO_2 sources at current emission levels. This research effort was funded by the American Recovery and Reinvestment Act of 2009 (ARRA). From *U.S. Department of Energy Press Release* on June 3, 2014.

July 2014

"Energy Department Project Captures and Stores more than One Million Metric Tons of CO_2." The U.S. Department of Energy (DOE) – in partnership with Air Products and Chemicals, Inc. – announced that more than 1 million metric tons of carbon dioxide (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 enhanced oil recovery (EOR) at the depleted West Hastings Field in southeast Texas. By using EOR, West Hastings is likely to yield as much oil as it would from traditional production activities; it is estimated that the West Hastings Field could produce in the range of 60 to 90 million additional barrels of oil using CO_2 injection. Air Products' vacuum swing adsorption project, supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program, is one of several ICCS projects advancing and deploying carbon capture and storage (CCS) technologies. From *U.S. Department of Energy Press Release* on June 26, 2014.

"DOE-Sponsored Project Shows Huge Potential for Carbon Storage in Wyoming." A DOE-sponsored study revealed that the Wyoming Rock Springs Uplift (a geologic feature in southwestern Wyoming) could potentially store 14 to 17 billion metric tons of CO_2. The project team, led by the University of Wyoming's Carbon Management Institute and sponsored by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), gathered geologic, hydrologic, and geochemical data from a stratigraphic test well. The Rock Springs Uplift was found to have ideal geological characteristics for carbon storage and proximity to large, anthropogenic CO_2 emission sources. The team performed digital imaging of a core sample to learn about the formation's grain size, mineralogy, facies distribution, and porosity and evaluate the site's potential for CO_2 storage. The team also studied a geophysical data from the test well and the overlying formations that would trap the CO_2. The researchers found that the deep saline waters of the Rock Springs Uplift contain high, commercially viable concentrations of lithium; for every 1 million metric tons of CO_2 stored, approximately 250 metric tons of lithium carbonate could be recovered from processed brine. Lithium, which is used in batteries

and other electronics applications, could generate revenue to offset the cost of CO_2 storage and help reduce the need for lithium import. In addition to the testing completed within the characterization well and the samples removed from it, the project team performed a three-dimensional seismic survey around the test site, allowing researchers to extrapolate the geologic properties measured in the well (e.g., porosity, permeability, and fluid saturation). The Wyoming Rock Springs Uplift storage potential is equal to 250 to 300 years' worth of CO_2 emissions produced by Wyoming's coal-fired power plants and other large regional anthropogenic CO_2 sources at current emission levels. This research effort was funded by the American Recovery and Reinvestment Act of 2009 (ARRA). From *U.S. Department of Energy Press Release* on June 3, 2014.

August 2014

"Projects Selected for Safe and Permanent Geologic Storage of Carbon Dioxide." The U.S. Department of Energy (DOE) selected 13 projects to develop technologies, methodologies, and characterization tools to improve the ability to predict geologic carbon dioxide (CO_2) storage capacity, understand geomechanical processes, and enhance geologic storage safety. The projects will be managed by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) and were awarded in two areas of interest: "Geomechanical Research" and "Fractured Reservoir and Seal Behavior." The Geomechanical Research area project performers include the University of Wyoming, Clemson University, University of Texas at Austin, Northern Illinois University, Battelle Memorial Institute, Pennsylvania State University, Sandia Technologies, Montana State University, and the Colorado School of Mines. The Fractured Reservoir and Seal Behavior area project performers include Princeton University, the Colorado School of Mines, Washington University, and University of Texas at Austin. Project details are available via the link. 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. Carbon capture and storage (CCS) research is focused on developing technologies to capture industrially generated CO_2 and safely and permanently storing it in underground geologic formations 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 has initiated on a DOE-funded carbon capture pilot project at Kentucky Utilities' E.W. Brown Generating Station near Harrodsburg, Kentucky, USA. The unit will test a novel system from the University of Kentucky Center for Applied Energy Research (UKCAER) at slipstream scale that captures 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 Kentucky. The project will be managed by NETL; DOE is contributing $14.5 million for the five-year project. 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, a commercial-scale, post-combustion carbon capture retrofit project. Once completed, the project is expected to capture approximately 1.4 million metric tons of CO_2 annually 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 pilot-scale test in Alabama that successfully captured more than 150,000 metric tons of CO_2 annually from a coal power plant. From *NETL News Release* on July 16, 2014.

"Energy Department Project Captures and Stores more than One Million Metric Tons of CO_2." In partnership with Air Products and Chemicals, Inc., DOE 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. By using EOR, West Hastings could yield as much oil as it would from traditional production activities; it is estimated that the West Hastings Field could produce in the range of 60 to 90 million additional barrels of oil using CO_2 injection. Air Products' vacuum swing adsorption project, supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program, is one of several ICCS projects advancing and deploying CCS technologies. From *U.S. Department of Energy Press Release* on June 26, 2014.

Carbon Storage in the News

September 2013

"Aquistore Project Prepares to Enter Second Phase of Eight-Year Life." Aquistore, a commercial-scale, post-combustion CO_2 storage project from a coal-fired power plant, is preparing to enter its second phase and expects to begin CO_2 injection in late 2013. The project, managed by the Petroleum Technology Research Centre (PTRC), will demonstrate that storing CO_2 in a geologic formation is a safe, feasible solution to reducing greenhouse gas (GHG) emissions. The project's first phase began in 2012 with the installation of project infrastructure and monitoring equipment, including: (1) two wells drilled to a depth of 3.4 kilometers outside of Estevan, Saskatchewan (one for CO_2 injection and the other for observations and measurements); seismic monitoring equipment; and additional monitoring equipment (groundwater stations, soil gas equipment, inSAR, GPS stations, and tiltmeters). These monitoring techniques are in accordance with the CSA Z741 standards for monitoring CO_2 in the subsurface. The injection and monitoring equipment also provides environmental monitoring and health and safety assurance. During the summer of 2013, collaborations were established with organizations in Europe, Australia, and Asia. *From Aquistore News Release* on September 17, 2013.

"Germany's Linde to Build Saudi Carbon Capture-and-Use Plant." Germany's Linde Group has been hired by Saudi Basic Industries Corp (SABIC) to build a carbon capture and utilization (CCU) plant. The plan is for SABIC affiliate United Jubail Petrochemical Company (UNITED) to capture approximately 1,500 tons of CO_2 per day from ethylene plants and then purify the CO_2 for use in petrochemical plants in Jubail. According to officials, the CCU plant is expected to prevent the release of approximately 500,000 tons of CO_2 per year, as well as supply 200 tons of liquid CO_2 per day to the food and drink industry. From *Reuters* on August 21, 2013.

"CO_2 Solutions Completes First Alberta Oil Sands Project Milestones." CO_2 Solutions Inc. announced that it has met and exceeded the first two technical performance milestones for its Alberta Oil Sands project, demonstrating its patented carbon capture technology is less expensive than existing carbon capture technology in terms of energy consumption, and that it can withstand industrial application. The project will move on to the large-bench scale testing phase (0.5 metric ton/day CO_2 capture) for the remainder of 2013, validating the same performance metrics under flue gas conditions. Upon successful validation, the project would begin field pilot-scale testing (approximately 15 metric ton/day CO_2 capture) in 2014. From *CO_2 Solutions Press Release* on August 29, 2013.

"EOR Upside Anchors OMV-Statoil North Sea Deal." OMV AG has agreed to acquire $2.65 billion in North Sea and Atlantic assets from Statoil ASA and taken options on 11 exploration licenses. In addition to acquiring assets in the North Sea off Norway and the United Kingdom west of Shetlands, OMV will establish an R&D partnership with Statoil to take advantage of OMV's knowledge in enhanced oil recovery (EOR), as well as Statoil's experience with offshore EOR. OMV said it is increasing its reserves and strengthening its presence in Organization for Economic Cooperation and Development (OECD) countries. The Statoil acquisition will generate an increase in proved and probable reserves from the current level and production is set to rise by 2014. OMV will have the option of participating in as many as 11 exploration licenses in the Faroe Islands, West of Shetland area, and the Norwegian North Sea; the majority of the licenses are underexplored areas with high resource potential. The exploration licenses in Norway are near Edvard Grieg field. From *Oil & Gas Journal* on August 19, 2013.

October 2013

"China and UK Announce CCS Collaboration." The UK Carbon Capture and Storage Research Center (UKCCSRC), Scottish Carbon Capture and Storage (SCCS), Guangdong Low-Carbon Technology and Industry Research Center (GDLRC), and the Clean Fossil Energy Development Institute (CFEDI) have formed a new initiative for research, development, and demonstration of innovative CCS technologies. The 10-year Memorandum of Understanding (MOU) will lead to the establishment of an international CCS network to promote joint R&D, advise local and regional governments, and develop ways to exchange knowledge. The partners also expect to demonstrate CCS technologies. The MOU builds upon more than five years of joint CCS activities. From *UK Carbon Capture and Storage Research Center News Release* on September 27, 2013.

"Petronas Looking to Implement EOR Technology at 14 Maturing Oilfields." Petronas has identified 14 of its projects for possible implementation of enhanced oil recovery (EOR) technology to advance production. Five of the maturing oil fields are located offshore Sarawak, four are located offshore Sabah, and the rest are located in Peninsular Malaysia. According to the company, the Tapis oilfield, which will be the first to have EOR technologies implemented, could be enhanced to reach in the range of 25,000 to 35,000 barrels per day (bpd) in 2016 to 2017; the current rate of production at Tapis is in the range of 4,000 and 6,000 bpd. In total, the company projects the introduction of EOR technology to have the potential to recover from 750 million to 1 billion barrels of oil from the maturing oilfields within the Malaysian waters. From *The Star Online* on September 25, 2013.

"SaskPower Signs Carbon Capture and Storage Monitoring System MOU with Chugai Technos, K-Coal." SaskPower and Chugai Technos have signed an MOU regarding a ground CO_2 monitoring system on CCS. Under the MOU, SaskPower will begin storing a portion of the CO_2 captured from the Boundary Dam Integrated CCS Demonstration Project in April 2014. With an investment from SaskPower, the Provincial Government of Saskatchewan, and the Federal Government of Canada, Boundary Dam Power Station generating unit #3 was rebuilt to be integrated with the newly constructed carbon capture facility. The new facility has the potential to capture approximately 1 million metric tons of CO_2 emissions per year, which would be sold to Cenovus Energy. A surplus of the captured CO_2 would be injected into a nearby saline formation. Chugai Technos' role will be to establish a monitoring system that allows access to the condition of the ground CO_2 concentration at a carbon capture storage site. Prototypes of such a ground monitoring system will be deployed at several onsite locations. From *SaskPower News Release* on September 30, 2013.

November 2013

"CSLF Endorses Five New Carbon Capture Projects." Five new CCS projects were approved at the CSLF's Fifth Ministerial Meeting in Washington, D.C., in early November. The projects were added to the organization's research and development (R&D) portfolio. The five new projects are the Uthmaniyah CO_2-EOR Demonstration project, the Alberta Carbon Trunk Line Project, the Kemper County Energy Facility, the Midwest Regional Carbon Sequestration Partnership (MRCSP) Development Phase Project, and the Southeast Regional Carbon Sequestration Partnership (SECARB) Phase II Anthropogenic Test and Plant Barry CCS Project. The projects are aimed at gathering the knowledge and experience required to initiate widespread carbon capture and conduct safe, secure geologic storage. The CSLF portfolio includes activities to identify potential CO_2 storage capacities and projects dedicated to matters such as CO_2 capture technology costs; developing new methods of combustion; identifying storage capacity and widening the understanding of geologic reservoirs; predicting the behavior of CO_2 in various kinds of reservoirs; and developing technologies for successful, reliable, and long-term monitoring, measurement, and verification (MVA). From *CSLF Media Release* on November 6, 2013.

"Masdar Digs Deep for Middle East's First Carbon Capture Project." Masdar, Abu Dhabi's state clean tech investment fund, and the Abu Dhabi National Oil Company (ADNOC) signed a joint venture agreement to deliver supporting infrastructure for the development of a $122.5 million carbon capture, utilization, and storage infrastructure project. The engineering, procurement, and construction (EPC) contract was awarded to Dodsal Group to build a CO_2 compression facility and 50-kilometer pipeline to connect Emirates Steel facility with oil fields in the Emirate. The project is designed to capture carbon emissions from the steel plant and transport it to ADNOC's oil fields for use in enhanced oil recovery (EOR). From *BusinessGreen* on November 14, 2013.

"Skyonic Begins Construction on Commercial-Scale Carbon Capture and Mineralization Plant." Construction has started on Skyonic's Capitol SkyMine carbon capture and mineralization plant at Capitol Aggregates Cement Factory in San Antonio, Texas. The plant is expected to capture 75,000 tons of CO_2 annually and offset an additional 225,000 tons from the production of green products. Skyonic's electrolytic carbon capture technology, SkyMine®, will capture CO_2, acid gases, and heavy metals from the flue gas of the Capitol Aggregates Cement Plant, where the Capitol SkyMine plant will be retrofitted. The captured emissions will be mineralized into products, such as sodium bicarbonate, which can then be stored, transported, and sold. Skyonic has operated a demonstration-scale plant at the Capitol Aggregates site since 2010. The plant is expected to be fully operational in 2014. From *Skyonic Press Release* on September 30, 2013.

December 2013

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

"Hitachi Carbon Capture Test Facility Construction Begins." Hitachi has commenced construction of its Carbon Capture Test Facility (CCTF) at SaskPower's Shand Power Station, located near Estevan, Saskatchewan. Expected to be operational by the end of 2014, the goal of the demonstration project is to determine the necessary properties required to scale-up to a large, commercial-size facility. In addition, demonstration tests will be conducted to evaluate the facility's overall reliability and economic feasibility. The CCTF will be capable of capturing 120 tons of CO_2 per day from the flue gas emitted from the 298-MW Shand Power Station by using a chemical scrubbing method with an amine-based absorbent. From *Carbon Capture Journal* on November 24, 2013.

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

January 2014

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

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

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

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

February 2014

"Demonstration Test for Capturing CO_2 In the Flue Gas from a Coal-Fired Power Generation Plant Completes Initial Demonstration Phase." A demonstration test conducted by Mitsubishi Heavy Industries, Ltd. (MHI) and Southern Company Services, Inc. (SCS) has completed an initial demonstration phase. The demonstration test involved capturing and storing CO_2 emissions at an SCS affiliate's coal-fired power plant in Alabama. The demonstration test, which began in June 2011, focused on recovering 500 metric tons of CO_2 per day. After verifying the technology for recovering CO_2 from the coal-fired plant flue gas, integrated capture and storage demonstration testing began in August 2012. The CO_2 capture demonstration plant that supplied the CO_2 under this project was built by MHI and SCS. The plant consists of a flue-gas scrubber, flue-gas CO_2 capture/re-generation system, CO_2 compression machinery, and electrical components. The plant has the capacity to recover 150,000

metric tons of CO_2 per year with recovery efficiency exceeding 90 percent. With the initial demonstration phase completed, SCS and MHI are considering additional demonstration phases and activities utilizing the plant. From *MHI News Release* on January 14, 2014.

"University of Calgary Receives $500k Grant." The Natural Sciences and Engineering Research Council (NSERC) of Canada issued a grant to the Energy and Environment Research Group at the University of Calgary to support CO_2 capture research. The three-year grant, worth $583,082, will be used to develop a novel, integrated approach to energy production and gasification. This specific approach combines gasification technology with solid absorbent materials to capture CO_2. From *Carbon Capture Journal* on January 12, 2014.

"CO_2 Pipeline Proposed for Catron, Socorro Counties." The United States Bureau of Land Management (BLM) is seeking public input for the proposed Kinder Morgan, Inc. Lobos CO_2 Pipeline. The 213-mile pipeline will transport CO_2 being produced at the St. Johns field in Arizona to the existing Kinder Morgan Cortez CO_2 pipeline in Torrance County. Kinder Morgan's 30-inch, 502-mile Cortez line delivers CO_2 from southwest Colorado to the Denver Hub oil fields in west Texas. The company will need 100-foot easements to build the pipeline (approximately 2,134 acres on private land, 773 on BLM land, 345 on state land, and 177 on tribal lands), according to a previous public meeting. The pipeline will be buried in the range of 3 to 36 feet deep, and up to 40 feet deep under the Rio Puerco and Rio Grande. Kinder Morgan is giving special consideration to reduce the pipeline's impact on farmers, protect topsoil during excavation, and minimize impacts on irrigation systems in the Rio Grande Valley. After construction, Kinder Morgan plans to retain an easement for maintenance and will install markers instead of fences. Landowners will be able to use the land as they did before the project. Public scoping meetings were held in December 2013 at Quemado, Socorro, Roswell, Mountainair, and Belen. The pipeline is scheduled for completion in 2015. From *El Defensor Chieftain* on January 16, 2014.

"Alberta Unveils State-of-the-Art Greenhouse Gas Emissions Monitoring." Alberta is utilizing an advanced air monitoring system that was designed and constructed at Utah State University's Space Dynamics Lab. The device fires an infrared laser beam at targets such as oil sands sites, tailings ponds, and coal-fired power plants to measure the GHG emission volume(s). According to an official, the air-light detection and ranging system fills an air monitoring gap, because satellite systems cannot determine how much an individual industry emits and other units cannot measure large areas. The laser on the roof of the unit can fire an infrared beam 360 degrees around the trailer to detect particles as far away as 15 kilometers and GHGs from a distance of 2 kilometers. The system detects the absorption of light by CH_4 or CO_2 and calculates the volume in the atmosphere. The unit is operated by a two-member team and will be tested for several more months before use at other emission sites. An official said that the system could be an important tool to monitor compliance as Alberta works to reduce its GHG emissions. From *The Calgary Herald* on January 20, 2014.

"Adnoc to Boost Oil Output by Injecting CO_2 into Reservoirs." As part of its plans to boost oil production and replace the use of hydrogen gas in fields, Abu Dhabi National Oil Company (Adnoc) will inject CO_2 into some reservoirs beginning in 2016. Adnoc and Masdar have agreed on a joint venture for carbon capture, usage, and storage projects that will utilize CO_2 emitted from Emirates Steel. From *The National* on January 21, 2014.

"Maersk and Masdar Sign Carbon Capture MOU." Maersk, a Danish shipping and energy conglomerate, and Masdar, the renewable energy company based in Abu Dhabi, signed a Memorandum of Understanding (MOU) to collaborate on carbon capture. Under the MOU, Maersk Oil will bring its TriGen technology to the emirate as it evaluates partners who could help it to boost its production capacity from 3 million barrels per day (bpd) to 3.5 million bpd. By building seven units with the TriGen technology, which generate CO_2 for injection into oil reservoirs, water, and power, Abu Dhabi would have the potential to boost production by 50,000 bpd through CO_2 injection, thus meeting its renewables target. The units have yet to be tested at commercial scale, but could be capable of producing 200

megawatts of power, in addition to producing distilled water that could be used for industrial or agricultural purposes. From *The National* on January 22, 2014.

March 2014

"Celebrating a Decade of Carbon Storage Research Through Partnership." For the past decade, DOE's NETL has managed a nationwide network of partnerships that team government, industry, academia, and nonprofit organizations to identify the best approaches for permanently storing CO_2 in deep geologic formations. Research performed by the seven RCSPs helps validate the most suitable technologies and infrastructure needs for CCS. To augment the information-sharing that occurs through avenues such as research papers, scientific conferences, and technical reports, DOE is posting a short series of lessons learned from the RCSPs' carbon storage projects over the next several weeks. These online blog posts include topics such as site characterization; industry partnerships; public outreach and education; and monitoring, verification, and accounting. More information on the RCSPs is available via the NETL website. From *DOE Fossil Energy Techline*.

"SaskPower to Roll Out World's First Carbon Capture-Embedded Power Plant." SaskPower will soon open a power plant installed with CCS technology in Estevan, Saskatchewan, Canada. Backed by $240 million of funding from the Canadian government, the $1.35-billion Boundary Dam Carbon Capture Project includes a coal-fired power plant at Boundary Dam Unit 3 rebuilt with a unit capable of storing CO_2 emissions. New Canadian federal regulations require all coal-burning power plants more than 50 years old to either be shut down or converted to emit 420 metric tons or less of CO_2 per gigawatt-hour by July 2015. Boundary Dam Unit 3 currently emits 1,100 metric tons of CO_2 per gigawatt-hour; however, after the CCS upgrade, emissions are expected to be reduced to 140 to 150 metric tons. From *Financial Post* on February 14, 2014.

"Shell Signs Agreement to Advance Major Clean Energy Project at Peterhead." An agreement has been reached between the United Kingdom (UK) government and Shell to progress the Peterhead CCS project to the next phase of design. The project, led by Shell and with support from SSE (owners of the Peterhead gas power station in Aberdeenshire), has a goal of capturing 10 million metric tons of CO_2 over 10 years. If successful, the Peterhead project will be an industrial-scale application of CCS technology at a gas-fired power station. The agreement marks the start of Front-End Engineering and Design (FEED), which is expected to continue until 2015. This timeline is subject to future investment decisions by Shell and the UK government and the receipt of all required consents and permits. If these conditions are met, the Peterhead project could be operating by the end of the decade. From *Shell Media Release* on February 24, 2014.

"TCM Delivers New Benchmark Tests for Global CCS Progression." The CO_2 Technology Centre Mongstad (TCM) has completed large-scale tests of the amine solvent monoethanolamine (MEA) on a gas-fired source. TCM, in cooperation with Aker Solutions, has been operating the amine plant since August 2012. MEA is a baseline solvent used in post-combustion carbon capture studies to compare the performance of amines and other CO_2 removal processes. The new tests included the measurement and evaluation of a number of parameters, such as energy consumption, emissions, and degradation. The testing will provide an MEA baseline for a variety of CCS applications in both the process industry and power production. TCM's laboratory collects data from more than 4,000 measuring points connected to online instruments and tests samples each day. The results of the MEA tests will be shared with the CCS community to accelerate global CCS implementation. TCM is comprised of two CO_2 capture plants, each with the capacity to capture approximately 80,000 tons of CO_2 from the nearby refinery or 20,000 tons from a gas-fired power plant; the center also has space and infrastructure available for next generation technologies. From *TCM Press Release* on February 24, 2014.

April 2014

"Ethanol plant CO_2 sequestration project reaches new milestone." The Midwest Geological Sequestration Consortium's (MGSC) Illinois Basin Decatur Project announced that the carbon storage project has stored 750,000 metric tons of CO_2 from ADM's ethanol plant in Decatur, Illinois. The project is a joint development between DOE/NETL, ADM, the Illinois State Geological Survey, and Schlumberger Carbon Services. The project began capturing CO_2 from the ADM plant in November 2011 and aims to store 1 million tons of CO_2 annually at a depth of approximately 7,000 feet in the Mount Simon Sandstone formation. More information about the project is available via a video from the Weather Channel, titled, "Capturing Carbon Dioxide." From *Ethanol Producer Magazine* on March 25, 2014.

"WMU Partners with Energy Company to Inject Carbon Dioxide Underground, Flush Out Leftover Oil." With help from Western Michigan University's (WMU) Michigan Geological Repository for Research and Education (MGRRE), Core Energy has recovered 1.6 million barrels of oil through EOR operations. MGRRE states that Michigan has 800 oil fields that could possibly be used for EOR, with the potential to recover in the range of 180 to 200 million barrels of oil. MGRRE has been partners with Core Energy, as well as Battelle Memorial Institute, since 2005 as part of the Midwest Regional Carbon Sequestration Partnership (MRCSP), one of seven DOE/NETL RCSPs. From *Mlive.com* on March 19, 2014.

"Sask. Spending $2 Million on Four Enhanced Oil Recovery Projects." Innovation Saskatchewan has approved $1.9 million to develop EOR technologies in oil fields in Saskatchewan, Canada. The funding will be used for four projects, including two for the Petroleum Technology Research Center (PTRC) – one project will develop technology to map the flow of oil in reservoirs, while the other will assess the potential of radio frequency heating to increase oil production. From *CTVNews.com* on March 6, 2014.

"Government of Saskatchewan Funds PTRC's Saskatchewan CO_2 Oilfield Use for Storage and EOR Research Project." The Saskatchewan Ministry of the Economy announced funding was awarded to PTRC to build on 12 years of research into CO_2 geological storage. The Saskatchewan CO_2 Oilfield Use for Storage and EOR Research ($SaskCO_2USER$) project builds on the 12 years of research conducted in the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project, including expanding research on storage and wellbore integrity, predicting CO_2 migration underground, and the identification of effective monitoring techniques. From *PTRC Media Release* on April 2, 2014.

"High Tech Spaghetti Shows Promise for Carbon Capture." A rig has been installed at Delta Electricity's Carbon Capture Research Facility at Vales Point Power Station in Australia to test new hollow-fiber membranes for capturing CO_2 from power stations. The hollow-fiber membrane modules contain tiny "spaghetti-like" tubes that maximize contact between the gas and the membrane surface by allowing only CO_2 to pass through to the inside of the tube; flue gas passes across the outside the tube. Hollow-fiber membranes have the potential to reduce the energy required to capture CO_2, while also having a smaller environmental and physical footprint than existing solvent systems. The rig was installed by Cooperative Research Center for Greenhouse Gas Technologies (CO2CRC) researchers at the University of South Wales. From *CO2CRC Media Release* on March 4, 2014.

"Flagship Carbon Capture Storage Site in WA's South-West." A joint venture called "The South West Hub" is using a piece of land in Southwest Australia as a national blueprint for CCS. In February, the South West Hub, a venture that incorporates the Department of Mines and Petroleum (DMP), industry, and research bodies like the Commonwealth Scientific and Industrial Research Organization (CSIRO), began a 3-D seismic survey project to map the underground rock layers at the Harvey-Waroona site. The South West Hub is working to determine the composition beneath the site's surface, while DMP is working to expand knowledge for industry to make a commercial decision whether to invest in CCS technology. From *ABC Rural* on March 19, 2014.

"Kinder Morgan to Invest Approximately $1 Billion to Expand Vast CO_2 Network." Kinder Morgan announced plans to build and operate a 213-mile, 16-inch diameter pipeline to transport CO_2 from the St. Johns field in Apache County, Arizona, to the Cortez Pipeline in Torrance County, New Mexico. The new Lobos Pipeline will have an initial capacity of 300 million standard cubic feet per day and support EOR projects in the Permian Basin. The company plans to invest approximately $300 million on the pipeline and an additional $700 million to drill wells and build field gathering, treatment, and compression facilities at St. Johns field. The project is expected to be in service in late 2016, depending on environmental and regulatory approval(s). From *MarketWatch* on March 26, 2014.

"Magellan Petroleum Begins Pilot CO_2 Injection at Poplar." Magellan Petroleum Corporation announced that CO_2 injection has initiated in the Charles formation at Poplar Dome through the EPU 202-IW well as part of an EOR pilot program. The pilot program consists of five wells, including the CO_2 injection well and four producer wells. Carbon dioxide injection is expected over a two-year period and preliminary results will be publicly communicated during the fourth quarter of 2014. The CO_2 is supplied by Air Liquide Industrial U.S. LP. From *MarketWatch* on March 25, 2014.

May 2014

"Construction Hits Midway Point on Shell's Quest Carbon-Capture Project." Company officials announced that construction on Shell Canada's Quest CCS project has reached the halfway point and the facility is expected to begin operation in late 2015. The project is expected to reduce emissions from the bitumen upgrader at Scotford by 1 million metric tons of CO_2 each year. The Quest project is being built by joint-venture owners Shell (60 percent), Chevron (20 percent), and Marathon Oil (20 percent) at an expected cost of $1.35 billion. The large-scale carbon-capture units under construction at Scotford will recover CO_2 from flue gases, which will then be compressed and transported via pipeline to an injection site approximately 60 kilometers north in Thorhild County, Alberta, Canada. The CO_2 will be injected into three storage wells, each more than two kilometers underground. The Government of Alberta has already invested in CCS projects; over 15 years, the province and the federal government will provide funding for Quest and a separate project, the Alberta Carbon Trunk Line. The 240-kilometer pipeline will carry 1.8 million metric tons of CO_2 each year from a bitumen refinery and a fertilizer plant in the Industrial Heartland area to Clive, Alberta. The CO_2 will be used at a depleted oilfield for EOR. The construction of the Quest facility is currently employing 600 workers. From *Edmonton Journal* on April 17, 2014.

"Kinder Morgan Set to Expand CO_2 Footprint in Southwestern Colorado and New Mexico." Kinder Morgan Energy Partners, L.P. announced it will invest approximately $671 million to expand CO_2 infrastructure in the Cow Canyon area of the McElmo Dome source field in Montezuma County, Colorado, and expand the approximately 500-mile Cortez Pipeline that transports CO_2 from southwestern Colorado to eastern New Mexico and West Texas for use in EOR projects. The Cow Canyon development will increase CO_2 production in the McElmo Dome source field by 200 million cubic feet per day (MMcf/d). The plan includes ongoing 3-D seismic acquisition; 16 new wells; one production well and one produced water disposal well; water separation facilities; one central compressor station; and water disposal pipelines. Pending regulatory approvals, it is anticipated that 100 MMcf/d of CO_2 will come online by July 2015, with the remaining 100 MMcf/d expected by the end of 2015. The Cortez Pipeline expansion will increase the pipeline's capacity from 1.35 billion cubic feet per day (Bcf/d) to 2 Bcf/d by constructing a 64-mile loop in New Mexico and three new pump stations and updating five existing pump stations. The expansion will accommodate the increased CO_2 supply from the McElmo Dome field at the St. Johns source field and other sources in southwestern Colorado. Pending regulatory approvals, the northern portion of the Cortez Pipeline expansion is expected to be completed by July 2015 to handle the additional volumes from Cow Canyon, while the southern portion is expected to be completed by mid-2016 to handle the 300 MMcf/d of CO_2 expected from the St. Johns source field.
From *MarketWatch* on May 6, 2014.

"Shell Joins CO_2-EOR Project." Shell has joined the second phase of a joint industry project (JIP) to study a potential CO_2-EOR industry in the North Sea. Shell joins project leader, SCCS, and its existing partners, the Scottish Government, Scottish Enterprise, 2Co Energy, and Nexen Petroleum UK Ltd. The project is focused on gaining a better understanding of CO_2-EOR operations and extending the life of North Sea oil fields by capturing CO_2 from large emitters and permanently storing the greenhouse gas (GHG) in offshore oil reservoirs. The first phase of research investigated issues that could affect CO_2-EOR development, such as the legal and regulatory frameworks, taxation, and public and private perception. During the second phase of research, the project partners will focus on research ranging from reservoir modeling, further analysis of fiscal arrangements and the carbon balance of CO_2-EOR operations, and public engagement. From *GasWorld.com* on May 2, 2014.

"ETI to Collaboratively Develop a Marine Monitoring System for Underwater CCS Sites." The Energy Technologies Institute (ETI) is developing a monitoring system using marine robotics to ensure that CO_2 stored below the seabed is secure. The project will develop a monitoring system that could be deployed using static monitoring equipment and marine robotics like autonomous underwater vehicles (AUVs). While technology exists to detect CO_2 in a marine environment, there are no commercially available systems that can record and report CO_2 levels above a large offshore storage site. The first 12 months of the project will study the economic and technological plans for the monitoring system at an approximate investment of $1.37 million. The project will be led by Fugro GEOS in collaboration with Sonardyne, the National Oceanography Centre (NOC) and the British Geological Survey (both part of National Environment Research Council [NERC]), Plymouth Marine Laboratory, and the University of Southampton. A video description of the project from ETI's Project Manager is available online. From *ETI News Release* on May 12, 2014.

"Elk Acquires the Singleton Unit in Nebraska." Elk Petroleum announced that it has acquired 19 wells in the Singleton Unit in Nebraska, USA, to conduct CO_2-EOR operations to tap the remaining oil potential in the Singleton Oil Field. The CO_2 source for the project is the Bridgeport Ethanol plant, located 25 miles northeast; Elk Petroleum is working to acquire a CO_2 pipeline right-of-way from the plant to the Singleton Oil Field. The Singleton Oil Field has produced 10.9 million barrels of oil and the potential exists to recover an additional 2 to 4 million barrels of incremental oil from the field through EOR. The Singleton Unit also has water injection facilities and a water source well that will be used. From *Elk Petroleum Ltd. News Release* on April 23, 2014.

"CO_2 Solutions Successfully Completes Second Oil Sands Project Milestones." CO_2 Solutions Inc., announced that it has achieved technical performance milestones for its oil sands project by operating its carbon capture technology process at the 0.5 ton/day scale. The project will now advance to the pilot demonstration phase at an approximately 15 metric ton-CO_2/day scale. The milestones are included in the Contribution Agreements for the Government of Canada's ecoENERGY Innovation Initiative (ecoEII) and Alberta's Climate Change and Emissions Management (CCEMC) Corporation grants funding the project. From *MarketWatch* on April 10, 2014.

June 2014

"Wells in Northern Montana Mark Big Step for MSU Carbon Sequestration Research." As part of BSCSP activities, Montana State University (MSU) researchers drilled two wells for the Kevin Dome Large-Scale Carbon Storage Project in Toole County of northern Montana. The wells will be used to test the formation's ability to store CO_2. Kevin Dome has the potential for large-scale carbon storage because the geologic formation has held naturally occurring CO_2 for millions of years in a deep, porous rock layer, known as the Duperow formation. BSCSP plans to extract CO_2 stored in Kevin Dome through one of the wells and transport CO_2 via pipeline into a portion of the Duperow formation where CO_2 does not naturally occur. The second well will be used to monitor the CO_2 and subsurface geochemistry near the injection well. Scientists will monitor geology, geochemistry, water quality, air quality, and

underground CO_2 behavior. Researchers also removed rock core to study the geology. One set of cores came from the well where the rock layers were subject to CO_2, while the other cores came from an area not subject to CO_2, allowing researchers to compare the chemical changes related to the presence of CO_2. Researchers conducted a seismic survey before any wells were drilled; this seismic data is being used in geologic modeling efforts and the production of 3-D subsurface images. BSCSP is one of several partnerships involved in DOE's RCSP Program. BSCSP created a short, educational film to highlight seismic survey science, titled, "What's Shaking on Kevin Dome?" From *Montana State University News Release* on June 9, 2014.

"Norway Plots Offshore Areas for CO_2 Storage." According to atlases for the Norwegian and Barents Sea, as well as the Norwegian waters of the North Sea, Norway's continental shelf has the potential to store more than 80 billion tons of CO_2. The publisher of the atlases, the Norwegian Petroleum Directorate (NPD), claims the volume is the equivalent to 1,000 years' worth of Norwegian CO_2 emissions. From *UPI.com* on May 20, 2014.

"Oil Recovery to Resume at Local, Abandoned Oil Field." The Michigan Department of Environmental Quality (DEQ) granted approval to Core Energy to begin CO_2-EOR operations at the Chester 16 oil field in Otsego County in Michigan. Such EOR methods have been used at seven additional oil fields throughout the county, leading to the recovery of more than 1.7 million barrels of oil. The Chester 16 oil field has been abandoned since 1992. From *Petoskey News-Review* on May 22, 2014.

July 2014

"UT Austin Receives $12 Million to Help U.S. Curtail Greenhouse Gas Emissions." DOE awarded the University of Texas (UT) at Austin a grant to fund carbon storage research at the Center for Frontiers of Subsurface Energy Security. A team from the Cockrell School, UT Austin's Jackson School of Geosciences, and Sandia National Laboratory will collaborate on the project. The research project includes 20 faculty members from across the university and will begin this fall. UT Austin's center is one of 32 Energy Frontier Research Centers (EFRCs) across the United States that will receive funding to accelerate the scientific breakthroughs needed to build a 21st-century energy economy. From *University of Texas News Release* on June 19, 2014.

"UK CCS Project Secures €300m EU Funding." The White Rose CCS project in the United Kingdom (UK) has been awarded funding of approximately $400 million by the European Commission. The project is located next to the existing Drax Power Station in North Yorkshire, UK, and includes the development of a new 426-megawatt, coal-fired power plant. The plant is expected to capture up to 90 percent of the CO_2 emissions from the site; the CO_2 will then be transported via pipeline for permanent storage under the North Sea. White Rose is the only CCS project in Europe to receive funds under the program. From *Energy Live News* on July 8, 2014.

"Wyoming Files Application to Establish CO_2 Pipeline Corridor Network on Federal Lands." Wyoming's Governor announced that a plan to establish pipeline corridors through Federal lands is complete. The Bureau of Land Management (BLM) application seeks to establish 1,150 miles of pipeline corridors on Federal lands in Wyoming. All of the corridors run parallel to existing pipelines and will reduce permitting timeframes. The project, called the Wyoming Pipeline Corridor Initiative (WPCI), would cross Federal lands in most of Wyoming's counties and involve nine BLM field offices. One of the primary purposes of the WPCI is to facilitate EOR in Wyoming. It is expected that some of the corridors will be available as soon as approvals are issued. The application is part of a multi-year collaboration between the state of Wyoming, BLM, and other Federal agencies. The pipeline plan is part of the Governor's Energy Strategy. From *Wyoming Governor Matt Mead News Release* on June 12, 2014.

"Montana Tech Engineers Explore EOR Options." The Montana Tech Petroleum Engineering Department is conducting a pilot project to assess EOR options for the Elm Coulee oilfield in Eastern Montana, USA. The pilot project will inject either CO_2 or natural gas into shale surrounding original wells; conventional drilling and production methods in Montana's Bakken oilfield extract 9 to 15 percent of available oil. The project is funded by the Montana Department of Natural Resources and Conservation through the Montana Board of Oil and Gas Conservation. The team is halfway through the five-year research effort. From *The Bakken Magazine* on June 24, 2014.

"UKCCSRC Announces £2.57M Funding for CCS Research." The UK Carbon Capture and Storage Research Centre (UKCCSRC) announced the distribution of approximately $4.4 million from its research budget to support 14 new CCS research projects, including 7 for CO_2 capture, 5 for CO_2 cross-cutting issues, and 2 for CO_2 storage. The projects address research needs identified by the Advanced Power Generation Technology Forum (APGTF) and the UK's Department of Energy and Climate Change (DECC) CCS Roadmap for Innovation and Research and Development (R&D). Two of the projects include academic collaboration with Australia and China. Project details are available via the link; the projects' progress and research outcomes will be made publicly available via the UKCCSRC website. The call builds upon initial funding for 13 projects in 2012. From *UKCCSRC Media Release* on June 19, 2014.

"Muon Detector Could Help Identify CO_2 Storage Sites." Physicists at Sheffield University are developing an advanced probe that can detect the properties of cosmic ray muons (naturally occurring sub-atomic particles that pass through Earth) as an option to existing seismic monitoring techniques for CCS. The Sheffield University team has been testing the technology at an underground research facility with funding from the UK's DECC and Premier Oil. The detectors have been deployed underground where they monitor muons travelling through the North Sea and then through approximately 1 kilometer of rock to reach a cavern in the Boulby Mine. Variations are detected by the system when the tide changes above the mine and the amount of water that muons must travel through changes. The team plans to design a system that could be used as a probe in an oilfield and other potential geologic CO_2 storage formations. The researchers are aiming to develop a working prototype by 2015. From *The Engineer* on June 13, 2014.

August 2014

"PSE Launches gCCS – World's First Full-Chain Modelling Software for CCS." Process Systems Enterprise (PSE) launched its gCCS modelling software designed for full CCS chains from power generation through CO_2 capture, compression, and transport to injection. The gCCS systems modeling environment, which will be used in PSE's gPROMS advanced process modelling platform, employs models to predict how the CCS chain's components will interact under different scenarios. According to PSE, the Peterhead CCS Project will use the software to investigate the flexibility of the operation of the capture process when integrated within the full system. From *PSE Press Release* on July 9, 2014.

"National Grid Awards CCS Pipeline Contract," and **"Study to Examine North Sea Carbon Dioxide Transport/Storage Needs."** National Grid Carbon Ltd (NGC) selected Genesis to conduct a front-end engineering and design (FEED) study for a pipeline that will transport CO_2 from the Drax Power Station in Humberside, United Kingdom (U.K.), to a storage site in the North Sea. The pipeline infrastructure will have the capacity to transport up to 18.7 million tons of CO_2 per year. The White Rose CCS Project requires approximately 2.2 million tons of CO_2 per year. Genesis will perform risk evaluation and cost estimates, along with the engineering and design of the transportation and storage system. NGC will provide the transportation and storage elements for the CCS project in collaboration with Capture Power Ltd. The CO_2 will be injected approximately 0.6 miles beneath the North Sea seafloor for storage. From *Energy Live News* on August 1, 2014, and from *Offshore Magazine* on July 4, 2014.

"Pilot Carbon Capture Project to Begin this Year." After signing a collaboration agreement in June 2014 for their pilot project to go online in April 2015, Neumann Systems Group (NSG) and CO_2 Solutions have agreed to begin operations by October 2014. The pilot facility, which is expected to capture approximately 10 tons of CO_2 per day, will use a system that combines NSG's NeuStream compact absorber and stripper systems with CO_2 Solutions' enzyme-based technology to strip CO_2 from flu gas. The pilot facility is located in Colorado Springs, Colorado, USA. From *Wyoming Business Report* on July 17, 2014.

Science

September 2013

"Climate Change Threatens Crunchy, Tart Apples." According to a 40-year study of Japanese apple orchards conducted by the National Agriculture and Food Research Organization in Tsukuba, Japan, potential climate change could be affecting the taste and texture of apples – specifically the Fuji. By analyzing the data, researchers found that over the four decades, the apples' hardness and acidity had declined, while their sweetness had increased. The researchers believe that warmer temperatures are causing plants to flower earlier, which yields a riper, sweeter fruit at harvest. From *Nature.com* on August 15, 2013.

"Study: Higher CO_2 Harms All Marine Life-Forms." According to a study conducted by German researchers at the Alfred Wegener Institute, rising CO_2 levels are causing harm to marine life due to acidification. As the CO_2 dissolves into the oceans, carbonic acid is formed, lowering the pH level. Published in the journal "Nature Climate Change," the study claims that the oceans' uptake of CO_2 has an impact on mollusks, corals, and echinoderms, like starfish and sea urchins. Researchers examined 167 previous studies regarding the effects of acidifying oceans on 153 species. Their findings were analyzed and forecasts of future emissions were used to predict impact(s). The research will be used for the second part of a United Nations' three-part study into the science of potential climate change scheduled to be released by the end of 2014. From *Pittsburgh Post-Gazette* on August 26, 2013.

"African Desert Plantations Could Help Carbon Capture." According to a study published by Earth System Dynamics, planting trees such as Eucalyptus microtheca and Jatropha curcas in African coastal deserts could help capture CO_2 emissions. Using data compiled in Mexico and Oman, the study states that over a 20-year period, large-scale plantations, specifically of the Jatropha curcas, could capture 17 to 25 tons of CO_2 per hectare per year from the atmosphere. From *UPI.com* on August 27, 2013.

"Sea Otter Populations Could be Key to Carbon [Storage]." Scientists from the University of California at Santa Cruz have found that sea otters can help keep undersea kelp forests alive by eating plant-eating animals like sea urchins, which can help to mitigate potential climate change. The researchers studied the effect of sea otters on coastal ecosystems over the past 40 years and found that higher sea otter populations shared healthier sea kelp forests. Focusing primarily on the Aleutian islands south near the coast of North America to the U.S.-Canada border, the researchers claim that the sea kelp help to store a sizable amount of CO_2. From *Public Radio International*, on August 29, 2013.

"Climate Change 'Driving Spread of Crop Pests.'" According to research conducted by the universities of Exeter and Oxford, potential climate change is allowing crop pests and diseases that attack crops to spread to areas once too cold for them to survive. Published in the journal "Nature Climate Change," the study focused on 612 crop pests and pathogens from the around the world that had been collected over the past 50 years. Researchers found that on average, pests have been spreading by two miles each year since 1960. From *BBC News* on September 1, 2013.

October 2013

"Global Warming to Spawn More Severe U.S. Thunderstorms: Study." According to a new study published in the journal "Proceedings of the National Academy of Sciences," potential climate change could create atmospheric conditions in the United States that would be susceptible to the development of severe thunderstorms and tornadoes. The findings are based on computer modeling work of the two main atmospheric ingredients believed to contribute to thunderstorm formation: (1) convective available potential energy (CAPE), which is created as air in the lower atmosphere warms; and (2) vertical wind shear, which is the change in wind speed and height. Scientists from Stanford University and Purdue

University conducted new computer simulations revealing that when CAPE is high, vertical wind shear is more likely to be high as well, meaning the frequency of occurrences of severe thunderstorm environments increases as a result of potential climate change. According to scientists, the simulations also showed that continued potential climate change could lead to increases in storm days over large areas of the eastern United States in the spring, winter, and autumn. In springtime alone, the result would be a 40 percent increase of severe thunderstorms over the eastern United States by the end of the century. From *National Geographic* on September 24, 2013.

"New Study Suggests Earthworms [Store] More CO_2 Than They Release." According to a paper published in the journal "Nature Communications," earthworms may store more CO_2 than they cause to be released into the atmosphere. When earthworms eat liter, some of the carbon is released immediately; however, some is retained and digested, eventually being deposited back into the soil where it cannot escape. Researchers from the United States and China attempted to detect how much CO_2 they can store by conducting lab experiments using two kinds of earthworms and various soil types. The researchers found that the worms' release of CO_2 eventually tapered off, and that the soil without worms emitted as much CO_2 as the soil with them. Although preliminary, their results led researchers to conclude that more CO_2 was being stored in soil than was being released into the air. From *Phys.Org* on October 16, 2013. \

November 2013

"Pacific Ocean Warming 15 Times Faster Than Before." According to a study published in the journal "Science," the middle depths of a part of the Pacific Ocean have warmed 15 times faster over the past 60 years than they did during the previous 10,000 years. Studied from the surface to approximately 2,200 feet below, the temperature of the Pacific Ocean water has increased by approximately one-third of a degree Fahrenheit over the past 60 years. Up until approximately 800 years ago, Pacific Ocean water had been cooling; but then it slowly began to rise and increase at a higher pace over the past few decades, researchers claim. According to the Intergovernmental Panel on Climate Change (IPCC), the majority of atmospheric greenhouse gas (GHG) emissions since the 1970s have been absorbed by the oceans. From *USA Today* on October 31, 2013.

December 2013

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

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

drowning in flooded nests. The study is among the first to directly link rainfall to survival of wild birds in Canada. From *Science Daily* on December 3, 2013.

January 2014

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

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

February 2014

"Polar Bears Hunt on Land as Ice Shrinks." According to researchers, polar bears in the western Hudson Bay area have shifted to a diet that is more land-based due to melting sea ice. Polar bears rely mainly on marine animals, such as seals, for food – especially in late spring. According to the research, higher temperatures are causing a reduction in Arctic sea ice extent, meaning that polar bears are coming ashore and eating a larger variety of foods, such as mushrooms and berries, as well as land-based animals, such as snow geese. The U.S. Endangered Species Act lists the polar bear as a threatened species and the International Union for Conservation of Nature lists them as vulnerable. From *Discovery News* on January 24, 2014.

"Large Old Trees Grow Fastest, Storing More Carbon." U.S. Geological Survey (USGS) researchers believe that on an individual basis, large, old trees are better at absorbing atmospheric CO_2 than smaller, younger trees. According to the research, while trees age, their growth rate continues to accelerate, as does their ability to store CO_2. Published in the journal "Nature," the research contradicts the previously accepted premise that tree growth rate declines in accordance with age. In the study, growth measurements of 673,046 trees belonging to 403 tree species from tropical, subtropical, and temperate regions across six continents were collected. The mass growth rates were calculated for each species and then analyzed for trends. The data showed that in most cases, mass growth rate increased continuously with tree size; in some cases, large trees appeared to be adding the carbon mass equivalent of an entire smaller tree each year. From *USGS News Release* on January 15, 2014.

"An alternative mechanism for accelerated carbon [storage] in concrete." The following is the Abstract of this article: "The increased rate of [CO_2 storage] (carbonation) is desired in many primary and secondary life applications of concrete in order to make the life cycle of concrete structures more carbon neutral. Most carbonation rate studies have focused on concrete exposed to air under various conditions. An alternative mechanism for accelerated carbon [storage] in concrete was investigated in this research based on the pH change of waters in contact with pervious concrete which have been submerged in carbonate laden waters. This may be pertinent for applications of concrete reuse in marine or other aqueous applications such as jetties and riprap. The results indicate that the concrete exposed to high levels of carbonate species in water may carbonate faster than when exposed to ambient air, and that the rate is higher with higher concentrations. Validation of increased [CO_2 storage] was also performed via thermogravimetric analysis (TGA). It is theorized that the proposed alternative mechanism reduces a limiting rate effect of [CO_2] dissolution in water in the micro pores of the concrete." **Liv M. Haselbach and Jonathan N. Thomle**, *Sustainable Cities and Society*. (Subscription may be required.)

March 2014

"Drought, Fires Impact Ability of Amazon to Hold Carbon Dioxide." According to research published in the journal "Nature," fires and drought in the Amazon could potentially reduce the forest's ability to store CO_2 emissions. The research shows that when coupled together in the Amazon, dry weather conditions and fires could potentially lead to the forest losing its ability to store more CO_2 than it releases. Using aircraft to study the CO_2 release, researchers found that the forests stored less of the CO_2 that comes with fires. Coupled with a slowdown in photosynthesis, this led to an upswing in CO_2 emissions from the forest dome. During wetter years, the forests offset emissions from the fires; however, this was not the case during the drought year that was studied, leading researchers to believe that if droughts and fires continue, the Amazon could potentially lose its ability to be a carbon sink. From *Phys.org* on February 25, 2014.

April 2014

"Climate Change Will Test Turtles' Mettle." Potential climate change could present new threats to all seven species of marine turtles, which are already considered at risk across the world. The temperature when eggs develop in the nest determines the sex of turtle hatchlings, with higher temperatures favoring the production of females. The reptiles also synchronize their nesting with the times of year when the incubation temperature produces approximately equal numbers of male and female hatchlings. Potential climate change could alter the incubation temperatures, causing the turtle population sex ratios to be distorted, affecting the population. In addition to unbalanced sex ratios, a potentially warming climate could also cause storm surges that could harm turtle nests and nesting beaches. From *National Geographic* on March 17, 2014.

May 2014

"Urbanization, Higher Temperatures Can Influence Butterfly Emergence Patterns." According to a recent study, a subset of common butterfly species are emerging later than usual in urban areas located in warmer regions. A team of international researchers studied data from 1996 to 2011 on 20 of the most common butterfly species in Ohio, focusing on (1) when each species emerged at each site every year, (2) when their population numbers peaked at each site every year, and (3) the last recorded observation of each species at each site every year. The research also looked at the temperature and urban density around each monitoring site. The data showed that in urban areas in a warmer part of the state, seven of the species emerged days or weeks after other butterflies of the same species in other areas and/or climates. The research was conducted by researchers from North Carolina State University, Case Western Reserve University, the Instituto de Pesquisas Ecológicas in Brazil, and the University of Maryland. From *ScienceDaily* on April 28, 2014.

"Climate Change Robs Frogs, Salamanders of Refuge." A potentially warming climate may dry up ponds and shallow waterways that frogs and salamanders had used for refuge from trout introduced to the Western United States' high-mountain lakes for recreational fishing. According to the study, which appeared in "*Frontiers in Ecology and Environment*," researchers are looking into novel tools that could determine where these amphibians are in the most need of help and use the data to develop plans for possible fish removal from selected areas. Aquatic species like frogs and salamanders thrived in high-elevation habitats due to the abundance of food and safety from predators. Beginning in the late 1800s, trout were brought to mountain lakes and ponds in the Western United States for recreational fishing. Today, 95 percent of the large mountain lakes have trout, putting these amphibians at risk. From *ScienceDaily* on May 1, 2014.

June 2014

"Global Warming Could Help Bolster Turtle Population Size." According to a study conducted by Swansea University (United Kingdom) researchers, potential climate change could bolster sea turtle population sizes in the Cape Verde Islands. According to the study, which was published in the journal "*Nature Climate Change*," the sex of sea turtle hatchlings is determined by the incubation temperature, through "temperature-dependent sex determination." The Cape Verde Islands is one of the world's largest rookeries for sea turtles. From *Phys.org* on May 19, 2014.

July 2014

"Coastal Winds Intensifying with Climate Change, Study Says." Summer winds are increasing along the west coasts of North and South America and southern Africa, and a recent study cites that potential climate change could be the cause. The winds have strengthened over the last 60 years in three out of the five regions of world, according to the analysis. While stronger winds offer potential benefits to coastal areas by bringing a surge of nutrients and boosting populations of plankton, fish, and other species, the study says they could also affect marine life by causing turbulence in surface waters, disrupting feeding, impacting acidification, and lowering oxygen levels. The study, titled, "Climate change and wind intensification in coastal upwelling ecosystems," was published in the journal *Science.* From *The Sydney Morning Herald* on July 7, 2014.

"Climate Change Threatens U.S. National Parks." According to a new National Park Service report, present-day temperatures are at the high end of the range of temperatures measured since 1901. In the report, titled, "Climate Exposure of U.S. National Parks in a New Era of Change," scientists took climate data of 289 national parks over the past 10 to 30 years and compared it to the historical range of variability from 1901 to 2012. Scientists were able to determine that 235 of the parks (81 percent) have experienced extreme recent warm conditions, 78 have undergone recent extreme wet conditions, 43 experienced recent extreme dry conditions, and 35 experienced recent warm and dry conditions. To view the report, which was published in the scientific journal *PLOS ONE*, click here. From *Scientific American* on July 3, 2014.

August 2014

"Climate Change May Reduce Corn, Wheat Crop Yields." According to a new study, rising temperatures may increase the odds of slower corn and wheat yields. The study, published in *Environmental Research Letters*, claims that there is as much as a 10 percent chance that the rate of corn yields, and a 5 percent probability for wheat, will slow as a result of potential climate change. When scientists removed potential climate change from the equation that predicted the crop yield growth, the chance of slower growth falls to approximately 1 in 200. According to estimates, a rise in global temperatures of approximately 1.8 degrees Fahrenheit would slow the rate of corn growth by seven percent and wheat by approximately six percent. From *Bloomberg* on July 25, 2014.

"Alaska Frogs Reach Record Lows in Extreme Temperature Survival." A recent paper from the University of Alaska Fairbanks demonstrates that freeze tolerance in Alaska wood frogs is greater than previously thought. In subarctic interior Alaska, wood frogs overwinter in the ground, creating hibernacula, where temperatures can remain below freezing for more than six months with a minimum temperature of -4 degrees Fahrenheit. Researchers tracked the wood frogs in their natural hibernacula to study how cold and for how long a period they could survive in their natural habitat. Researchers discovered that when outside their natural environment, wood frogs accumulate higher concentrations of glucose in their tissues. By packing their cells with glucose, frogs are able to stabilize their cells and reduce the drying out of cells that the ice creates. From *ScienceDaily* on July 22, 2014.

Policy

September 2013

"United States, China, and Leaders of G-20 Countries Announce Historic Progress Toward a Global Phase Down of HFCs." The United States, China, and the Group of 20 (G-20) announced separate agreements to address potential climate change by reducing the use of hydrofluorocarbons (HFCs). In the first agreement, G-20 leaders expressed support for initiatives that are complimentary to efforts under the United Nation's Framework Convention on Climate Change (UNFCCC), including phasing down the use of HFCs using the Montreal Protocol, while retaining HFCs within the scope of the UNFCCC and its Kyoto Protocol for accounting and reporting of emissions. In a related agreement, the United States and China reaffirmed their June 2013 announcement that the nations would also collaborate with other countries through multilateral approaches to phase down the production and consumption of HFCs using the Montreal Protocol, which was established in 1987 with the goal of protecting the ozone layer. According to the White House, if left unabated, HFC emissions could grow to nearly 20 percent of CO_2 emissions by 2050. From *White House Press Release* on September 6, 2013.

"The social cost of carbon emissions: Seven propositions." The following is the Abstract of this article: "Determining the social cost of carbon emissions (SCC) is a crucial step in the economic analysis of climate change policy as the US government's recent decision to use a range of estimates of the SCC centered at \$77/tC (or, equivalently, \$21/tCO_2) in cost-benefit analyses of proposed emission-control legislation underlines. This note reviews the welfare economics theory fundamental to the estimation of the SCC in both static and intertemporal contexts, examining the effects of assumptions about the typical agent's pure rate of time preference and elasticity of marginal felicity of consumption, production and mitigation technology, and the magnitude of climate-change damage on estimates of the SCC. [The authors] highlight three key conclusions: (i) an estimate of the SCC is conditional on a specific policy scenario, the details of which must be made explicit for the estimate to be meaningful; (ii) the social discount rate relevant to intertemporal allocation decisions also depends on the policy scenario; and (iii) the SCC is uniquely defined only for policy scenarios that lead to an efficient growth path because marginal costs and benefits of emission–mitigation diverge on inefficient growth paths. [The authors] illustrate these analytical conclusions with simulations of a growth model calibrated to the world economy." **Duncan K. Foley, Armon Rezai, and Lance Taylor**, *Economics Letters*. (Subscription may be required to view article.)

"CO_2 transport strategy and its cost estimation for the offshore CCS in Korea." The following is the Abstract of this article: "Republic of Korea is the ninth largest CO_2 emission country in 2009 according to the International Energy Agency (IEA). To mitigate the effect of CO_2 on the climate change and global warming, Korea should reduce the anthropogenic CO_2 emissions from sources such as power plants and iron works. [Carbon dioxide] Capture and Storage (CCS) technology is regarded as one of the most promising carbon reduction options. The demonstration project of CCS is funded by the Korean government to demonstrate the capture, transportation and storage of 1 Mt CO_2 per year in Korea by 2020. This study established the CO_2 transport strategies from the sources to [formations] for the CCS demonstration in Korea. Also the cost estimations were carried out with the CO_2 transport strategies. The CO_2 transport methods suggested in this study are the pipelines for both onshore and offshore, and a ship-based concept consisting of a pipeline from the source to coastal terminal (including the liquefaction facility on a barge) and a CO_2 carrier from the terminal to [formation] (including the temporary storage near offshore sink). Although the present study is now [ongoing] to optimize the CO_2 transport infrastructure for the offshore CCS in Korea, the preliminary results show the CO_2 transport cost for the pipeline system is lower than that for the shipping in the present status. The result is meaningful only for the specific source and storage sites studied in this study." **Jung-Yeul Jung, Cheol Huh, Seong-Gil Kang, Youngkyun Seo, and Daejun Chang**, *Applied Energy*. (Subscription may be required to view article.)

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

October 2013

"EPA Proposes Carbon Pollution Standards for New Power Plants." The U.S. Environmental Protection Agency (EPA) has proposed Clean Air Act standards to reduce CO_2 emissions from new power plants in order to combat potential climate change. In addition, EPA also initiated outreach and direct engagement with state, tribal, and local governments; industry and labor leaders; non-profits; and others to establish CO_2 emissions standards for existing power plants. The proposal achieves the first milestone outlined in a Memorandum to EPA, titled, "Power Sector Pollution Standards." Under the proposal, new large gas-fired turbines would need to meet a limit of 1,000 pounds of CO_2 per megawatt-hour, while new small gas-fired turbines, as well as new coal-fired units, would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour. New coal-fired units would have the option to choose to meet a tighter limit if they average their emissions over multiple years. The proposed standards are expected to ensure that new power plants are built with available clean technology to limit CO_2 emissions. Click here for a statement by the Energy Secretary on the new standards. From *EPA News Release* on September 20, 2013.

"A comparison of techniques used to collect informed public opinions about CCS: Opinion quality after focus group discussions versus information-choice questionnaires." The following is the Abstract of this article: "Both focus group discussions and information-choice questionnaires (ICQs) have previously been used to examine informed public opinions about [CCS]. This paper presents an extensive experimental study to systematically examine and compare the quality of opinions created by these two research techniques. Depending on experimental condition, participants either participated in a focus group meeting or completed an ICQ. In both conditions participants received identical factual information about two specific CCS options. After having processed the information, they indicated their overall opinion about each CCS option. The quality of these opinions was determined by looking at three outcome-oriented indicators of opinion quality: consistency, stability, and confidence. Results for all three indicators showed that ICQs yielded higher-quality opinions than focus groups, but also that focus groups did not perform poor in this regard. Implications for the choice between focus group discussions and ICQs are discussed." **Emma ter Mors, Bart W. Terwel, Dancker D.L. Daamen, David M. Reiner, Diana Schumann, Sorin Anghel, Ioanna Boulouta, Diana M. Cismaru, Carmencita Constantin, Chris C.H. de Jager, Alexandra Dudu, Andrea Esken, Oana C. Falup, Rebecca M. Firth, Vassiliki Gemeni, Chris Hendriks, Loredana Ivan, Nikolaos Koukouzas, Angelos Markos, Robert Naess,**

Katja Pietzner, Irene R. Samoila, Constantin S. Sava, Michael H. Stephenson, Claudia E. Tomescu, Hans Y. Torvatn, Sturle D. Tvedt, Daniel Vallentin, Julia M. West, and Fotini Ziogou, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Pressure profiles for CO_2-EOR and CCS: Implications for regulatory frameworks." The following is from this article: "Analysts and regulators around the world have devoted a great deal of effort in recent years to crafting a regulatory framework for geologic storage of CO_2. The work has been premised largely on the assumption that CO_2 will be captured from emissions sources and then injected and geologically stored solely for the purpose of reducing atmospheric emissions of a [GHG], as is done in several of the high-profile demonstration projects (such as Sleipner and In Salah). While well-suited for its intended purpose, this approach risks creating a serious regulatory obstacle to the successful deployment of [CCS] technology in the United States or other jurisdictions where the captured CO_2 will be used – and incidentally stored – in EOR operations. Although EOR is not intended as a CCS technology strategy, the geologic storage of CO_2 that occurs during routine EOR operations can provide tangible and measureable emission reduction benefits where the CO_2 has been captured from an emissions source. Hence a sound CCS policy should avoid creating regulatory barriers to integrating supplies of captured CO_2 into traditional EOR operation. A problem may arise, however, where the regulatory paradigm fails to recognize the fundamental operational differences between geologic storage in active CO_2-based EOR operations and the storage operations in non-EOR-based projects (whether in saline formations or non-producing hydrocarbon reservoirs). This feature focuses on the regulatory implications of the differing pressure profile of CO_2-EOR operations, a point that is little discussed in the relevant literature. As explained later, the subsurface formation pressure profile of a CO_2-EOR operation is essentially constant as a result of the continual removal of formation fluids from production wells (oil, water, and CO_2) at the same time as incremental quantities of CO_2 are added via injection wells." **Marston, P. M.**, *Greenhouse Gases: Science and Technology*. (Subscription may be required to view article.)

November 2013

"[President] Creates Climate Change Task Force." The White House has announced the creation of a "Task Force on Climate Preparedness and Resilience" that will include state, local, and tribal leaders from across the United States. According to the executive order, the group will "advise the Administration on how the Federal Government can respond to the needs of communities nationwide that are dealing with the impacts of climate change." For more information, view the FACT SHEET: Executive Order on Climate Preparedness. From *USA Today* on November 1, 2013.

"Identification of management strategies for CO_2 capture and [storage] under uncertainty through inexact modeling." The following is the Abstract of this article: "Geologic [storage] has been considered as an effective and critical means for significant reductions of CO_2 amounts to the atmosphere among various mitigation approaches. A CCS management system must be a complex system to accommodate the relevant social, economic, environmental, and political factors. Effective management of such a complex system involves balancing tradeoffs among these key influencing factors. In addition, carbon-emission trading is increased attention as a mechanism for addressing emissions quota shortage problems. Emissions markets have potentials to mediate between various emission sources and CO_2 capture and [storage] projects in a systematic manner. The objective of this study is to develop an inexact management model (ICSM) to identify optimal strategies for planning CO_2 capture and [storage] with a CCS system involving multiple emission sources, multiple capture technologies and multiple project periods. Two mechanisms are considered including with and without carbon emission trading. The proposed model is based on the interval programming method, where uncertain information is directly incorporated and communicated into the optimization processes through the use of interval numbers. The ICSM model has been applied to a hypothetical case study in CCS management to demonstrate its applicability. The results indicated that total system costs under a trading mechanism would be less than those under a non-trading mechanism through more effective re-

allocation of emission quota to different sources within the entire CCS system. The obtained solutions could provide more flexibility for the decision makers in generating appropriate management practices for carbon capture and [storage]." **Xiaodong Zhang, Ian J. Duncan, Gordon Huang, and Gongchen Li**, *Applied Energy*. (Subscription may be required.)

"**Greensites and brownsites: Implications for CO_2 [storage] characterization, risk assessment, and monitoring.**" The following is the Abstract of this article: "Proposed CO_2 storage sites will require different approaches in characterization, risk assessment, and monitoring, given prior site history and land use. Those sites lacking previous subsurface development are defined as *greensites*, whereas sites where the subsurface is developed, particularly for hydrocarbon production, are defined as *brownsites*. Greensite CO_2 injection is specifically for storage of CO_2. Most CO_2 [EOR] operations using incidental storage would be characterized as a brownsite. Application of monitoring approaches developed for greensites is inadequate when applied to brownsites because intrinsically different uncertainties may lead to investment in ineffective monitoring." **Brad D. Wolaver, Susan D. Hovorka, and Rebecca C. Smyth**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

December 2013

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

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

"**A novel modeling based real option approach for CCS investment evaluation under multiple uncertainties.**" The following is the Abstract of this article: "In this study, a trinomial tree modeling-based real option approach was developed to evaluate the investment in CCS retrofitting for two typical types of power plants from the perspective of power generation enterprises. A method based on the cumulative probability was proposed using trinomial decision tree calculations for the exercising of options in order to evaluate the optimal retrofit timing. Uncertainties in carbon prices, government incentives, annual running time, power plant lifetime, and technological improvements were considered. From the result, the

cost saving effect of CCR pre-investment was apparent. When the current carbon price increased to 350.0 RMB/ton CO_2, a power plant with CCR pre-investment would execute CCS retrofitting immediately, while this value would have to increase to 371.8 RMB/ton CO_2 for the SC scenario. The two typical types of power plants were not optimal for immediate investment in CCS technology in the current market situation. Given a full government subsidy, the critical carbon prices for SC and SC + CCR were 239.2 and 230.0 RMB/ton CO_2, respectively, while the current carbon price in the voluntary emission reduction market was 3.5 RMB/ton CO_2. By introducing CO_2 utilization technology, the critical carbon prices fell to 195.5 and 186.3 RMB/ton CO_2, but they were still not optimal for immediate investment. CCR pre-investment was conducive to CCS retrofitting deployment; this would be more significant when considering CO_2 utilization technologies. The results indicated that a large gap existed between the carbon price needed for CCS retrofitting of both typical types of power plants and the current prices in the voluntary emission reduction market. Moreover, the results obtained could also provide useful information for the CCS policy-making of power enterprises in an uncertain environment." **Xian Zhang, Xingwei Wang, Jiajun Chen, Xi Xie, Ke Wang, and Yiming Wei**, *Applied Energy*. (Subscription may be required.)

January 2014

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

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

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

"Engaging the public with low-carbon energy technologies: Results from a Scottish large group process." The following is the Abstract of this article: "This paper presents the results of a large group process conducted in Edinburgh, Scotland investigating public perceptions of climate change and low-carbon energy technologies, specifically CCS. The quantitative and qualitative results reported show that the participants were broadly supportive of efforts to reduce [CO_2] emissions, and that there is an expressed preference for renewable energy technologies to be employed to achieve this. CCS was considered in detail during the research due to its climate mitigation potential; results show that the workshop participants were cautious about its deployment. The paper discusses a number of interrelated factors which appear to influence perceptions of CCS; factors such as the perceived costs and benefits of the technology, and people's personal values and trust in others all impacted upon participants' attitudes towards the technology. The paper thus argues for the need to provide the public with broad-

based, balanced and trustworthy information when discussing CCS, and to take seriously the full range of factors that influence public perceptions of low-carbon technologies." **Rhys Howell, Simon Shackley, Leslie Mabon, Peta Ashworth, and Talia Jeanneret**, *Energy Policy*. (Subscription may be required.)

"Not Under Our Back Yards? A case study of social acceptance of the Northern Netherlands CCS initiative." The following is the Abstract of this article: "[The authors] analyze the decision-making process of the abandonment of a CCS initiative in the Northern-Netherlands. [The authors] investigate the social acceptance of the Northern-Netherlands CCS initiative using the results from a survey among the key stakeholders. [The authors] find that local opposition can only be held partially responsible for the abandonment of the CCS project. This result differs from the broadly accepted notion 'no local public acceptance, no CCS.' [The authors'] study finds that the views from key stakeholders regarding the prospects of the CCS initiative were conflicting and this played a role in abandoning the initiative. [The authors] conclude that the way in which responsibilities between key stakeholders were arranged has had a dominant impact on the level of acceptance. [The authors] recommend that future policy and policy instruments for subsurface activities, like CCS, should be designed in accordance with the object, subject and inter-subject dimension of the decision-making process. In addition there should be a strategic framework, which accounts for the interaction between social-political, market and community acceptance." **Herman W.A. van Os, Rien Herber, and Bert Scholtens**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

February 2014

"EU to Cut Carbon Emissions by 40 [Percent] by 2030." According to a recently reached deal, the European Union (EU) will cut its GHG emissions by 40 percent compared with 1990 levels by 2030. In addition, 27 percent of the EU's energy will be produced by renewable sources within the same timeframe. As part of the 2030 energy and climate package, Europe's emissions trading system will also be reformed, with a more flexible mechanism allowing the surplus of carbon permits to be curbed. Member states participating in the emissions trading system will have a non-legally binding target of improving energy efficiency by 24 percent by 2030. Before they can be fully accepted, the new measures will be debated by member state governments and the European parliament; the European council will discuss the proposals in March 2014. From *The Guardian* on January 22, 2014.

"A strategic decision-making model considering the social costs of carbon dioxide emissions for sustainable supply chain management." The following is the Abstract of this article: "Incorporating sustainability into supply chain management has become a critical issue driven by pressures from governments, customers, and various stakeholder groups over the past decade. This study proposes a strategic decision-making model considering both the operational costs and social costs caused by the [CO_2] emissions from operating such a supply chain network for sustainable supply chain management. This model was used to evaluate [CO_2] emissions and operational costs under different scenarios in an apparel manufacturing supply chain network. The results showed that the higher the social cost rate of [CO_2] emissions, the lower the amount of the emission of [CO_2]. The results also suggested that a legislation that forces the enterprises to bear the social costs of [CO_2] emissions resulting from their economic activities is an effective approach to reducing [CO_2] emissions." **Shih-Chang Tseng and Shiu-Wan Hung**, *Journal of Environmental Management*. (Subscription may be required.)

"Energy related CO_2 emissions and the progress on CCS projects: A review." The following is the Abstract of this article: "This review paper discusses the perspectives for development of CCS technologies in the global fight against climate change, such as low-carbon technology which is a vital component to reduce future carbon emissions. The information on the level and growth of CO_2 emissions, their source and geographic distribution, will be essential to lay the foundation for a global agreement; considering only for energy-related CO_2, and not for any other [GHGs]. [The authors] analyzed the distribution of the CO_2 emission intensity related to them. Besides, in order to predict possible future situations of energy consumption, CO_2 emissions intensity and the CCS role like the

largest emission reduction potential, IEA has developed a number of scenarios; the baseline scenarios and comparative scenarios. [The authors] used the approach of the Blue Map Scenarios, bringing the 2005s emissions to a level of 50 [percent] by 2050 for a non-catastrophic human intervention in the climate system. Moreover, this paper shows the barriers, strategies for accelerating and the stages in the technology deployment. [The authors] also analyzed the CCS projects status; Challenges, SWOT analysis, and the currently Global CCS Technology Activity. For this, [the authors] consider the Large Scale Integrated Projects (LSIP), and the asset life-cycle model was used to categorize the status of a project according to its development stage. Alongside, the analysis involves: Total LSIPs by geographic region, by Industry and CO_2 Capture Technology. In addition, [the authors] also made a scope on some of the most relevant international actions in order to stimulate the fulfillment of the CO_2 intensity target." **Ruth Nataly Echevarria Huaman and Tian Xiu Jun**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

March 2014

"A public choice view on the climate and energy policy mix in the EU – How do the emissions trading scheme and support for renewable energies interact?" The following is the Abstract of this article: "In this paper, [the authors] analyze the rationale for an energy policy mix when the European Emissions Trading Scheme (ETS) is considered from a public choice perspective. That is, [the authors] argue that the economic textbook model of the ETS implausibly assumes (1) efficient policy design and (2) climate protection as the single objective of policy intervention. Contrary to these assumptions, [the authors] propose that the ETS originates from a political bargaining game within a context of multiple policy objectives. In particular, the emissions cap is negotiated between regulators and emitters with the emitters' abatement costs as crucial bargaining variable. This public choice view yields striking implications for an optimal policy mix comprising RES supporting policies. Whereas the textbook model implies that the ETS alone provides sufficient climate protection, [the authors'] analysis suggests that support for renewable energies (1) contributes to a more effective ETS-design and (2) may even increase the overall efficiency of climate and energy policy if other externalities and policy objectives besides climate protection are considered. Thus, [the authors'] analysis also shows that a public choice view not necessarily entails negative evaluations concerning efficiency and effectiveness of a policy mix." **Erik Gawel, Sebastian Strunz, and Paul Lehmann**, *Energy Policy*. (Subscription may be required.)

"Pricing Contracts Under Uncertainty in a Carbon Capture and Storage Framework." The following is the Abstract of this article: "CCS has been demonstrated as a viable option for reducing carbon emissions to the atmosphere. [The authors] consider a situation where a tax on emissions is imposed on CO_2 producers to encourage their participation in CCS. Operators of CO_2 transportation pipelines and storage sites enter into individual contracts with emissions producers to store CO_2. [The authors] study the problem of selecting the optimal price and volume of these contracts under both cost and emissions uncertainty to optimize the storage operator's expected profit." **W. Caia, D.I. Singhamb, E.M. Craparob, and J.A. Whitec**, *Energy Economics*. (Subscription may be required.)

"Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design?" The following is the Abstract of this article: "Economists traditionally view a Pigouvian fee on CO_2 and other GHG emissions, either via carbon taxes or emissions caps and permit trading ('cap-and-trade'), as the economically optimal or 'first-best' policy to address climate change-related externalities. Yet several political economy factors can severely constrain the implementation of these carbon pricing policies, including opposition of industrial sectors with a concentration of assets that would lose considerable value under such policies; the collective action nature of climate mitigation efforts; principal agent failures; and a low willingness-to-pay for climate mitigation by citizens. Real-world implementations of carbon pricing policies can thus fall short of the economically optimal outcomes envisioned in theory. Consistent with the general theory of the second-best, the presence of binding political economy constraints opens a significant 'opportunity space' for the design of creative climate policy instruments with superior political feasibility, economic

efficiency, and environmental efficacy relative to the constrained implementation of carbon pricing policies. This paper presents theoretical political economy frameworks relevant to climate policy design and provides corroborating evidence from the United States context. It concludes with a series of implications for climate policy making and argues for the creative pursuit of a mix of second-best policy instruments." **Jesse D. Jenkins**, *Energy Policy*. (Subscription may be required.)

April 2014

"South Korean Signs CCS Collaboration with Australian and German Scientists." Korea CCS R&D Center (KCRC) has signed strategic agreements with Australian and German researchers to advance CCS. Under the agreements, KCRC will work together with CO2CRC and the Helmholtz Centre Postdam GFZ - German Research Centre for Geosciences to develop technologies for reducing CO_2 emissions from power generation and industry. The agreements will also enable knowledge sharing between the two institutes and provide training opportunities for researchers from all three countries. From *Carbon Capture Journal* on March 16, 2014.

"Air District Board Approves Climate Action Work Program." The San Francisco Bay Area Air Quality Management District (BAAQMD) Board of Directors approved a Climate Action Work Program designed to focus the Air District's climate protection activities and identify necessary resources for future action. The Bay Area climate protection work program includes measures for updating efforts to inventory, forecast, and monitor greenhouse gases (GHGs); imitating development of rules limiting GHG emissions; expanding enforcement; and working with state, regional, and local agencies and stakeholders to develop the regional climate action strategy. From *BAAQMD News Release* on April 3, 2014.

"Spare the details, share the relevance: The dilution effect in communications about carbon dioxide capture and storage." The following is the Abstract of this article: "The mitigation of climate change may require the implementation of CCS. Both proponents and opponents of CCS will try to convince the public of the (dis)advantages of this technology. This research examines the relative persuasiveness of communications that only contain highly relevant information (e.g., the argument that the implementation of CCS would have important climate benefits) or combine highly relevant with irrelevant or moderately relevant information. The results of three experiments consistently show that adding irrelevant information dilutes the impact of highly relevant information: Irrelevant information reduced the persuasiveness of communications (Experiments 1 and 2) and weakened people's beliefs about the issue (Experiment 3). This dilution effect occurred with both positive (pro-CCS) information and negative (con-CCS) information, but the effect was stronger with positive information. Awareness of the source of the communications moderated the dilution effect. Implications for public communications about CCS are discussed." **Gerdien de Vries, Bart W. Terwel, and Naomi Ellemers**, *Journal of Environmental Psychology*. (Subscription may be required.)

"The impact of carbon capture and storage on a decarbonized German power market." The following is the Abstract of this article: "The European energy policy is substantially driven by the target to reduce the CO_2-emissions significantly and to mitigate climate change. Nevertheless European power generation is still widely based on fossil fuels. The CCS technology could be part of an approach to achieve ambitious CO_2 reduction targets without large scale transformations of the existing energy system. In this context the paper investigates on how far the CCS-technology could play a role in the European and most notably in the German electricity generation sector. To account for all the interdependencies with the European neighboring countries, the embedding of the German electricity system is modeled using a stochastic European electricity market model (E2M2s). After modeling the European side constraints, the German electricity system is considered in detail with the stochastic German Electricity market model (GEM2s). The focus is thereby on the location of CCS plant sites, the structure of the CO_2-pipeline network and the regional distribution of storage sites. Results for three different European energy market scenarios are presented up to the year 2050. Additionally, the use of

CCS with use of onshore and offshore sites is investigated." **S. Spiecker, V. Eickholt, and C. Weber**, *Energy Economics*. (Subscription may be required.)

May 2014

"Ricardo-AEA to Support Evaluation of Carbon Capture and Storage Directive." Ricardo-AEA won a European Commission contract to study the European Union (EU) Directive on CCS technology. The CCS Directive (Directive 2009/31/EC on geologic CO_2 storage), which provides a legal framework for safe geological CO_2 storage in the EU, sets forth requirements for the lifetime of a storage site and has provisions on CO_2 capture and transport. The European Commission is required to review its implementation and will submit a report to the European Parliament and Council by March 2015. The project will deliver an assessment of the CCS Directive, including stakeholder consultation, literature review, and recommendations. Ricardo-AEA will work in collaboration with Triple E Consulting (TEC) and research organization TNO. More information on the CCS Directive is available via the European Commission Climate Action website. From *Ricardo-AEA Newsroom* on April 29, 2014.

"MOU Signals New Era of Cooperation between Research Centers." Representatives from CMC Research Institutes, Inc., (CMC) and the United Kingdom Carbon Capture and Storage Research Center (UKCCSRC) signed a memorandum of understanding (MOU) for research to ensure CCS projects are designed and operated in a cost-effective, safe, secure manner. The agreement builds on the current relationship between the two organizations, which have funded a researcher exchange program and participated in meetings. Potential areas for collaboration under the MOU include: research projects by CMC and UKCCSRC researchers; joint workshops, seminars, and webinars; regular bi-annual meetings of management teams; further researcher exchanges; and research publication. From *UKCCS Media Release* on May 8, 2014.

"Resolving or managing uncertainties for carbon capture and storage: Lessons from historical analogues." The following is the Abstract of this article: "CCS technologies are often highlighted as a crucial component of future low carbon energy systems in the UK and internationally. While these technologies are now in the demonstration phase worldwide, they are still [characterized] by a range of technical, economic, policy, social and legal uncertainties. This paper applies a framework for the analysis of these uncertainties that was previously developed by the authors to a historical evidence base. This evidence base comprises nine case studies, each of which focuses on a technology that is partly analogous to CCS. The paper's analysis of these case studies examines the conditions under which the uncertainties concerned have been at least partly resolved, and what lessons can be drawn for CCS. The paper then uses the case study evidence to discuss linkages between the uncertainties in the analysis framework, and how these linkages differ from those that were originally expected. Finally, the paper draws conclusions for the methodological approach that has been used and for strategies to develop and deploy CCS technologies." **Jim Watson, Florian Kern, and Nils Markusson**, *Technological Forecasting and Social Change*. (Subscription may be required.)

"When to invest in carbon capture and storage technology: A mathematical model." The following is the Abstract of this article: "[The authors] present two models of the optimal investment decision in CCS—one where the carbon price is deterministic (based on the newly introduced carbon floor price in Great Britain) and one where the carbon price is stochastic (based on the [emissions trading system (ETS)] permit price in the rest of Europe). A novel feature of this work is that in both models investment costs are time dependent which adds an extra dimension to the decision problem. [The authors'] deterministic model allows for quite general dependence on carbon price and consideration of time to build and simple calculus techniques determine the optimal time to invest. [The authors] then [analyze] the effect of carbon price volatility on the optimal investment decision by solving a Bellman equation with an infinite planning horizon. [The authors] find that increasing the carbon price volatility increases the critical investment threshold and that adoption of this technology is not optimal at current prices, in

agreement with other works. However reducing carbon price volatility by switching from carbon permits to taxes or by introducing a carbon floor as in Great Britain would accelerate the adoption of carbon abatement technologies such as CCS." **D.M. Walsh, K. O'Sullivan, W.T. Lee, and M.T. Devine**, *Energy Economics*. (Subscription may be required.)

"Perceptions of sub-seabed carbon dioxide storage in Scotland and implications for policy: A qualitative study." The following is the Abstract of this article: "The geological storage of CO_2 offers notable potential, as part of larger CCS processes, to be a significant climate change mitigation technology. This paper challenges the argument often put forward that, due to the greater distances from [centers] of population, it will be 'easier' to garner public and stakeholder support for offshore CO_2 storage than onshore. Based on the results of research interviews carried out with stakeholders and informed publics in Scotland, challenges for public and stakeholder acceptance of sub-seabed CO_2 storage that may require further policy attention are identified. Whilst existing policy for sub-seabed CO_2 storage is [cognizant] of the need for societal engagement, it may be the case that these regulations may need further reinforcement to ensure future developments are able to address social acceptability issues as fully as possible. The value of taking into account social as well as physical characteristics at the site selection phase, the need for mechanisms to take seriously stakeholder conceptions of uncertainty, and the importance of extending social engagement beyond risk communication are discussed." **Leslie Mabon, Simon Shackley, and Nathan Bower-Bir**, *Marine Policy*. (Subscription may be required.)

"Predictors of risk and benefit perception of carbon capture and storage (CCS) in regions with different stages of deployment." The following is the Abstract of this article: "CCS is a technological option for mitigating climate change. Public risk perception plays a key role in the decision whether it should be adopted at a large scale. In this study, a comparison was made between regions with different levels of CCS deployment: the three Canadian provinces of British Columbia, Alberta and Saskatchewan. While familiarity with the technology differed greatly among the different regions, predictors of risk perception were stable and unrelated to familiarity. Results were similar for benefit perceptions, but a comparison with results from a similar Swiss study seems to suggest that benefit perceptions of CCS are likely to be influenced by the national context of deployment." **Selma L'Orange Seigo, Joseph Arvail, Simone Dohle, and Michael Siegrist**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

June 2014

"EPA Proposes First Guidelines to Cut Carbon Pollution from Existing Power Plants." The U.S. Environmental Protection Agency (EPA) released the Clean Power Plan, a proposal to ensure a healthier environment, spur innovation, and strengthen the economy. EPA is proposing guidelines that build on trends underway in states and the power sector to increase efficiency and reduce carbon emissions from existing power plants. By 2030, the proposal would: (1) cut carbon emissions from the power sector by 30 percent nationwide below 2005 levels; (2) cut particle emissions, nitrogen oxides, and sulfur dioxide by more than 25 percent as a co-benefit; (3) provide up to $93 billion in climate and public health benefits; and (4) reduce electricity bills by increasing energy efficiency and reducing demand in the electricity system. DOE will provide technical assistance and engage with state regulators, regional reliability coordinators, independent system operators, regional transmission operators, state public utility commissions, and other stakeholders. The proposal follows the Climate Action Plan and the June 2013 Presidential Memorandum. For more information on how the proposal will reduce carbon emissions, click here. From *U.S. EPA News Release* on June 2, 2014.

"Government Proposes Carbon Offset Plan." South Africa's government announced policy plans to address the financial impact on business and industry when the nation's first tax on carbon is introduced in January 2016. According to a paper published by South Africa's National Treasury, the new "carbon offsets scheme" has the potential to reduce the total volume of GHGs at a smaller cost, while also reducing carbon intake by up to 10 percent. In addition, the proposed carbon offsets scheme could lead

to a domestic trading market where companies could buy and sell carbon credits as part of the government's voluntary pledge to reduce South Africa's projected GHG emissions by 34 percent by 2020 and up to 42 percent by 2025. According to the National Treasury's paper, offsets have the potential to reduce domestic GHGs emissions by 15 million to 41 million tons every year. Currently, there are 111 registered carbon offset projects in South Africa, which were developed under the Kyoto Protocol or other voluntary market standards. From *The Mercury* on May 2, 2014.

"Scottish and Cypriot Scientists Forge Research Link." The University of Nicosia's Center for Green Development and Energy Policy (CGD) and Scottish Carbon Capture & Storage (SCCS) reached an agreement to seek funding for European Union (EU) researchers to collaborate to identify likely geological CO_2 storage sites beneath the Mediterranean Sea to the south of Cyprus. The scientists, using methodology developed in previous SCCS projects, will study seismic data and other information to search for storage sites with the potential to increase Cyprus' carbon storage capacity. From *SCCS News Release* on May 21, 2014.

"Washington State Enacts New Regulation for Refineries." A new rule was enacted in the state of Washington that requires refineries to limit GHG emissions by 2025. According to Washington's Department of Ecology (DEC), the rule establishes "reasonably available control technology" (RACT) to limit GHG emissions from the state's refineries. The rule, titled, "WAC Petroleum Refinery Greenhouse Gas Emissions Requirements," allows the five refineries throughout Washington to choose one of two options to meet the GHG emission reduction requirements: the energy efficiency standard (EES) or the emission reduction requirement (EER). Under EES, a refinery may demonstrate reasonably available energy efficiency performance by scoring in the 50th percentile of similar-sized U.S. refineries. Under EER, the refinery must implement GHG emission reduction projects that cumulatively achieve reductions adding up to 10 percent of the refinery's baseline year GHG emissions. From *Oil & Gas Journal* on May 29, 2014.

"Reforming the EU approach to LULUCF and the climate policy framework." The following is the Abstract of this article: "[The authors] focus on recent progress in reforming the role of forests and other land use in the EU climate policy framework. EU inclusion of LULUCF (Land Use, Land-Use Change and Forestry) in the climate policy framework still lags international developments, remaining at odds even with the United Nations Framework Convention on Climate Change's (UNFCCC) Kyoto framework. Though the EU has made some important changes that eclipse even the UNFCCC framework—in particular regarding the inclusion of cropland and grazing land management in mandatory EU-level carbon accounting practices—in other respects the EU has far to go. As part of a strategy for fulfilling emission reduction commitments within the EU burden-sharing agreement, Member states are not permitted to trade either in domestically nor foreign produced forest-based carbon credits. On the other hand, both the EU and the UNFCCC/Kyoto LULUCF frameworks remain distant from an idealized model that could facilitate increased climate change mitigation and a more efficient and balanced use of forest-based resources. Limiting the incorporation of forests in the climate policy framework has significant consequences for the cost and rapidity of emission reductions. Forest potential thus remains under-mobilized for climate change mitigation. In this context, [the authors] draw particular attention to the fact that forest-based carbon [storage's] potential contribution to negative emissions represents an important missed opportunity. In the context of ongoing discussions over the EU and UNFCCC's Post-Kyoto frameworks, [the authors] propose an all-encompassing LULUCF carbon accounting model incorporating all previously omitted carbon pools and activities, thus weighing LULUCF removals and emissions on a par with emissions from other sectors (industry, the energy sector, end-users). The successful integration of LULUCF into the EU climate policy and carbon-trading frameworks could dovetail neatly with emerging international climate change mitigation efforts." **David Ellison, Mattias Lundblad, and Hans Petersson**, *Environmental Science & Policy*. (Subscription may be required.)

"Investment under uncertain climate policy: A practitioners' perspective on carbon risk." The following is the Abstract of this article: "This paper introduces the concept of payment probability as an important component of carbon risk (the financial risk associated with CO_2 emissions under uncertain climate policy). In modeling power plant investment decisions, most existing literature uses the expected carbon price (e.g., the price of traded permits or carbon tax) as a proxy for carbon risk. In contrast, this paper identifies expected carbon payment as a more accurate measure of carbon risk as perceived by industry practitioners. This measure of carbon risk incorporates both expected price and the probability that this price would actually be faced in the case of a particular investment. This concept helps explain both the surge of activity in 2005–2006 and the subsequent decline in interest in coal-fired power plant development in the [United States]. The data for this case study comes from an extensive online survey of 700 U.S. energy professionals completed in 2006, as well as interviews conducted with industry representatives from 2007 to 2009. By analyzing industry views on policy uncertainty and future carbon legislation, [the authors] gain a better understanding of investor attitudes toward carbon risk. This understanding will help policy makers design better incentives for investing in low-carbon technologies." **Merrill Jones Barradale**, *Energy Policy*. (Subscription may be required.)

July 2014

"CCS Hub Study for Scotland and the Central North Sea." A comprehensive analysis into the development of CCS in the UK, titled, "Scotland and Central North Sea CCS Hub Study," was completed by Element Energy Ltd, working with partners SCCS, AMEC, and Dundas Consultants. The report examines scenarios for how CCS might develop and uses these scenarios to create blueprints and business plans for delivering CCS. The report details how the combination of CCS with EOR in the Central North Sea (CNS) provides a beneficial opportunity because the region has a variety of stakeholder interests, legacy facilities (pipelines, platforms, and wells), and commercial and regulatory frameworks for CCS development. The report provides a series of recommendations for Scotland based on the following: (1) support for early CCS demonstration in Scotland; (2) maximizing the UK and European market for CCS in the 2010s and 2020s; (3) supporting infrastructure targeting CNS; (4) improving CCS readiness and optimizing infrastructure; and (5) improving the commercial attractiveness of CO_2 transport, storage, and EOR. From *Element Energy Press Release* on June 1, 2014.

"Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design?" The following is the Abstract of this article: "Economists traditionally view a Pigouvian fee on [CO_2] and other greenhouse gas emissions, either via carbon taxes or emissions caps and permit trading ('cap-and-trade'), as the economically optimal or 'first-best' policy to address climate change-related externalities. Yet several political economy factors can severely constrain the implementation of these carbon pricing policies, including opposition of industrial sectors with a concentration of assets that would lose considerable value under such policies; the collective action nature of climate mitigation efforts; principal agent failures; and a low willingness-to-pay for climate mitigation by citizens. Real-world implementations of carbon pricing policies can thus fall short of the economically optimal outcomes envisioned in theory. Consistent with the general theory of the second-best, the presence of binding political economy constraints opens a significant 'opportunity space' for the design of creative climate policy instruments with superior political feasibility, economic efficiency, and environmental efficacy relative to the constrained implementation of carbon pricing policies. This paper presents theoretical political economy frameworks relevant to climate policy design and provides corroborating evidence from the United States context. It concludes with a series of implications for climate policy making and argues for the creative pursuit of a mix of second-best policy instruments." **Jesse D. Jenkins**, *Energy Policy*. (Subscription may be required.)

"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 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 [organizations'] (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.)

"Communication approaches for carbon capture and storage: Underlying assumptions of limited versus extensive public engagement." The following is the Abstract of this article: "A pertinent issue in the literature on communication on emerging technologies such as CCS concerns the degree to which the public is actively involved in the communication process. While researchers have highlighted the pros and cons of limited versus extensive public engagement, the assumptions underlying various communication approaches have been largely neglected. Illuminating assumptions are important for scholarly understandings of what influences communication and for practitioner reflexive awareness in designing communication plans. This paper explores assumptions made about senders and receivers when involving the public to various degrees in CCS communication and how these assumptions relate to different communication objectives. [The authors] describe two contrasting communication approaches, the transmission and participatory approaches, relating them to CCS characteristics and research. [The authors] find that CCS communication may, deliberately or not, be based on different assumptions about the social framing of CCS concerning who should formulate the message, the public's ability to understand complex science, the public's interest in helping frame CCS, and whether public opinions should be taken into account. These assumptions also relate to different communication objectives – convincing the public or increasing dialogue – implying different communication fora, predictability, and input." **Katarina Buhr and Victoria Wibeck**, *Energy Research & Social Science*. (Subscription may be required.)

August 2014

"Japan, Mexico Sign Carbon Trade Deal." Japan and Mexico signed an agreement under the Joint Crediting Mechanism (JCM) program that allows for Japanese companies to earn carbon credits by investing in technologies, products, systems, services, and infrastructure to cut greenhouse gas (GHG) emissions in Mexico. The program will to help Japan meet a domestic GHG emission target of three percent above 1990 emissions by 2020. Mexico has several projects registered under the United Nations' (U.N.) Clean Development Mechanism (CDM), which allows for investment in emission reduction projects to earn credits to offset emissions. Mexico has pledged to reduce GHG emissions by 30 percent from the level forecast in 2010 by 2020. Participants in the JCM will not be able to use projects registered under other international emission reduction schemes. Japan has also partnered with Costa Rica, Ethiopia, Indonesia, Kenya, Mongolia, and Vietnam under the JCM. From *Reuters* on July 28, 2014.

"California and Mexico Sign Pact to Fight Climate Change." California's Governor and Mexican environmental officials signed a memorandum of understanding (MOU) to reduce GHG emissions. The MOU calls for the development of carbon pricing systems and the alignment of the systems in the future. California operates a carbon cap-and-trade system that sets a limit on carbon emissions and requires businesses to either reduce emissions or purchase credits to meet the target. California plans to link its carbon cap-and-trade market with a similar effort in Quebec (Canada) and expand the system to encourage price stability and the program's environmental impact. In 2013, California signed similar agreements with British Columbia (Canada), Oregon (United States), and Washington (United States). California also has an agreement with China's National Development and Reform Commission to share carbon trading and related information. From *Reuters* on July 28, 2014.

"A risk-based framework for measurement, monitoring and verification of the Quest CCS Project, Alberta, Canada." The following is the Abstract of this article: "The Quest Carbon Capture and Storage Project will make an early contribution to reducing CO_2 emissions generated by upgrading bitumen from the Alberta oil sands by injecting up to 1.08 million tonnes of CO_2 per year for 25 years into a deep saline [formation] located north-east of Edmonton, Alberta. Regulatory approvals and societal acceptance for this project are contingent on gaining and maintaining confidence in the safety and long-term security of the storage site. Site selection, [characterization] and engineering designs are the prime means of ensuring CO_2 storage risks are as low as reasonably practicable. As a further precaution, a comprehensive [program] of Measurement, Monitoring and Verification (MMV) will evaluate storage performance. The purpose of MMV is to monitor conformance and containment. Conformance monitoring is designed to track the build-up of pressure and CO_2 inside the storage complex to demonstrate the long-term security of storage. Containment monitoring is designed to demonstrate containment and, if necessary, to trigger timely control measures to mitigate any unexpected [release] pathways and to protect the environment. To achieve this, the MMV [program] is designed according to a systematic site-specific risk assessment, diversified to avoid dependence on single technologies and will be adapted through time according to observed performance." **Stephen Bourne, Syrie Crouch, and Mauri Smith**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Framework for the analysis of the low-carbon scenario 2020 to achieve the national carbon Emissions reduction target: Focused on educational facilities." The following is the Abstract of this article: "Since the increase in GHG emissions has increased the global warming potential, an international agreement on carbon emissions reduction target (CERT) has been formulated in Kyoto Protocol (1997). This study aimed to develop a framework for the analysis of the low-carbon scenario 2020 to achieve the national CERT. To verify the feasibility of the proposed framework, educational facilities were used for a case study. This study was conducted in six steps: (i) selection of the target school; (ii) establishment of the reference model for the target school; (iii) energy consumption pattern analysis by target school; (iv) establishment of the energy retrofit model for the target school; (v) economic and environmental assessment through the life cycle cost and life cycle CO_2 analysis; and (vi) establishment of the low-carbon scenario in 2020 to achieve the national CERT. This study can help facility managers or policymakers establish the optimal retrofit strategy within the limited budget from a short-term perspective and the low-carbon scenario 2020 to achieve the national CERT from the long-term perspective. The proposed framework could be also applied to any other building type or country in the global environment." **Choongwan Koo, Hyunjoong, and Taehoon Hong**, *Energy Policy*. (Subscription may be required.)

Geology

September 2013

"A technical assessment of CO_2 Interim Storage in deep saline [formations]." The following is the Abstract of this article: "[Carbon dioxide] Interim Storage (CIS) involves storing [CO_2] in subsurface reservoirs for a finite period of time to be subsequently withdrawn and utilized in EOR or other industrial processes. Through its potential role in matching CO_2 supply and demand and buffering any variability in each, CIS could facilitate the expansion of EOR operations in a number of small and dispersed oil fields, and it could reduce the cost of CCS by allowing increased flexibility in CO_2 capture and economies of scale in transportation infrastructure. This study identifies and assesses the technical challenges and energy requirements of [CIS] by examining two scenarios simulating different patterns of variable CO_2 injection and production in an underground saline [formation]. The results from reservoir modeling show that the pressure buildup and CO_2 plume associated with variable injection are similar to those of constant injection, and the overall variability in pressure transients reduces away from the injection site and as injection proceeds with time. The position of injection and production zones along the well plays a significant role in controlling CO_2 plume migration; injection throughout the entire reservoir thickness can prevent early water invasion into the well. Furthermore, CIS presents some unique tradeoffs. On the downside, water vaporization by injected CO_2 leads to salt accumulation in the [formation] after every production-then-injection sequence, which is not commonly experienced in underground natural gas storage. High and rapidly fluctuating injection and production rates accelerate salt buildup and may block the flow near the well. On the upside, the same water vaporization phenomenon facilitates the formation of a dry-out zone near the well, which, under relatively high injection and low production rates, allows the recovery of dry CO_2 while preventing the undesirable liquid-water production. Still, a clear compromise exists between produced CO_2 purity and overall CO_2 recovery. In the well, lower water-cut leads to lower pressure drop during CO_2 production, thus reducing the overall energy penalty for interim storage. The energy needed to dehydrate and recompress the produced CO_2 is estimated to be around 88.6 kJ/kg; compared to CO_2 capture and compression, the energy costs for interim storage are small but not insignificant." **Karim Farhat and Sally M. Benson**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Investigation of coalbed methane potential in low-rank coal reservoirs – Free and soluble gas contents." The following is the Abstract of this article: "In low-rank coal (lignite and subbituminous coal) reservoirs, it is difficult to investigate the potential of free and soluble gases at different burial depths because of the lack of measuring methods available in practice. In this work, Mariotte's law was adopted to predict free gas content and methane solubility in coal seam water was studied to calculate soluble gas content. Coal samples were collected from Chinese typical low-rank coal-bearing basins. This study shows volume of pores occupied by free gas becomes smaller when moisture content and confining pressure are high. Methane dissolving tests in four coal seam water samples under set temperatures and pressures show that methane solubility increases with increasing pressure and temperature. Pressure seems to be a more effective influencing factor than temperature on methane solubility although temperature effect is enhanced at high temperature and pressure. A mathematical model of in situ methane content containing adsorbed, free and soluble gases, was established to evaluate the in situ gas content of low-rank coal reservoirs at burial depths from 600 m to 1400 m. While the in situ gas content of the studied coal reservoirs increases with burial depth, the percentage of the free and soluble gases in the in situ contents ranges from 8 [percent] to 34 [percent], and hence have to be taken into account in the evaluation of coalbed methane (CBM) potential of low-rank coal reservoirs for CBM recovery." **Aihua Liu, Xuehai Fu, Kexin Wang, Hui An, and Geoff Wang**, *Fuel*. (Subscription may be required to view article.)

"Tracing the movement and the fate of injected CO_2 at the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage project (Saskatchewan, Canada) using carbon isotope ratios." The following is the Abstract of this article: "Stable isotope data can assist in successful monitoring of the movement and the fate of injected CO_2 in [EOR] and geological storage projects. This is demonstrated for the IEA-GHG Weyburn-Midale CO_2 Monitoring and Storage Project (Saskatchewan) where fluid and gas samples from multiple wells were collected and analyzed for geochemical and isotopic compositions for more than a decade. Carbon isotope ratios of the injected CO_2 (−20.4‰) were sufficiently distinct from median $\delta^{13}C$ values of background CO_2 ($\delta^{13}C$ = −12.7‰) and HCO_3^- ($\delta^{13}C$ = −1.8‰) in the reservoir to reveal the movement and geochemical trapping of injected CO_2 in the reservoir. The presented 10-year data record reveals the movement of injected CO_2 from injectors to producers, dissolution of CO_2 in the reservoir brines, and ionic trapping of injected CO_2 in conjunction with dissolution of carbonate minerals. [The authors] conclude that carbon isotope ratios constitute an excellent and cost effective tool for tracing the fate of injected CO_2 at long-term CO_2 storage sites with injection rates exceeding 1 million tons per year." **Bernhard Mayer, Maurice Shevalier, Michael Nightingale, Jang-Soon Kwon, Gareth Johnson, Mark Raistrick, Ian Hutcheon, and Ernie Perkins**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Regional capacity estimates for CO_2 geological storage in deep saline [formations] – Upper Miocene sandstones in the SW part of the Pannonian basin." The following is the Abstract of this article: "Deep saline [formations] are regarded as the most suitable sites or options for CO_2 geological storage, mainly due to their large storage capacity and extensive spatial distribution in most sedimentary basins. The estimation of the storage capacity in this type of sinks presents a problem due to the lack of subsurface data. A significant step from regional towards local capacity estimation is redefinition of regional storage capacity by applying modified methodology for integrated studies of hydrocarbon reservoirs. The suggested procedure was investigated by detailed mapping of the Sava West [formation] in the Croatian part of the Pannonian basin. First, the [caprock] was chosen based on its depth, thickness and lateral continuity, and then the target reservoir – Upper Miocene Poljana sandstone layers underlying the regional [caprock]. Their depth and effective thickness, as well as the subsurface pressure, temperature and resulting density of CO_2 were mapped based on the well data. The [formation] body was then divided into square elements and the storage capacity was calculated for each of them. Mapping of specific storage capacity in this way enables identification of the areas of greater potential for geological storage that should be further investigated for detailed definition of the potential storage objects." **Iva Kolenković, Bruno Saftić, and Dario Perešin**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Dipping open [formations]—The effect of top-surface topography and heterogeneity on CO_2 storage efficiency." The following is the Abstract of this article: "The Forties [formation] underlying the North Sea is used as an exemplar base case to provide a quantitative framework for assessing the CO_2 storage efficiency of dipping open [formation] storage units. Storage under a set of putative regulatory constraints is considered: pressure, migration distance and migration velocity. The effects of permeability, heterogeneity, [formation] dip and top-surface topography are all assessed and the results presented in terms of quantitative storage regimes. Permeability and [formation] dip are key determinants of storage efficiency, since they control the flow speed of the CO_2 and the amount of pressure build-up. Heterogeneity reduces storage efficiency due to localized pressure build-up, if this is a constraint. However, where pressure does not limit capacity, vertical heterogeneity improves storage efficiency through boosting the lateral sweep of CO_2. Top-surface topography introduces structural closures, regions of higher and lower dip than the model average, and channels. When compared to smooth models, structural closures increase efficiency and channels generally decrease efficiency. The net effect of all the competing topographical effects depends on which storage regime describes the smooth model. Overall, it is demonstrated that the storage regime and topography play important roles in determining storage capacity." **Aaron L. Goater, Branko Bijeljic, and Martin J. Blunt**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

October 2013

"Permeability prediction of coalbed methane reservoirs during primary depletion." The following is the Abstract of this article: "Permeability increase in coalbed methane (CBM) reservoirs during primary depletion, particularly in the San Juan Basin, is a [well-accepted] phenomenon. It is complex since it is influenced by stress conditions and coal matrix shrinkage associated with gas desorption. Understanding the variations in coal permeability is critical in order to reliably project future gas production, or consider other gas migration issues in the reservoir. Since sorption-induced strain plays a critical role in changing the permeability, typically observed, the theoretical strain model should be incorporated into the permeability prediction models. An effort is made in this paper to couple the recently developed Liu and Harpalani sorption-induced strain model with various permeability models. The model first calculates the theoretical coal matrix shrinkage strain and, using the calculated strain, various commonly used permeability models are applied to two sets of field data. The results of the coupled models show that the agreement between the predicted permeability and that observed in the field is very good. The merit of the coupled models is that it can theoretically predict the permeability with less experimental work, making it a more time efficient and economical technique compared to models used in the past." **Shimin Liu and Satya Harpalani**, *International Journal of Coal Geology*. (Subscription may be required to view article.)

"CO_2-Induced Dissolution of Low Permeability Carbonates, Part I: Characterization and Experiments." The following is the Abstract of this article: "The effect of elevated dissolved CO_2 concentrations on compositionally and structurally distinct carbonate sample cores from the Weyburn-Midale CO_2-EOR and storage site (Canada) was measured from analysis of 3-D sample characterization and fluid chemistry data from core-flood experiments. Experimental conditions (60°C; 24.8 MPa confining pressure) and brine composition were chosen to mimic in situ reservoir conditions. Mineralogy and pore space distributions within the eight individual cores were characterized with X-ray computed microtomography and scanning electron microscopy both before and after exposure to brine with $0.5 \leqslant pCO_2 \leqslant 3$ MPa, while solution chemistry and differential fluid pressures were monitored during experiments. [The authors'] experimental study aimed to quantify the relationship between fluid flow, heterogeneity, and reaction specific to carbon storage at the Weyburn-Midale field by integrating characterization imaging, pressure data, and solution chemistry. Through the use of non-invasive microtomographic imaging, a variety of dissolution behaviors were observed, with variable effects on the evolution of solution chemistry and permeability as a result of heterogeneity within these two relatively low permeability carbonate samples. Similar-sized, evenly distributed pores, and steadily advancing dissolution fronts suggested that uniform flow velocities were maintained throughout the duration of the higher permeability 'Marly' dolostone core experiments. The development of unstable dissolution fronts and fast pathways occurred in the 'Vuggy' sample experiments when fluid velocities varied widely within the sample (as a result of increased pore structure heterogeneity). The overall effect of fast pathway development was to increase bulk permeability values by several orders of magnitude, allowing CO_2-acidified fluids to travel through the cores largely unmodified by carbonate mineral reaction, as indicated by a lack of change in later-time solution pH levels at the core outlet. Given the impact of heterogeneity within low permeability cores, effort should be taken to incorporate smaller-scale heterogeneity into predictive models and such an averaging approach (utilizing the data and observations discussed here) is the topic of [the authors'] companion manuscript. Solution chemistry results indicated that steady-state carbonate mass transfer conditions were attained in the Marly dolostone experiments and during the earlier (pre-pressure breakthrough) portions of the Vuggy limestone experiments. Steady-state calcium and magnesium concentrations coincided with outlet solutions that were calculated to be at or very near to equilibrium with respect to both calcite and dolomite, relative to available thermodynamic data and considering experimental data scatter. Carbonate mass transfer data were evaluated against a variety of proposed carbonate dissolution mechanisms, including both pH- and pCO_2-dependent expressions as well as a simplified pH-independent formulation. Based on this analysis, the calcite reaction rate coefficient was estimated to be ~17 times faster than that for dolomite dissolution under [the authors'] experimental conditions. This ratio is consistent with the use of rate equations that depend on carbonate

mineral saturation without specifying additional dependence on solution pH or CO_2 levels, and may be a result of the narrow experimental pH range. In addition, solution chemistry data were combined with time-dependent pressure data to constrain the exponent in a power-law expression describing the relationship between evolving porosity and permeability within the Vuggy limestones. This relationship as well as proposed carbonate kinetic expressions are further evaluated in [the authors'] companion paper." **Megan Smith, Yelena Sholokhova Yue Hao, and Susan Carroll**, *Advances in Water Resources*. (Subscription may be required to view article.)

"Effect of temperature on permeability of geopolymer: A primary well sealant for carbon capture and storage wells." The following is the Abstract of this article: "Geological [storage] of [CO_2] has been found to be the most promising solution to reduce anthropogenic [GHG] emissions without affecting the usage of fossil fuel. Wellbore integrity needs to be maintained for [release]-free storage and well cement plays a major role in wellbore integrity as it provides the required zonal isolation. Ordinary Portland cement (OPC)-based sealant has been used in injection wells and it has been found that it experiences cement degradation and is unstable under CO_2-rich down-hole conditions. Therefore, an experimental program was conducted to study the suitability of geopolymer as well cement and the apparent CO_2 permeability of geopolymer was tested under the following test conditions using a high pressure triaxial experiment: (a) temperatures of 23–70°C; (b) CO_2 injection pressures of 6–17 MPa; and (c) confining pressures of 12–20 MPa. From the preliminary experimental results, it was noted that the apparent CO_2 permeability of geopolymer increases with the curing temperature and increment rates are as high as 200–1000 [percent]. However, the maximum permeability (0.04 μD) value obtained for any temperature studied is approximately 5000 times lower than the permeability value (200 μD) recommended by the American petroleum industry (API) for a typical well sealant. The increase in permeability is related to increased pore diameter and highly heterogeneous pore structure at elevated temperatures for longer curing periods. Even though the permeability of geopolymer increases with the temperature, the values are well below those of traditional OPC cement and API recommended limits. Therefore, geopolymers have potential as primary sealant material in a typical wellbore. An attempt is made to develop an empirical formulation to predict the permeability of geopolymer at different temperatures under various confining pressures." **M.C.M. Nasvi, P.G. Ranjith, J. Sanjayan, and H. Bui**, *Fuel*. (Subscription may be required to view article.)

November 2013

"Changes in reservoir heterogeneity and quality as a response to high partial pressures of CO_2 in a gas reservoir, New Zealand." The following is from the Abstract of this article: "The Kapuni Field is the largest onshore petroleum field in New Zealand and produces CO_2-rich, gas (c. 40–45 mol% CO_2). Diagenesis within the reservoir is dominated by CO_2-related reactions that have resulted in [localized] precipitation of kaolin (abundant), quartz, calcite, dolomite, and siderite, along with [localized] generation of secondary porosity. Most of the CO_2 in the reservoir is thought to have been sourced from intraformational coals, with subsequent up-dip migration to the crest of the Kapuni structure. During migration, CO_2 will have dissolved into undersaturated pore fluids and the resulting acidic pore fluids [catalyzed] feldspar (and minor carbonate) dissolution, thereby providing ions for precipitation of authigenic minerals. Timing of the diagenetic reactions, as determined by paragenetic observations and fluid inclusion analysis, suggests that both quartz and carbonate formed at a very late stage (>100°C, corresponding to 0–4 Ma), which is consistent with [modeled] maturation and expulsion of CO_2 from intraformational source rocks (5 Ma to present). The carbon isotope composition of carbonate cements (median $\delta^{13}C_{PDB}$ −12.4‰) is similar to that of the reservoired CO_2 ($\delta^{13}C_{PDB}$ −14.5‰), and this is supportive of late-stage cement formation with carbon sourced primarily from thermal maturation reactions." **Karen E. Higgs, Rob H. Funnell, and Agnes G. Reyes**, *Marine and Petroleum Geology*. (Subscription may be required.)

"Evaluation of experimentally measured and model-calculated pH for rock–brine–CO_2 systems under geologic CO_2 [storage] conditions." The following is the Abstract of this article: "Reliable pH estimation is essential for understanding the geochemical reactions that occur in rock–brine–CO_2 systems when CO_2 is injected into deep geologic formations for long-term storage. Due to a lack of reliable experimental methods, most laboratory studies of CO_2–rock–brine interactions conducted under geologic CO_2 [storage] (GCS) conditions have relied on thermodynamic modeling to estimate pH; however, the accuracy of these model predictions is typically uncertain. In this study, [the authors] expanded the measurement range of a spectrophotometric method for pH determination, and [the authors] applied the method to measure the pH in batch-reactor experiments at 75°C and 100 atm utilizing rock samples from five ongoing GCS demonstration projects. A combination of color-changing pH indicators, bromophenol blue and bromocresol green, was shown to enable measurements over the pH range of 2.5–5.2. In-situ pH measurements were compared with pH values calculated using geochemical models. Calculations with four different thermodynamic databases resulted in a maximum difference of 0.16 pH units. Among these databases, the Phrqpitz database generally provided the most accurate pH predictions for rocks comprised of carbonate, siltstone, and sandstone. With Phrqpitz, the differences between measured and calculated pH values were within 0.03 pH units for these three rocks. However, for basalt, significant differences (0.10–0.25 pH units) were observed even with Phrqpitz. These discrepancies may be due to the models' failure to fully account for certain proton consuming and producing reactions that occur between the basalt minerals and CO_2-saturated brine solutions." **Hongbo Shao, Christopher J. Thompson, and Kirk J. Cantrell**, *Chemical Geology*. (Subscription may be required.)

"Effect of fluid topology on residual nonwetting phase trapping: Implications for geologic CO_2 [storage]." The following is the Abstract of this article: "This work examines the influence of *initial* (i.e. post drainage) nonwetting (NW) fluid topology on total *residual* (i.e. after imbibition) NW phase saturation. Brine and air (used as a proxy for supercritical CO_2) flow experiments were performed on Bentheimer sandstone; results were quantified via imaging with X-ray computed microtomography (X-ray CMT), which allows for three dimensional, non-destructive, pore-scale analysis of the amount, distribution, and connectivity of NW phase fluid within the sandstone cores. In order to investigate the phenomenon of fluid connectivity and how it changes throughout flow processes, the Bentheimer sandstone results are compared to previously collected X-ray CMT data from similar experiments performed in a sintered glass bead column, a loose packed glass bead column, and a column packed with crushed tuff. This allows [the authors] to interpret the results in a broader sense from the work, and draw conclusions of a more general nature because they are not based on a single pore geometry. Connectivity is quantified via the *normalized Euler number* of the NW fluid phase; the Euler number of a particular sample is normalized by the maximum connectivity of the media, i.e. the Euler number of the system at 100 [percent] NW phase saturation. General connectivity-saturation relationships were identified for the various media. In terms of trapping, it was found that residual NW phase trapping is dependent on initial (i.e. post-drainage) NW phase connectivity as well as imbibition capillary number for the Bentheimer sandstone. Conversely, the sintered glass bead column exhibited no significant relationship between trapping and NW topology." **Anna L. Herring, Elizabeth J. Harper, Linnéa Andersson, Adrian Sheppard, Brian K. Bay, and Dorthe Wildenschild**, *Advances in Water Resources*. (Subscription may be required.)

December 2013

"CO_2 geological storage in the Italian carbonate successions." The following is the Abstract of this article: "Carbonate successions have a large distribution in the Italian territory, both onshore and offshore, and they are commonly hydrocarbons exploration targets. However, an evaluation of the suitability of these sedimentary successions for CCS projects has never been performed. The present study has allowed for the first time the recognition and the geological and structural characterization of areas potentially suitable for CO_2 geological storage in carbonate rocks in Italy. To achieve this objective, public available well data and 2-D multichannel seismic profiles were analyzed and interpreted,

allowing to define eight areas (Malossa–San Bartolomeo, Lachiarella–Binasco, Abruzzi offshore, Abruzzo–Molise, Southern Adriatic, Northern Bradanic Trough, Southern Bradanic Trough, Sicily Channel) characterized by potential reservoirs in carbonate rocks sealed by relatively thick and laterally continuous caprocks. The present results have also highlighted marked spatial heterogeneities in the recognized reservoirs, inferred to result from primary depositional processes, diagenesis and fracturing due to tectonic events. Most reservoirs were recognized within shallow marine carbonate platform succession, among which the most suitable for CCS purposes are those composed of dolostones, showing maximum porosity and permeability values of 25 [percent] and 400-450 mD, respectively. Among the identified areas, the so called 'Sicily Channel' and 'Abruzzi offshore' are probably those most promising because of their location in offshore settings, closeness to significant sources of CO_2 and distance from the main seismogenetic tectonic structures, as well as for the occurrence of one or multiple reservoir–caprock systems. However, the information provided by this study is at a regional scale, and therefore more detailed analyses are needed to identify and characterize potential individual storage sites for CCS projects." **Dario Civile, Massimo Zecchin, Edy Forlin, Federica Donda, Valentina Volpi, Barbara Merson, and Sergio Persoglia**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

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

"Long-term assessment of geochemical reactivity of CO_2 storage in highly saline [formations]: Application to Ketzin, In Salah and Snøhvit storage sites." The following is the Abstract of this article: "Saline [formations] are choice targets for geological storage of CO_2 because of their storage potential and because these formations are not suitable for other uses. Geochemical modeling is an interesting tool to assess the geochemical behavior of CO_2 in the saline [formation], including its dissolution in the brine and its interactions with minerals. Two key parameters which determine the confidence one can have in the results of geochemical modeling are tested in this paper: (i) the establishment of the conceptual model, including the selection of the primary and secondary minerals expected to react; and (ii) the activity model and the associated thermodynamic databases to calculate the interaction energies within the saline solution. In this study, [the authors] performed an analysis of a large set of CO_2 storage natural analogs, which makes it possible to identify the minerals that are likely to precipitate and dissolve during CO_2–brine–rock interactions. Interestingly, this analysis indicates a strong dependence of Dawsonite precipitation on the initial sandstone mineralogy…" **Joachim Trémosa, Christelle Castillo, Chan Quang Vong, Christophe Kervévan, Arnault Lassin, and Pascal Audigane**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

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

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

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

January 2014

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

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

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

February 2014

"Environmental concerns of underground coal gasification." The following is the Abstract of this article: "Underground Coal Gasification is the conversion of solid Coal to gas in-situ by heating the coal and injecting oxidants air/oxygen to cause the gasification by partial combustion instead of complete combustion of coal. UCG is the promising technology having a lot of health, safety and environmental advantages over the conventional mining techniques; the major motivational aspects of UCG involves increased worker health and safety by using no man underground, no surface disposal of ash and coal tailings, low dust and noise pollution, low water consumption, larger coal reserves exploitation, and low volatile organic components, methane and [GHGs] emission to atmosphere. UCG is an inherently clean coal technology as it reduces deadly sulfur and nitrogen oxide emissions to very low levels. Total solid waste from UCG is typically half the volume generated by conventional coal plants and water use is substantially lower as well." **Muhammad Imran, Dileep Kumar, Naresh Kumar, Abdul Qayyum, Ahmed Saeed, and Muhammad Shamim Bhatti**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

March 2014

"Combination of CO_2 geological storage with deep saline water recovery in western China: Insights from numerical analyses." The following is the Abstract of this article: "[Carbon dioxide] geological storage, when combined with deep saline water recovery (CO_2-EWR), not only achieves the relatively secure storage of CO_2 that was captured from the coal chemical industry, due to lower pressure, but also enhances saline water for drinking and industrial or agricultural utilization. This storage will undoubtedly become a win–win choice for the enhancement of energy security and for the promotion of regional development in China, particularly for western regions with a relative shortage of water resources and a more fragile ecological environment. In this paper, a three-dimensional injection–extraction model is established that uses the TOUGH2/ECO2N program according to typical formation parameters of a coal chemical industry in the Xinjiang Uyghur Autonomous Region. Numerical results showed that under the guarantee of sufficient water conditions, 1.73 × 108 tons of saline water could be

produced when the CO_2-EWR is adopted. Well arrangements and formation parameters are also analyzed, and the following conclusions can be drawn: arrangements of pumping wells, such as pumping well number, pumping rate and distance, have considerable influences on the reservoir pressure, and in addition, the sensitivity of pressure on the distance and pumping rate decreases as their values increase. In view of these features, it is necessary to find an optimal point to achieve the best combination of pressure, the [release] time and the amount of dissolution. Formation parameters primarily control the mechanism of CO_2 migration and dissolution. Salinity in the salt water has the greatest impact on CO_2 dissolution trapping followed by permeability and porosity. The arrival time that is allowable for saline water production primarily depends on porosity followed by the permeability ratio and the arrangements of pumping wells. The reservoir pressure change that is caused by parameters is not obvious compared with setting pumping wells. Overall, CO_2-EWR technology is a potential strategic choice for China, particularly in western regions. Additionally, the analysis results provide a reliable guide and reference for CO_2 storage site selection, as well as the practical arrangements of wells." **Qi Li, Ya-Ni Wei, Guizhen Liu, and Qing Lin**, *Applied Energy*. (Subscription may be required.)

"Geochemical modeling of CO_2–water–rock interactions for two different hydrochemical types of CO_2-rich springs in Kangwon District, Korea." The following is the Abstract of this article: "Naturally outflowing CO_2-rich springs are a natural analogue of the seepage of [stored] CO_2 in geological storage sites. In Kangwon district of South Korea, two hydrochemically different types of CO_2-rich springs (i.e., Ca–HCO_3-type and Na–HCO_3-type) occur together in a granitic terrain. Hydrochemical and water-isotope data (i.e., $\delta^{18}O$–δD and tritium) show that Na–HCO_3-type springs have experienced significant silicate weathering processes over a long residence time at depths, while Ca–HCO_3-type springs were formed by the mixing of Na–HCO_3-type springs with shallow groundwater during ascent. In this study, diverse geochemical models including mixing, ion exchange and reaction path were investigated to verify the geochemical processes accounting for the occurrence of two contrasting types of CO_2-rich springs. The mixing and ion exchange models reveal that Ca–HCO_3-type springs are well explained by reverse cation exchange occurring during the mixing of Na–HCO_3-type springs with shallow groundwater. The Na–HCO_3-type springs are well explained by the reaction path modeling including the dissolution of silicate minerals (plagioclase, K-feldspar and biotite) and the precipitation of secondary minerals (calcite, kaolinite, muscovite and Mg-beidellite), implying that dissolved carbon is [stored] by calcite precipitation (i.e., mineral trapping). However, the concentrations of K in [the authors'] modeling results are far below those of K observed in Na–HCO_3-type springs, because of the precipitation of muscovite considered in the model, suggesting the partial disequilibrium state of the [formation] during the hydrolysis of K-feldspar under high P_{CO2} conditions. This result implies that to better predict long-term CO_2–water–rock interactions in a geological storage site with abundant K-feldspar, the secondary K-bearing minerals should be carefully predicted, because a target [formation] can be far from chemical equilibrium during the storage period. This study shows that geochemical modeling can be effectively used to predict the hydrochemical changes of groundwater during long-term CO_2–water–rock interactions and subsequent leakage toward surface in K-feldspar rich [formation], although it should be included in a fully coupled computational approach between fluid flow, heat transfer and reactive mass transport processes in the future research." **Byoung-Young Choi, b, Seong-Taek Yun, Kyoung-Ho Kim, Hyeon-Su Choi, Gi-Tak Chae, Pyeong-Koo Lee**, *Journal of Geochemical Exploration*. (Subscription may be required.)

"Fluid flow and CO_2–fluid–mineral interactions during CO_2-storage in sedimentary basins." The following is the Abstract of this article: "Modelling the progress of geochemical processes in CO_2 storage sites is frustrated by uncertainties in the rates of CO_2 flow and dissolution, and in the rates and controlling mechanisms of fluid–mineral reactions that stabilize the CO_2 in geological reservoirs. Dissolution of CO_2 must be controlled by the complexities of 2-phase flow of CO_2 and formation brines and the smaller-scale heterogeneities in the permeability in the reservoirs which increase the fluid contact areas. The subsequent fluid mineral reactions may increase storage security by precipitating CO_2 in carbonate minerals but the consequences of fluid–mineral reactions on caprock rocks or potential leakage pathways up fault zones are less certain as the CO_2-charged brines may either corrode minerals or decrease permeabilities by precipitating carbonates. Observations from CO_2-injection experiments

and natural analogues provide important constraints on the rates of CO_2 and brine flow and on the progress of CO_2 dissolution and mineral–fluid reactions. In these experiments brines in contact with the propagating plume appear to rapidly saturate with CO_2. Dissolution of the CO_2 drives the dissolution of oxide and carbonate minerals, on times scales of days to weeks. These reactions buffer fluid pH and produce alkalinity such that carbonate dissolution moves to carbonate precipitation over time-scales of weeks to months. The dissolution of Fe-oxide grain coatings and the release of Fe to solution is important in stabilizing insoluble Fe–Mg–Ca carbonate minerals but the rate limiting step for carbonate mineral precipitation is the transport of CO_2-charged brines and silicate mineral dissolution rates. Observations from CO_2-EOR experiments and natural analogues suggest that the silicate mineral dissolution reactions are initially fast in the low pH fluids surrounding the CO_2 plume but that reaction progress over months to years drives minerals towards thermodynamic equilibrium and dissolution rates slow over 2–5 orders of magnitude as equilibrium is approached. The sluggish dissolution of silicate minerals is likely to preside over the long-term fate of the CO_2 in geological reservoirs. Observations from injection experiments and natural analogues suggest that the potentially harmful trace elements mobilized by the drop in pH are immobilized as adsorbed and precipitated phases as fluid pH is buffered across mineral reaction fronts." **Niko Kampmana, Mike Bickle, Max Wigley, Benoit Dubac**, *Chemical Geology*. (Subscription may be required.)

"Long-term assessment of geochemical reactivity of CO_2 storage in highly saline [formations]: Application to Ketzin, In Salah and Snøhvit storage sites." The following is the Abstract of this article: "Saline [formations] are choice targets for geological storage of CO_2 because of their storage potential and because these formations are not suitable for other uses. Geochemical modeling is an interesting tool to assess the geochemical behavior of CO_2 in the saline [formation], including its dissolution in the brine and its interactions with minerals. Two key parameters which determine the confidence one can have in the results of geochemical modeling are tested in this paper: (i) the establishment of the conceptual model, including the selection of the primary and secondary minerals expected to react; and (ii) the activity model and the associated thermodynamic databases to calculate the interaction energies within the saline solution. In this study, [the authors] performed an analysis of a large set of CO_2 storage natural analogs, which makes it possible to identify the minerals that are likely to precipitate and dissolve during CO_2–brine–rock interactions. Interestingly, this analysis indicates a strong dependence of Dawsonite precipitation on the initial sandstone mineralogy. Dawsonite can precipitate in lithic and feldspar rich sandstones but was not observed in quartz rich sandstones. These observations on mineral reactivity are used to establish reactivity conceptual models for three CO_2 storage case-studies in saline sandstone [formations] (Ketzin, In Salah and Snøhvit) and a methodology is proposed to evaluate the long-term geochemical reactivity of these saline [formations] as a result of CO_2 injection. Noticeable differences are obtained between the case-studies as a function of the initial mineralogy and chemical conditions in the sandstones, which highlight that CO_2 mineral trapping can take place in a given storage site but can be almost absent in other storage sites. Regarding the activity model and the database, the Pitzer interaction model is rarely used for simulating CO_2 geochemical behavior in saline [formations] despite the fact that more conventionally used activity models are not valid for such salinities. A comparison between calculated mineral solubility evolution with salinity versus experimental data is performed here using both B-dot and Pitzer activity models as well as six different databases. This comparison exercise shows that chemical interactions within saline solutions can only be reproduced using the Pitzer model, even though Pitzer databases are still incomplete or are not coherent for a wide range of chemical species and temperatures. The geochemical simulations of CO_2 injection in Ketzin, In Salah and Snøhvit saline [formations] give divergent results using different activity models and databases. A high uncertainty on the simulation results is then linked to the database choice and this study clearly stresses the need for a Pitzer database that can be confidently used in all physical/chemical conditions found in deep sedimentary [formations]." **Joachim Trémosa, Christelle Castillo, Chan Quang Vong, Christophe Kervévan, Arnault Lassin, and Pascal Audigane**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Life cycle and cost assessment of mineral carbonation for carbon capture and storage in European power generation." The following is the Abstract of this article: "Large-scale GHG emission reductions are crucial for achieving the European goals for climate change mitigation. A frequently discussed option is CCS, where CO_2 emissions from point sources are captured and stored in geologic structures. However, concerns about risks of [releases] of CO_2 from geological storage have been raised. These risks could be avoided with ex situ mineral carbonation, where the captured CO_2 is stored in an inert and stable solid form after reacting with calcium and magnesium silicates. For a comprehensive assessment of the environmental and economic performance of this CO_2 storage option in fossil-fueled power generation chains, LCA and levelized cost of electricity (LCoE) calculations are performed. The implementation of CCS using mineral carbonation leads to life cycle GHG emission reductions of 15–64 [percent] and LCoE increases of 90–370 [percent] on a per kWh_{el} basis compared to a reference power plant without CCS. The life cycle GHG emission reduction achievable with mineral [storage] is less substantial than with geological storage of CO_2 due to significant energy and chemical additives requirements. Accordingly, LCA results for other environmental indicators are worse than those of the reference plant without CCS and the geological CO_2 storage option." **Stylianos Giannoulakis, Kathrin Volkart, and Christian Bauer**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

April 2014

"An evaluation of carbon dioxide [storage] potential of the Permian Cedar Mesa Sandstone, northeastern Arizona." The following is the Description of this article: "Northeastern Arizona encompasses the southwestern part of the Colorado Plateau, an area of gently dipping to slightly tilted Paleozoic and Mesozoic strata that include porous and permeable sandstone units. The Lower Permian Cedar Mesa Sandstone was identified for study as a potential target for CO_2 [storage] in order to reduce anthropogenic CO_2 emissions to the atmosphere. The Cedar Mesa Sandstone is overlain by the impermeable Organ Rock Formation, which is necessary to prevent escape of [stored] CO_2. The salinity of groundwater in the Cedar Mesa Sandstone is unknown, but must be determined before CO_2 can be [stored] because CO_2 [storage] is not permitted in potable groundwater under current regulatory conditions. Well logs for 755 drill holes were used to evaluate the extent, depth, and thickness of subsurface formations. ESRI® ArcMap™ software was then used to calculate the volume of the Cedar Mesa Sandstone where the top of the unit is below 3,000 feet (915 meters) depth, which is the minimum depth necessary for CO_2 [storage] where the CO_2 is under sufficient pressure to remain in a dense, near liquid state. Well logs were used to evaluate porosity, which was then used to calculate the amount of pore space that is theoretically available for CO_2 storage (the effective porosity). [The authors] calculate that there are between 30 km^3 and 80 km^3 of pore space in the Cedar Mesa Sandstone. The fraction of pore-space volume that is accessible to CO_2 injection is estimated to be approximately 0.5 [percent] to 5 [percent]. Applying this storage efficiency to the Cedar Mesa Sandstone indicates that 0.15 km^3 to 4.3 km^3 of pore space is accessible to injected CO_2, and that 0.114 to 3.24 billion tonnes of CO_2 could be [stored] in this pore space at a density of approximately 750 kg/m^3." **Rauzi, S.L., and Spencer, J.E.**, *Arizona Geological Survey Open File Reports*. (Subscription may be required.)

"Permeability and relative permeability measurements for CO_2-brine system at reservoir conditions in low permeable sandstones in Svalbard." The following is the Abstract of this article: "[Storage] of CO_2 in a saline [formations] is currently being evaluated as a possible way to handle CO_2 emitted from a coal-fueled power plant in Svalbard. The chosen reservoir is a 300-m thick, laterally extensive, shallow marine formation of late Triassic-mid Jurassic age, located below Longyearbyen in Svalbard. The reservoir consists of 300 m of alternating sandstone and shale and is sealed by 400 m of shale. Experimental and numerical studies have been performed to evaluate CO_2 storage capacity. A total of 51 samples of core material from one well (Dh4) were collected and tested to find the potential units for CO_2 injection. Analysis of the results shows that the permeability is generally less than 2 millidarcies and the capillary entry pressure is high. This poses a serious challenge with respect to achieving practical levels of injectivity and injection pressure. For further investigation, two 32-cm-long

sandstone samples from the depth 675 m (Sample 1) and 679 m (Sample 2) were selected for laboratory core flooding experiments at reservoir conditions. This review presents the experimental protocol and detailed CO_2-brine drainage and imbibition relative permeability data for these two different samples of rock. Capillary pressure measurements and simulation of the transient process was used to support the interpolation of the experimental flooding data. Initial x-ray computed tomography scan showed no sign of fractures inside the cores, whereas after the core flooding experiment, there were visible fractures especially in Sample 1. Scanning electron microscopy analysis showed a high proportion of diagenetic iron-minerals in the sandstones like Fe-chlorite, Fe-carbonate, and pyrite. A brownish output flow was seen in the sample with highest porosity and permeability. Dissolution of CO_2 in the brine forms a weak acid that reacts with iron-minerals (e.g., siderite) to form iron-hydroxides. Severe hysteresis effects on one of the samples most likely resulted from changes in the rock composition." **Raheleh Farokhpoor, Erik Gøsta Bruno Lindeberg, Ole Torsaeter, Mai Britt Mørk, and Atle Mørk**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Regional CO_2 [storage] capacity assessment for the coastal and offshore Texas Miocene interval." The following is the Abstract of this article: "Estimating regional geologic storage capacity potential for [CO_2] will play an important role in determining the feasibility of widespread CCS programs in the United States and worldwide. The sandstone reservoirs of the Miocene Age located off the Texas coast in the northern Gulf of Mexico are a promising target for CCS due to favorable geologic properties (high porosity/permeability, effective traps and seals, etc.) and proximity to high [CO_2] emission sources. The common method for regional storage capacity estimation involves the calculation of a pore volume which is modified by some discount or efficiency factor. Though efficiency factors have a large effect on calculated capacity, little work has been done to validate the use and effectiveness of these terms. In this paper [the authors] aim to provide an estimate for the storage potential of the coastal and offshore Texas Miocene interval using a common calculation methodology and to begin expanding on this calculation by developing and incorporating an additional sand picking refinement step. This step allows for an initial investigation into the accuracy and utility of typical efficiency factors and regional storage calculations. [The authors] find that in [their] study area, capacity that is calculated using the actual net sand thickness, or 'net capacity', is ~25 [percent] less than capacity that is calculated using the total interval thickness, or 'gross capacity', though, ideally, the two should be equal. Discrepancies between the two calculations emphasize the large uncertainty inherent in efficiency factors and highlight the need for further investigation." **Kerstan J. Wallace, Timothy A. Meckel, David L. Carr, Ramón H. Treviño, and Changbing Yang**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

May 2014

"Experimental Observation of Permeability Changes In Dolomite at CO_2 [Storage] Conditions." The following is the Abstract of this article: "Injection of cool CO_2 into geothermally warm carbonate reservoirs for storage or geothermal energy production may lower near-well temperature and lead to mass transfer along flow paths leading away from the well. To investigate this process, a dolomite core was subjected to a 650 h, high pressure, CO_2 saturated, flow-through experiment. Permeability increased from $10^{-15.9}$ to $10^{-15.2}$ m^2 over the initial 216 h at 21°C, decreased to $10^{-16.2}$ m^2 over 289 h at 50°C, largely due to thermally driven CO_2 exsolution, and reached a final value of $10^{-16.4}$ m^2 after 145 h at 100°C due to continued exsolution and the onset of dolomite precipitation. Theoretical calculations show that CO_2 exsolution results in a maximum pore space CO_2 saturation of 0.5, and steady state relative permeabilities of CO_2 and water on the order of 0.0065 and 0.1, respectively. Post-experiment imagery reveals matrix dissolution at low temperatures, and subsequent filling-in of flow passages at elevated temperature. Geochemical calculations indicate that reservoir fluids subjected to a thermal gradient may exsolve and precipitate up to 200 cm^3 CO_2 and 1.5 cm^3 dolomite per kg of water, respectively, resulting in substantial porosity and permeability redistribution." **Benjamin M. Tutolo, Andrew J. Luhmann, Xiang-Zhao Kong, Martin O. Saar, and William E. Seyfried, Jr.**, *Environ. Sci. Technol.* (Subscription may be required.)

"Inverse Modeling of Water-Rock-CO_2 Batch Experiments: Potential Impacts on Groundwater Resources at Carbon [Storage] Sites." The following is the Abstract of this article: "This study developed a multicomponent geochemical model to interpret responses of water chemistry to introduction of CO_2 into six water-rock batches with sedimentary samples collected from representative potable [formations] in the Gulf Coast area. The model simulated CO_2 dissolution in groundwater, aqueous complexation, mineral reactions (dissolution/precipitation), and surface complexation on clay mineral surfaces. An inverse method was used to estimate mineral surface area, the key parameter for describing kinetic mineral reactions. Modeling results suggested that reductions in groundwater pH were more significant in the carbonate-poor [formations] than in the carbonate-rich [formations], resulting in potential groundwater acidification. Modeled concentrations of major ions showed overall increasing trends, depending on mineralogy of the sediments, especially carbonate content. The geochemical model confirmed that mobilization of trace metals was caused likely by mineral dissolution and surface complexation on clay mineral surfaces. Although dissolved inorganic carbon and pH may be used as indicative parameters in potable [formations], selection of geochemical parameters for CO_2 [release] detection is site-specific and a stepwise procedure may be followed. A combined study of the geochemical models with the laboratory batch experiments improves understanding of the mechanisms that dominate responses of water chemistry to CO_2 leakage and also provides a frame of reference for designing monitoring strategy in potable [formations]." **Changbing Yang, Zhenxue Dai, Katherine D. Romanak, Susan D. Hovorka, and Ramón H. Treviño**, *Environ. Sci. Technol.* (Subscription may be required.)

"Effects of Carbon Dioxide on the Mobilization of Metals from [Formations]." The following is the Abstract of this article: "Potential [releases] of CO_2 from storage sites to shallow [formations] could have adverse impacts on the quality of potable groundwater. The mineralogy of well-sorted silica sand is modified by the pH-controlled precipitation of eight metals (Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd). Continuous flow tests are performed in two fixed-bed columns packed with the modified sand by coinjecting gas CO_2/distilled water (2-phase column) and distilled water (1-phase column/control test) at constant influx rates for a period of two months. The concentration of dissolved metals is measured in the effluents of columns with atomic absorption spectroscopy (AAS). Mineralogical analysis of the surface of sand grains is done before and after the flow tests with scanning electron microscopy–X-ray energy dispersive spectroscopy (SEM–EDS) and X-ray photoelectron spectroscopy (XPS), whereas the precise quantitative measurement of the metal content in the sand is done with AAS. A dynamic numerical model that couples the flow and mass-transfer processes in porous media with the equilibrium and kinetically driven metal desorption processes is developed. Inverse modeling of the continuous flow test enables us to quantify and rank the selectivity of metal mobility in terms of equilibrium and kinetic desorption parameters. The continuous CO_2 dissolution and water acidification causes significant mobilization and dissolution of several metals (Mn, Ni, Cu, Zn, Co), moderate mobilization of Cr, acceleration of Cd dissolution, whereas Fe remains strongly bonded on the sand grains as goethite. The parameters estimated from lab-scale column tests might be helpful for interpreting field-scale CO_2 [release] scenarios and installing relevant early warning monitoring systems." **Katerina Terzi, Christos A. Aggelopoulos, Ioannis Bountas, and Christos D. Tsakiroglou**, *Environ. Sci. Techno.* (Subscription may be required.)

"Control of CO_2 Permeability Change in Different Rank Coals during Pressure Depletion: An Experimental Study." The following is the Abstract of this article: "The gas permeability of different rank coals varies because of the summative effects of increasing effective stress, gas slippage, and coal matrix shrinkage during gas pressure depletion. In this paper, the natures of CO_2 permeability change were primarily investigated in a high-volatile A bituminous coal (core D2-2), a moderate volatile bituminous coal (core S1), and an anthracite coal (core P11-2-1). Under a 4.3 MPa confining stress condition, as the gas pressure declines, the CO_2 permeability of core D2-2 gradually decreases and then has a slight increase at mean gas pressures of less than approximately 0.8 MPa, the CO_2 permeability of core S1 initially decreases but subsequently increases above a mean gas pressure of approximately 1.3 MPa, and the CO_2 permeability of core P11-2-1 continuously increases, especially at mean gas

pressures of less than approximately 1.8 MPa. These pressure-depletion observations on CO_2 permeability are considered to be the result of three effects: (a) increasing effective stress decreases CO_2 permeability; (b) increased gas slippage increases CO_2 permeability exponentially, becoming significant at mean gas pressures of less than approximately 0.8 MPa for the three cores; and (c) a positive effect on CO_2 permeability from matrix shrinkage occurs at mean pressures of less than approximately 1.3 and 1.8 MPa for cores S1 and P11-2-1, respectively, whereas the CO_2 permeability of core D2-2 is negatively affected by matrix shrinkage at all tested pressures. Additionally, it is found that the three effects on the CO_2 permeability depend upon the permeability of the coal and gas pressure." **Junqian Li, Dameng Liu, Yanbin Yao, Yidong Cai, Lulu Xu, and Saipeng Huang**, *Energy Fuels*. (Subscription may be required.)

June 2014

"Seismic and structural geology constraints to the selection of CO_2 storage sites – The case of the onshore Lusitanian basin, Portugal." The following is the Abstract of this article: "The Lusitanian sedimentary basin, in Portugal, has a complex tectonic history and a seismic activity determined by its proximity to the Eurasian–Nubian tectonic plate boundary. Seismic activity and geological structure impose serious constraints to the selection of CO_2 storage sites. This article focuses on the constraints imposed by active seismicity, geological structure and, as a direct consequence of the latter, by the hydrogeology and geothermal framework on the identification of onshore CO_2 storage sites in deep saline [formations] of the Lusitanian basin (central and north sectors). Several active faults and areas of higher seismic hazard have been defined, [favoring] the selection of storage sites in the northern part of the basin. The halokinetic tectonics, responsible for emplacement of salt domes, constrains the regional groundwater flow system, and suggests that it is unreasonable to consider post-salt reservoirs. In most of the Lusitanian basin the pre-salt Silves Formation is the only reservoir worth considering. Four areas have been selected where the reservoir is at adequate depth, but given the other criteria for site selection, the area designated as S. Mamede is the most interesting one for CO_2 injection." **Nadine Pereira, Júlio F. Carneiro, Alexandre Araújo, Mourad Bezzeghoud, and José Borges**, *Journal of Applied Geophysics*. (Subscription may be required.)

"Molecular Simulation of Carbon Dioxide, Brine, and Clay Mineral Interactions and Determination of Contact Angles." The following is the Abstract of this article: "Capture and subsequent geologic storage of CO_2 in deep brine reservoirs plays a significant role in plans to reduce atmospheric carbon emission and resulting global climate change. The interaction of CO_2 and brine species with mineral surfaces controls the ultimate fate of injected CO_2 at the nanoscale via geochemistry, at the pore-scale via capillary trapping, and at the field-scale via relative permeability. [The authors] used large-scale molecular dynamics simulations to study the behavior of supercritical CO_2 and aqueous fluids on both the hydrophilic and hydrophobic basal surfaces of kaolinite, a common clay mineral. In the presence of a bulk aqueous phase, supercritical CO_2 forms a nonwetting droplet above the hydrophilic surface of kaolinite. This CO_2 droplet is separated from the mineral surface by distinct layers of water, which prevent the CO_2 droplet from interacting directly with the mineral surface. Conversely, both CO_2 and H_2O molecules interact directly with the hydrophobic surface of kaolinite. In the presence of bulk supercritical CO_2, nonwetting aqueous droplets interact with the hydrophobic surface of kaolinite via a mixture of adsorbed CO_2 and H_2O molecules. Because nucleation and precipitation of minerals should depend strongly on the local distribution of CO_2, H_2O, and ion species, these nanoscale surface interactions are expected to influence long-term mineralization of injected [CO_2]." **Craig M. Tennery and Randall T. Cygan**, *Environ. Sci. Technol.* (Subscription may be required.)

July 2014

"Groundwater hydrogeochemistry in injection experiments simulating CO_2 [release] from geological storage reservoir." The following is the Abstract of this article: "Geologic carbon [storage] has the potential to reduce [GHG] concentrations in the atmosphere. However, one barrier to large scale implementation is concern for water quality degradation from [the release] of high CO_2 fluids into drinking water [formations]. The hydrogeochemical response to simulated CO_2 [release] was studied to estimate major and trace element release and to develop criteria for water quality monitoring and risk assessment. In this study, approximately 3100 L [formation] water enhanced with 1 atmosphere pressure CO_2 gas was injected into a fracture zone located at 362–366 m below the ground surface in a sandstone/siltstone/mudstone interbedded [formation] in the Newark Basin. This was followed by a 3–6 week long incubation and then continuous monitoring of the hydrogeochemistry in the pumped-back water samples. Relative to background conditions, the recovered [formation] water displayed a decrease of pH, increase of alkalinity, Ca, Mg and Si concentrations, decrease of sulfate and Mo concentrations, and increased concentrations of trace elements including Fe, Mn, Cr, Co, Ni, Cu, Zn, Rb, Sr, Ba and U. These changes in [formation] water geochemistry can be explained by (a) dissolution of silicate and carbonate minerals and (b) trace element release that appear to be dependent on pH and pCO_2 and affected by the altered redox conditions in the [formation]]. Rapid and simultaneous changes of pH, specific conductance, major and trace metal release in [formation] water could be used as indicators of CO_2 [release] from geologic [storage] sites. Hydrogeochemical parameters including pH, total dissolved solids and trace elements, particularly Fe, Mn, and Zn, need to be monitored in compliance with the U.S. Environmental Protection Agency (EPA) drinking water regulations." **Qiang Yang, Juerg Matter, Martin Stute, Taro Takahashi, Gregory O'Mullan, Kelsey Umemoto, Kale Clauson, M. Elias Dueker, Natalie Zakharova, John Goddard, and David Goldberg**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Comparison of different methods for determining key parameters affecting CO_2 storage capacity in oil reservoirs." The following is the Abstract of this article: "Storing CO_2 in oil reservoirs is not only an effective method for reducing CO_2 emissions and greenhouse effects, but also a means to be more economical by enhancing oil recovery. The evaluation of CO_2 storage capacity in oil reservoirs which is very important for the implementation of CO_2 storage includes the evaluation of theoretical, effective, practical and matched storage capacities. Based on the volumetric balance theory, considering CO_2 dissolved in remaining oil and water, sweep efficiency and displacement efficiency, this paper utilizes three methods to calculate theoretical and effective CO_2 storage capacity in oil reservoirs, in which CO_2 volumetric sweep efficiency, oil recovery factor and [storage] factor are key parameters. This work presents a reservoir numerical simulation method, an empirical formula method, and a stepwise regression method. The feasibility, superiority and limitations of the methods for calculating these three key parameters and storage capacities – including theoretical and actual CO_2 storage capacities – were analyzed through simulated applications in three reservoirs of the Xinjiang Oilfield of China. The results indicated that the assessment results of stepwise regression has a high level of accuracy, and that this oilfield can provide a large storage capacity and is thereby worthy of further study." **Changlin Liao, Xinwei Liao, Xiaoliang Zhao, Hongna Ding, Xiaopeng Liu, Yongge Liu, Jing Chen, and Ning Lu**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

August 2014

"Interaction between CO_2-rich sulfate solutions and carbonate reservoir rocks from atmospheric to supercritical CO_2 conditions: Experiments and modeling." The following is the Abstract of this article: "A test site for CO_2 geological storage is situated in Hontomín (Burgos, northern Spain) with a reservoir rock that is mainly composed of limestone. During and after CO_2 injection, the resulting CO_2-rich acid brine gives rise to the dissolution of carbonate minerals (calcite and dolomite) and gypsum (or anhydrite at depth) may precipitate since the reservoir brine contains sulfate. Experiments using columns

filled with crushed limestone or dolostone were conducted under different P–pCO_2 conditions (atmospheric: 1–$10^{-3.5}$ bar; subcritical: 10–10 bar; and supercritical: 150–34 bar), T (25, 40 and 60°C) and input solution compositions (gypsum-undersaturated and gypsum-equilibrated solutions). [The authors] evaluated the effect of these parameters on the coupled reactions of calcite/dolomite dissolution and gypsum/anhydrite precipitation. The CrunchFlow and PhreeqC (v.3) numerical codes were used to perform reactive transport simulations of the experiments. Within the range of P–pCO_2 and T of this study only gypsum precipitation took place (no anhydrite was detected) and this only occurred when the injected solution was equilibrated with gypsum. Under the P–pCO_2–T conditions, the volume of precipitated gypsum was smaller than the volume of dissolved carbonate minerals, yielding an increase in porosity ($\Delta\phi$ up to ≈ 4 [percent]). A decrease in T favored limestone dissolution regardless of pCO_2 owing to increasing undersaturation with decreasing temperature. However, gypsum precipitation was favored at high T and under atmospheric pCO_2 conditions but not at high T and under 10 bar of pCO_2 conditions. The increase in limestone dissolution with pCO_2 was directly attributed to pH, which was more acidic at higher pCO_2. Limestone dissolution induced late gypsum precipitation (long induction time) in contrast to dolostone dissolution, which promoted rapid gypsum precipitation. Moreover, owing to the slow kinetics of dolomite dissolution with respect to that of calcite, both the volume of dissolved mineral and the increase in porosity were larger in the limestone experiments than in the dolostone ones under all pCO_2 conditions ($10^{-3.5}$ and 10 bar). By increasing pCO_2, carbonate dissolution occurred along the column whereas it was localized in the very inlet under atmospheric conditions. This was due to the buffer capacity of the carbonic acid, which maintains pH at around 5 and keeps the solution undersaturated with respect to calcite and dolomite along the column. 1D reactive transport simulations reproduced the experimental data (carbonate dissolution and gypsum precipitation for different P–pCO_2–T conditions). Drawing on reaction rate laws in the literature, [the authors] used the reactive surface area to fit the models to the experimental data. The values of the reactive surface area were much smaller than those calculated from the geometric areas." **Maria Garcia-Rios, Jordi Cama, Linda Luquot, and Josep M. Soler**, *Chemical Geology*. (Subscription may be required.)

"Core flooding experiments of CO_2 enhanced coalbed methane recovery." The following is the Abstract of this article: "This paper presents the results of CO_2 enhanced coal bed methane (ECBM) core floods on intact coal core from the Bowen Basin and the Hunter Valley, Australia, at pore pressures of 4 MPa and 10 MPa. The core floods involved flooding with CO_2 to displace methane from the core and then reversing the flood by injecting methane to displace the CO_2 from the previous flood. An important parameter for ECBM is the displacement or sweep efficiency which was estimated directly from the mass balance over the core flood. Displacement efficiencies obtained through CO_2 injection were excellent with more than 99 [percent] of the CH_4 recovered during the core floods. The reverse experiments in which CH_4 was injected to displace CO_2 were notably less effective with an average of 95 [percent] displacement obtained for the Bowen Basin core sample and only 71 [percent] displacement obtained for the Hunter Valley core sample by the end of the experiment. History matching was performed with the reservoir simulator SIMED II which used a hydrostatic permeability model, the extended Langmuir model, and a bi-disperse diffusion model. In general, good history matches were obtained between simulated and observed flow rates, mass balances, and breakthrough times demonstrating that the model could accurately represent the ECBM process. It was found that the triple porosity gas diffusion model provided an improved agreement to observations over the unipore model. Connell–Lu–Pan's hydrostatic permeability model was used in the history matching which differentiates between bulk and pore sorption strain. During the CO_2 flooding experiments a change in permeability was observed as CO_2 displaced CH_4 in the core. As the stress conditions were constant, this was the result of the sorption strain impacting on the porosity and thus permeability. However, for the reverse core flood in which CH_4 was injected to displace CO_2, no permeability changes were observed, implying that pore and bulk strain were the same and thus cancelled out." **R. Sander, L.D. Connell, Z. Pan, M. Camilleri, D. Heryanto, N. Lupton**, *International Journal of Coal Geology*. (Subscription may be required.)

"Fluid-rock interaction in CO_2-saturated, granite-hosted geothermal systems: Implications for natural and engineered systems from geochemical experiments and models." The following is the Abstract of this article: "Hydrothermal experiments were conducted and geochemical models constructed to evaluate the geochemical and mineralogical response of fractured granite and granite + epidote in contact with thermal water, with and without supercritical CO_2, at 250°C and 25–45 MPa. Illite ± smectite ± zeolite(?) precipitate as secondary minerals at the expense of K-feldspar, oligoclase, and epidote. Illite precipitates in experiments reacting granite and granite + epidote with water; metastable smectite forms in the experiments injected with supercritical CO_2. Waters are supersaturated with respect to quartz and saturated with respect to chalcedony in CO_2-charged experiments, but neither mineral formed. Carbonate formation is predicted for experiments injected with supercritical CO_2, but carbonate only formed during cooling and degassing of the granite + epidote + CO_2 experiment. Experimental results provide insight into the buffering capacity of granites as well as the drivers of clay formation. Metastable smectite in the experiments is attributed to high water–rock ratios, high silica activities, and high CO_2 and magnesium–iron concentrations. Smectite precipitation in supercritical CO_2-bearing geothermal systems may affect reservoir permeability. Silicate formation may create or thicken caps within or on the edges of geothermal reservoirs. Carbonate formation, as desired for carbon [storage] projects coinciding with geothermal systems, may require extended periods of time; cooling and degassing of CO_2-saturated waters leads to carbonate precipitation, potentially plugging near-surface production pathways." **Caroline Lo Ré, John P. Kaszuba, Joseph N. Moore, and Brian J. McPherson**, *Geochimica et Cosmochimica Acta*. (Subscription may be required.)

Technology

September 2013

"Techno-economic assessment of hydrogen production from underground coal gasification (UCG) in Western Canada with carbon capture and [storage] (CCS) for upgrading bitumen from oil sands." The following is the Abstract of this article: "This paper examines the techno-economic viability of hydrogen production from underground coal gasification (UCG) in Western Canada, for the servicing of the oil sands bitumen upgrading industry. Hydrogen production for bitumen upgrading is predominantly achieved via steam methane reforming (SMR); which involves significant GHG emissions along with considerable feedstock (natural gas) cost volatility. UCG is a formidable candidate for cost-competitive environmentally sustainable hydrogen production; given its negligible feedstock cost, the enormity of deep coal reserves in Western Canada and the [favorable] CO_2 [storage] characteristics of potential UCG sites in the Western Canadian sedimentary basin (WCSB). Techno-economic models were developed for UCG and SMR with and without CCS, to estimate the cost of hydrogen production including delivery to a bitumen upgrader. In this paper, at base case conditions, a [five percent] internal rate of return (IRR) differential between UCG and SMR was considered so as to account for the increased investment risk associated with UCG. The cost of UCG hydrogen production without CCS is estimated to be \$1.78/kg of H_2. With CCS, this increases to range of \$2.11–\$2.70/kg of H_2, depending on the distance of the site for CO_2 [storage] from the UCG plant. The SMR hydrogen production cost without CCS is estimated to be \$1.73/kg of H_2. In similar fashion to UCG, this rises to a range of \$2.14 to \$2.41/kg of H_2 with the consideration of CCS. Lastly, for hydrogen production without CCS, UCG has a superior cost competitiveness in comparison to SMR for an IRR differential less than 4.6 [percent]. This competitive threshold rises to 5.4 [percent] for hydrogen production with CCS." **Babatunde Olateju and Amit Kumar**, *Applied Energy*. (Subscription may be required to view article.)

"First field test of linear gas sensor net for planar detection of CO_2 [releases] in the unsaturated zone." The following is the Abstract of this article: "Gases from subsurface sources can present risks for the biosphere. To extend the lead time in managing such risks, reliable gas detection in the subsurface is required. A monitoring system was developed that is able to: (i) gather information from large areas, (ii) work efficiently within the subsurface; insensitive to changing subsurface environmental conditions while sensitive to changes in target gas concentrations, and (iii) provide a fast response. [The authors] report the first field test of linear membrane-based gas sensors: Fourteen 40 m long sensors were installed in two horizontal nets one above the other within a homogenized soil and scanned from a control station. 10 L/min of CO_2 was injected into a point-like port 25 cm below the lower sensor net. Two operation modes were successfully tested to detect the CO_2 plume: an active mode, which is sensitive to the concentration, and a passive mode, which is sensitive to changes in concentration. By conversion of the monitoring results the minimum contact range of seeping gas and sensor could be determined. Based on this valuable approach, an unexpectedly high level of lateral gas spread within the soil and the formation of a gas pillow below the soil surface could be observed." **Detlef Lazik and Sebastian Ebert**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Sensitivity of injection costs to input petrophysical parameters in numerical geologic carbon [storage] models." The following is the Abstract of this article: "Numerical simulations are widely used in feasibility studies for geologic carbon [storage]. Accurate estimates of petrophysical parameters are needed as inputs for these simulations. However, relatively few experimental values are available for CO_2–brine systems. Hence, a sensitivity analysis was performed using the STOMP numerical code for supercritical CO_2 injected into a model confined deep saline [formation]. The intrinsic permeability, porosity, pore compressibility, and capillary pressure-saturation/relative permeability parameters (residual liquid saturation, residual gas saturation, and van Genuchten α and m values) were varied independently. Their influence on CO_2 injection rates and costs were determined and the parameters were ranked based on normalized coefficients of variation. The simulations resulted in differences of up

to tens of millions of dollars over the life of the project (i.e., the time taken to inject 10.8 million metric tons of CO_2). The two most influential parameters were the intrinsic permeability and the van Genuchten m value. Two other parameters, the residual gas saturation and the residual liquid saturation, ranked above the porosity. These results highlight the need for accurate estimates of capillary pressure-saturation/relative permeability parameters for geologic carbon [storage] simulations in addition to measurements of porosity and intrinsic permeability." **C.-L. Cheng, M.J. Gragg, E. Perfect, M.D. White, P.J. Lemiszki, and L.D. McKay**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Modeling the performance of large-scale CO_2 storage systems: A comparison of different sensitivity analysis methods." The following is the Abstract of this article: "In this study, [the authors] perform sensitivity analyses using a high-resolution basin-scale reservoir model developed for a hypothetical carbon [storage] project located in the Southern San Joaquin Basin in California, USA. [The authors] use the massively parallel version of the multiphase multicomponent simulator TOUGH2 to simulate CO_2/brine migration and pressure buildup within the CO_2 storage formation and overlying/underlying formations. [The authors] evaluate the impact of parameter uncertainty on risk-related performance measures, i.e., CO_2 saturation and pressure buildup at multiple locations, and the extent of the CO_2 plume and overpressure zone. [The authors] compare three sensitivity analysis methods: a local sensitivity method and the global Morris and Sobol'/Saltelli methods. The uncertainty of sensitivity indices in the global methods is evaluated so that [the authors] can interpret the results even when [the authors] have a limitation in the computational resources. Results show that the three methods provide complementary information for identifying important parameters and system understanding. All three methods give consistent interpretations and importance rankings, except when a parameter has a significant non-linear effect and/or strong interaction with some other parameters. In addition to the magnitude of parameter sensitivity, [the] analysis emphasizes the direction (i.e., favorable or adverse in the risk perspective), non-linearity and/or interaction effects, and physical interpretation of each parameter sensitivity trend. Parameter importance varies with time and space, and also depends on the CO_2 plume or pressure behaviors. In this study, the reservoir permeability is among the most important parameters for all measures, although it has a large trade-off effect in risk such that a higher permeability would tend to reduce reservoir pressure but, at the same time, increase the size of the CO_2 plume footprint." **Haruko M. Wainwright, Stefan Finsterle, Quanlin Zhou, and Jens T. Birkholzer**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

October 2013

"Dense gas dispersion modeling of CO_2 released from carbon capture and storage infrastructure into a complex environment." The following is the Abstract of this article: "Two scenarios for atmospheric dispersion relevant for consequence assessment associated with the loss of containment from [CCS] related infrastructure was investigated using a physics-based mathematical model: namely, the [release] of CO_2, which is a heavier-than-air (or, dense) gas, from storage tanks and transportation pipelines. Simulations of these two scenarios (viz., a storage tank release in the vicinity of a cubical obstacle and a pipeline rupture in a complex topography involving two axisymmetric hills) were performed using computational fluid dynamics, in which the density variations of the fluid (containing the dense gas) were simplified using the Boussinesq approximation. It is shown that the presence of an obstacle and/or complex terrain has a significant influence on the dispersion of the dense gas. Owing to the 'slumping' of the dense gas under the action of gravity, regions well upwind of the source of the gas release can also lie within the hazard zone. The research reported herein provides an improved model for analyzing hazards associated with the dispersion of dense gas clouds and their interaction with local building wakes and/or topographic (terrain) features and contributes to providing a sophisticated method for the assessment of safety and security related to the transportation and geological storage of CO_2." **Kun-Jung Hsieh, Fue-Sang Lien, and Eugene Yee**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

"Selection of monitoring techniques for a carbon storage and enhanced coalbed methane recovery pilot test in the Central Appalachian Basin." The following is the Abstract of this article: "The goals of monitoring, verification, and accounting (MVA) for CCS studies include improved understanding of injection and storage processes, evaluation of interactions among CO_2, reservoir fluids, and formation solids, and assessment and minimization of environmental impacts. Site-specific selection of tools for a well-rounded MVA program may include technologies for atmospheric, near-surface, and subsurface monitoring. An upcoming small-scale CCUS study in an active coalbed methane field in Buchanan County, Virginia, presents a unique application for several established, effective MVA methods. The study will involve injecting up to 20,000 tonnes of CO_2 into three injection wells over a one-year period in order to test the injection and storage potential of the coal seams and to assess the potential for enhanced coalbed methane (ECBM) recovery at offset production wells. The reservoir consists of approximately 15 to 20 coal seams, averaging 0.3 m (1.0 ft) in thickness and distributed over 300 m (1000 ft) of vertical section. This reservoir geometry creates an unusual target for CO_2 injection and also a challenging one for many monitoring and imaging techniques. MVA for the Buchanan County test will include gas content measurements at offset wells, groundwater monitoring, injectate tracer analysis, well logging, surface deformation measurement, passive microseismic monitoring, and tomographic fracture imaging. Multiple monitoring wells will be drilled in order to facilitate the MVA efforts. Surface deformation measurement, microseismic monitoring, and tomographic fracture imaging are state-of-the art tools that have potential to define the subsurface CO_2 plume beyond the borehole scale. The results of the MVA program for the Buchanan County injection demonstration can be used to improve design for potential future studies of CCUS in thin coals." **Ellen S. Gilliland, Nino Ripepi, Matthew Conrad, Michael J. Miller, and Michael Karmis**, *International Journal of Coal Geology*. (Subscription may be required to view article.)

"Comparison of CO_2 capture economics for iron and steel mills." The following is the Abstract of this article: "One of the largest energy consuming manufacturing industries in the world is the iron and steel industry which emits almost [five percent] of the total world CO_2 emissions. Previous studies examining the application of CO_2 capture at iron and steel mills evaluated capture at conventional and Corex iron and steel mills. This study extends the analysis to include Hismelt, Midrex and the mini mill. In the first part of [the authors'] study, [the authors] present a high level scoping assessment of the opportunities for implementing CO_2 capture at existing direct atmospheric CO_2 emission points. Implementing CO_2 capture using commercial [monoethanolamine (MEA)] solvent at a conventional iron and steel mill costs from A$80 to A$250 per tonne of CO_2 avoided. Estimated costs to capture from the existing point sources at the Hismelt and Corex iron and steel mills also range from A$80 to A$250 per tonne of CO_2 avoided. At a direct reduction iron process such as Midrex, the cost of CO_2 capture from the process stack gas is estimated at about A$90 per tonne of CO_2 avoided. A cost of approximately A$110 to A$130 per tonne of CO_2 avoided is estimated to capture from the EAF unit of the steel production route for the Midrex and mini mill processes. Alternatively, CO_2 can also be captured where it is produced from processes such as the blast furnace or reduction vessel. Although these streams contain a high level of CO_2, they are used as a low-grade fuel throughout the plant and the produced CO_2 is vented elsewhere. This study also estimates the cost of capturing the CO_2 before further combustion and venting. The costs are estimated for the conventional iron and steel mill blast furnace, the top gas recycling blast furnace (TGRBF), Hismelt and Corex reduction vessel gases. Capture using MEA solvent absorption, the costs range from A$65 to almost A$80 per tonne CO_2 avoided. Using Vacuum Pressure Swing Adsorption technology in place of MEA solvent absorption, the capture costs for these gases reduce by approximately 25–40 [percent]." **Minh T. Ho, Andrea Bustamante, and Dianne E. Wiley**, *International Journal of Greenhouse Gas Control*. (Subscription may be required to view article.)

November 2013

"Uncertainty quantification for evaluating impacts of caprock and reservoir properties on pressure buildup and ground surface displacement during geological CO_2 [storage]." The following is the Abstract of this article: "A series of numerical test cases reflecting broad and realistic ranges of geological formation properties was developed to systematically evaluate and compare the impacts of those properties on pressure build-up and ground surface displacement and therefore risks of induced seismicity during CO_2 injection. A coupled hydro-geomechanical subsurface transport simulator, STOMP (Subsurface Transport over Multiple Phases), was adopted to simulate the migration of injected CO_2 and geomechanical behaviors of the surrounding geological formations. A quasi-Monte Carlo sampling method was applied to efficiently sample a high-dimensional parameter space consisting of injection rate and 12 other parameters describing hydrogeological properties of subsurface formations, including porosity, permeability, entry pressure, pore-size index, Young's modulus, and Poisson's ratio for both reservoir and caprock. Generalized cross-validation and analysis of variance methods were used to quantitatively measure the significance of the 13 input parameters. For the investigated two-dimensional cases, reservoir porosity, permeability, and injection rate were found to be among the most significant factors affecting the geomechanical responses to the CO_2 injection, such as injection pressure and ground surface uplift. [The authors] used a quadrature generalized linear model to build a reduced-order model that can estimate the geomechanical response instantly instead of running computationally expensive numerical simulations." **Jie Bao, Zhangshuan Hou, Yilin Fang, Huiying Ren, and Guang Lin**, *Greenhouse Gases: Science and Technology***.** (Subscription may be required.)

"The role of CO_2 in CH_4 exsolution from deep brine: Implications for geologic carbon [storage]." The following is the Abstract of this article: "The partial pressure exerted by dissolved CO_2 in water (aqueous phase) containing dissolved [methane (CH_4)] at concentrations near-saturation can lead to the formation of a CH_4-rich gas phase. [The authors] have used numerical simulation with TOUGH2/EOS7C to investigate the process of CH_4 exsolution caused by CO_2 injection for geologic carbon [storage]. [The authors] validated the solubility model in TOUGH2/EOS7C against published measurements of solubility and corresponding Henry's Law coefficients. [The authors] verified [their] simulation results against a previously published 1D test problem, and investigated the effects of numerical dispersion on the CH_4 exsolution and flow processes. In 2D radial simulations of a model system, [the authors] found that highly concentrated CH_4 gas regions form at the leading edge of the CO_2 injection front. Because the gas saturations are small in the CH_4-rich gas regions in the generic system studied here, (i) CH_4 exsolution does not appear to be a problem for seismic monitoring of CO_2 plumes, (ii) reservoir pressurization due to dilution of supercritical CO_2 by CH_4 does not appear to be a concern, and (iii) relative permeability to water is not strongly reduced." **Curtis M. Oldenburg, Christine Doughty, and Nicolas Spycher**, *Greenhouse Gases: Science and Technology***.** (Subscription may be required.)

"Source terms calculation and atmospheric dispersion for a dynamic release from a CO_2 pipeline containing methane and water as impurities." The following is the Abstract of this article: "A method for calculating the source terms including values of leak rate, phase fraction, final velocity, and temperature at the position where the leakage jet has expanded to atmospheric pressure from a CO_2 pipeline containing impurities (methane and water) is presented with regard to the time-dependency of the source terms during the [release]. The thermodynamical properties for the mixture are calculated using the Soave-Redlich-Kwong equation of state with modified 1st order Huron-Vidal mixing rule, which is adjustable in PVTsim. The results for the solubility of water in CO_2 have shown that this thermodynamic model provides accurate predictions for the mixture properties. The thermodynamic model has been used along with a robust transient two-phase flow simulator, OLGA, to simulate the [release] from the pipeline. Finally, the predicted time-dependent source terms (Release Rate, Phase Fraction, Final Velocity, and Temperature in the downstream of the [release]) were used as input into the dispersion model (UDM) in form of sequential segments." **Leila Esfahanizadeh and Bahram Dabir**, *Greenhouse Gases: Science and Technology***.** (Subscription may be required.)

"Modeling and monitoring of geological carbon storage: A perspective on cross-validation." The following is the Abstract of this article: "Effective monitoring and numerical simulations are essential to understanding the implications of long-term geological carbon storage; in particular, the predictions of CO_2 plume flow under storage conditions, storage integrity of sites, and the design and operational aspects of the CO_2 storage projects could be significantly supplemented. Site monitoring data can assure reliability and accuracy of the numerical simulation while numerical prediction results will provide more detailed information on the storage process. The cross-validation between numerical modeling results and monitoring data can play a major role in the development of carbon capture and storage technology. This paper briefly reviews the monitoring and modeling technologies associated with geological carbon storage. In addition, the spatial and temporal resolutions of the numerical simulations are highlighted, while estimations on the resolutions of some commonly used monitoring technologies are also presented. It is revealed that there are gaps in the correlations and cross-validation between the two technologies, where a possible option to reduce the gaps is to enforce more research efforts on multi-scale modeling and appropriate variable correlations." **Xi Jiang, Wasim A. Akber Hassan, and Jon Gluyas**, *Applied Energy*. (Subscription may be required.)

December 2013

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

"Modeling and economic evaluation of the integration of carbon capture and storage technologies into coal to liquids plants." The following is the Abstract of this article: **"**This paper analyzes the technical and economic feasibility of the integration of Fischer–Tropsch process based Coal to Liquid (CTL) plants with CCS technologies. CTL plants could be multipurpose, and for this reason, starting from coal can produce different energy products like liquid fuels, such as diesel and gasoline, chemicals, electricity and hydrogen. Different plant configurations are possible especially in the case of integration with CCS technologies. Obviously, the choice of the optimal process configuration is one that better meets technical and economical requirements. In order to make a first assessment, a screening of suitable technologies has been made. The CTL facility study here proposed is based on commercial coal gasification and Fischer–Tropsch technologies. The system configuration selected and the plant performance has been evaluated using Aspen Plus software. The plant size considered is [approximately] 10,000 bbl/d of liquid fuel products, equivalent to a consumption of [approximately] 4,500 ton/d of coal fed to the gasification island. The declared objective is to evaluate the potential of the identified plant and to perform a first economic evaluation. The ultimate goal is to determine the specific cost of produced liquid fuels and to evaluate the economic performance of the system. The economic

analysis was done to estimate the Internal Rate of Return (IRR), the payback period and the net present value for configurations with CCS or without CO_2 capture. Results show that the CCS introduction in CTL plants has a lighter impact on plant costs and performance since CO_2 capture is already included in the base plant." **Claudia Bassano, Paolo Deiana, and Giuseppe Girardi**, *Fuel*. (Subscription may be required.)

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

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

January 2014

"Carbon dioxide injection for enhanced gas recovery and storage (reservoir simulation)." The following is the Abstract of this article: "[Carbon dioxide] injection for EOR had been broadly investigated both physically and economically. The concept for enhanced gas recovery (EGR) is a new area under discussion that had not been studied as comprehensively as EOR. In this paper, the 'Tempest' simulation software was used to create a three-dimensional reservoir model. The simulation studies were investigated under different case scenarios by using experimental data produced by Clean Gas Technology Australia (CGTA). The main purpose of this study is to illustrate the potential of enhanced

natural gas recovery and CO_2 storage by re-injecting CO_2 production from the natural gas reservoir. The simulation results outlined what factors are [favorable] for the CO_2-EGR and storage as a function of CO_2 breakthrough in terms of optimal timing of CO_2 injection and different injection rates. After [analyzing] the results for each case scenario, it had been concluded that CO_2 injection can be applied to increase natural gas recovery simultaneously [storing] a large amount of the injected CO_2 for this particular gas reservoir. In addition, various CO_2 costs involved in the CO_2-EGR and storage were investigated to determine whether this technique is feasible in terms of the CO_2 content in the production as a preparation stage to achieve the economic analysis for the model." **Chawarwan Khan, Robert Amin, and Gary Madden**, *Egyptian Journal of Petroleum*. (Subscription may be required.)

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

"Numerical assessment of CO_2 geological [storage] in sloping and layered heterogeneous formations: A case study from Taiwan." The following is the Abstract of this article: "[CO_2] geological [storage] (CGS) has been recognized as one of the potential solutions for reducing anthropogenic CO_2 emissions. The Changhua Coastal Industrial Park (CCIP) in central Taiwan has been preliminarily evaluated as a potential site for CGS. The CCIP site possesses sloping and layered heterogeneous formations with stagnant groundwater flow. Previous geophysical investigations of seismic reflection survey have found no significant faults near this site. Prior to the actual application of CGS in the field, it is important to carry out numerical simulations to predict the short- and long-term evolution of injected CO_2 into deep geological formations. In this study, the TOUGHREACT/ECO2N simulator is employed in order to conduct comprehensive CGS assessments at the CCIP site. Field scale CGS simulations are utilized to capture the details of the physical features, such as the displacement of saline brine by the injection of CO_2, buoyancy/gravity convection, and salt precipitation due to pore water dry-out, in the vicinity of the CO_2 injection well. Simulation results show that (1) the migration of CO_2 plume did not penetrate the low permeability formation at 500 years, (2) formation tilting caused a slightly asymmetric CO_2 plume oriented toward the up-tilt direction, and (3) the amount of solubility and residual gas trapping accounted for 26.8 [percent] and 19.0 [percent], respectively, of injected CO_2 by weight at 500 years." **Rui-Tang Sung, Min-Hsu Li, Jia-Jyun Dong, Andrew Tien-Shun Lin, Shu-Kun Hsu, Chien-Ying Wang, and Chien-Nan Yang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

February 2014

"A simplified method for the evaluation of the performance of coal fired power plant with carbon capture." The following is the Abstract of this article: "This paper presents a study of carbon capture systems based on chemical absorption and stripping with amines in pulverized coal fired power plants. The technical feasibility is shown for a 90 [percent] CO_2 removal on 100 [percent] of the exhaust gas flow rate. A simplified method to calculate the performance penalty in comparison with the original power plant is presented including the effect of coal ultimate analysis. The method is verified with data from an existing 75 MW coal fired power plant. The economic analysis is presented in terms of cost of electricity and cost of carbon capture and the results are that the cost of electricity nearly doubles in comparison with the reference plant, whereas the cost of captured CO_2 is considerably higher than the actual cost of CO_2 in the carbon trading markets." **Umberto Desiden and Marco Antonelli**, *Applied Thermal Engineering*. (Subscription may be required.)

"Targeting for carbon [storage] retrofit planning in the power generation sector for multi-period problems." The following is the Abstract of this article: "Carbon constrained energy planning (CCEP) is useful to ensure that the CO_2 emissions limit for a region is met through deployment of low-carbon technologies. The increased demand in energy consumption due to economic growth requires additional energy supply and generation which would subsequently increase the carbon emissions. Nevertheless, most countries are now committed to reduce carbon emission to achieve long term sustainability goals. However, the development of alternative energy sources or CCS initiatives for power plants entails major capital investments. This paper demonstrates how these issues may be handled using CCEP with insight- and [optimization]-based targeting techniques for multi-period scenarios. Both approaches were developed recently for CCEP problems, but previous techniques were limited to single-period planning. The extensions to multi-period scenarios are demonstrated in this work with hypothetical illustrative examples, as well as a Malaysian case study." **Raymond E.H. Ooi, Dominic C.Y. Foo, and Raymond R. Tan**, *Applied Energy*. (Subscription may be required.)

"Power generation plants with carbon capture and storage: A techno-economic comparison between coal combustion and gasification technologies." The following is the Abstract of this article: "Worldwide energy production requirements could not be fully satisfied by nuclear and renewables sources. Therefore a sustainable use of fossil fuels (coal in particular) will be required for several decades. In this scenario, CCS represents a key solution to control the global warming reducing [CO_2] emissions. The integration between CCS technologies and power generation plants currently needs a demonstration at commercial scale to reduce both technological risks and high capital and operating cost. This paper compares, from the technical and economic points of view, the performance of three coal-fired power generation technologies: (i) ultra-supercritical (USC) plant equipped with a conventional flue gas treatment (CGT) process, (ii) USC plant equipped with SNOX technology for a combined removal of sulphur and nitrogen oxides and (iii) integrated gasification combined cycle (IGCC) plant based on a slurry-feed entrained-flow gasifier. Each technology was [analyzed] in its configurations without and with CO_2 capture, referring to a commercial-scale of 1000 MW_{th}. Technical assessment was carried out by using simulation models implemented through Aspen Plus and Gate-Cycle tools, whereas economic assessment was performed through a properly developed simulation model. USC equipped with CGT systems shows an overall efficiency (43.7 [percent]) comparable to IGCC (43.9 [percent]), whereas introduction of SNOX technology increases USC efficiency up to 44.8 [percent]. Being the CCS energy penalties significantly higher for USC (about 10.5 [percent] points vs. about 8.5 for IGCC), the IGCC with CCS is more efficient (35.3 [percent]) than the corresponding CO_2-free USC (34.2 [percent] for the SNOX-based configuration). Whereas, for the case study, USC is most profitable than IGCC (with a net present value, NPV, of 190 M€ vs. 54 M€) for a conventional configuration, CO_2-free IGCC shows a higher NPV (−673 M€) than USC (−711 M€). In any cases, the NPV of all the CO_2-free configurations is strongly negative: this means that, with the current market conditions, the introduction of a CCS system cannot be economically justified without a significant incentive." **Vittorio Tola and Alberto Pettinau**, *Applied Energy*. (Subscription may be required.)

March 2014

"Effect of accelerated carbonation on AOD stainless steel slag for its valorisation as a CO_2-sequestering construction material." The following is the Abstract of this article: "Non-stabilized Argon Oxygen Decarburization (AODNS) slag in powdered form was examined for its CO_2 [storage] capacity and for its potential utilization in the fabrication of high value building materials. The curing of the sample was carried out in two accelerated carbonation environments: i) in a carbonation chamber, maintained at atmospheric pressure, 22°C, 5 vol.% CO_2 and 80% RH; and ii) in a carbonation reactor, where the CO_2 partial pressure (pCO_2) and temperature could be further increased. In the carbonation chamber, an average compressive strength of over 20 MPa, on a 64 cm^3 cubic specimen, was obtained after one week of curing, which is sufficient for many construction applications. Further carbonation resulted in a linear increase of strength up ~30 MPa after three weeks. The CO_2 uptake followed a similar trend, reaching a maximum of 4.3 wt%. In the reactor, the compressive strength improved with an increase in pCO_2 up to 8 bar, temperature up to 80°C, and duration up to 15 h where the maximum CO_2 uptake was 8.1 wt%. The reduction in porosity in the carbonated specimens was approximately in line with the strength gain in the samples. Phase analysis by X-ray powder diffraction and inspection by scanning electron microscopy showed the precipitation of calcite and formation of significant amounts of amorphous material after carbonation. Infrared spectroscopy also pointed to the presence of aragonite and vaterite. In the carbonation chamber, the calcite morphology was uniform throughout the specimen. In the reactor, however, the calcite crystals near the outer edges of the cubes had different morphology than those near the core. Carbonation of the slag resulted in the reduction of basicity by up to one pH unit, and contributed to controlling the leaching of several heavy metals and metalloids." **Muhammad Salman, Özlem Cizer, Yiannis Pontikes, Rafael M Santos, Ruben Snellings, Lucie Vandewalle, Bart Blanpain, Koen van Balen**, *Chemical Engineering Journal*. (Subscription may be required.)

"Estimating the likelihood of pipeline failure in CO_2 transmission pipelines: New insights on risks of carbon capture and storage." The following is the Abstract of this article: "Previous studies of risks associated with CO_2 pipelines for future CCS activities have used either the frequency of incidents associated with existing CO_2 pipelines or from natural gas pipelines as a proxy. Risks of CO_2 pipeline failure have been estimated as in the range of 1.2×10^{-4} to 6.1×10^{-4} km^{-1} yr. This paper demonstrates that for U.S. natural gas pipeline data, incident/failure metrics are not correlated with fatality rates. Both CO_2 and natural gas pipelines are fabricated from the same grades of carbon steel, and both are installed using the same equipment and practices. However, natural gas is lighter than air and explosive in air, whereas CO_2 is nonflammable but toxic (and heavier than air). Their risk profiles are therefore not identical, and the differences in hazard certainly impact the nature of individual and societal risk. This study focuses on the likelihood of events that could result in fatalities or injuries. The average fatality rate for natural gas transmission pipelines constructed over the last [three] decades is 1.0 × 10−6 km^{-1} yr. This value can be viewed as an upper bound for estimating individual risks associated with CO_2 transmission pipelines. Use of incident rates to model individual risks for CO_2 pipelines, has overestimated these risks by 2–3 orders of magnitude. When pipelines are designed with factors of safety required by regulators for populated areas, analysis of natural gas pipeline data demonstrates that risks of significant accidental releases are extremely low. These results require a significant rethinking of previous notions of the risks associated with CO_2 pipelines." **Ian J. Duncan and Hui Wang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Model complexity in carbon [storage]: A design of experiment and response surface uncertainty analysis." The following is the Abstract of this article: "Geologic carbon [storage] (GCS) is considered a promising means of reducing atmospheric CO_2. In Wyoming, GCS is proposed for the Nugget Sandstone in Moxa Arch, a deep, regional-scale saline [formation] with a large CO_2 storage potential. For a proposed storage site, this study builds a suite of increasingly complex conceptual geologic model families, using subsets of the site characterization data: a homogeneous model family (FAM1), a stationary petrophysical model family (FAM2), a stationary facies model family with sub-facies petrophysical variability (FAM3), and a non-stationary facies model family (with sub-facies variability)

conditioned to soft data (FAM4). These families, representing alternative conceptual site models built with increasing data, were simulated with the same CO_2 injection test (50 years at 1/10 Mt (1.0 × 108 kg) per year), followed by 2950 years of monitoring. Using the design of experiment, an efficient sensitivity analysis (SA) is conducted for all families, systematically varying uncertain [formation] parameters, while assuming identical well configuration, injection rate, bottomhole pressure constraint, and boundary conditions, i.e., the model is considered a part of a larger, semi-infinite system, where both the injected CO_2 and the formation brine can flow out. The SA results are compared among the families to identify parameters that have 1st order impact on predicting CO_2 storage ratio (SR) at two different time scales, i.e., end of injection and end of monitoring. This comparison indicates that, for this deep [formation] with a gentle incline, geologic modeling factors do not significantly influence the short-term prediction of the CO_2 storage ratio. However, these factors become more important over the monitoring time, but only for those families where such factors are accounted for (in other words, their long-term importance cannot be revealed by the relatively simple conceptual models). Based on the SA results, a response surface analysis is conducted to generate prediction envelopes of the storage ratio, which are also compared among the families, and at both time scales. Results suggest a large uncertainty in the predicted storage ratio, given the uncertainties in model parameters and modeling choices: the SR varies from 5–60 [percent] (end of injection) to 18–100 [percent] (end of monitoring), although its variation among the model families due to different modeling choices is relatively minor. Moreover, long-term [release] risk is considered small at the proposed site. This is because, in the lowest-SR scenarios, all model families predict gravity-stable supercritical CO_2 migrating toward the bottom of the [formation]. In the highest-SR scenarios, supercritical CO_2 footprints are relatively insignificant by the end of monitoring." **Shuiquan Li and Ye Zhang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

April 2014

"On the CO_2 storage potential of cyclic CO_2 injection process for enhanced oil recovery." The following is the Abstract of this article: "In this study, the potential of cyclic CO_2 injection process was examined for CO_2 storage and EOR. For this purpose, a detailed phase behavior study on the light crude oil–CO_2 and brine–CO_2 systems was conducted. CO_2 solubility in the oil and brine samples as well as oil swelling factor as a result of CO_2 dissolution was experimentally measured. The equilibrium interfacial tension of the crude oil–CO_2 system was also determined by applying the axisymmetric drop shape analysis technique for the pendant drop case. Furthermore, the minimum miscibility pressure (MMP) of CO_2 with crude oil was calculated by means of vanishing interfacial tension technique and found to be MMP = 9.18 MPa. Thereafter, series of cyclic CO_2 injection tests were designed and carried out at constant temperature of T = 30°C and various operating pressures in the range of Pop = 5.38–10.34 MPa to cover immiscible and miscible conditions. The results showed that 40–50 [percent] of the injected CO_2 was stored in the porous medium mainly through residual and solubility trappings' mechanisms. It was found that during immiscible injection condition (i.e., Pop < MMP), higher amount of CO_2 can be stored in the porous medium at higher operating pressures. The results also revealed that optimum potential of CO_2 storage is almost at operating pressures near the MMP, while beyond that pressure, the CO_2 storage capacity was not substantially increased. From the EOR point of view, the oil recovery factor was significantly improved when operating pressure increased and reached its maximum value at miscible condition (i.e., Pop $\geqslant$ MMP). During the immiscible injection scenario, mechanisms involved in oil production were mainly oil swelling and reduction of interfacial tension. However, the light component extraction was the major production mechanism contributing to the oil recovery during miscible injection process." **Ali Abedini and Farshid Torabi**, *Fuel*. (Subscription may be required.)

"Above-zone pressure monitoring and geomechanical analyses for a field-scale CO_2 injection project in Cranfield, MS." The following is the Abstract of this article: "Pressure and temperature monitoring of an above-zone monitoring interval (AZMI), as well as of an injection zone (IZ), has been attempted at a field-scale CO_2 injection site in Cranfield, MS. Recorded pressure data in the AZMI revealed a certain amount of increase with no evidence of direct fluid flow between the IZ and the AZMI. [The authors] therefore attempted to interpret the field-measurement data from a geomechanical

perspective. First, [the authors] tried an analytical approach that combined Green's functions with a poroelastic theory that is based on Segall's derivation (1992). The analysis was shown to provide fast first-order and probabilistic estimation. Next, [the authors] attempted a numerical simulation in which fully coupled calculation between fluid flow and poroelasticity was implemented. Numerical-simulation results using COMSOL matched well with the field data at one monitoring location in the AZMI. However, field data differ from those of a numerical simulation at the other monitoring well. [The authors] suggest that field measurement at the other location in the AZMI might be disturbed during the pressure monitoring, based on bottom-hole pressure records in the IZ and thermal signals. Following the numerical simulation, [the authors] discuss the effect of single-phase fluid flow assumption, observations for thermal effect and pore-pressure–stress coupling, and desirable resolution of pressure gauges for the optimal utilization of above-zone pressure monitoring." **Seunghee Kim and Seyyed Abolfazl Hosseini**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Storage compliance in coupled in CO_2-EOR and storage." The following is the Abstract of this article: "[Carbon dioxide] storage compliance refers to the safe and consistent storage of a captured anthropogenic CO_2 slug in an underground geological structure. This paper investigates the storage compliance in coupled CO_2-EOR and storage projects. Storage compliance requires an oilfield operator to maintain sufficient CO_2 injection and storage capacities throughout an industrial-scale CO_2 capture and EOR-storage operation. [The authors] investigate the uncertainty in two operational parameters that may raise a compliance consideration: annual captured CO_2 from the power plant and CO_2 injection loss in the oilfield. The objective is to maintain sufficient CO_2 injection and storage capacities and maximize the economic benefits from the EOR-storage operation. [The authors] formulate and optimize the storage compliance problem using the method of optimization with Monte Carlo simulation. The results show that appropriate adjustment of the water-alternating-gas (WAG) ratio increases both the compliance and the economic benefits. Also, a CO_2 storage back-up in a saline [formation] allows the oilfield operator to implement more profitable EOR-storage designs. A risk-seeking operator may practice the saline [formation] back-up option to simultaneously maximize the benefits and mitigate the risk of storage capacity shortage. Finally, EOR-storage operation is less efficient than [formation] storage in terms of storage efficiency, and considerably more profitable in terms of tangible economic benefits." **Amin Ettehad**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Seabed mapping to support geological storage of carbon dioxide in offshore Australia." The following is the Abstract of this article: "The geological storage of CO_2 has the potential to provide future clean energy solutions. Geoscience Australia has demonstrated how its national seabed mapping [program] can be successfully applied in assessing containment integrity in offshore basins. These assessments include targeted seabed research that aims to reduce uncertainty around the risks of CO_2 storage by developing an integrated understanding of the physical relationships between the deeper basin structures, the shallow (<100 m) sub-surface and seabed environments. This paper presents an overview of the science strategy developed to undertake this work in the Australian context, with reference to case studies." **Andrew D. Heap, Scott L. Nichol, and Brendan P. Brooke**, *Continental Shelf Research*. (Subscription may be required.)

"A unified model for the deployment of carbon capture and storage." The following is the Abstract of this article: "This paper presents a comprehensive unified model for planning the retrofit of power plants with carbon capture (CC) technologies and the subsequent CO_2 source-sink matching. The planning horizon is divided into time intervals that are not necessarily of equal duration, but which represent time slices generated by specific events (e.g. start and end of plant operation) occurring in the system as well as the required degree of flexibility in planning. In CCS systems, CO_2 sources have variable flow rates and fixed operating lives, while CO_2 sinks have finite injection rate and storage capacity limits, as well as earliest times of availability. The model takes into account such physical and temporal considerations, and also accounts for the need for additional power generation to compensate for energy loss penalties resulting from the capture of CO_2. A case is used to demonstrate the application of the proposed model. Sensitivity analyses are carried out to examine the tradeoff between

carbon emissions reduction and power cost, as well as the effects of uncertainties in sink characteristics and properties of compensatory power on CCS." **Jui-Yuan Leea, Raymond R. Tanb, and Cheng-Liang Chen**, *Applied Energy*. (Subscription may be required.)

May 2014

"3D geomechanical modeling for CO_2 geological storage in faulted formations. A case study in an offshore northern Adriatic reservoir, Italy." The following is the Abstract of this article: "One of the six CCS demonstration projects recently selected within the European Energy Programme for Recovery (EEPR) is located in Italy. In the framework of the feasibility study, the selection of a geological formation suitable to store the required 1 Mt/yr of CO_2 over 10 years and the safety of the CO_2 disposal are two major issues. In the present modeling study, [the authors] investigate the role played by geomechanics in assessing the maximum CO_2 amount that can be [stored] into a 2000 m deep multi-compartment reservoir seated in the off-shore northern Adriatic sedimentary basin. [The authors] use a three-dimensional finite element–interface element geomechanical model to simulate the possible mechanical failure in both the injected formation and caprock, the fault reactivation, and the ground surface displacement. The faulted geological structure is reproduced based on detailed seismic surveys, with petrophysical/geomechanical properties based on the several well-logs available from several oil/gas explorations in the area. The pore pressure distribution due to two injection wells is provided by a fluid-dynamic simulator and a sensitivity analysis is carried out to investigate the role of the major uncertainties in the geomechanical setting. The modeling results suggest that a safe and permanent containment may be secured over a few years only. Afterwards, mechanical failure by shear stress is likely to be experienced by a significant portion of reservoir's injected compartments. Shear failure and fault reactivation can occur much before attaining the hydraulic fracturing pressure, hence represent two major issues in assessing the maximum allowable CO_2 injection overpressure." **Pietro Teatini, Nicola Castelletto, and Giuseppe Gambolati**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Microfluidic Studies of CO_2 [Storage] by Frustrated Lewis Pairs." The following is the Abstract of this article: "Frustrated Lewis pairs (FLPs) comprising sterically hindered Lewis acids and bases offer the capability to reversibly capture CO_2 under mild reaction conditions. The determination of equilibrium constants and thermodynamic properties of these reactions should enable assessment of the efficiency of a particular FLP system for CO_2 [storage] and provide insights for design of new, efficient formulations of FLP catalysts for CO_2 capture. [The authors] have developed a microfluidic approach to studies of FLP–CO_2 reactions, which provides their thermodynamic characterization that is not accessible otherwise. The approach enables the determination of the equilibrium reaction constants at different temperatures, the enthalpy, the entropy, and the Gibbs energy of these reactions, as well as the enhancement factor. The microfluidic methodology has been validated by applying it to the well-characterized reaction of CO_2 with a secondary amine. The microfluidic approach can be applied for fundamental thermodynamic studies of other gas–liquid reactions." **Dan Voicu, Milad Abolhasani, Rachelle Choueiri, Gabriella Lestari, Caroline Seiler, Gabriel Menard, Jesse Greener, Axel Guenther, Douglas W. Stephan, and Eugenia Kumacheva**, *J. Am. Chem. Soc.* (Subscription may be required.)

June 2014

"Evaluation of two alternative carbon capture and storage technologies: A stochastic model." The following is the Abstract of this article: "In this paper [the authors] evaluate two alternative CCS technologies at a coal-fired power plant from an investor's point of view. The first technology uses CO_2 for EOR paired with storage in deep saline formations (DSF) and the second merely stores CO_2 in DSF. The paper updates and improves on an earlier publication by Tzimas et al. (2005). For projects of this type there are many sources of risk, three of which stand out: the price of electricity, the price of oil and

the price of carbon allowances. In this paper [the authors] develop a general stochastic model that can be adapted to other projects such as enhanced gas recovery (EGR) or industrial plants that use CO_2 for either EOR or EGR with CCS. The model is calibrated with UK data and applied to help understand the conditions that generate the incentives needed for early investments in these technologies. Additionally, [the authors analyze] the risks of these investments. Investments with EOR and secondary DSF storage can only be profitable (NPV > 0) when there is a high long-term equilibrium price for oil of more than $56.38/barrel. When the investment decision can be made at any time, i.e. there is an option value, then the trigger value for optimal investment is significantly higher." **Luis M. Abadie, Ibon Galarraga, and Dirk Rübbelke**, *Environmental Modeling & Software*. (Subscription may be required.)

"Power system planning with emission constraints: Effects of CCS retrofitting." The following is the Abstract of this article: "Today, the world's energy needs are still supplied mainly from fossil fuel based resources. This is true for electricity generation as well, thus making the power sector responsible for 45 [percent] of GHG emissions. The present climate crisis has made it necessary to [minimize] emissions in power generation, with low-carbon energy sources taking on greater significance in recent years. However, most low-carbon sources have inherent problems, like intermittency and high capital expenditure. A suitable alternative is CCS technology which allows continued fossil fuel-based electricity generation at much lower rates of emission. Two approaches are possible in the deployment of CCS technology. The first is to introduce new power plants equipped for CO_2 capture, while systematically shutting down existing coal power plants. Another is to retrofit existing power plants for CO_2 capture. These approaches are compared in this work. The study shows that allowing CCS retrofitting of existing power plants can reduce the overall cost requirement significantly. In addition, a sensitivity analysis is also done to study the effect of nuclear energy on the overall energy mix." **Krishna Priya G.S., Santanu Bandyopadhyay, and Raymond R. Tan**, *Process Safety and Environmental Protection*. (Subscription may be required.)

"Atmospheric measurement techniques to quantify greenhouse gas emissions from cities." The following is the Abstract of this article: "There is growing interest to constrain and validate GHG emission inventories at urban and intra-urban scales. This contribution reviews methods to identify, quantify and attribute emissions (and [storage]) of [CO_2], methane and nitrous oxide in cities using in-situ measurements in the atmosphere. Measurements of GHG mixing ratios and fluxes in cities will allow validation of inventories, identification and quantification of poorly-known sources and accounting for the effects of urban land-cover change. In-situ measurements of GHG emissions (and [storage]) in the urban atmosphere are possible (i) at the micro-scale by capturing GHG plumes of individual sources using mobile platforms and measuring vertical profiles of GHGs in the urban canopy layer, (ii) at the local-scale by direct eddy-covariance flux measurements of GHGs on towers, and, (iii) at the meso-scale by measurements of mixing ratios and isotopologues of GHGs in the urban and rural boundary layer combined with box and inverse models. This paper reviews all approaches and highlights their potential and current limitations. These observational methods combined with models will support future endeavors in fine-scale GHG emission monitoring in cities and allow for validation of upcoming remote-sensing products of urban-scale GHG emissions." **Andreas Christen**, *Urban Climate*. (Subscription may be required.)

"Parametric sensitivity analysis for CO_2 geosequestration." The following is the Abstract of this article: "[Carbon dioxide storage] (CCS) in geological formations appears to be a viable technology for large-scale storage of CO_2 to mitigate the impacts of climate change. Simulations of the [behavior] of [storage] systems using mathematical models play a significant role in risk estimation and consequently in decision-making processes. Uncertainty arises in the application of models because of physical complexities, simplifying assumptions, and parameter variability. A sensitivity analysis comparing the influence of different model parameters on predicted CO_2 plume evolution uncertainty is presented. Both the role of the parameter in the model and the parameter uncertainty are included in the measure of sensitivity to distinguish between parameters with equal influence in the model output but having different degrees of intrinsic uncertainty. The sensitivity of the plume interface location, the maximum

breakthrough distance of CO_2, and the moment of inertia of the CO_2 plume with respect to intrinsic physical system parameters and parameters introduced in constitutive relationships is investigated in a hypothetical site. [Parameters] are used, each with a probability density obtained from measurements of the Nisku Aquifer, targeted for CO_2 injection in Alberta, Canada. [The authors] sensitivity analysis shows that formation porosity, residual brine saturation, and entry capillary pressure are the most influential parameters in the uncertainty of plume evolution. Thus, the influence of constitutive relationship parameters in plume evolution uncertainty is as high as that of the physical characteristics of the system. Simulation outputs where insensitive to CO_2 viscosity and the exponents in the Brooks-Corey model for capillary pressure and relative permeability; therefore, it is possible to reduce the dimensionality of future uncertainty and risk analyses, based on the model presented, by neglecting the uncertainty of these parameters and assuming them to be deterministic. While results are specific to the synthetic problem presented in the article, the methodology is general and applicable to other CO_2 geosequestration sites." **Mirhamed Sarkarfarshi, Farshad A. Malekzadeh, Robert Gracie, and Maurice B. Dusseault**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

July 2014

"Fuzzy optimization of multi-period carbon capture and storage systems with parametric uncertainties." The following is the Abstract of this article: "CCS is an important technology option for reducing industrial [GHG] emissions. In practice, CO_2 sources are easy to characterize, while the estimation of relevant properties of storage sites, such as capacity and injection rate limit (i.e., injectivity), is subject to considerable uncertainty. Such uncertainties need to be accounted for in planning CCS deployment on a large scale for effective use of available storage sites. In particular, the uncertainty introduces technical risks that may result from overestimating the limits of given storage sites. In this work, a fuzzy mixed integer linear program (FMILP) is developed for multi-period CCS systems, accounting for the technical risk arising from uncertainties in estimates of sink parameters, while still attaining satisfactory CO_2 emissions reduction. In the model, sources are assumed to have precisely known CO_2 flow rates and operating lives, while geological sinks are characterized with imprecise fuzzy capacity and injectivity data. Three case studies are then presented to illustrate the model. Results of these examples illustrate the tradeoff inherent in planning CCS systems under parametric uncertainty." **John Frederick D. Tapia and Raymond R. Tan**, *Process Safety and Environmental Protection*. (Subscription may be required.)

"CO_2 [Release] Identification in Geosequestration Based on Real Time Correlation Analysis Between Atmospheric O_2 and CO_2." The following is the Abstract of this article: "The paper describes a method for monitoring CO_2 [release] in geological [CO_2 storage]. A real time monitoring parameter, apparent leakage flux (ALF), is presented to monitor abnormal CO_2 [release], which can be calculated by atmospheric CO_2 and O_2 data. The computation shows that all ALF values are close to zero-line without the [release]. With a step change or linear perturbation of concentration to the initial CO_2 concentration data with no [release], ALF will deviate from background line. Perturbation tests prove that ALF method is sensitive to linear perturbation but insensitive to step change of concentration. An improved method is proposed based on real time analysis of surplus CO_2 concentration in least square regression process, called apparent [release] flux from surplus analysis (ALFs), which is sensitive to both step perturbation and linear perturbations of concentration. ALF is capable of detecting concentration increase when the [release] occurs while ALFs is useful in all periods of [release]. Both ALF and ALFs are potential approaches to monitor CO_2 [release] in geosequestration project." **Denglong MA, Jianqiang DENG, and Zaoxiao ZHANG**, *Chinese Journal of Chemical Engineering*. (Subscription may be required.)

August 2014

"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.)

"Multi-scale experimental study of carbonated water injection: An effective process for mobilization and recovery of trapped oil." The following is the Abstract of this article: "Steady flow of a disconnected gas phase (bubbles) is realized in porous media during carbonated water injection (CWI) under conditions that promote continuous exsolution of the dissolved gas. Using microfluidic pore networks etched on glass as well as a miniature core-flooding setup integrated with micro computed tomography (CT) imaging apparatus, [the authors] demonstrate capillary interactions of the flowing gas bubbles with a previously trapped oil phase (three-phase ganglion dynamics), which lead to mobilization of oil ganglia and remarkably high oil recovery. When three-phase ganglion dynamics are induced by carbonated water injection in low-permeability Berea sandstone core samples containing waterflood residual oil, more than 34 [percent] and 40 [percent] of the original oil in place additional recoveries are achieved in macro- and micro-scale flow tests, respectively, while a significant amount of CO_2 is permanently [stored] in the pore space as capillary-trapped and dissolved gas. It is observed that when oil globules come into contact with CO_2, they form thick spreading layers between brine and gas and are carried by moving gas clusters. The oil layers stay stable until the gas clusters leave the medium. Individual oil and gas blobs captured during micro-CT imaging are statistically analyzed to further examine underlying pore-level displacement physics of the process." **A.H. Alizadeh, M. Khishvand, M.A. Ioannidis, and M. Piri**, *Fuel*. (Subscription may be required.)

“Multi-branched horizontal wells for coalbed methane production: Field performance and well structure analysis.” The following is the Abstract of this article: “Horizontal wells, such as multi-lateral and multi-branched horizontal wells (MBHWs) have been effectively used in the development of coalbed methane (CBM) fields, especially for coal beds with very low permeability and low compressive strength, in which the performance of conventional fracture-stimulated vertical wells is ineffective. In this study, the performance of MBHWs in the Liulin block of the Ordos Basin in central North China is analyzed and compared to that of hydraulically fractured vertical wells. The field pilot data show that the gas production rate of most fractured vertical wells decreased rapidly after a short period of time, far below expectation, while the performance of MBHWs is satisfactory and relatively stable during [three] years of production. A numerical simulation model was established based on the coal reservoir characteristics. The productivities of different well types are predicted and compared to the field data. The poor performance of the fractured vertical wells is thought to be caused by the early closure of the fractures and proppant embedded in the coal matrix or by a poor proppant delivery inside the fractures. The high and stable productivity of the MBHWs is attributed to their large drainage volume and to the stability of the wellbores. Simulation results show that the parameters of a MBHW, such as the branch angle, length, and spacing, can be optimized to maximize its productivity. Though the drilling cost of a MBHW is relatively high in comparison to vertical wells, its high and stable productivity can compensate for the drilling cost. Therefore, MBHWs are thought to be more appropriate than vertical wells for the successful exploitation of the CBM resource potential in the Liulin Block and surrounding area.” **Jianhua Ren, Liang Zhang, Shaoran Ren, Jingde Lin, Shangzhi Meng, Guangjun Ren, and Thomas Gentzis**, *International Journal of Coal Geology*. (Subscription may be required.)

Terrestrial

September 2013

"Glacial deep ocean [storage] of CO_2 driven by the eastern equatorial Pacific biologic pump." The following is the Abstract of this article: "The potential influence of low latitude ocean primary productivity on glacial atmospheric [CO_2] levels has proven challenging to deduce using mass accumulation rates (MARs) of biogenic particulates in deep sea sediment cores. Benthic foraminiferal B/Ca serves as a proxy for past seawater calcite saturation state, and thereby provides a fresh perspective on this outstanding paleoceanographic problem. Here [the authors] employ Cibicidoides wuellerstorfi B/Ca in the Panama Basin region of the eastern equatorial Pacific (EEP) to investigate the nature of deep tropical Pacific carbon storage over the past 50 ka BP. [The authors] present evidence for persistently lower deep Panama Basin calcite saturation state, reflecting an increase in total [CO_2] storage, during the last ice age relative to the Holocene. These results reflect the modification of inflowing deep waters by overlying export productivity, and support the concept of an invigorated glacial EEP soft-tissue pump possibly driven by oceanic nutrient (iron and silica) redistribution. Benthic Cibicidoides spp. carbon-13 is consistent with this conclusion by exhibiting substantially lighter values during glacial time, reflecting the accumulation of metabolic [CO_2] in the deep tropical Pacific. Counterintuitively, downcore application of the Globorotalia menardii calcite fragmentation index (MFI) reveals enhanced glacial sedimentary calcite preservation in the Panama Basin. Together these results point towards a systematic decoupling of bottom water chemistry from biogenic burial fluxes: the crux of the aforementioned traditional paleoproductivity problem." **Whitney Doss and Thomas M. Marchitto**, *Earth and Planetary Science Letters*. (Subscription may be required to view article.)

October 2013

"Development and testing of allometric equations for estimating above-ground biomass of mixed-species environmental plantings." The following is the Abstract of this article: "To quantify the impact that planting indigenous trees and shrubs in mixed communities (environmental plantings) have on net [storage] of carbon and other environmental or commercial benefits, precise and non-biased estimates of biomass are required. Because these plantings consist of several species, estimation of their biomass through allometric relationships is a challenging task. [The authors] explored methods to accurately estimate biomass through harvesting 3139 trees and shrubs from 22 plantings, and collating similar datasets from earlier studies, in non-arid (>300 mm rainfall year−1) regions of southern and eastern Australia. Site-and-species specific allometric equations were developed, as were three types of [generalized], multi-site, allometric equations based on categories of species and growth-habits: (i) species-specific, (ii) genus and growth-habit, and (iii) universal growth-habit irrespective of genus. Biomass was measured at plot level at eight contrasting sites to test the accuracy of prediction of tonnes dry matter of above-ground biomass per hectare using different classes of allometric equations. A finer-scale analysis tested performance of these at an individual-tree level across a wider range of sites. Although the percentage error in prediction could be high at a given site (up to 45 [percent]), it was relatively low (<11 [percent]) when [generalized] allometry-predictions of biomass was used to make regional- or estate-level estimates across a range of sites. Precision, and thus accuracy, increased slightly with the level of specificity of allometry. Inclusion of site-specific factors in generic equations increased efficiency of prediction of above-ground biomass by as much as [eight percent]. Site-and-species-specific equations are the most accurate for site-based predictions. Generic allometric equations developed here, particularly the generic species-specific equations, can be confidently applied to provide regional- or estate-level estimates of above-ground biomass and carbon." **Keryn I. Paul. Stephen H. Roxburgh, Jacqueline R. England, Peter Ritson, Trevor Hobbs, Kim Brooksbank, R. John Raison, John S. Larmour, Simon Murphy, Jaymie Norris, Craig Neumann, Tom Lewis, Justin Johnson, Jenny L. Carter, Geoff McArthur, Craig Barton, and Ben Rose**, *Forest Ecology and Management*. (Subscription may be required to view article.)

November 2013

"Assessment of variability and uncertainty of soil organic carbon in a mountainous boreal forest." The following is the Abstract of this article: "Mountain environments are heterogeneous and dynamic geomorphic environments sensitive to land use and climate change. Heterogenic environmental conditions result in a large variability of mountain soil properties, and thus in large uncertainties of inventories of soil organic carbon (SOC). In this study [the authors] analyzed the variability of soil properties associated with the calculation of a SOC inventory in a mountain environment in the Canadian Rocky Mountains (Alberta). Therefore, [the authors] calculated the analytical uncertainty and spatial variability of SOC stocks using Gaussian error propagation and Taylor series expansion along seventeen 36 m long transects to identify major sources of uncertainty. SOC stocks in the upper 10 cm and 30 cm are 2.4 ± 0.7 kg C m^{-2} and 6.4 ± 5.6 kg C m^{-2}, respectively. The bulk densities generated the largest uncertainty associated with the analytical precision (10.0 percent). However, analytical uncertainties (ranging between 2.3 and 24.2 percent) are much smaller than the uncertainty introduced by the spatial variability, for instance of the coarse fraction (63.8 percent) and SOC concentration (40.1 percent). This study contributes to insufficiently considered analysis of uncertainties in SOC stocks and demonstrate the high potential of nested sampling approaches to identify sources of uncertainties of SOC stocks. To reduce the uncertainties associated with heterogeneous mountain environments, [the authors] propose to apply more sophisticated statistics (e.g. regression analysis considering frequency distributions of measured coarse fractions in different geomorphic environments) rather than simple mean per unit approaches, as frequently applied in regionalization studies of soil properties." **Ulrike Hoffmann, Thomas Hoffmann, E.A. Johnson, and Nikolaus J. Kuhn**, *CATENA*. (Subscription may be required.)

"Buried black soils on the slopes of Mt. Kilimanjaro as a regional carbon storage hotspot." The following is the Abstract of this article: "Mt. Kilimanjaro attracts much scientific and public attention due to its dramatically shrinking ice caps, still known as 'the white top' of Africa. In this mountain system forming a type of island within the surrounding savannah, a new phenomenon has recently been discovered. On the slopes of Mt. Kilimanjaro, Late Quaternary paleosol sequences, composed of dark or black buried soils, are widespread in the montane rainforest zone (1800–3000 m a.s.l.). In this study [the authors] investigated in detail the SOC content and SOC stocks in soil profiles (mostly Andosols) along two altitudinal transects, situated on both the humid southern slopes and on the drier northern slopes of the mountain. In the montane forest zone, up to 3 m thick paleosol sequences are frequently found. SOC content is remarkably high, reaching values of up to more than 10 percent. This testifies to good preservation of soil organic matter (SOM) which may be due to such factors as rapid burial by dust, low temperatures alongside more resistant litter during glacial periods, formation of stable organo-mineral complexes and high black carbon (BC) content. The buried black soils are estimated to contain ~ 82 kg m^{-2} mean SOC stocks in the montane rainforest. As compared to the SOC storage in the surrounding savannah soils of the Maasai Steppe, the buried black soils constitute a distinctive regional carbon storage hotspot." **Michael Zech, Claudia Hörold, Katharina Leiber-Sauheitl, Anna Kühnel, Andreas Hemp, and Wolfgang Zech**, *CATENA*. (Subscription may be required.)

December 2013

"A time series sequestration and storage model of atmospheric carbon dioxide." The following is the Abstract of this article: "One of the main challenges of environment planning is to identify a model that connects all factors that determine the carbon cycle, that is: ocean–terrestrial ecosystem–anthropogenic emissions–atmosphere. Basic principle of mass conservation can be applied in statistical modeling with a historic time series to obtain the atmospheric CO_2 concentration, making it possible to create scenarios that will help in the decision making process. A model that links all carbon cycle factors has been developed this article, focusing on the Boreal, Temperate, Tropical, and Polar thermal climatic zones to calculate atmospheric CO_2 level. It was developed with nonparametric models based on [CO_2] records from measurement stations: EIA (Energy Information Administration), CDIAC (Carbon Dioxide

Information Analysis Center), FAO (Food and Agriculture Organization), and SIO (Scripp Institution Oceanography). The advantage of the model developed here is that it is able to analyze different scenarios, considering both the behavior of particular countries or groups of countries in each thermal zone and their influence on the predicted concentrations of atmospheric CO_2. Results show that in 2100, the atmospheric CO_2 concentration will be four times that of the pre-industrial period..." **G.L.A.F. Arcea, J.A. Carvalho Jra, and L.F.C. Nascimentob**, *Ecological Modelling*. (Subscription may be required.)

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

January 2014

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

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

February 2014

"Carbon dioxide emissions from horizontal sub-surface constructed wetlands in the Mediterranean Basin." The following is the Abstract of this article: "Constructed wetlands (CWs) are widely used natural-like systems for wastewater treatment where organic matter is removed through CO_2 emissions. Several studies have been conducted regarding emissions and the [storage] of CO_2 in CWs in the Northern Hemisphere; however, to the best of [the authors'] knowledge, no studies have been performed in the Mediterranean Basin. This work quantified daily and cumulative CO_2 emissions from a full-scale CW horizontal subsurface flow (HSSF) bed during semiarid Mediterranean spring climate conditions. The average daily CO_2-C that was released in the atmosphere during the first 50 days ranged from approximately 17.5 [percent] to 32.6 [percent] of the C that was removed from wastewater. Considering both the Phragmites australis aerial part dry matter production (0.83 kg m^{-2}) and the average CO_2-C emissions, after 50 days of vegetative regrowth, the HSSF bed was demonstrated to act as a CO_2 sink. The cumulative CO_2 efflux was 452.15 ± 50.40 CO_2 g m^{-2} and 276.02 ± 12.07 CO_2 g m^{-2} for vegetated and unvegetated sites, respectively." **Antonio C. Barbera, Maurizio Borin, Antonio Ioppolo, Guiseppe L. Cirelli, and Carmelo Maucieri**, *Ecological Engineering*. (Subscription may be required.)

"The Arctic Ocean carbon sink." The following is the Abstract of this article: "[The authors] present observation based estimates of the transport of dissolved inorganic carbon (DIC) across the four main Arctic Ocean gateways (Davis Strait, Fram Strait, Barents Sea Opening and Bering Strait). Combining a recently derived velocity field at these boundaries with measurements of DIC, [the authors] calculated a net summertime pan-Arctic export of 231 ± 49 *Tg C* yr^{-1}. On an annual basis, [the authors] estimate that at least 166 ± 60 *Tg C* yr^{-1} of this is due to uptake of CO_2 from the atmosphere, although time-dependent changes in carbon storage are not quantified. To further understand the region's role as a carbon sink, [the authors] calculated the volume-conserved net DIC transport from beneath a prescribed mixed layer depth of 50 m, referred to as 'interior transport', revealing an export of 61 ± 23 *Tg C* yr^{-1}. Applying a carbon framework to infer the sources of interior transport implied that this export is primarily due to the sinking and [remineralization] of organic matter, highlighting the importance of the biological pump. Furthermore, [the authors] qualitatively show that the present day Arctic Ocean is accumulating anthropogenic carbon beneath the mixed layer, imported in Atlantic Wate." **G.A. MacGilchrist, A. Naveira Garabato, T. Tsubouchi, S. Bacon, S. Torres-Valdés, and K. Azetsu-Scott**, *Deep Sea Research Part I: Oceanographic Research Papers*. (Subscription may be required.)

March 2014

"The effects of urea fertilization on carbon [storage] in Douglas-fir plantations of the coastal Pacific Northwest." The following is the Abstract of this article: "If long-term carbon (C) [storage] can be quantifiably attributed to forest plantation nitrogen (N) fertilization, the net C credits could be used to offset the rising cost of fertilization and C released during the production, transportation, and application of N fertilizer and the effect of [nitrogen oxide (NO_X)] volatilized after application. The purpose of [the authors'] study was to determine the net change in C [storage] following N fertilization of second-growth Douglas-fir plantations in the Pacific Northwest. The C content of the trees, understory vegetation, forest floor, and mineral soil was quantified at age 26–33 at five sites, each with a fertilized plot that received a total of 896–1120 kg N ha^{-1} as urea over 16 years paired with an unfertilized control plot. Tree biomass was estimated using biometric equations and by subtracting the difference between treatment and control at the year of site establishment from the difference between treatment and control final measurement. Understory vegetation on the fertilized plots contained significantly more C than on the control plots (0.2 Mg C ha^{-1}, S.D. 0.2). Nitrogen fertilization significantly increased C [stored] per tree by 2.2 Mg C ha^{-1} (S.D. 1.8), but there was no significant increase in C [stored] in trees per plot. No significant change was found in forest floor, A horizon, and subsoil C contents due to fertilization. These results indicate that, while there is a greater amount of C stored per tree after fertilization, there was more difficulty in accessing C [stored] in forest plantations due to tree mortality and assumed soil variability between plots." **Benjamin Shryock, Kim Littke, Marcia Ciol, David Briggs, and Robert Harrison**, *Forest Ecology and Management*. (Subscription may be required to view article.)

April 2014

"Australia's Soil Carbon Baseline Mapped." CSIRO created a new map of Australia's stored soil carbon to provide a benchmark for Australia to track future changes in soil carbon storage. The map provides soil organic carbon stocks to a depth of 30 centimeters at a national scale. CSIRO used three datasets, including CSIRO's National Soil and Spectral databases and the national Soil Carbon Research Program. The average amount of soil organic carbon in the top 30 centimeters of Australian soil was estimated at 29.7 metric tons (or "tonnes") per hectare and the total stock for Australia at 25.0 Gigatonnes with a 95 percent confidence within the range of 19.0 to 31.8 Gigatonnes. According to a CSIRO official, the maps could be used to set a baseline for national soil carbon stocks; help design national soil monitoring networks; guide future soil sampling to improve estimates of soil carbon stocks; help assess the potential of the soil to store carbon; improve terrestrial carbon budgeting; and/or assist with strategies to mitigate and adapt to the effects of a changing climate. From *Spatial Source* on March 18, 2014.

"Identifying soil organic carbon fractions sensitive to agricultural management practices." The following is the Abstract of this article: "Agricultural management practices play a major role in the process of (soil organic carbon [SOC] storage). However, the large background of stable carbon (C) already present in the soil and the long period of time usually required to observe changes in SOC stocks have increased the necessity to identify soil C fractions with a fast response to changes in agricultural management practices. Consequently, [the authors] quantified the response of total SOC, permanganate oxidizable organic carbon (POxC), particulate organic carbon (POC) and the carbon concentration of water-stable macroaggregates, microaggregates within macroaggregates and the silt-plus clay-sized fraction (M-C, mM-C, s+cM-C, respectively) to changes in management. [The authors] chose a long-term tillage and N fertilization field experiment (18 years) located in NE Spain. In the first 5 cm depth under no-tillage (NT) compared with conventional tillage (CT), the POxC fraction and total SOC increased similarly (about 59 [percent]). However, other C pools studied (i.e., M-C, M-POxC, mM-C, POC and s+cM-C) had lower increases with values ranging from 17 [percent] to 31 [percent]. For the 5–20 and 20–40 cm soil depths, the POC was the most sensitive fraction to tillage with 46 [percent] and 54 [percent] decrease when NT was compared to CT, respectively. Likewise, the POC fraction presented the highest response to N fertilization in the three depths studied (i.e., 0–5, 5–20 and 20–40 cm). The mM-C and s+cM-C fractions presented the lowest sensitivity to changes in tillage and N fertilization management. [The authors'] results showed that the POC fraction had the greatest sensitivity to changes in agricultural management practices, proving its ability as an early indicator of optimized practices to [store] C in soil." **Daniel Plaza-Bonilla, Jorge Álvaro-Fuentes, and Carlos Cantero-Martínez**, *Soil and Tillage Research*. (Subscription may be required.)

"Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years." The following is the Abstract of this article: "Although numerous studies have been conducted on the effect of tillage on soil organic carbon (SOC), there is still no consensus on the importance of [storage] which can be expected from reduced tillage. Most studies have used a synchronic approach in fields or long-term experiments which were often poorly characterized with respect to initial conditions. In this paper, [the authors] used a diachronic approach to quantify SOC changes in a 41 years experiment comparing no-till (NT), shallow till (ST) and full inversion tillage (FIT) combined with crop managements (residues removal, rotation and catch crops). It included SOC measurements at time 0 and every 4 years, calculations at equivalent soil mass within or below the old ploughed layer. Results show that tillage or crop management had no significant effect on SOC stocks after 41 years both in the old ploughed layer (ca. 0-28 cm) and deeper (ca. 0-58 cm). Tillage had no effect on crop yields and residues. In the reduced tillage treatments (ST and NT), SOC accumulated in the surface layer (0-10 cm), reaching a plateau after 24 years but declined continuously in the lower layer (10-28 cm) at a rate of 0.42-0.44 [percent] yr^{-1}. The difference in SOC stocks (ST or NT minus FIT) over the old ploughed layer followed a non-monotonic pattern over time. Reduced tillage caused a rapid SOC [storage] during the first 4 years which remained more or less constant (mean = 2.17 and 1.31 t ha^{-1}, resp.) during the next 24 years and disappeared after 28 years. The drop was attributed to the higher water balance recorded during years 24-28. In the reduced tillage treatments, the changes in SOC over time were negatively correlated with the water balance, indicating that [storage] rate was positive in dry periods and negative in wet conditions. This study highlights the interest of diachronic approaches to understand the effect of tillage and its interaction with environmental and management factors." **Bassem Dimassi, Bruno Mary, Richard Wylleman, Jerome Labreuche, Daniel Couture, Francois Piraux, and Jean-Pierre Cohan**, *Agriculture, Ecosystems & Environment*. (Subscription may be required.)

May 2014

"Pyrogenic carbon stocks and storage mechanisms in podzolic soils of fire-affected Quebec black spruce forests." The following is the Abstract of this article: "Wildfire, a recurrent disturbance in the boreal, converts part of the forest floor into pyrogenic carbon (PyC). The latter is an important component of the global soil carbon pool, yet knowledge of its stocks and storage mechanisms in these boreal ecosystems is scarce. Podzolization processes, which are frequent under boreal vegetation, result in distinctive patterns of soil organic carbon (SOC) accumulation in the mineral subsoil; how this may affect PyC storage remains largely unknown. The objectives of this study were to estimate SOC and PyC stocks in podzolic soils from fire-affected black spruce forests, and to explore the storage mechanisms taking place in their mineral horizons. [The authors] also compared PyC stocks in mineral soils to forest floor stocks. Samples were collected from 23 soil profiles under black spruce forests located throughout the province of Quebec. To further explore the relationship between podzolization and PyC storage mechanisms, [the authors] measured SOC and PyC contents in size and density fractions of a subset of 11 podzolic B horizons. Total SOC stocks in the mineral horizons and forest floors were comparable. Pyrogenic carbon stocks in the mineral soils, estimated by a H_2O_2/dilute HNO_3 digestion, averaged 0.2 (± 0.1) kg C m^{-2}. This was significantly lower than forest floor stocks, which ranged from 0.2 to 1.2 kg C m^{-2}. Consequently, PyC constituted a smaller fraction of total SOC (2–15 [percent]) in mineral soils than in forest floors, where it was as high as 68 [percent] (± 5) in some horizons. In the mineral soils, SOC and PyC concentrations were strongly correlated. While some PyC was found in unprotected particulate organic matter (POM), the rest was associated with organo-mineral and organo-metallic complexes in the micro-aggregate protected POM and fine fraction. Patterns of PyC accumulation in mineral soils were similar to SOC, and the greater PyC stocks were found in podzolic B horizons." **Laure N. Soucémarianadin, Sylvie A. Quideau, and M. Derek MacKenzie**, *Geoderma*. (Subscription may be required.)

"Soil carbon stock and accumulation in young mangrove forests." The following is the Abstract of this article: "Mangrove reforestation and afforestation programs have been initiated in many countries recently to compensate for historical losses. At the same time, awareness of the high carbon (C) sink potential of mangrove forests is growing, and C [storage] is beginning to be considered among forestation goals. To assess whether and at what rate C accumulates in the soil of young mangrove forests following afforestation, [the authors] conducted a field study at an afforestation project in southeast China, including repeated measures taken over six years at two young forests (consisting of Kandelia obovata and Sonneratia apetala, aged 0–6 years old), and also a chronosequence of forests aged 0 (mudflat), 6 (both species), 20 (S. apetala), and 70 (K. obovata) years old. In the repeated measures, surface (0–10 cm) soil C concentration ([percent] C of dry soil mass) increased significantly over six years, from 1.14 [percent] to 1.52 [percent] (K. obovata) and 1.23 [percent] to 1.68 [percent] (S. apetala). The rates of increase did not differ significantly between the two species, despite much greater biomass of S. apetala. In the chronosequence, soil C also increased with age across sites, but only the 70-year-old forest was statistically different, suggesting that localized environmental differences may obscure age-related patterns in soil C. At all sites, soil C concentration for 1-m soil depth (0.62 [percent] –2.43 [percent]) was low compared to published global averages, yet the estimated soil C accumulation rate (155 g C m^{-2} y^{-1}) was comparable to published averages for mature forests. [The authors] supported this field study with a literature review of similar studies containing soil C concentration data from young mangrove forests: data compiled from 15 studies, comprising 31 sites, showed consistent, positive changes in soil C concentration with forest age, even in the youngest (<5 years old) forests, supporting [the authors'] field observation that soil C increases over time following mangrove afforestation." **Abby Lunstrum and Luzhen Chen**, *Soil Biology and Biochemistry*. (Subscription may be required.)

June 2014

"Soil carbon stocks and forests biomass following conversion of pasture to broadleaf and conifer plantations in southeastern Brazil." The following is the Abstract of this article: "Increased soil carbon [storage] can potentially mitigate CO_2 emission and can indicate sustainable forest management. This study aims to determine the relative influence of commercial plantation tree species on soil carbon following establishment on former tropical pastures. Soil carbon (organic horizon plus mineral soil from 0 to 45 cm) and stemwood productivity were quantified from 6 to 34 year-old conifer and broadleaf plantations in a sandy Oxisol (Typic Hapludox) in southeastern Brazil. Study plots consisted of [10] pastures paired with broadleaf plantations and [10] additional broadleaf plantations paired with conifer plantations. Pastures primarily consisted of *Brachiaria decumbens Stapf.*, while broadleaf plantations were primarily *Eucalyptus*, but also included one plot each of three other broadleaf species. Conifer stands were made up of *Pinus* species. Average stemwood productivity (± standard error) was 9.7 (±1.0) Mg C ha^{-1} yr^{-1} for broadleaf and 5.7 (±0.5) Mg C ha^{-1} yr^{-1} for conifer plantations, but did not correlate to soil C. The soil C in the paired Pasture–Broadleaf plots averaged 36.0 ± 1.7 Mg C ha^{-1} in pastures and 36.8 ± 1.9 Mg C ha^{-1} in broadleaf plantations. The Broadleaf–Conifer plots averaged 38.3 ± 1.9 Mg C ha^{-1} for broadleaf plantations and 36.0 ± 1.6 Mg C ha^{-1} for conifers. [The authors'] results show little difference in soil C across vegetation types, providing evidence that conifer and broadleaf plantations overall maintain similar levels of soil carbon to pasture land-use up to 34 years following land conversion. Soil C differences between Pasture–Broadleaf pairs indicated a small decline in soil C accretion early after plantation establishment, followed by recovery to slightly higher accretion rates." **Rachel L. Cook, Dan Binkley, João Carlos T. Mendes, and Jose Luiz Stape**, *Forest Ecology and Management*. (Subscription may be required.)

"Assessing carbon storage and [storage] by Canada's urban forests using high resolution earth observation data." The following is the Abstract of this article: "[Trees] are important components of the landscape and offer numerous benefits; both socio-economical and biophysical. Urban trees act as a sink for CO_2, helping to offset carbon emissions from urban areas by removing the GHG from the atmosphere through photosynthesis. Environment Canada develops estimates of Canada's [GHG] emissions and removals which are submitted annually to the United Nations as part of ongoing commitments under the United Nations Framework Convention for Climate Change. As part of these reporting commitments countries are required to develop estimates of emissions and removals of [GHG] that are the result of direct impact of human activities in the Land-Use, Land-Use Change and Forestry Sector. Here, [the authors] present an approach which involves sampling high resolution aerial photographs to determine urban tree coverage across Canada's major urban areas. [The author's] results suggest Canadian urban areas have an estimated tree canopy cover of 27 [percent]. This tree cover is estimated to store approximately 34,000 kt C and annually [store] approximately 2,500 kilotons of CO_2. These estimates show significant improvement over previous methods used to provide Canadian estimates. The methods developed here are easily repeatable which allow for temporal changes to be analyzed and assessed over time." **Jon Pasher, Mark Mcgovern, Michael Khoury, and Jason Duffe**, *Urban Forestry & Urban Greening*. (Subscription may be required.)

July 2014

"Carbon and nitrogen [storage] in soils under different management in the semi-arid Pampa (Argentina)." The following is the Abstract of this article: "Soil management affects distribution and the stocks of soil organic carbon and total nitrogen. The aim of this study was to evaluate the effect of different crop sequences and tillage systems on the vertical distribution and stocks of soil carbon and nitrogen. [The authors] hypothesized that no-tillage promotes surface organic carbon and total nitrogen accumulation, but does not affect the C and N stocks, when compared with reduced tillage. In addition, the incorporation of maize in the crop sequence increases total organic carbon and total nitrogen stocks. Observations were carried out in 2010 in an experiment located in the semiarid Argentine Pampa, on an

Entic Haplustoll. A combination of three tillage systems (no tillage, no tillage with cover crop in winter and reduced tillage) and two crop sequences (soybean–maize and soybean monoculture) were assessed. After 15 years of management treatments, soil samples to a depth of 100 cm at seven intervals, were taken and analyzed for bulk density, organic carbon and total nitrogen. Total organic carbon stock up to a depth of 100 cm showed significant differences between soils under different tillage systems (reduced tillage < no tillage = no tillage with cover crop), the last ones having [eight percent] more than the reduced tillage treatment. Soybean–maize had [three percent] more organic C up to 100 cm depth than the soybean monoculture. Total nitrogen stock was higher under no-till treatments than under reduced tillage, both at 0–50 and 0–100 cm depths. Total organic carbon stratification ratios (0–5 cm/5–10 cm) were around 1.6 under no-till and lower under reduced tillage. The stratification ratio explains less than 40 [percent] of soil carbon stock. Tillage system had a greater impact on soil carbon stock than crop sequence." **Carolina Alvarez, Carina R. Alvarez, Alejandro Costantini, and María Basanta**, *Soil and Tillage Research*. (Subscription may be required.)

"Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada." The following is the Abstract of this article: "Agroforestry land-use systems have significant potential for increasing soil carbon (C) storage and mitigating increases in atmospheric GHG concentrations. [The authors] studied the impact of three agroforestry systems (hedgerow, shelterbelt, and silvopasture) on soil organic C (SOC) and nitrogen (N) in the 0–10 cm mineral layer, by comparing SOC and N distributions in whole soils and three particle-size fractions (<53, 53–250, 250–2000 μm) to assess the potential role of physical protection on soil C and N storage. [The authors] assessed [35] sites (12 hedgerows, 11 shelterbelts and 12 silvopastures), each comprised of 2 paired plots (forest and adjacent agricultural herbland), that were distributed along a 270 km long north–south soil/climate gradient in central Alberta, Canada. Across all sites, 48.4 [percent], 28.5 [percent], and 23.1 [percent] of SOC was found in the fine (<53 μm), medium (53–250 μm) and coarse fractions (250–2000 μm), respectively. Mean SOC in the whole soil was 62.5, 47.7 and 81.3 g kg^{-1} in hedgerow, shelterbelt and silvopasture systems, respectively. Soil C in the more stable fine fraction was 34.3, 28.8 and 29.3 g kg^{-1} in the hedgerow, shelterbelt and silvopasture systems, respectively. Within each agroforestry system, the forested land-use consistently had greater total SOC and SOC in all size fractions than the agricultural component. [The authors'] results demonstrate the potential for trees to increase soil C [storage] in agroforestry systems within the agricultural landscape." **Mark Baah-Acheamfour, Cameron N. Carlyle. Edward W. Bork, Scott X. Chang**, *Forest Ecology and Management*. (Subscription may be required.)

August 2014

"Calculating carbon mass balance from unsaturated soil columns treated with $CaSO_4$-minerals: Test of soil carbon [storage]." The following is the Abstract of this article: "Renewed interest in managing C balance in soils is motivated by increasing atmospheric concentrations of CO_2 and consequent climate change. Here, experiments were conducted in soil columns to determine C mass balances with and without addition of $CaSO_4$-minerals (anhydrite and gypsum), which were hypothesized to promote soil organic carbon (SOC) retention and soil inorganic carbon (SIC) precipitation as calcite under slightly alkaline conditions. Changes in C contents in three phases (gas, liquid and solid) were measured in unsaturated soil columns tested for one year and comprehensive C mass balances were determined. The tested soil columns had no C inputs, and only C utilization by microbial activity and C transformations were assumed in the C chemistry. The measurements showed that changes in C inventories occurred through two processes, SOC loss and SIC gain. However, the measured SOC losses in the treated columns were lower than their corresponding control columns, indicating that the amendments promoted SOC retention. The SOC losses resulted mostly from microbial respiration and loss of CO_2 to the atmosphere rather than from chemical leaching. Microbial oxidation of SOC appears to have been suppressed by increased Ca^{2+} and SO_4^{2-} from dissolution of $CaSO_4$ minerals. For the conditions tested, SIC accumulation per m^2 soil area under $CaSO_4$-treatment ranged from 130 to 260 g C m^{-1} infiltrated water (20–120 g C m^{-1} infiltrated water as net C benefit). These results demonstrate the potential for increasing C [storage] in slightly alkaline soils via $CaSO_4$-treatment." **Young-Soo Han and Tetsu K. Tokunaga**, *Chemosphere*. (Subscription may be required.)

Trading

September 2013

"21st Auction Marks Five Years of Success for RGGI." The nine Northeastern and Mid-Atlantic states participating in RGGI announced the results of their 21st auction of CO_2 allowances. The auction marked five years since the launch of the RGGI auctions in 2008. All of the 38,409,043 CO_2 allowances offered were sold at a clearing price of $2.67; bids ranged from $1.98 to $12.85 per allowance. The auction generated $102.5 million for reinvestment by the RGGI states in a variety of consumer-benefit initiatives, such as energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. To date, RGGI auctions have generated a total of $1.4 billion. According to the independent market monitor's report, 84 percent of CO_2 allowances sold in RGGI auctions have been awarded to electricity generators and their corporate affiliates. The next RGGI auction is scheduled for December 4, 2013.

October 2013

"Air Resources Board Prepares to Issue First Carbon Offset Credits." The California Air Resources Board (CARB) announced that it will issue the first compliance offset credits eligible for use in the state's cap-and-trade GHG emissions reduction program. Each credit, issued for GHG emission reductions that take place in sectors not covered under California's cap-and-trade program, represents one metric ton of CO_2. Facilities covered under the program may use the carbon offsets to cover up to eight percent of their compliance obligation. A total of 600,000 credits are expected to be issued. More information on the Compliance Offset Program is available on the CARB website. From *California Air Resources Board News Release* on September 17, 2013.

"California and Quebec Sign Agreement to Integrate, Harmonize Their Cap-and-Trade Programs." Representatives from CARB and Quebec's Minister of International Relations signed an agreement to fully integrate their respective cap-and-trade programs. The linkage, which will enable carbon allowances and offset credits to be exchanged between participants in both jurisdictions' programs, is set to begin on January 1, 2014. The California EPA is expected to release a report in November detailing the progress toward linking. For more information on the linkage, including both English and French versions of the "Agreement between the California Air Resources Board and the Government of Quebec Concerning the Harmonization and Integration of Cap-and-Trade Programs for Reducing Greenhouse Gas Emissions," visit the CARB website. From the *California Air Resources Board News Release* on October 1, 2013.

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

projects. Violation analyses are also conducted to demonstrate that different violation levels for model's objective and constraints have different effects on system benefit and satisfaction degree as well as emission trading and clean-energy development." **Y.P. Li, G.H. Huang, and M.W. Li**, *Renewable Energy*. (Subscription may be required.)

November 2013

"Costa Rica's Carbon Market is Open for Business." On October 17, Costa Rica opened "BANCO2," an environmental bank that will trade and verify carbon credits. Part of a series of Costa Rican government programs and investments to reach its goal of carbon neutrality by 2012, BANCO2 will provide commercialization and brokerage services for CO_2 credits, as well as promote, monitor, report, and verify CO_2 mitigation and reduction projects. From *Tico Times* on October 18, 2013.

"Three U.S. States, British Columbia to Ink Climate Pact." California officials will reportedly sign an agreement to formally align the state's climate and clean energy policies with those of Oregon, Washington state, and the Canadian province of British Columbia. The four are members of the Pacific Coast Collaborative, formed in 2008 as a forum to share ideas on climate policies. From *Reuters* on October 24, 2013.

"Mexico's Exchange to Launch Platform for Carbon Trading." Mexico's stock exchange announced it will launch an electronic platform to trade carbon credits. The mechanism, called MEXICO2, is expected to offer different types of carbon credits to companies willing to offset emissions traded in an over-the-counter market. The platform will trade United Nations-certified emissions reduction (CER) units, as well as credits from voluntary markets. From *Trust.org* on November 8, 2013.

"RFID-enabled carbon offsetting and trading." The following is the Abstract of this article: "This paper presents a novel approach to carbon credit trading with pervasive computing technologies, particularly RFID (or barcode) technology. It introduces RFID tags as certificates for the rights to claim carbon credits in carbon offsetting and trading. It enables buyers, including end-consumers, which buy products with carbon credits to hold and claim these credits unlike existing carbon offsetting schemes. It also supports the simple intuitive trading of carbon credits by trading RFID tags coupled to the credits. The approach was constructed and evaluated with real customers and real carbon credits in a real supply chain. It can also be used to encourage industries and homes to reduce [GHG] emissions." **Ichiro Satoh**, *Pervasive and Mobile Computing*. (Subscription may be required.)

"International carbon emissions trading and strategic incentives to subsidize green energy." The following is the Abstract of this article: "[The authors] examine strategic incentives to subsidize green energy in a group of countries that operates an international carbon emissions trading scheme. In [the authors'] model, green subsidies of either sign on top of emissions cap regulation reduce the welfare of the group of countries, but this may not hold for individual countries. The cases of small and large countries turn out to exhibit significant differences. While small countries refrain from subsidizing green energy and thus implement the efficient allocation, large permit-importing countries may subsidize green energy in order to influence the permit price in their favor." **Thomas Eichner and Rüdiger Pethig**, *Resource and Energy Economics*. (Subscription may be required.)

"Climate game analyses for CO_2 emission trading among various world organizations." The following is the Abstract of this article: "This paper simulates the saving in terms of the total abatement cost of CO_2 emission reductions for different trading games reflecting the potential cooperation among organizations including the European Union (EU), the Asia-Pacific Economic Cooperation (APEC) countries, the Union of South American Nations (USAN), and the Indian Ocean Rim Association for Regional Cooperation (IOR-ARC). A game approach is conducted to determine if the cooperation will come into existence among the organizations stated above. A similar idea is applied to the four largest emission countries, China, the United States, Russia, and India, as four individual players in the trading

game." **Pei-Ing Wu, Chai Tzu Chen, Pei-Ching Cheng, and Je-Liang Liou**, *Economic Modelling*. (Subscription may be required.)

December 2013

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

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

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

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

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

January 2014

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

"Guangdong Launches World's Second Largest Carbon Market." China's Guangdong province launched a carbon trading scheme, with carbon allowances selling at approximately $9.58. According to analysts, the first auction saw 28 companies buy 3 million metric tons of allowances for $9.58 per metric ton. On the first day of exchange, approximately 120,000 metric tons of allowances were sold, each priced in the range of $9.84 to $10. More than 200 companies from the power, cement, iron, and steel sectors are required to participate in Guangdong's pilot project, which is part of a wider pilot being rolled out across China over the next two years. Shanghai and Beijing began carbon trading in November 2013; other schemes are expected to follow in 2014 in Tianjin, Chongqing, and the province of Hubei. According to China's National Development and Reform Commission, Guangdong's carbon trading scheme will allow the province to meet an emissions intensity reduction target of 19.5 percent from 2010 to 2015. From *BusinessGreen* on December 23, 2013.

"Introducing carbon taxes in South Africa." The following is the Abstract of this article: "South Africa is considering introducing a carbon tax to reduce [GHG] emissions. Following a discussion of the motivations for considering a carbon tax, [the authors] evaluate potential impacts using a dynamic economy wide model linked to an energy sector model including a detailed evaluation of border carbon adjustments. Results indicate that a phased-in carbon tax of US$30 per ton of CO_2 can achieve national

emissions reductions targets set for 2025. Relative to a baseline with free disposal of CO_2, constant world prices and no change in trading partner behavior, the preferred tax scenario reduces national welfare and employment by about 1.2 and 0.6 percent, respectively. However, if trading partners unilaterally impose a carbon consumption tax on South African exports, then welfare/employment losses exceed those from a domestic carbon tax. South Africa can lessen welfare/employment losses by introducing its own border carbon adjustments. The mode for recycling carbon tax revenues strongly influences distributional outcomes, with tradeoffs between growth and equity." **Theresa Altona, Channing Arndtb, Rob Daviesa, Faaiqa Hartleya, Konstantin Makrelova, James Thurlowc, and Dumebi Ubogua**, *Applied Energy*. (Subscription may be required.)

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

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

February 2014

"KRX to Launch Carbon Trading Market in 2015." Korea's stock market operator, the Korean Exchange (KRX), announced it was designated as the sole operator of the country's carbon trading market, set to begin in 2015. KRX will adopt systems for emissions trading that are similar to current stock market trading schemes. Under the cap-and-trade scheme, local Korean companies would be allowed to either buy rights to emit more carbon, or, if they can successfully reduce their GHG emissions, sell their emissions rights on the trading platform. Free permits will be allotted to companies by the

Korean government through 2017; however, the portion of paid permits will be raised to three percent from 2018 to 2020, and to more than 10 percent from 2021 to 2025. Companies that emit at least 125,000 tons of GHGs per year will be affected by the regulations, as will individual plants that emit at least 25,000 tons of GHGs per year. KRX expects approximately 500 companies to join the carbon trading market. From *Global Post* on January 15, 2014.

"Climate game analyses for CO_2 emission trading among various world organizations." The following is the Abstract of this article: "This paper simulates the saving in terms of the total abatement cost of CO_2 emission reductions for different trading games reflecting the potential cooperation among organizations including the EU, the Asia-Pacific Economic Cooperation (APEC) countries, the Union of South American Nations (USAN), and the Indian Ocean Rim Association for Regional Cooperation (IOR-ARC). A game approach is conducted to determine if the cooperation will come into existence among the organizations stated above. A similar idea is applied to the four largest emission countries, China, the United States, Russia, and India, as four individual players in the trading game. Joining the market is the strictly dominant strategy for any organization from the results. The Nash equilibrium shows that, regardless of the organizations that have already existed in the market, joining the market is always the best policy for the remaining organizations which are currently not in the market. Similarly, India likes the organization to which it belongs, i.e. IOR-ARC, to trade with the EU and APEC, and the [United States] wants the organization to which it belongs, i.e., APEC, to cooperate with the organizations USAN and IOR-ARC. However, China and Russia prefer trading with other countries within their own organizations." **Pei-Ing Wu, Chai Tzu Chen, Pei-Ching Cheng, and Je-Liang Liou**, *Economic Modelling*. (Subscription may be required.)

"The European Union Emission Trading System and technological change: The case of the Italian pulp and paper industry." The following is the Abstract of this article: "[The authors] evaluate the contribution of technological change in reducing CO_2 emissions in the Italian pulp and paper industry during the first and second phases of application of the European Union Emission Trading System (EU-ETS). [The authors] decompose the variation in emission and emission intensity into three different types of effects: a composition effect, a technique effect and a scale effect. The composition effect measures the change in emissions and emissions intensity due to a shift in production towards products that cause less emissions. The technique effect measures the change per each type of product, thereby accounting for technology improvements in the production of each type of good produced. The scale effect singles out the reduction in total emission due to an overall reduction in output. [The authors] show that the first phase of the application of EU-ETS has led to a reduction in both emissions and emission intensity due to the composition effect. The technological change has had a limited negative impact on emissions in the first phase, while in the second phase there has been limited technology improvement in the industry. However, the figures of the scale effect show that the larger reduction in emission is due to the overall decrease in output." **Fulvio Fontini and Giulia Pavan**, *Energy Policy*. (Subscription may be required.)

"Enforcement and price controls in emissions trading." The following is the Abstract of this article: "This paper examines how enforcement affects the structure and performance of emissions trading programs with price controls under uncertainty about firms' abatement costs. The analysis highlights how an enforcement strategy can cause abatement-cost risk to be transmitted to enforcement costs via the price of permits. When this occurs, accommodating the effect of abatement-cost risk with an optimal policy results in higher expected emissions and lower expected permit price than their second-best optimal values. However, it is possible to design an enforcement strategy that shields enforcement costs from abatement-cost risk by tying sanctions directly to permit prices. This enforcement strategy stabilizes enforcement effort, the optimal permit supply and price controls are independent of enforcement costs, and the policy produces the second-best optimal outcome." **John K. Stranlund and L. Joe Moffitt**, *Journal of Environmental Economics and Management*. (Subscription may be required.)

March 2014

"CO_2 Allowances Sold at $4.00 at 23rd RGGI Auction." The states participating in RGGI announced that 23,491,350 CO_2 allowances were sold at the 23rd auction of CO_2 allowances a clearing price of $4.00. Allowances sold include the 18,491,350 allowances offered for sale by the nine participating states and all of the 5,000,000 allocation year 2014 cost containment reserve (CCR) allowances. Bids for the CO_2 allowances ranged from $2.00 to $11.85 per allowance. The CCR is a fixed additional supply of allowances that are available for sale only if CO_2 allowance prices exceed certain price levels. There are no more CCR allowances available for sale in 2014. According to an independent market monitor's report, electricity generators and their corporate affiliates have won 78 percent of CO_2 allowances sold in RGGI auctions since 2008. The auction generated $93.96 million for reinvestment in a variety of consumer benefit initiatives, including energy efficiency, renewable energy, direct bill assistance, and GHG abatement programs. Cumulative proceeds from all RGGI CO_2 allowance auctions currently total more than $1.6 billion dollars. From *RGGI News Release* on March 7, 2014.

"Qingdao City Next In Line to Set Up Emissions Market in China." Advisors are negotiating rules for an emissions trading scheme in Qingdao, a Chinese city of 3 million people in the northeastern Shandong province. Qingdao plans to institute CO_2 caps on up to 300 companies and launch a market for trading CO_2 permits by 2015, with a target of reducing CO_2 emissions per unit of GDP to 19 to 20 percent below 2010 levels by 2015. From *Reuters* on February 18, 2014.

"Another $329.7 Million Spent on California Carbon Permits." California state officials announced that the state's most recent carbon permit auction, the sixth state-run auction since the cap-and-trade market system began in 2012, raised $329.7 million. Allowances that can be used in 2014 sold for $11.34 per ton, while future permits that can be used in 2017 sold for $11.38. Since the program began, California firms have spent a total of $1.54 billion for the right to emit GHGs, according to the California Air Resources Board (CARB). From *The Sacramento Bee* on February 24, 2014.

April 2014

"Second Control Period Interim Adjustment for Banked Allowances Announcement." The nine Northeast and Mid-Atlantic states participating in RGGI conducted a comprehensive 2012 program review and released an updated Model Rule. Each state, in accordance with their independent legal authority, has revised its CO_2 Budget Trading Program in order to be substantially consistent with the updated Model Rule. The updated Model Rule contains language to address the private bank of allowances through two distinct interim budget adjustments. The First Control Period Interim Adjustment for Banked Allowances, made over the seven-year period of 2014 to 2020, is a reduction to the CO_2 allowance base budget equivalent to the private bank of first control period allowances (allocation year 2009, 2010, and 2011). The Second Control Period Interim Adjustment for Banked Allowances, made over the six-year period of 2015 to 2020, is a reduction to the CO_2 allowance base budget equivalent to the private bank of 2012 and 2013 allocation year CO_2 allowances that are in addition to the total quantity of 2012 and 2013 CO_2 emissions. From *RGGI News Release* on March 17, 2014.

"What makes carbon traders cluster their orders?" The following is the Abstract of this article: "The ability to trade large amounts of assets at low costs could be hindered when the size of the orders is concentrated at specific trade sizes. This paper documents evidence of size clustering behavior in the European Carbon Futures Market and analyzes the circumstances under which it happens. [The authors'] findings show that carbon trades are concentrated in sizes of one to five contracts and in multiples of five. [The authors] have also demonstrated that more clustered prices have more clustered sizes, suggesting that price and size resolution in the European Carbon Market are complementary and that carbon traders round both the price and the size of their orders. Finally, the analysis of the key determinants of the size clustering reveals that traders use a reduced number of different trade sizes

when uncertainty is high, market liquidity is poor, and the desire to open new positions and cancel old ones is strong." **Fernando Palaoa and Ángel Pardo**, *Energy Economics*. (Subscription may be required.)

"The construction of Shenzhen's carbon emission trading scheme." The following is the Abstract of this article: "The Shenzhen [emission trading scheme (ETS)] is the first urban-level 'cap-and-trade' carbon emissions trading scheme to operate in China. This paper gives an overview of the economic and emissions situation in Shenzhen and focuses on the development of the Shenzhen ETS regulatory framework. It is devised as an ETS with an intensity-based cap, output-based allocation and a market for trading of allowances. The design of the Shenzhen ETS attaches great importance to coordinate the dynamic relationships between economic growth, industrial transition and emissions control. The cap and its allocation are determined by carbon intensity reduction targets and economic output, with an aim to slow down emissions growth while mitigating shocks from economic fluctuation and industrial adjustment to market stability. The Shenzhen ETS features extensive coverage consisting of three types of regulated entities and four categories of covered emissions, in order to control carbon emissions by both improving energy efficiency and restraining growing energy demand. A competitive game theory method is created for allocation of free allowances to manufacturing enterprises. Mechanisms for carbon offsets and market stabilization are developed to promote active and orderly trading in the carbon market. Moreover, several challenges and their policy choices are detailed for the development of the Shenzhen ETS." **Jing Jing Jianga, Bin Yeb, and Xiao Ming Maa**, *Energy Policy*. (Subscription may be required.)

"A Microstructure Analysis of the Carbon Finance Market." The following is the Abstract of this article: "The European Union Emissions Trading Scheme is the key policy instrument of the European Commission's Climate Change Program aimed at reducing greenhouse gas emissions to eight percent below 1990 levels by 2012. The key asset traded under the scheme is the European Union allowance (EUA). This article examines ultra-high frequency data to assess the extent of the development in the futures market of the EU Emissions Trading Scheme. [The authors'] results indicate significant developments consistent with sequential information arrival. They also indicate a negative contemporaneous relationship between volume and volatility for all contracts. The implication is that liquidity traders dominate any role played by informed traders. Incorporating the duration between trades in [the authors'] analysis has significant impact suggesting that any empirical investigation of the intra-day volume-volatility relationship needs to actively account for the impact of time elapse between trades." **Don Bredina, Stuart Hydeb, and Cal Muckleya**, *International Review of Financial Analysis*. (Subscription may be required.)

May 2014

"Gov. Inslee Announces Executive Action to Reduce Carbon and Promote Clean Energy." Washington State's Governor signed an executive order that outlines a series of steps to reduce carbon emissions in Washington State and advance development and use of clean energy technologies. Instead of implementing new programs, the executive order builds upon earlier studies and work groups to create an action plan in six key areas: reducing carbon emissions through a new cap-and-trade program; ending the use of electricity generated by coal; developing clean transportation options and cleaner fuels; accelerating development and deployment of clean energy technology; improving the energy efficiency of offices and homes; and reducing the state government's carbon footprint. More information on the executive order is available via a policy brief. From *Washington Governor Jay Inslee News Release* on April 29, 2014.

"Reducing energy consumption and CO_2 emissions by energy efficiency measures and international trading: A bottom-up modeling for the U.S. iron and steel sector." The following is the Abstract of this article: "Using the [Industry Sector Energy Efficiency Modeling (ISEEM)] modeling framework, [the authors] analyzed the roles of energy efficiency measures, steel commodity and international carbon trading in achieving specific CO_2 emission reduction targets in the U.S iron and steel sector from 2010 to 2050. [The authors] modeled how steel demand is balanced under three alternative emission reduction scenarios designed to include national energy efficiency measures, commodity trading, and international carbon trading as key instruments to meet a particular emission restriction target in the U.S. iron and steel sector; and how production, process structure, energy supply, and system costs change with those scenarios. The results advance [the authors] understanding of long-term impacts of different energy policy options designed to reduce energy consumption and CO_2 emissions for U.S. iron and steel sector, and generate insight of policy implications for the sector's environmentally and economically sustainable development. The alternative scenarios associated with 20 [percent] emission-reduction target are projected to result in approximately 11–19 [percent] annual energy reduction in the medium term (i.e., 2030) and 9–20 [percent] annual energy reduction in the long term (i.e., 2050) compared to the Base scenario." **Nihan Karali, Tengfang Xu, and Jayant Sathaye**, *Applied Energy*. (Subscription may be required.)

June 2014

"Québec and California Announce Plans for Joint Auction of Greenhouse Gas Emission Allowances." The California Air Resources Board (ARB) and Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change (MDDELCC) announced plans to conduct a joint practice auction for the California and Québec cap-and-trade programs. All registered participants in the two programs will be eligible to participate in the practice auction, which will begin in the last week of July 2014, with the bidding window open one day during the first week of August 2014. The practice auction will give participants the opportunity to test the updated auction platform and familiarize themselves with the new features that support a joint auction. Both ARB and MDDELCC officials will monitor the practice auction, testing and verifying joint oversight and communication procedures. If the practice auction is successful, the two programs will hold the first joint auction of emission allowances in November 2014. From *California Air Resources Board News Release* and *MDDELCC of Québec* on June 6, 2014.

"The timeline of trading frictions in the European carbon market." The following is the Abstract of this article: "During its trial phase (Phase I), the [European Union (EU)] GHG Emission Trading Scheme (EU-ETS) collapsed because of an over-allocation of emission allowances. [The authors] evaluate the progress of this market from the trial phase to the next commitment period (Phase II) from a microstructure angle. [The authors] show that trading frictions, as measured by the relative spread, information-asymmetry risk, and market-making profits decreased from Phase I to Phase II. Although volatility decreased, its noise-related component gained in importance at the expense of its information-related component, resulting in lower quality of the price changes." **Vicente Medina, Ángel Pardo, and Roberto Pascual**, *Energy Economics*. (Subscription may be required.)

"Cross-border electricity market effects due to price caps in an emission trading system: An agent-based approach." The following is the Abstract of this article: "The recent low CO_2 prices in the European Union Emission Trading Scheme (EU ETS) have triggered a discussion whether the EU ETS needs to be adjusted. [The authors] study the effects of CO_2 price floors and a price ceiling on the dynamic investment pathway of two interlinked electricity markets (loosely based on Great Britain, which already has introduced a price floor, and on Central Western Europe). Using an agent-based electricity market simulation with endogenous investment and a CO_2 market (including banking), [the authors analyze] the cross-border effects of national policies as well as system-wide policy options. A common, moderate CO_2 auction reserve price results in a more continuous [decarbonization] pathway. This reduces CO_2 price volatility and the occurrence of carbon shortage price periods, as well as the average

cost to consumers. A price ceiling can shield consumers from extreme price shocks. These price restrictions do not cause a large risk of an overall emissions overshoot in the long run. A national price floor lowers the cost to consumers in the other zone; the larger the zone with the price floor, the stronger the effect. Price floors that are too high lead to inefficiencies in investment choices and to higher consumer costs." **Jörn C. Richstein, Emile J.L. Chappin, and Laurens J. de Vries**, *Energy Policy*. (Subscription may be required.)

July 2014

"Auction Notice for CO_2 Allowance Auction 25 on September 3, 2014." The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2014 auctions have released the Auction Notice and application materials for their 25th quarterly CO_2 allowance auction, to be held on September 3, 2014. The Auction Notice for CO_2 Allowance Auction 25 provides potential participants with the information needed to submit a Qualification Application and indicate their intent to bid. To view the Auction Notice and bidder application materials, visit the RGGI website. From *RGGI News Release* on July 7, 2014.

"International carbon emissions trading and strategic incentives to subsidize green energy." The following is the Abstract of this article: "[The authors] examine strategic incentives to subsidize green energy in a group of countries that operates an international carbon emissions trading scheme. In [the others'] model, green subsidies of either sign on top of emissions cap regulation reduce the welfare of the group of countries, but this may not hold for individual countries. The cases of small and large countries turn out to exhibit significant differences. While small countries refrain from subsidizing green energy and thus implement the efficient allocation, large permit-importing countries may subsidize green energy in order to influence the permit price in their favor." **Thomas Eichner and Rüdiger Pethig**, *Resource and Energy Economics*. (Subscription may be required.)

August 2014

"Washington State Outlines Plans for Carbon Trading." According to a memorandum released by Washington State's Governor, the state is considering plans for a cap-and-trade system. The memorandum suggests the possibility of the state linking with the Western Climate Initiative (WCI) trading scheme, which also includes California and the Canadian provinces of British Columbia, Ontario, Quebec, and Manitoba. The state's current climate legislation looks to achieve 1990 GHG emission levels by 2020, with a 25 percent reduction on 1990 levels by 2035. In addition, the state has also established a green employment initiative that aims for jobs in the low-carbon sector to increase from 8,400 in 2004 to 25,000 in 2020. From *RTCC.org* on July 29, 2014.

"Case study on initial allocation of Shanghai carbon emission trading based on Shapley value." The following is the Abstract of this article: "Carbon emission trading is an effective measure to reduce GHG emissions worldwide. China has publicized plans to initiate the demonstration of carbon emission trading in seven regions as of 2013. Initial allocation is fundamental, but it proposes difficulty in the mechanism design of the carbon emission trading system. Benchmark, grandfathering and the Shapley value have been employed to simulate a specific case, which consists of the initial allocation of carbon emission allowances of three power plants in Shanghai, China. The results of the Shapley value are regarded as a theoretical equitable reference. The results of benchmark are similar to those of the Shapley value. However, it is apparent that the allocation regarding grandfathering is inequitable. Considering other factors, [the authors] proposed the following: At the introduction of experimental stage, free allocation pertaining to grandfathering can be adopted; meanwhile, benchmark should be prepared and adopted at the appropriate time. Furthermore, a portion of the initial allowances can be reserved for auction, and this portion for auction will escalate to the extent of 100 [percent] upon entering the formal stage. In addition, the tiered price mechanism and the subsidy policy are also suggested." **Zhenliang Liao, Xiaolong, and Jiaorong Shi**, *Journal of Cleaner Production*. (Subscription may be required.)

"Does EU emissions trading bite? An event study." The following is the Abstract of this article: "The aim of this paper is to examine whether shareholders consider the EU Emissions Trading Scheme (EU ETS) as value-relevant for the participating firms. An analysis is conducted of the share prices changes as caused by the first publication of compliance data in April, 2006, which disclosed an over-allocation of emission allowances. Through an event study, it is shown that share prices actually increased as a result of the allowance price drop when firms have a lower carbon-intensity of production and larger allowance holdings. There was no significant value impact from firms' allowance trade activity or from the pass-through of carbon-related production costs (carbon [release]). The conclusion is that the EU ETS does 'bite'. The main impact on the share prices of firms arises from their carbon-intensity of production. The EU ETS is thus valued as a restriction on [emissions]." **Thijs Jong, Oscar Couwenberg, and Edwin Woerdman**, *Energy Policy*. (Subscription may be required.)

Recent Publications

September 2013

"Global and Regional Markets for Carbon Capture and [Storage] (CCS) Infrastructure and Equipment." The following is a summary of this report: "Portrayed in the past five years as a pipe dream, technological savior and prudent investment to complement existing energy infrastructure, CCS is projected by SBI Energy as a complementary, sometimes marginal, technology in the global effort towards [CO_2] emissions reduction. Representing approximately $(U.S.) 650 million in 2013 investment, global CCS infrastructure deployment is projected to intensify significantly to over $2.4 billion in 2020. Through the end of this report's scope (2037), CCS is not projected to represent more than 25 percent of carbon emissions reductions below baseline even in the most active markets (e.g., North America, Europe). Other regions such as Latin America and Asia-Pacific will rely on CCS for less than [five] percent of necessary carbon emissions reductions. Carbon management is already a prime destination for energy and industrial sector investment dollars. Regulatory limits, taxation and price setting on [CO_2] emissions as a GHG pollutant has spurred industries worldwide to invest in emissions reduction technologies and practices. Improvements to energy efficiency, use of alternative lower- or non-emitting energy resources and economic transformation have largely produced the carbon emissions reductions in the past decade. However, these trends alone will be unable to achieve the global carbon emissions reductions necessary to avert catastrophic climate change. CCS is widely viewed as a technologically viable method for the significant mitigation of fossil fuel-associated carbon emissions worthy of additional development and future deployment. This report provides extensive and detailed projections for global and regional CCS markets through 2037, as well as a review of the historical markets for CCS technology since 2008. Markets are valued by total capital expenditure (CAPEX) investment in CCS infrastructure and by equipment orders. Cumulative estimated equipment orders for the period of 2020-2037 are segmented by carbon post-combustion absorption and removal, compression, air separation (ASU), water-gas shift (WGS), and balance of plant (BoP) equipment. Market segmentation is provided by CCS phase (capture, transportation, storage), region, capture source (power/industry), client or project type (historical market only/merchant capture, EOR, CCS project) and capture method (post-combustion, pre-combustion, oxyfuel). Regional carbon capture capacities and [storage] rates are also provided in terms of million metric tons (MMT) annually. The relative contribution of CCS and other factors to carbon emissions reductions below baseline (or default emissions trajectories) are also provided through 2037."

"Capacity Charging Mechanism for Shared CO_2 Transportation and Storage Infrastructure." The following is a summary of this National Grid Carbon authored publication: "Technical and legal barriers to CCS and risks associated with the technology are diminishing. A serious obstacle to growth of the CCS industry, however, is difficulty in building a sound commercial case for the development and operation of CCS infrastructure. One way to significantly reduce the cost of CCS is to [realize] economies of scale by sharing a single CO_2 transportation and storage infrastructure system among several operators of separate CO_2 generating plants. This report, prepared by National Grid Carbon (UK), sets out a commercial charging mechanism for the development of, access to, and subsequent use of a shared CCS infrastructure system. The study also explored a number of options for allocating the proportion of system development and operational costs between members of a shared CCS infrastructure."

"Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies." The following is from the Executive Summary of this Development Technologies International authored publication: "Developing Asia-Pacific Economic Cooperation (APEC) economies are among the most rapidly growing economies in the world, necessitating a major expansion in electric power generation in the next several decades. Much of this new power generation will likely rely on fossil fuels, especially coal. Concern about global climate change and the growth of CO_2 emissions from the region's rapidly expanding coal-fired power generation sector raises the question of

when capture and storage of CO_2 emissions from these plants may be implemented. CCS technologies, which can be coupled with CO_2 utilization such as EOR, offer a viable technology solution to address the dramatic growth of CO_2 emissions from the rapidly expanding coal-fired generation sector of many developing APEC economies. This study examines CCS legal and regulatory regimes for nine developing APEC economies: People's Republic of China, Indonesia, Republic of Korea, Malaysia, Mexico, the Philippines, Chinese Taipei, Thailand and Vietnam. These APEC economies were selected for this study based on four criteria: (1) the economy is considered a developing economy; (2) the economy consumes a significant amount of coal as fuel for electricity generation; (3) the economy possesses potential CO_2 storage capacity, and (4) the economy has a likely need for CCS to achieve [GHG] emissions reductions and/or the presence of policies that offer an enabling environment for CCS. Given the importance of CCS regulatory frameworks, there is a clear need for capacity building to prepare for the possible adoption of CCS in developing APEC economies. In line with these broader goals, the objectives of this project are: (1) Review the work in progress in the region and around the world on relevant legal, regulatory, and permitting issues and frameworks; (2) Identify issues likely to arise under a permitting regime for CCS projects in developing APEC economies, and (3) Recommend capacity building efforts needed to advance CCS regulatory framework development and commercial readiness in developing APEC economies."

"CO_2 Storage Prospectivity of Selected Sedimentary Basins in the Region of China and South East Asia." The following is from the Executive Summary of this Innovative Carbon Technologies Pty. Ltd. authored publication: "This report is a desk top study of the geological prospectivity for [CO_2] subsurface storage in selected member economies of the APEC region. The focus regions were selected by excluding those that have undertaken, or are about to complete, a CO_2 geological storage assessment, and those with very low emissions as documented by IEA (2000). The regions assessed within APEC are China, Indonesia, South Korea, Malaysia, Philippines, Chinese Taipei and Thailand."

"Assessment of the capture and storage potential of CO_2 co-produced with natural gas in South-East Asia." The following is from the Conclusions and Recommendations section of this CO_2CRC and University of New South Wales authored publication: "The results of this study suggest that, depending on any future carbon price and fiscal policies, there is significant potential for transport and injection of CO_2 emitted from natural gas field developments in South-East Asia. A significant number of projects are likely to be viable with a carbon price up to $20 per [metric ton] in real terms ignoring the effects of the fiscal terms that operate across the region and up to US$60 per [metric ton] in real terms assuming that the fiscal terms that apply to gas field developments also apply to CO_2 transport and injection. However, this study is based on limited high-level data and therefore the findings are only broadly indicative. More detailed project-specific studies are required. In addition, realizing the potential for CO_2 [storage] requires more work in establishing the economic, fiscal and regulatory environment in which such projects could be developed. [The authors] recommend further study based on more specific data on actual gas field developments and potential storage sites, particularly depleted or depleting fields for which data is plentiful. Depending on the circumstances, this might involve a study of enhanced oil or gas recovery in addition to CO_2 storage. In [the authors] view, such a study would first require obtaining the cooperation of oil and gas companies in the region and then working closely with them. The study is likely to proceed in stages. First it would involve contacting companies at a high level to gauge their level of interest in collaborating in such a study. Then it would involve negotiating agreements with interested companies to determine the terms of reference before the study begins. Finally, it would involve preparing the study with the close cooperation of the interested companies."

October 2013

"Evaluation of Options to Handle CO_2 Capture, Transport and [Storage] Disruption: Amine-, Oxycombustion-, and IGCC-based Plant Design Issues." The following is from the Executive Summary of this document: "This report highlights potential issues with CCS system operation that may prevent CO_2 from being captured and/or [stored] from fossil-based power plants. It identifies potential modes of failure of CCS equipment/system operation, CO_2 transport, and [storage]. Finally, it proposes appropriate system design considerations for the issues identified. This report was produced at a level of engineering consistent with Class 4 as defined by the Association for the Advancement of Cost Engineering International (AACE); this is consistent with the level of engineering considered in typical system studies. As such, proposed corrective or preventive actions were developed at this level of rigor. Key findings of the report were: [a] Major disruptions in CO_2 [storage] are related to pipeline failures and are determined to be unlikely, with most, if not all, corrective action understood to be common industrial knowledge through previous experiences in related pipeline operations; [b] Disruptions in capture operations are determined to be manageable with detailed hazardous operations analyses. Most mitigating actions here are related to (1) system redundancy, (2) CO_2 venting and, (3) alternate design; [c] In no case was the anticipated result of any failure mode considered to be reason to decide against CCS implementation, from either cost or safety considerations; [d] As with all projects, as more detailed design information is produced, corrective actions may need to be implemented and their costs more explicitly defined. In general, the potential CCS system disruptions examined in this report include: [a] Problems in any part of the CO_2 supply chain involving capture, pipeline transport, and geologic storage; [b] Off-specification CO_2 product stream composition, temperature, or pressure. The above is presented in detail with respect to three different types of fossil-based power plants. [Pulverized coal (PC) plant with 90 percent amine-based post-combustion carbon capture; supercritical oxycombustion plant with 100 percent carbon capture; and integrated gasification combined cycle (IGCC) plant with 90 percent carbon capture.]"

"U.S. Department of Energy Investment in Carbon, Capture and Storage (CCS)." The following is from the Introduction of this document: "[DOE's] Office of Fossil Energy (FE) is the Department's primary lead for CCS. FE's key activities are funded through annual Congressional appropriations. In recent years, FE's overall annual budget for fossil energy [R&D] has fluctuated from approximately $420 million to $875 million dollars, of which $270 to $580 million has supported CCS-related activities. Before 2009, FE's annual budget mainly funded CCS [R&D], but it also provided support for the development of commercial-scale CCS projects, including the FutureGen project and Southern Company's Kemper County Energy Facility. The Congressional Research Service report estimates that between FY1997 and FY2008, DOE provided $900 million for activities related to CCS. In 2009, DOE greatly increased its funding for CCS by allocating approximately $3.38 billion in funding for CCS under the American Recovery and Reinvestment Act of 2009 (ARRA). FE has used a large portion of this ARRA funding to support the development of multiple commercial-scale CCS projects in both the power and industrial sectors. Currently, DOE is involved in the development of eight active commercial-scale CCS projects, both in the industrial and electric power sectors. As of September 2013, FE had awarded more than $3.23 billion under ARRA to over 90 recipients, including companies, universities, national laboratories, and others in the private sector working on CCS. Of the $3.23 billion awarded, approximately $1.03 billion, or approximately 32 percent, has been spent to date. Approximately $153 million in funding has not been awarded. Beyond FE, DOE selected four commercial-scale CCS projects to receive loan guarantees in 2009 under its 1703 program (though these projects have not moved forward), and the Advanced Research Projects Agency-Energy (ARPA-E) has funded numerous projects involving the [R&D] of next generation CCS technologies. In July 2013, DOE announced that it will be providing $8 billion in new loan guarantees to CCS and other clean energy projects. Overall, DOE's financial support for the eight active commercial-scale CCS projects has been an important factor in determining whether these projects have moved forward. Currently, only a small number of commercial-scale CO_2 capture projects, mostly natural gas processors, where the cost and difficulty of capturing CO_2 are relatively low have come online without DOE support. At the same time, despite DOE support, several of the active

projects have been subject to delays and setbacks in progressing toward construction or financial close and in line with original estimates of overall cost. In addition, several commercial-scale projects have been cancelled despite being selected for DOE support. While the track record of commercial-scale projects receiving DOE support has been mixed, the perception among CCS stakeholders is that DOE's support for the [R&D] of CCS component technologies (particularly through the NETL and Regional Carbon Sequestration Partnerships) has been essential. Going forward, however, it is uncertain whether DOE and FE will have sufficient funding to support the development of the next generation of commercial-scale CCS projects, but its involvement in [ongoing R&D] is expected to continue."

"Carbon Reduction Opportunities in the California Petroleum Industry." The following is from the Summary of this document: "As industry leaders and policymakers seek to reduce the carbon [emissions] impacts caused by human activity, the petroleum supply chain and the use of petroleum products present numerous and significant opportunities for emission reductions. From crude oil production and refining to gasoline and diesel use in vehicles, each portion of the supply chain contributes to the oil industry's carbon footprint. While substitution of cleaner energy sources for oil is a key strategy to reduce carbon [emissions], it is also important to take advantage of the technologies currently available that can directly reduce the carbon footprint of petroleum from production to final use. Opportunities to shrink this footprint include, but are not limited to: (1) renewable steam generation: generating steam for EOR using solar power, rather than combusting fossil fuels in once-through steam generators; (2) steam generation with CCS: capturing and storing the flue gas emissions from once-through steam generators used in EOR; (3) refinery energy efficiency: enabling refineries to use less energy in their operations, thereby reducing their carbon emissions; (4) refinery CCS: capturing and storing carbon emissions resulting from the energy-intensive hydrogen processes needed for refining crude oil; and (5) renewable refinery feedstocks: displacing part of the refinery's crude oil with natural oils, such as animal fats and waste oils, thereby reducing the full-fuel-cycle carbon intensity of the final refinery products."

November 2013

"The Thermal Enhanced Oil Recovery (EOR) Market 2013-2023." The following is a summary of this report: "Growth in the thermal EOR market will be driven primarily by increasing production from the Albertan oil sands, though heavy oil developments in several global locations will also be seen. Many thermal EOR projects have been around for a long time and the more established national markets are now looking to maintain production and improve existing technologies. Strong growth is expected in the emerging markets of the Middle East as tertiary recovery methods are applied to various large fields over the coming years. High oil prices, increasing global energy demand and the development of new technologies will all help to drive the thermal EOR industry over the coming decade as the market enters a period of strong growth. Visiongain's analysis indicates that the thermal EOR market will see production of 2.259 million barrels per day in 2013." (Purchase may be required.)

"Synthesis of CCS social research: Reflections and current state of play in 2013." The following is a summary of this document: "CCS has a critical role to play in mitigating climate change and providing energy security. Fundamental to that advocacy role is a commitment to sharing the best possible research and information about the technology to members and the wider public. This report has been designed to provide an accessible summary of an extremely comprehensive body of research. It is hoped that the review will provide a quick and helpful guide to emerging thinking and best practices for those working to improve public understanding and acceptance of CCS technology, with extended bibliographical references to assist with further research."

"**The Global Status of CCS: 2013."** The following is a summary of this document: "The *Global Status of CCS: 2013* is the fifth edition of the Global CCS Institute's key publication on the progress and challenges facing CCS. These reports provide a comprehensive overview of the state of development of CCS projects and technologies, and of actions taken to facilitate the demonstration of those technologies at a large scale."

"Legal and Regulatory Frameworks for CO_2–EOR and CO_2–CCS." The following is a summary of this document: "This paper seeks to assist policymakers in evaluating the potential for integrating supplies of captured anthropogenic CO_2 into profitable EOR operations as one part of a long-term strategy for developing widespread deployment of CCS technology. Part I reviews the existing legal and regulatory frameworks governing CO_2 transactions, transport, injection and storage in the context of EOR operations. Part II reviews the changes to this existing EOR–based framework that are in various stages of adoption in order to allow for CCS–based storage. Part III builds on these two prior sections to summarize issues that need to be addressed, and to set forth conclusions and recommendations for steps that may be taken by jurisdictions looking to harness the potential value of CO_2–based EOR as part of a long-term strategy of using CCS technology as an emissions reduction tool."

"Technical Aspects of CO_2 Enhanced Oil Recovery and Associated Carbon Storage." The following is a summary of this document: "Injection of [CO_2] into mature oil reservoirs is a proven effective method for improving oil production that can be applied to a variety of oil reservoirs in different geological settings. Retention of the injected [CO_2] within the reservoir is an intrinsic part of the CO_2 EOR process, and effectively all CO_2 purchased for injection will ultimately remain stored within the oil field at the end of EOR operations. This storage aspect has driven interest in CO_2 EOR as a potential method of CCS that has a supportive business component. The storage opportunities within CO_2 EOR floods are generally not maximized, although there are no over-riding technical impediments preventing using more of the pore space for storage. Transitional, or residual oil zones, and stacked reservoirs all pose significant opportunities to increase storage amounts well beyond that used strictly for EOR. While deploying monitoring equipment and determining suitable baselines may present challenges to some existing operations, technical solutions can be found to address most of these issues."

"Unlocking North Sea CO_2 Storage for Europe: Practical actions for the next five years." The following is a summary of this document: "Carbon dioxide emissions are the major cause of climate change: that is unequivocal. To limit the effects, [the author] must reduce the amount of fossil carbon combusted and emitted as CO_2. CCS is the only technology that directly reduces emissions at source, and enables countries to manage carbon budgets for both power plants and process industries. The next five years will be crucial in putting CCS back into position as an enabler of Europe's transition to a low-carbon economy. Practical actions must be combined with durable policy drivers to rebuild confidence and attract investment. This will be essential for large-scale emissions reductions from both industry and power generation to 2030 and 2050 as Europe seeks to manage climate risk, retain jobs and improve its low-carbon competitiveness. The North Sea is the largest CO_2 storage resource in Europe, and offers the ideal location for immediate efforts. By using low-cost available CO_2 from industrial sources, Europe can accelerate the development of enabling infrastructures for CO_2 transport and storage."

"World Energy Outlook 2013." The following is a summary of this document: "Many of the long-held tenets of the energy sector are being rewritten. Major importers are becoming exporters, while countries long-defined as major energy exporters are also becoming leading centers of global demand growth. The right combination of policies and technologies is proving that the links between economic growth, energy demand and energy-related CO_2 emissions can be weakened. The rise of unconventional oil and gas and of renewables is transforming [the authors'] understanding of the distribution of the world's energy resources. Awareness of the dynamics underpinning energy markets is essential for decision makers attempting to reconcile economic, energy and environmental objectives. Those that anticipate global energy developments successfully can derive an advantage, while those that fail to do so risk making poor policy and investment decisions. This edition of the World Energy Outlook (WEO-2013) examines the implications of different sets of choices for energy and climate trends to 2035, providing insights along the way that can help policymakers, industry and other stakeholders find their way in a fast-changing energy world."

December 2013

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

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

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

January 2014

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

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

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

"CO_2 Storage Atlas: Barents Sea." The following is from the Preface of this document: "The CO_2 Storage Atlas of the Barents Sea has been prepared by the Norwegian Petroleum Directorate, at the request of the Ministry of Petroleum and Energy. The studied areas are located in opened parts of the Norwegian Continental Shelf (NCS). The main objectives have been to identify the safe and effective areas for long-term storage of CO_2 and to avoid possible negative interference with ongoing and future petroleum activity. [The authors] have also built on the knowledge [they] have from the petroleum industry and from the two CO_2 storage projects on NCS (Sleipner and Snøhvit). This study is based on detailed work on all relevant geological formations, discoveries and hydrocarbon fields in the Barents Sea. The work is based on several studies as well, as data from more than 40 years of petroleum activity on the [NCS]. [Nine] geological formations have been assessed, and grouped into saline [formations]. The [formations] were evaluated with regard to reservoir quality and presence of relevant sealing formations. Those [formations] that may have a relevant storage potential in terms of depth, capacity and injectivity have been considered. Structural maps and thickness maps of the geological formations are presented in the atlas, and were used to calculate pore volumes. Several structural closures have been identified and some of them were further assessed. A study of the CO_2 storage potential in relevant dry-drilled structures and mapped structures in the area is provided. [Carbon dioxide] storage in [EOR] projects is also discussed and a new study of CO_2 for EOR and CO_2 injected in residual oil zones has been outlined. The methodology applied for estimating storage capacity is based on previous assessments, but the storage efficiency factor has been assessed individually for each [formation] based on simplified reservoir simulation cases. The assessed [formations] have been ranked according to guidelines developed for the CO_2 Storage Atlas of the Norwegian part of the North Sea (2011). This atlas

is based on data from seismic, exploration and production wells, together with production data. The data base is essential for the evaluation and documentation of geological storage prospectivity. [The authors] hope that this study will fulfill the objective of providing useful information for future exploration for CO_2 storage sites. [The authors] have not attempted to assess the uncertainty range for storage capacities in this atlas, but [the authors] have made an effort to document the methods and main assumptions. The assessments described in this atlas will be accompanied by a [geographical information system (GIS)] database."

February 2014

"Integration of Capture Plant and Power Plant ROAD Special Report for the Global Carbon Capture and Storage Institute." The following is a summary of this document: "This report focuses on the integration of the existing coal-fired [1,070] MW Unit 3 of Maasvlakte Power Plant (MPP3) with the proposed new 250 MW scale carbon capture plant of the Rotterdam Opslag en Afvang Demonstratieproject (ROAD). Carbon capture technology has been the subject of considerable research to reduce the costs of CCS, and the subject of many publications. However, the integration with the main power plant also has important impacts on the efficiency and operability of the CCS chain, and is a significant project cost in its own right."

"CO_2 Pipeline Infrastructure." The following is from the "Background to the Study": "The aim of this study is to collate information from the public domain on existing CO_2 pipelines into a comprehensive reference document. Other objectives are to discuss the similarities and differences between CO_2 and other, specifically natural gas, pipelines and to provide an overview. The overall lessons learned from this study should support project developers, decision makers, regulators and governmental bodies who do not deal with engineering calculations and cost estimates on a regular basis." The CO_2 pipeline database is accessible online.

"A UK Vision for Carbon Capture and Storage." The following is from the Executive Summary of this document: "The UK's CCS industry is at a crossroads. Urgent Government action is needed to ensure that this new technology-based industry develops in a timely manner, delivering significant economic growth and employment benefits and contributing towards the UK's carbon reduction targets. Delivering the optimum UK energy mix over the next 20 years involves multiple challenges: (1) a significant rise in demand for electricity, driven by economic growth and greater use of electricity at home and in industry and transport; (2) replacing a fifth of older power plant by 2020; and (3) delivering legally binding CO_2 emissions reductions of 60 percent by 2030, with the near-complete decarbonization of electricity supply sector, and significant reductions in industry. A balanced and effective energy strategy will be critical to ensuring that electricity and heat remain on tap and affordable to both industry and domestic consumers alike. Through a series of energy market reforms the government's Energy Bill is tasked with delivering the framework for £110bn [approximately $181 billion] of secure, low carbon and affordable energy investment by 2020. Investing in 'green growth' within the UK economy will provide jobs, tax revenues, inward investment and export potential. CCS technology can deliver on all these counts – providing least cost, secure energy in association with green growth…" A summary of the report, titled, "The Economic Benefits of CCS in the UK," is also available.

March 2014

"The Global Status of CCS: February 2014." The following is from the Executive Summary of this document: "This report, 'The Global Status of CCS: February 2014,' [summarizes] the current status of large-scale integrated CCS projects worldwide and provides an overview of significant international CCS project and policy, legal and regulatory developments. CCS is essential to keep global temperature increases below two degrees Celsius. It is a vital part of a least cost portfolio of low-carbon technologies required to deal with climate change. In the past few months there have been a series of expert reports acknowledging this reality. A broad chorus of leading voices is to be welcomed, especially if it encourages decision makers to take action to progress CCS technology. Despite continuing progress in large-scale CCS projects moving into construction and operation in most regions, the overall global effort to date has been slower than ideal. Nonetheless, there are positive signals that decision makers may act to accelerate CCS implementation. The 5th Carbon Sequestration Leadership Forum (CSLF) Ministerial Meeting in November 2013 [emphasized] the importance of CCS in tackling climate change and identified actions to [reenergize] the global momentum for the deployment of CCS. This is needed to support existing activity and advance new projects. As of February 2014 there are 12 projects in operation globally, nine under construction and another 39 in various stages of development planning, of which six may make a final investment decision during 2014. The 21 projects in operation or under construction represent a 50 [percent] increase since 2011, a sign of growing confidence in the application of CCS technology at large scale. North America is leading in the implementation of CCS technology and China is quickly increasing in importance. Momentum has been regained in the UK though prospective project start dates are towards the end of this decade. Continental Europe on the other hand has lost a project leadership position that it aspired to several years ago, though the importance of CCS technologies at large scale and continued robust research and development efforts have been [recognized] by a number of European bodies in recent months. The first large-scale CCS projects in the power sector – the Boundary Dam Integrated Carbon Capture and Sequestration Project and the Kemper County Integrated Gasification Combined Cycle (IGCC) Project – are nearing operational status in North America. These projects are of global importance to the development of CCS. Similarly, in the Middle East, the world's first large-scale CCS project in the iron and steel sector has progressed into construction. Projects such as these will build confidence by showing the technology in action, and through innovation combined with advances in capture technology, bring down costs."

"Cleaner Fossil Power Generation in the 21st Century – Moving Forward." The following is from the Executive Summary of this document: "CCS has a pivotal role to play if the use of fossil fuels in power stations and vital energy-intensive industries is to keep in step with the low-carbon agenda. Globally, recognition is growing that CCS must be at the forefront of efforts to limit increases in average temperatures caused by climate change; it has been calculated that, in the UK, successful deployment could cut the cost of meeting carbon reduction targets by up to [one percent] of Gross Domestic Product (GDP) by 2050. Yet the annual amount of CO_2 captured and stored worldwide currently totals tens of megatons, compared to the thousands of megatons that need to be achieved by the middle of the 21st century. This technology strategy aims not only to confront the challenge and help unleash the potential but also to keep the UK at the vanguard of CCS technology development and [commercialization]. [Decarbonizing] the UK's energy system; achieving major cuts in industrial carbon emissions; boosting energy security; generating billions of pounds in income and tens of thousands of jobs for 'UK plc' – these benefits are all within reach if large-scale deployment of CCS becomes a reality in this country. Taking full and realistic account of work currently under way and wider developments in the UK and worldwide, as well as the recommendations of the UK's CCS Cost Reduction Task Force (CRTF), this strategy sets out a clear vision that has three components: [1] Adoption of a target of around 10 [percent of UK electricity to be generated from fossil fuel plant fitted with CCS by 2025. [2] Creation of capability that enables CCS to make a major contribution to meeting the UK's target of an 80 [percent] cut in [GHG] emissions by 2050. [3] Positioning of the UK to succeed in global CCS markets and to play an influential role in the CCS policy dialogue at both European Union (EU) and global level. [Realizing] this vision presents several challenges. These include: cutting costs and risks so that CCS is economically

competitive with other low-carbon technologies; putting appropriate, effective market frameworks in place; and removing a range of barriers to deployment. In close conjunction with other [organizations] wherever appropriate, the APGTF will work to pursue this vision and address these challenges. This document sets out Strategic targets and Technology Implementation targets, plus a suite of research, development and demonstration (RD&D) priorities and other recommendations designed to ensure that key CCS development criteria – in terms of scale, cost and timelines – can be met effectively."

"Carbon Capture and Storage in the EU's 2030 climate and energy framework." The following is from the Introduction of this document: "Europe was at one time the world leader in supporting CCS. In 2007, the European Council called for 12 demonstration projects to be in operation by 2015: not one has been delivered to date. In the light of the economic crisis, EU CCS policy has failed to deliver a sufficiently bankable business case for individual CCS projects, and has not provided credible long-term signals to stimulate the development of supply chains, CO_2 infrastructure investments or the proactive [characterization] of geological CO_2 storage. Previous European technological leadership on CCS is now at risk as commercial-scale projects for power generation and industrial sources of emissions enter into operation and construction in Canada, USA, Australia, China and the United Arab Emirates. The Global CCS Institute warns that Europe is now 'lagging behind.' Without explicit actions to address the weaknesses of EU CCS policy, the new EU2030 framework on climate and energy will also fail to deliver. This would leave Europe facing higher costs of [decarbonization] and increased risk of employment loss from carbon intensive and process industries from energy intensive and process industries. In November 2013, SCCS published 'Unlocking North Sea CO_2 Storage for Europe: Practical actions for the next five years.' [The SCCS] report identified how decisions to improve the policy context and undertake practical enabling actions could combine to rebuild momentum for CCS deployment in the EU. [SCCS] set these out as a five-year framework and highlighted key elements on the critical path to deploying CCS in the EU, focusing on the North Sea as the prime location in Europe for the geological storage of CO_2. This briefing follows on from that analysis and identifies decisions that the European Council can take in March 2014 to accelerate progress on CCS. The recommendations above relate closely to the headline findings from [the] report, which included calls for: a strategic vision for CCS in 2030; policies and incentives that drive investment; and the sourcing of low-cost CO_2."

April 2014

"Cost and Performance Metrics Used to Assess Carbon Utilization and Storage Technologies." The following is the Background of this DOE/NETL document: "In an effort to reduce CO_2 emissions from various industrial and power generation processes to the atmosphere, DOE NETL is funding research intended to advance state-of-the-art technologies that address the use of CO_2 in a variety of processes. Much of this research is funded and managed in the CO_2 Utilization Focus Area of the Carbon Storage Program. [Carbon dioxide] utilization efforts focus on pathways and novel approaches for reducing CO_2 emissions by developing beneficial uses for CO_2 that will mitigate GHG emissions. Utilization is an important component in carbon sequestration, also called storage. Some of the applicable approaches are conversion of CO_2 into useful chemicals and polycarbonate plastics, storage of CO_2 in solid materials having economic value, indirect storage of CO_2, and other breakthrough concepts. The term sequestration for this report is defined as the segregation of CO_2, either chemically, as in chemical utilization, or physically, as in geologic storage. This concept is therefore named CCS. Critical challenges identified in the utilization focus area include the cost-effective use of CO_2 as a feedstock for chemical synthesis, or its integration into pre-existing products. The efficiency (reaction conversion and the amount of CO_2 sequestered in a product) and energy use (the amount of energy required to utilize CO_2 in existing products) of these utilization processes also represent a critical challenge. In order to meet these challenges, metrics are developed to enable comparison of such technologies and utilization processes. In the not-too-distant past, authors and organizations have described using 'sustainability metrics' to guide decision-making in the process industries for the goals of environmental protection, economic prosperity, and social benefit."

"Opportunities for CO_2 Storage Pilot Projects across Europe." The following is the Preamble of this document: "In the field of the geological storage of CO_2, a 'pilot' project is one that has a research objective and where less than 100,000 tons of CO_2 are injected into the subsurface, typically over a few years. Although CO_2 Geological Storage (CGS) is well advanced from a technological point of view, research based on real field sites is now strongly needed in order to maximize the efficiency of these technologies, to optimize the tools needed for monitoring and verification, and to be able to adapt to the specificity of local geological conditions. Pilot projects can thus benefit investment decisions for deployment of CCS in the foreseeable future. The CGS Europe Project consortium, involving 34 research institutes from 28 European countries (including the CO_2GeoNet Association), gathers together broad experience in many different fields of research related to CO_2 geological storage, as well as geological knowledge across the whole of Europe. A key aim of CGS Europe is to contribute to research and technological development of storage activities, in order to provide scientific knowledge to the authorities and the society in general, enabling policy makers and the public to have an informed opinion about the potential industrial development of CCS technologies. In this context, the present CGS Europe report 'Opportunities for CO_2 Storage Pilot Projects across Europe' provides an overview of the many potential pilot projects across Europe. Although currently still in the proposal stage, [the authors] take stock here of the wide range of scientific achievements that could be gained if some of the projects become a reality in the near future. CGS Europe hopes this work will contribute to building new knowledge on geological storage that can be used for the industrial demonstration and deployment of these technologies."

May 2014

"Methods to assess geologic CO_2 storage capacity: status and best practice." The following is from the Executive Summary of this document: "To understand the emission reduction potential of CCS, decision makers need to understand the amount of CO_2 that can be safely stored in the subsurface and the geographical distribution of storage resources. Estimates of storage resources need to be made using reliable and consistent methods. This report offers recommendations for an internationally shared approach to quantifying this potential. Previous estimates of CO_2 storage potential for a range of countries and regions have been based on a variety of methodologies, with access to widely differing amounts of data, resulting in a correspondingly wide range of capacity estimates. Some of these estimates have even been in conflict with others. Consequently, there has been uncertainty about which of the methodologies were most appropriate in given settings, and whether the estimates produced by these methods were useful to policy makers trying to determine the appropriate role for CCS. In 2011, the International Energy Agency (IEA) convened two workshops, which brought together experts from six national geological survey [organizations] to review geologic CO_2 storage assessment methodologies and make recommendations on how to [harmonize] CO_2 storage estimates worldwide. This workshop report presents the outcome of the workshops. It first gives an overview of factors to consider before undertaking a CO_2 storage assessment on saline [formations]. This is followed by a comparison of ten of the more recently published CO_2 storage resource assessment methods and resource estimates, which are [characterized] according to ten parameters and the results tabulated. The method comparison is then followed by a set of steps that can be used to assess geologic CO_2 resources. As the overall goal of the workshops was to [harmonize] CO_2 storage estimates, the participants identified best practice in the form of steps that can be followed to conduct a thorough assessment of storage resource, throughout the world, across geologic settings, regardless of the amount of available geologic data… "

"Moving Below Zero: Understanding Bioenergy with Carbon Capture & Storage." The following is the Summary of this document: "Carbon dioxide (CO_2) in the air is already at dangerous levels – 40 [percent] above pre-industrial quantities, and rising fast. To reduce the level of CO_2 in the air and limit dangerous climate change, [humans] need to boost carbon sinks. [Humans] need to find ways to remove that excess carbon from the air. In this report [the authors] turn attention to one of the more prospective large-scale carbon removal technologies: bioenergy with carbon capture and storage (also known as bio-

CCS, BECCS or renewable-CCS). As plants grow, they harness energy from the sun and CO_2 from the air. Certain plants can be harvested, transported and processed to form a fuel which can be combusted or fermented to produce bioenergy (heat, power or transport). This process releases the CO_2 which can be captured, compressed and transported to a location for geological storage. This means the CO_2 absorbed from the air during plant growth can be removed from the natural carbon cycle..."

"Modelling Bio-[storage] to Reduce Greenhouse Gas Emissions." The following is the Introduction of this document: "The Climate Change Authority has outlined the task Australia faces in reducing emissions to achieve global ambitions to [minimize] the rise in temperatures to [2°C]. According to the Authority this task translates to zero emissions from activities in Australia by 2040. As it could be difficult to achieve zero emissions across all sectors it is likely that [bio-storage] options will have a major role to play to offset emissions. Such options include storage of carbon from native plantations and agricultural soils. Another option includes using biomass fuel to generate power or heat and then capturing the carbon emissions and storing them underground. The focus of this study is on the role that bioenergy carbon capture and storage (BECCS) technology can play in achieving long term ambitions to reduce emissions. This report describes the assumptions and methods used to determine the impact of adoption of BECCS in the power sector and for large applications entailing direct combustion. A number of scenarios were modelled with and without the availability of BECCS to determine the relative contribution of BECCS. The results of the modelling are discussed in this report."

"Enhanced Oil Recovery (EOR) Market: Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 – 2023." The following is from the Description of this document: "The EOR market report by Transparency Market Research provides an in-depth analysis of the global EOR industry. The report segments the market on the basis of technology and region and also provides the forecasts and estimates for each technology. The report also analyses the demand and supply characteristics of the market by providing a detailed forecast and analysis of volume and revenue for the period 2013 to 2023. EOR method mainly uses three technologies including Thermal injection, Gas injection and Chemical injection…The report provides a detailed analysis of the various factors influencing the EOR industry with the help of Porter's five force analysis. The analysis also helps to understand the degree of competition in the market. The report also analyses the value chain and the various drivers and restraints of the EOR market."

June 2014

"Geological CO_2 Storage Characterization." The following is from the Preface of this document: "The primary purpose of this book is to assist future CCS investigations in characterizing potential geological CO_2 storage sites well enough so that all of the information required by regulators to permit commercial CO_2 storage facilities are provided. The Wyoming Carbon Underground Project (WY-CUSP) is part of the [DOE] Geological CO_2 Storage Site Characterization Program. In 2010 DOE awarded funding to 10 CO_2 geological storage characterization projects. The WY-CUSP program under the direction of the University of Wyoming Carbon Management Institute (CMI) was one of the awardees (project DE-FE0002142: Site Characterization of the Highest-Priority Geologic Formations for CO_2 Storage in Wyoming; Principal Investigator, Ronald C. Surdam). The State of Wyoming through the U.W. School of Energy Resources generously provided matching funds for the WY-CUSP program. This book deals with most of the trials and tribulations required to achieve the ultimate goal of the WY-CUSP program: delivery of a certified commercial CO_2 storage site that could be used either as a surge tank for CO_2 utilization or for permanent [storage] of GHG emissions, or for both. The rationale for the WY-CUSP program is manifold: first is the effort to establish a mechanism that provides the potential to stabilize or reduce GHG emissions in order to reduce the rate of global warming; secondly to protect Wyoming's coal extraction and future coal-to-chemical industries by providing storage capacity for anthropogenic CO_2; thirdly to provide a source of anthropogenic CO_2 for EOR projects (at present rates of CO_2 production from gas processing plants it would take 150–200 years to recover Wyoming's stranded oil; fourthly to retrieve reservoir information essential for the expansion of natural gas storage in Wyoming; and lastly to

establish more robust databases for two very important hydrocarbon reservoirs in Wyoming (substantially reduce uncertainty for all dynamic models of Tensleep/Weber Sandstone and Madison Limestone fluid-flow and rock/ fluid systems). To satisfy the WY-CUSP program rationale the following goals were set: to improve estimates of CO_2 reservoir storage capacity, to evaluate the long-term integrity and permanence of confining layers, and to manage injection pressures and brine production in order to optimize CO_2 storage efficiency for the most significant storage reservoir (Tensleep/Weber and Madison Formations) at the Rock Springs Uplift (RSU), a premier CO_2 storage site in Wyoming."

"Energy Technology Perspectives 2014 – Harnessing Electricity's Potential." The following is from the Executive Summary of this document: "Energy Technology Perspectives 2014 (ETP 2014) charts a course by which policy and technology together become driving forces – rather than reactionary tools – in transforming the energy sector over the next 40 years. Recent technology developments, markets and energy-related events have asserted their capacity to influence global energy systems. They have also reinforced the central role of policy in the increasingly urgent need to meet growing energy demand while addressing related concerns for energy security, costs and energy-related environmental impacts. Radical action is needed to actively transform energy supply and end use. In addition to [analyzing] the global outlook to 2050 under different scenarios, across the entire energy system for more than 500 technology options, ETP 2014 explores pathways to a sustainable energy future in which policy support and technology choices are driven by economics, energy security and environmental factors. Starting from the premise that electricity will be an increasingly important vector in energy systems of the future, ETP 2014 takes a deep dive into actions needed to support deployment of sustainable options for power generation, distribution, and end-use consumption. ETP 2014 analyses three possible energy futures to 2050: [(1)] 6°C Scenario (6DS), where the world is now heading with potentially devastating results; [(2)] 4°C Scenario (4DS) reflects stated intentions by countries to cut emissions and boost energy efficiency; [and (3)] 2°C Scenario (2DS) offers a vision of a sustainable energy system of reduced [GHG] and CO_2 emissions. Status and recent trends are highlighted in Tracking Clean Energy Progress, providing a snapshot of advances or lack of progress in major low-carbon energy technologies. Collectively, ETP 2014 lays out the wide range of necessary and achievable steps that can be taken in the near and medium terms to set the stage for long-term energy policy objectives, clearly identifying the roles of energy sector players, policy makers and industry."

"Annual Report on the Market for RGGI CO_2 Allowances: 2013." The following is from the Executive Summary of this document: "The Regional Greenhouse Gas Initiative (RGGI) became the first mandatory cap-and-trade program to limit CO_2 emissions in the United States in 2009. Electric power generators located in the states participating in RGGI are required to obtain a number of CO_2 allowances equal to the number of tons of CO_2 they emit. RGGI distributes CO_2 emissions allowances to the market primarily through auctions, making it distinctive among existing cap-and-trade programs. Ninety-four percent of the CO_2 allowances that have entered into circulation initially entered the market through one of the auctions. Through the end of 2013, RGGI has conducted 22 successful auctions, selling a total of 651 million CO_2 allowances for $1.6 billion. Following a 2012 Program Review, the Participating States announced changes to the Model Rule, including a new CO_2 emissions cap. The new CO_2 emissions cap is 91 million tons for 2014, and will be reduced by 2.5 percent per year until it reaches approximately 78 million tons for 2020. The Model Rule also included further interim adjustments to the cap to account for the surplus of allowances from 2009 to 2013 in circulation. Since these program adjustments were announced in February 2013, there have been significant changes in market activity which are discussed throughout this report. This report evaluates activity in the market for RGGI CO_2 allowances in 2013, focusing on the following areas: allowance prices, trading and acquisition of allowances in the auctions and the secondary market, participation in the market by individual firms, and market monitoring."

July 2014

"CO_2-EOR Offshore Resource Assessment." The following is a summary of this NETL-published document: "The Gulf of Mexico accounts for about 20 percent of total domestic crude oil production. Since reaching a peak of 1.54 million barrels a day in 2003, Gulf of Mexico's (GOM) outer continental shelf (OCS) oil production has declined to 1.23 MMB/D, as of mid-2013. While there is optimism that new discoveries in the deep and ultra-deep waters of the GOM OCS will reverse this decline, another option seems to offer even more promise -- the application of [CO_2-EOR]."

"Near-Term Projections of CO_2 Utilization for Enhanced Oil Recovery." The following is a summary of this NETL-published document: "In 2013 a total of 113 CO_2-EOR projects inject 3.1 billion cubic feet per day (Bcfd) (60 million metric tons (MMmt) per year) of CO_2 for [EOR] in the United States. The associated crude oil production in 2012 was 282,000 barrels per day. Based on the increased volumes of CO_2 supplies, the completion of major CO_2 pipelines, and the announced new, large-scale CO_2-EOR floods, production of crude oil from CO_2-EOR floods is forecast to grow significantly, reaching 615,000 barrels per day from at least 124 active CO_2 floods by year 2020. While the Permian Basin remains the largest CO_2-EOR oil producer, much of the growth occurs in the Gulf Coast, the Rockies, and the Mid-Continent."

"Subsurface Sources of CO_2 in the Contiguous United States. Volume 1: Discovered Reservoirs." The following is a summary of this NETL-published document: "Twenty-one CO_2 fields in the contiguous states contain an estimated 311 Tcf of CO_2 gas-initially-in-place (GIIP). Of that, 168 Tcf (54 percent) is estimated to be accessible and technically recoverable. The estimated economically recoverable resource (ERR) is 96.4 Tcf, based on a CO_2 price of 1.06 $/mcf ($20/tonne) at the field gate. Cumulative production to date is 18.9 Tcf, leaving 77.5 Tcf remaining or net ERR. The Big Piney-LaBarge field in Wyoming contains an estimated net ERR of 52 Tcf, 67 percent of the total for the United States. The remaining ERR in reservoirs that feed into the Permian Basin and Gulf Coast is on the order of 10 to 20 years of supply."

"Subsurface Sources of CO_2 in the United States. Volume II: Exploration of CO_2 Systems." The following is a summary of this NETL-published document: "A study of the genesis and tectonic setting of subsurface CO_2 systems in the United States indicates that undiscovered CO_2 reservoirs could contribute materially to CO_2 supply for [EOR]. Five geographic areas are estimated to contain 42 Tcf of risked technically recoverable CO_2 resource (TRR). Two lead areas near the Permian Basin, Val Verde and San Juan, contain 34 Tcf CO_2 risked TRR, an amount roughly equivalent to the remaining TRR in discovered reservoirs that are currently supplying the region. The number of lead areas studied was limited and the aggregate TRR estimates are not comprehensive."

"Targeted Report: Financing Large Scale Integrated CCS Demonstration Projects." The following is from the Introduction of this document: "It is clear that the Global Financial Crisis (GFC) and knock-on effects on the financial markets have created a difficult environment for the financing of large-scale infrastructure projects. Whilst financing is still available and conditions are improving, financial institutions have become increasingly focused on the technical, economic and commercial fundamentals of the projects being financed. Against this background, there are now a number of CCS projects around the world moving towards the execution phase and likely to be seeking external financing as a key part of their funding plan. The financing challenge facing these projects not only relates to the challenges of the financial markets, but is compounded, in many cases, by the 'first of a kind' nature of the early CCS development projects and associated non-standard risks (technology/scale up/integration) of the industry. CCS investors and authorities, therefore, need to be very [cognizant] of the requirements of the financial institutions (in the broadest sense) whilst structuring the regulatory and commercial terms of the early projects in order to be able to access the debt required to finance the projects under development, and the industry as a whole in the longer term… this report looks at among other things: [1] The perception of CCS in the financial community; [2] Structuring considerations to [optimize] the availability

of finance; [3] The potential roles and requirements of various financing sources, including commercial banks, Export Credit Agencies, Public Finance Institutions and 'green banks'; [4] Likely appetite and capacity of identified financing sources now and in the future; and [5] The impact of funding source on debt terms including structure, tenor, covenants and pricing. [The authors] conclude by using three projects currently in development to illustrate, based on publically available information, how the findings of the work for this report could impact on the financing for the early CCS projects."

August 2014

"Second-Generation Reduced-Order Model for Calculation of Groundwater Impacts as a Function pH, Total Dissolved Solids, and Trace Metal Concentrations." The following is a summary of this NETL-published document completed as part of the National Risk Assessment Partnership (NRAP): "NRAP is developing a science-based toolset for the quantitative analysis of the potential risks associated with changes in groundwater chemistry from CO_2 injection. In order to address uncertainty probabilistically, NRAP is developing efficient, reduced-order models (ROMs) as part of its approach. These ROMs are built from detailed, physics-based process models to provide confidence in the predictions over a range of conditions. The ROMs are designed to reproduce accurately the predictions from the computationally intensive process models at a fraction of the computational time, thereby allowing the utilization of Monte Carlo methods to probe variability in key parameters. This report presents the development of ROMs designed to predict the evolution of several groundwater metrics over time in response to leakage of CO_2 and/or brine. The ROMs are based on simulations from continuum-scale reactive transport simulations in which the inherent uncertainties in the groundwater system were propagated throughout the predictive process. Lawrence Livermore National Laboratory's (LLNL) focus was on the assessing the magnitude of the trace element source term found in CO_2-rich brines, the impact of leakage from multiple wells, and aquifer heterogeneity. Potentially variable parameters that were considered include aquifer heterogeneity, permeability, porosity, regional groundwater flow, CO_2, total dissolved solids (TDS), and trace metal leakage rates over time. Aquifer heterogeneity was characterized from the proportions of geologic units identified from lithologic well logs from the High Plains Aquifer to derive spatial correlation lengths; variation in CO_2 and brine flux was derived from first-generation reservoir and wellbore models; and TDS and trace metal concentrations were based on reported storage reservoir compositions. The overall fidelity of the ROMs was very good with linear correlations greater than 0.9 when directly compared with simulated results."

"NSealR—A Brief User's Guide." The following is from the Executive Summary of this NETL-published document completed as part of NRAP: "This report provides a guide to the use 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 leakage 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 by 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, 1 relatively impermeable, fractured rock unit, initially saturated with a 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 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."

"Carbon Capture & Sequestration Market – Global Trends & Forecasts to 2019." The following is the Summary of this document: "[CCS] witnessed high growth in recent years due to increasing climatic concerns, environmental concerns, and regulatory norms imposed by local governments, which speed up the market. The various technologies in different regions helped [CCS] the companies in this market to create a niche market by capturing of carbon and their storage. The key services include capture, transport, and storage activities for safe [CCS] of the excessive carbon present in the atmosphere.
The CCS market is estimated to reach about $6.8 billion by 2019, signifying a firm growth rate of over 27.18 [percent] from 2013 to 2019. Currently, strict environmental regulations force operators to implement cost efficient carbon capturing practices and transportation that need to be addressed and corresponded to safe storage policies. The ongoing and upcoming developments in capture and storage activities are high opportunity areas for the [CCS] market. Geographically, the market has been studied for different regions such as the Americas, Europe, Asia-Pacific, and Middle East-Africa. The value of the market is analyzed in detail for all major countries…The study represents the trend of growth strategies adopted by the service provider companies of various types. The major strategies are identified: [1] Industrial expansion; [2] Contract agreements; [3] Merger and acquisitions; [4] Others. Key companies [CCS] market are Shell Cansolv (Canada), Siemens (Germany), Hitachi (Japan), Schlumberger (U.S.), Honeywell's UOP (U.S.) and Mitsubishi Heavy Industries (Japan). The leading companies in the [CCS] market focus on the growth of their industrial expansions with the key objective of serving power and gas companies. Thus, from 2010 to 2014, the contract agreements lead the growth strategies, accounting for around a share of 46 [percent]."

"CO_2 EOR Market - Permian Basin Industry Analysis, Size, Share, Growth, Trends and Forecast 2013 - 2019." The following is a description of this document: "The CO_2 EOR market report by Transparency Market Research provides an in-depth analysis of the Permian Basin CO2 EOR industry. The report provides comprehensive analysis of the CO_2 EOR fields, operators and their production capacities and also provides the forecasts and estimates for the Permian Basin CO2 supply market by volume. The report also analyses the demand and supply characteristics of the market by providing a detailed forecast and an analysis of volume and revenue for the period 2013 to 2019...."

Legislative

September 2013

"Media attention for climate change around the world: A comparative analysis of newspaper coverage in 27 countries." The following is the Abstract of this article: "Climate change is a global phenomenon, and its outcomes affect societies around the world. So far, however, studies on media representations of climate change have mostly concentrated on Western societies. This paper goes beyond this limited geographical scope by presenting a comparative analysis of issue attention in 27 countries. The sample includes, among others, countries that have committed themselves to [GHG] emission reductions under the Kyoto Protocol such as Germany as well as countries that are strongly affected by the consequences of climate change like India. In a first step, it describes the development of media attention for climate change in these countries from 1996 to 2010. Second, it compares the amount of media attention and explores whether it corresponds with indicators measuring the relevance of climate change and climate policies for a country. The analyses show that climate change coverage has increased in all countries. Still, overall media attention levels, as well as the extent of growth over time, differ strongly between countries. Media attention is especially high in carbon dependent countries with commitments under the Kyoto Protocol." **Andreas Schmidt, Ana Ivanova, and Mike S. Schäfer**, *Global Environmental Change*. (Subscription may be required to view article.)

October 2013

"Canadian energy and climate policies: A SWOT analysis in search of federal/provincial coherence." The following is the Abstract of this article: "This paper presents an analysis of Canadian energy and climate policies in terms of the coherence between federal and provincial/territorial strategies. After briefly describing the institutional, energy, and climate contexts, we perform a SWOT analysis on the themes of energy security, energy efficiency, and technology and innovation. Within this analytical framework, we discuss the coherence of federal and provincial policies and of energy and climate policies. [The authors'] analysis shows that there is a lack of consistency in the Canadian energy and climate strategies beyond the application of market principles. Furthermore, in certain sectors, the Canadian approach amounts to an amalgam of decisions made at a provincial level without cooperation with other provinces or with the federal government. One way to improve policy coherence would be to increase the cooperation between the different jurisdictions by using a combination of policy tools and by relying on existing intergovernmental agencies." **Camille Fertel, Olivier Bahn, Kathleen Vaillancourt, and Jean-Philippe Waaub**, *Energy Policy*. (Subscription may be required.)

"Incorporating ecosystem services into the implementation of existing U.S. natural resource management regulations: Operationalizing carbon [storage] and storage." The following is the Abstract of this article: "Many agencies and organizations, including in the United States federal government, are expressing interest in the measurement and valuation of ecosystem services. Despite this interest, specific guidance on whether and how to incorporate ecosystem services into federal activities remains scarce. This analysis examines three regulations that are important parts of the National Oceanic and Atmospheric Administration's mission to protect coastal and marine habitats: the Clean Water Act, the Coastal Zone Management Act, and the Natural Resources Damage Assessment process that is part of the Oil Pollution Act. Case studies of each reveal that it is possible to incorporate the carbon [stored] in coastal habitats, or 'carbon services,' into existing processes—consultative, regulatory, and mitigative—that are employed to implement these regulations. Specific examples illustrate how carbon services could be incorporated into the implementation of each federal regulation. The study concludes that incorporating carbon services into the implementation of existing environmental regulations could provide increased protection or restoration of coastal habitats. Increased conservation outcomes could result from changing the way the federal government implements national policy and/or by stimulating increased investment in coastal habitat conservation through private carbon markets.

These outcomes would result in a 'win-win' for both climate regulation and habitat conservation and would preserve not only the carbon services, but also the many ecosystem services these habitats provide." **Ariana E. Sutton-Grier, Amber K. Moore, Peter C. Wiley, and Peter E.T. Edwards**, *Marine Policy*. (Subscription may be required.)

November 2013

"U.K. Lawmakers Propose Amending Energy Law to Set Carbon Goal." A carbon target for power generation has been proposed by United Kingdom (U.K.) lawmakers in Parliament's upper chamber. Under the plan, the proposed law would be amended to persuade the government to set a target to reduce carbon emissions from the government by 2014 and the power industry by 2030. The proposal includes a provision for a target to be set in 2016, after the U.K.'s fifth carbon budget is set for the five years through 2032. The carbon budgets set limits on how much CO_2 the U.K. can emit in five-year periods, with the goal of cutting the country's overall emissions by 80 percent in the six decades through 2050. From *Businessweek* on October 27, 2013.

December 2013

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

January 2014

"Carbon Capture and Storage and the London Protocol: Recent Efforts to Enable Transboundary CO_2 Transfer." The following is the Abstract of this article: "In the absence of new energy policies or supply constraints, the International Energy Agency (IEA) estimates that energy-related CO_2 emissions in 2050 will be twice 2007 levels. However, the ETP 2012 2DG Scenario provides a technically achievable, low-cost strategy to reduce greenhouse gas emissions to a level consistent with a 2°C temperature increase. Under the 2DG Scenario, CCS would contribute just under one-fifth of total emissions reductions by 2050. To enable CCS to contribute at the levels in the 2DG Scenario, rapid growth in the number CCS projects is needed between today and 2020, and then the number of projects must grow steadily through 2050. As well as being a major financial, technical and logistical challenge, this is a significant regulatory challenge. Legal obstacles associated with global CCS deployment must be removed today including the prohibition on transboundary CO_2 transfer under the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972

(London Protocol). This paper reviews recent international actions to remove this prohibition; undertakes a legal analysis to identify possible options available to contracting parties under international law to allow transborder movement, pending entry into force of a formal, 2009 amendment enabling cross-border transportation of CO_2; and makes clear recommendations on the next best approach. It then looks at efforts undertaken by contracting parties and other organizations in 2011 and 2012 to update the 2007 Specific Guidelines for Assessment of Carbon Dioxide Streams for Disposal into Sub-seabed Geological Formations (2007 CO_2 Storage Guidelines) in light of the 2009 amendment." **Justine Garrett and Sean McCoy**, *Energy Procedia*. (Subscription may be required.)

February 2014

"[CO_2 Capture Wholesale Energy Price]." DOE officials told the House Energy and Commerce Oversight and Investigations Subcommittee the first generation of CCS technologies have a CO_2 captured cost of $70 to $90 per ton for wholesale electricity production and a second generation of technologies could reduce the cost to $40 to $50 per ton. Officials also said that projects highlighting the second generation of CCS technologies are likely to emerge in the coming years and the overall impact on electric prices would depend on the size and type of power plant installing the technology. Officials stated that each of the three aspects of CCS (carbon capture, carbon compression and transportation, and carbon injection and storage) have been shown and individually demonstrated and industrial applications of CCS are in use throughout the United States. To view the testimony and watch a video of the hearing, visit the Energy & Commerce Committee website. From *Bloomberg News* on February 12, 2014.

"Michigan Weighs Lower Tax for Carbon Dioxide-Injected Oil Wells." In January, Michigan lawmakers discussed bills that would reduce the severance tax from 6.6 percent to 4 percent for oil (EOR) and from 5 percent to 4 percent for gas (EGR) extracted (some smaller oil wells currently pay a 4 percent tax), allow CO_2 pipelines, and specify that eminent domain could be used to site pipelines in the same manner as oil and natural gas lines. The tax rate would decline for certain projects and may spur additional oil production, but it is unclear to lawmakers how the change could impact state revenues, according to a Michigan House Fiscal Agency analysis. The oil and gas severance tax currently generates approximately $60 million each year. From *MLive.com* on January 28, 2014.

March 2014

"Pipeline Bill Headed to Senate." A bill requiring any privately built intrastate pipeline to open the line for public use was discussed in the Mississippi Senate. By declaring eminent domain, Senate Bill 2568 would open up such pipelines, referred to as "common carriers," to other companies able to access them. As a result, property owners containing CO_2 reserves would be able to utilize the pipelines for enhanced oil recovery (EOR) and create jobs and revenue streams within the state. In addition, the bill would allow the Mississippi Public Service Commission to regulate disputes between shippers of natural gas and its derivatives and pipeline owners. From *Hattiesburg American* on February 10, 2014.

"House Approves Outman Bill Allowing Enhanced Oil Recovery." The Michigan House approved a four-bill package that will enable the statewide development of CO_2 enhanced oil and gas recovery, reduce the amount of CO_2 released into the atmosphere, generate new revenue for the Natural Resources Trust Fund, and create jobs within the state. House Bill 5254, which requires Senate approval, also updates the definition of a pipeline to include transportation of CO_2 to a well site. From *Michigan House Newsroom* on February 17, 2014.

"Steinberg Announces Major Proposal to Strengthen CA Climate Policy." California's Senate President pro Tempore announced a plan that would incentivize reduced fuel consumption and strengthen California's climate policies through 2050. The Senate leader announced a proposal to set targets in statute, beyond 2020, related to fossil fuel consumption and reinforce the climate goals of AB32 through 2030 and 2050; continue cap-and-trade for industrial plants but replace its current 2015 expansion into a carbon tax of a similar amount; return two-thirds of the carbon tax revenues to Californians through a state earned income tax credit; and invest the remaining carbon tax revenues into developing California's mass transit infrastructure. Full text of the speech is available here. From *California Senate President Pro Tempore Darrell Steinberg News Release* on February 20, 2014.

April 2014

"Heitkamp Announces Major Legislation To Put Coal On A Viable Path Forward." The U.S. Senator for North Dakota announced new legislation to help make it affordable for coal plants to lower their carbon emissions through the use of advanced clean coal technologies and provide a path forward for coal-fired power. Heitkamp's bill incentivizes companies to invest in technologies that reduce the carbon footprint of coal-fired power through Federal funding programs, Federal support for private investment, and recommendations to Congress that provide insight on how best to support future CCS projects in the United States. The bill supports the development and implementation of technologies that reduce the carbon footprint of coal-fired power plants through the following: developing large-scale carbon storage programs; increasing the accessibility of funds in existing Federal programs; revamping the existing R&D programs for advanced coal and CCS technologies; increasing the current tax credit for carbon storage from coal facilities; creating a variable price support for companies that capture CO_2; creating clean energy coal bonds; and requiring DOE reports to Congress on the economic and technical status of CCS research and projects. From *U.S. Senator Heidi Heitkamp News Release* on March 24, 2014.

"Calley signs legislation encouraging further recovery of oil from existing wells." Michigan's Lieutenant Governor signed House Bill 4885 (now Public Act 82 of 2014), which reduces taxes paid by companies that use the EOR process to extract oil. In Michigan, oil and gas production is taxed under the Severance Tax Act. The tax rates are 6.6 percent for oil and 5 percent for natural gas, though the rate is reduced to 4 percent on wells that produce less than 10 barrels per day or 20 to 35 barrels a day. HB 4885 sets a flat four percent severance tax rate for companies using EOR. According to the news release, there are currently eight EOR projects underway that have combined to produce approximately 1.5 million barrels of oil since the first project began in 1997. An additional 200 million to 350 million barrels of oil could potentially be recovered through EOR, totaling 30 to 50 times Michigan's current annual production. Projects can only be undertaken with approval of Michigan's Department of Environmental Quality. Also signed were three bills that provide for the use of eminent domain when laying pipelines to transport CO_2: HB 5254, HB 5255, and HB 5274 (now Public Acts 83, 84 and 85, respectively). From *Governor Rick Snyder Press Release* on April 4, 2014.

May 2014

"Rockefeller Announces Major Initiatives to Promote Clean Coal Technology." A U.S. Senator from West Virginia introduced two bills to advance commercial deployment of clean coal technologies. The legislation, "Carbon Capture and Sequestration Deployment Act of 2014" and "Expanding Carbon Capture through Enhanced Oil Recovery Act of 2014," would, among other provisions, invest in Federal CCS research and development (R&D); expand tax credits for innovative companies investing in CCS technologies; and create loan guarantees for construction of new CCS facilities, as well as retrofits of existing facilities that utilize CCS. From *U.S. Senator Jay Rockefeller News Release* on May 5, 2014.

June 2014

"Planning for offshore CO_2 storage: Law and policy in the United Kingdom." The following is the Abstract of this article: "'Offshore CO_2 storage' refers to the injection of liquefied CO_2 into deep geological formations beneath the seabed (e.g. depleted oil and gas reservoirs, and saline [formations]) for the purpose of storing it there on a permanent basis. The storage in this manner of captured CO_2 emissions from industrial installations and power plants has attracted considerable scientific and technical interest as a potential mitigation response to climate change. A key issue facing policymakers in several countries is how to reconcile policy commitments to develop offshore CO_2 storage with other competing – and potentially conflicting – uses of the marine environment. With a view to informing policy responses to this issue, this paper presents a case study of legal and policy frameworks concerning offshore CO_2 storage in United Kingdom. The paper maps key design features of the United Kingdom's framework for marine permitting and planning, appraising the extent to which they enable orderly development of offshore CO_2 storage in a manner consistent with relevant high-level policy objectives." **Ben Milligan**, *Marine Policy*. (Subscription may be required.)

"Carbon capture and storage and transboundary pollution: A differential game approach." The following is the Abstract of this article: "[The authors] study the strategic behavior of two countries facing transboundary CO_2 pollution under a differential game setting. In [the authors'] model, the reduction of CO_2 concentration occurs through the [CCS] process, rather than through the adoption of cleaner technologies. Furthermore, [the authors] first provide the explicit short-run dynamics for this dynamic game with symmetric open-loop and a special Markovian Nash strategy. Then, [the authors] compare these strategies at the games' steady states and along some balanced growth paths. [The authors'] results show that if the initial level of CO_2 is relatively high, state dependent emissions reductions can lead to higher overall environmental quality, hence, feedback strategy leads to less social waste." **Luisito Bertinelli, Carmen Camacho, and Benteng Zoi**, *European Journal of Operational Research*. (Subscription may be required.)

July 2014

"Missouri Governor Signs Bill on Carbon Emissions." The Governor of Missouri signed legislation that directs Missouri regulators to develop standards for CO_2 emissions from power plants. The bill follows the U.S. Environmental Protection Agency's (EPA) proposed rules, which would require Missouri to cut CO_2 emissions from power plants by more than 20 percent by 2030. Missouri legislators had passed the measure before the EPA-proposed regulations were released. The bill is available via the Missouri House of Representatives website. From *SF Gate* on July 7, 2014.

"The cost of carbon dioxide abatement from state renewable portfolio standards." The following is the Abstract of this article: "Renewable portfolio standards (RPSs) have become a popular tool for state governments to promote renewable electricity generation and to decrease [CO_2] emissions within a state or region. Renewable portfolio standards are a policy tool likely to persist for many decades due to the long term goals of many state RPSs and the likely creation of a federal RPS alongside any comprehensive climate change bill. Even though RPSs have become a popular policy tool, there is little empirical evidence about their costs. Using the temporal and regional variation in RPS requirements, [the author estimates] the long-run price elasticity of supply of renewable electricity generation to be 2.67 (95% CI of 1.74, 3.60). Using [the author's] preferred elasticity estimate, [the author calculates] the marginal cost of abatement from RPSs is at least $11 per ton of CO_2 compared to a marginal cost of abatement of $3 per ton in the Regional Greenhouse Gas Initiative." **Erik Paul Johnson**, *Resource and Energy Economics*. (Subscription may be required.)

"Carbon strategies and management practices in an uncertain carbonomic environment – lessons learned from the coal-face." The following is the Abstract of this article: "For many businesses, carbon strategies are undertaken within a backdrop of an uncertain national carbon policy. Such was the case in Australia with the major political parties having radically different policies as to tackle the issue of climate change. However, despite such uncertainty, forward-thinking early movers have incorporated carbon awareness into their business decisions. This research investigates the carbon strategies and carbon management practices that were adopted by two firms operating at different levels of the Australian national energy market – one operates in energy transmission and distribution, and the other is an energy generator and retailer. The metaphor of 'the coal-face' is used to analogize the business practitioners from the studied firms who understand and are directly involved in day-to-day practices to handle carbon emissions issues in their organizations. The research findings highlight that while operating in the same industry, the firms employ different carbon strategies and carbon management practices to manage their compliance liabilities. Applying the lens of contingent resource-based view, the factors that explain their different carbon practices include the extent of carbon exposures, the sector-specific regulatory setting and the in-house capabilities to deal with carbon issues. In addition, this study synthesizes a general template of corporate carbon management framework, based on the real practices of studied firms, to provide practical guidelines for effectively developing carbon management strategies in an uncertain environment." **Dina Wahyuni and Janek Ratnatungab**, *Journal of Cleaner Production*. (Subscription may be required.)

August 2014

"Carbon Capture and [Storage]." The following is the Abstract of this article: "This chapter examines U.S. laws applicable to CCS and identifies reforms that will be necessary for CCS to operate as a viable GHG emissions control strategy domestically. In the United States, few, if any, new coal-fired power plants are some have been designed to facilitate economical retrofitting. In September 2013, the U.S. Environmental Protection Agency (EPA) issued a proposed rule to limit GHG emissions from use of CCS at some new plants. [EPA was directed] to propose a rule by 2014 to limit GHG emissions from existing plants. U.S. policy on CCS is potentially critical to its adoption as an emissions control strategy in other countries, as well. Adoption of CCS by high GHG-emitting countries such as China and India may require effective demonstration of both the capture technology and sequestration at commercial scale in the United States. China has taken steps towards developing CCS technology, but more widespread adoption of CCS globally may be facilitated or accelerated by its development at commercial scale in the United States." **Wendy B. Jacobs**, *Chapter 17, in Global Climate Change and U.S. Law*. (Subscription may be required.)

Announcements

September 2013

DOE's NETL Releases Revised Editions of Best Practice Manuals (BPMs). The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) released revised editions of the following Best Practice Manuals (BPMs): "Public Outreach and Education for Carbon Storage Projects," "Risk Analysis and Simulation for Geologic Storage of CO_2"; "Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations"; and "Carbon Storage Systems and Well Management Activities." The BPMs are available via the Carbon Storage Program Reference Shelf.

RGGI Releases Q2 2013 Secondary Market Report. The Regional Greenhouse Gas Initiative (RGGI) released the "Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2013" as part of the ongoing monitoring of RGGI auctions and secondary markets. The report, prepared by Potomac Economics, found that RGGI CO_2 allowance prices stabilized in the second quarter of 2013, as prices averaged $3.40, prices of Intercontinental Exchange (ICE) futures averaged $3.41, and the clearing price in Auction 20 was $3.21.

November 2013

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

RGGI States Initiate Bidding Process for Auction 22. The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2013 auctions released an Amendment to the Auction Notice for the 22nd CO_2 allowance auction, scheduled for December 4, 2013. The Auction Notice Amendment is available via the RGGI website. RGGI is the first market-based regulatory program in the United States.

December 2013

Regional Greenhouse Gas Initiative (RGGI) Q3 2013 Secondary Market Report. The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) market, Potomac Economics, found no evidence of anti-competitive conduct in the RGGI CO_2 allowance secondary market. The report also showed that that RGGI CO_2 allowance prices fell 11 percent in the third quarter of 2013, as prices recorded in RGGI's CO_2 Allowance Tracking System averaged $3.03 and prices of ICE futures averaged $3.01. Secondary market prices exhibited a premium over the auction clearing price in the third quarter of 2013. The Auction 21 clearing price was $2.67. At the end of the third quarter of 2013, 82 percent of RGGI CO_2 allowances were held by compliance entities and their affiliates.

January 2014

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

February 2014

Draft of the Climate Registry's General Verification Protocol Version 2.1. The Climate Registry released a draft of General Verification Protocol (GVP) Version 2.1 for a public comment in January. The proposed updates to GVP v. 2.1 included a new option for verifications to be conducted to a limited level of assurance (existing policy requires a reasonable level of assurance). The proposed updates provide Members with the flexibility to choose the level of assurance that best meets their needs and objectives. The Climate Registry has also proposed that only inventories verified to a reasonable level of assurance are eligible for Climate Registered™ Silver, Gold, or Platinum, or to serve as a base-year report through The Registry.

March 2014

DOE Releases $8 Billion Solicitation for Advanced Fossil Energy Projects. DOE published a solicitation in December 2013, making up to $8 billion in loan guarantee authority available to support innovative advanced fossil energy projects that avoid, reduce, or store greenhouse gases (GHGs). The loan guarantees under this new solicitation will help provide financing to support new or significantly improved advanced fossil energy projects, such as advanced resource development, carbon capture, low-carbon power systems, and efficiency improvements, which reduce emissions of CO_2, methane (CH_4), and other GHGs.

RGGI Releases Report: Regional Investment of RGGI CO_2 Allowance Proceeds, 2012. The Regional Greenhouse Gas Initiative (RGGI) released a report summarizing the consumer, economic, and environmental impact of investments made from 2009 to 2012 using proceeds from RGGI's CO_2 allowance auctions. The report estimates that RGGI investments in energy efficiency, clean and renewable energy, and other strategic energy programs will return more than $2 billion in lifetime energy bill savings to more than 3 million participating households and more than 12,000 businesses in the region.

RGGI Releases Fourth Quarter Secondary Market Report. Potomac Economics, the independent market monitor for RGGI, released a report, titled, "Report on the Secondary Market for RGGI CO_2 Allowances: Fourth Quarter 2013." According the report, CO_2 allowance prices rose from approximately $2.70 in early October to approximately $3.35 in late December, and secondary market prices were consistent with the auction clearing price. The report also found that volumes increased during the quarter for both the physical transfers of CO_2 allowances and the trading of CO_2 allowance futures and options.

April 2014

RGGI States Initiate Bidding Process for Auction 24. The states participating in the Regional Greenhouse Gas Initiative (RGGI) 2014 auctions released the Auction Notice and application materials for the 24th CO_2 allowance auction scheduled for June 4, 2014. The Auction Notice provides potential auction participants with the information needed to submit a Qualification Application and indicate their intent to bid. States will offer 18,062,384 CO_2 allowances for sale at a reserve price of $2.00.

NETL-Led Laboratory-Industry-Academia Collaboration Is Accelerating Carbon Capture Technologies. The National Energy Technology Laboratory (NETL) established the Carbon Capture Simulation Initiative (CCSI) to take carbon capture concepts from the laboratory to the power plant more quickly, at a lower cost, and with reduced risk. The CCSI Toolset, a suite of computer models and computational tools that enable the development and deployment of new carbon-capture technologies, is part of this initiative. Five companies from the CCSI industry team have licensed the toolset, with industry partners demonstrating how they are applying the toolset, sharing experiences to help improve the tools, and identifying opportunities for further collaboration.

Draft Permit Approved for FutureGen 2.0. The U.S. Environmental Protection Agency (EPA) approved a preliminary permit for FutureGen 2.0, a project that expects to store millions of metric tons of CO_2 over a period of more than 20 years in Illinois. An open house and public hearing are scheduled and written comments will be accepted through May 15. The ruling on a final permit depends on the number of public comments submitted to EPA.

May 2014

BSCSP Breaks Ground at Kevin Dome. The Big Sky Carbon Sequestration Partnership (BSCSP) broke ground for the first production well for the Kevin Dome Carbon Storage project. Well drilling is scheduled to begin in early May, dependent on weather conditions. The production well will be used to extract naturally occurring CO_2 located at an approximate depth of 3,800 feet. BSCSP will be logging and coring the well, in addition to testing CO_2 chemical composition and measuring "producibility." BSCSP is also preparing a nearby site for drilling the first monitoring well for geochemical monitoring throughout the project.

National Climate Assessment Available. The National Climate Assessment summarizes the present and future impacts of climate change on the United States. The report includes analyses of impacts on seven sectors (human health, water, energy, transportation, agriculture, forests, and ecosystems) and the interactions of these sectors at the national level. The report also assesses impacts on U.S. regions (Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawaii and Pacific Islands, and U.S. coastal areas, oceans, and marine resources). A team of individuals guided by a Federal Advisory Committee produced the report, which was reviewed by the public and experts, including Federal agencies and a panel of the National Academy of Sciences (NAS).

Global CCS Map Re-launched. The Scottish Carbon Capture & Storage (SCCS) organization re-launched their Global CCS Map to provide information on projects that support the development of the full CCS chain. The database contains information on more than 200 small- to large-scale CCS projects. The map offers display buttons allowing the user to filter information in the viewing window (e.g., the project's developer, current status, CO_2 capture method, planned volume of CO_2 storage, project data, useful links, and news updates).

June 2014

DOE Announces Demonstration Project Startup. DOE and Tampa Electric Company (TECO) announced the startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida. The Polk Power Station is the first coal integrated gasification combined cycle (IGCC) plant in the United States. IGCC technology has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, while increasing reliability and reducing the cost of capturing CO_2 and other contaminant emissions from power plants.

State Approves FutureGen Plans. The Illinois Commerce Commission approved transportation and storage plans for the FutureGen 2.0 initiative, which will capture and transport CO_2 by pipeline

approximately 28 miles to Morgan County, Illinois, for injection. The Illinois Commerce Commission approval is the last needed from the state agency, although approval is contingent upon receiving all necessary permits from Federal agencies.

BSCSP Kevin Dome Carbon Storage Project Blog Available. The Big Sky Carbon Sequestration Project (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. For more information, please see the “Carbon Storage in the News” section of this newsletter.

July 2014

DOE Reaches Agreement to Test Carbon Capture and Gasification Technologies. DOE signed a new five-year cooperative agreement with Southern Company to evaluate advanced carbon capture and gasification technologies at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama, USA. Under the NETL-managed agreement, Southern Company will test pre- and post-combustion carbon-capture technologies, materials, and processes that support advanced fossil-fuel conversion systems, primarily coal gasification.

August 2014

DOE-Sponsored Project Shows Potential for Carbon Storage in Wyoming. A DOE-sponsored study revealed that the Wyoming Rock Springs Uplift (a geologic feature in southwestern Wyoming) could potentially store 14 to 17 billion metric tons of CO_2. The Rock Springs Uplift was found to have ideal geologic characteristics for carbon storage and proximity to large, anthropogenic CO_2 emission sources. The Wyoming Rock Springs Uplift storage potential is equal to 250 to 300 years’ worth of CO_2 emissions produced by Wyoming’s coal-fired power plants and other large regional anthropogenic CO_2 sources at current emission levels.

Contact Information:

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

13131 Dairy Ashford Road, Suite 225
Sugar Land, TX 77478-4396

1450 Queen Avenue SW
Albany, OR 97321-2198

420 L Street, Suite 305
Suite 201
Anchorage, AK 99501-5901

Contacts:

Traci Rodosta
U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507
Phone: (304) 285-1345
Fax: (304) 285-4638
traci.rodosta@netl.doe.gov

For more information on the Carbon Storage Program please visit:

DOE's Carbon Storage Program