NETL's Carbon Storage Newsletter: Annual Index

September 2015 – September 2016

This is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters published over the last 13 months. The newsletter is produced by NETL to provide information on activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news. This Annual Index covers newsletters issued from September 2015 to September 2016. Outdated Information (e.g., conference dates, paper submittals, etc.) has been removed.

For more information on the U.S. Department of Energy's (DOE) Carbon Storage Program, click here.

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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Highlights

September 2015

"DOE Selects Nine Projects to Receive Funding for Carbon Storage Intelligent Monitoring and Well Integrity and Mitigation Research." Nine projects have been selected by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) to receive funding through DOE's Carbon Storage Program to research new carbon dioxide (CO_2) storage technologies devoted to intelligent monitoring systems and advanced well integrity and mitigation approaches. The selected projects focus on the following three research priorities: (1) carbon capture and storage (CCS)-specific intelligent systems for monitoring, controlling, and optimizing CO_2 injection operations; (2) diagnostic tools and methods capable of characterizing borehole release pathways or fluid flow in existing wells; and (3) next-generation materials and methods for mitigating wellbore release. From *energy.gov* on August 17, 2015.

October 2015

"NETL's 2015 Carbon Storage Atlas Shows Increase in U.S. CO_2 Storage Potential." The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) released the fifth edition of the Carbon Storage Atlas (Atlas V), which shows prospective carbon dioxide (CO_2) storage resources of at least 2,600 billion metric tons – an increase over the findings of the 2012 Atlas. Atlas V highlights potential CO_2 storage resources in saline formations, oil and natural gas reservoirs, and unmineable coal seams. This edition also presents a detailed look at the Regional Carbon Sequestration Partnership (RCSP) Initiative's large-scale field projects, which are uniquely tailored to address technical and non-technical challenges within their respective regions. For each large-scale field project, Atlas V provides a summary of approaches taken, technologies validated, and lessons learned in carrying out key aspects of a carbon capture and storage (CCS) project: site characterization; risk assessment; simulation and modeling; monitoring, verification, accounting, and assessment; site operations; and public outreach. These efforts collectively contribute to the development of regional carbon management plans, aid in regulatory development, and help determine appropriate infrastructure for CCS commercialization in each region. From *NETL News Release* on September 28, 2015.

"Energy Department Selects Five Projects in First Step to Produce Fresh Water from CO_2 Storage Sites." DOE/NETL selected five projects to develop and validate strategies to manage pressure and the flow of CO_2 in saline formations through a Brine Extraction Storage Test (BEST). The projects will be managed by DOE/NETL under the Carbon Storage Program. In addition, the selected projects will also support the clean energy and climate goals announced by the U.S. and Chinese governments in November 2014. Following the feasibility and design phase, one of the recipients will be selected for a pilot project to validate brine/water injection and treatment technology. From *energy.gov* on September 16, 2015.

November 2015

"Secretary Moniz Announces New CO_2 Storage Network at Multinational Carbon Sequestration Forum." The U.S. Department of Energy (DOE) announced the formation of an international initiative to facilitate collaborative testing of advanced carbon capture and storage (CCS) technologies in a real-world, saline storage environment. The Carbon Sequestration Leadership Forum's (CSLF) Large-Scale Saline Storage Project Network will form a global network of large-scale carbon dioxide (CO_2) injection sites that can share best practices, operational experience, and key lessons to advance the deployment of CCS. The collaboration builds on the CO_2 Capture Test Center Network, which has been chaired by

Norway since 2013; the United States will chair the capture center in 2016. From *energy.gov* on November 4, 2015.

"Underground CO_2 Storage, Natural Gas Recovery Targeted by Virginia Tech/NETL Researchers." Researchers from DOE's National Energy Technology Laboratory (NETL) and Virginia Polytechnic Institute and State University (Virginia Tech) are investigating the feasibility of permanently and safely storing CO_2 underground while simultaneously recovering natural gas. The research is testing the use of CO_2 captured from power plants and industrial facilities to force natural gas out of the pores of organic-rich sedimentary rocks where the natural gas becomes trapped over time. In the process, the injected CO_2 would remain safely and permanently stored. Virginia Tech's Virginia Center for Coal and Energy Research (VCCER) initiated the injection of up to 20,000 tons of CO_2 into a coalbed methane field in Buchanan County, Virginia, USA, in July 2015. Researchers will use a state-of-the-art monitoring, verification, and accounting (MVA) program to monitor and collect data as the CO_2 is injected into the coal seams. The NETL-VCCER project was initiated in 2011 and builds upon earlier carbon storage tests conducted by the Southeast Regional Carbon Sequestration Partnership (SECARB), one of DOE's Regional Carbon Sequestration Partnerships (RCSPs). From *energy.gov* on October 20, 2015.

February 2016

"President's FY 2017 Budget Includes $878 Million for Fossil Energy Programs." The FY 2017 Budget includes a request for $90.9 million for carbon storage research and development (R&D). The funding request supports: (1) storage field management projects, including the Regional Carbon Sequestration Partnerships (RCSPs), and other field characterization and injection projects; (2) risk and integration tool development; and (3) advanced storage R&D efforts, as part of the U.S. Department of Energy's (DOE) Subsurface crosscut, to develop laboratory- and bench-scale technologies for identifying and obtaining new subsurface signals, ensuring wellbore integrity, and increasing understanding of the stress state and induced seismicity. From *energy.gov* on February 9, 2016.

"NETL Carbon Capture Technologies to be Used in Commercial Biomass-to-Biofuel Conversion Process with Power Generation." Two patented sorbent technologies that capture carbon dioxide (CO_2) from streams of mixed gases have been granted a license by DOE's National Energy Technology Laboratory (NETL). CogniTek Management Systems will incorporate the technologies into its integrated biomass-to-biofuels conversion process with power generation. The process will have naturally low CO_2 emissions, as the plants used as feedstock consume CO_2 from the atmosphere as part of their growth process. The technologies are expected to result in a "near 100 percent carbon negative" process. To learn more about NETL's role, visit their Technology Transfer webpage. From *NETL News Release* on January 20, 2016.

March 2016

"New Tools to Monitor Carbon Storage Risks Released for Testing." Simulation tools developed by the U.S. Department of Energy (DOE)-led National Risk Assessment Partnership (NRAP) are under review by members of industry, regulatory agencies, universities, and other organizations, such as the Regional Carbon Sequestration Partnerships (RCSPs). The successful deployment of the tools will enable users to predict the safety and permanence of carbon storage systems. Following review, the NRAP project team will implement improvements based on the feedback, with the final tool release expected in late 2016. For more information on NRAP and the new tool set, visit the NRAP website. From *Energy.gov* on February 11, 2016.

"U.S. Takes the Helm of International Carbon Capture Test Network." The International Test Center Network (ITCN), a global consortium of facilities conducting research and development (R&D) on carbon capture technologies, will be led by the United States (represented by the Office of Fossil Energy [FE]),

according to an announcement from DOE and Norway's Technology Centre Mongstad (TCM). The ITCN, which also includes facilities in Australia, Canada, Germany, and the United Kingdom (UK), was formed by the DOE-sponsored National Carbon Capture Center (NCCC) and TCM to facilitate knowledge transfer from carbon capture test facilities around the world. Since its inception, the ITCN members have shared lessons learned from carbon capture R&D to aid in the commercial development of carbon capture and storage (CCS) technologies. From *Energy.gov* on February 24, 2016.

April 2016

"U.S. Department of Energy Announces Funding Opportunities for Subsurface Technology and Engineering Crosscut Initiative." The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) announced a collaborative funding opportunity that will focus on advanced research projects aimed at the deployment and validation of carbon storage monitoring, verification, and accounting technologies in an operational field environment. The Funding Opportunity Announcement (FOA), titled "Development of Technologies for Sensing, Analyzing, and Utilizing Novel Subsurface Signals in Support of the Subsurface Technology and Engineering (SubTER) Crosscut Initiative," will also focus on the identification and validation of new technologies that characterize and image critical subsurface features. The FOA is sponsored through the Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office (GTO) and the Office of Fossil Energy's (FE) Carbon Storage Program. The closing date for applications is May 5, 2016. From *Energy.gov* on March 10, 2016.

May 2016

**"UK Center for Applied Energy Research Receives $2.4M Grant for U.S.-China Clean Energy Research Center."** The U.S. Department of Energy (DOE) selected the University of Kentucky's Center for Applied Energy Research (CAER) for a renewal of its U.S.-China Clean Energy Research Center (CERC) grant. The five-year DOE grant will support CAER efforts to develop advanced coal technologies. CAER is a member of CERC's Advanced Coal Technologies Consortium, whose purpose is to advance American and Chinese collaboration in advanced coal technologies, specifically carbon capture and utilization, advanced combustion systems, and geologic carbon dioxide (CO_2) storage. CERC, created in 2009 by DOE, the China Ministry of Science and Technology, and the China National Energy Administration, facilitates joint research and development (R&D) on clean energy by research teams from the United States and China. From *University of Kentucky Center for Applied Energy Research* on April 29, 2016.

June 2016

"Energy Department Selects Projects to Demonstrate Feasibility of Producing Usable Water from CO_2 Storage Sites." The U.S. Department of Energy (DOE) selected two projects to test enhanced water recovery (EWR) technologies for their potential to produce useable water from carbon dioxide (CO_2) storage sites. The two projects, which will be managed by DOE's National Energy Technology Laboratory (NETL), were selected from the five Brine Extraction Storage Test (BEST) projects awarded in September 2015. The projects will receive funding to implement their field plan to validate their proposed approaches for managing reservoir pressure and the flow of stored CO_2 in saline reservoirs. The purpose of BEST field projects are to develop and validate engineering strategies and approaches for managing formation pressure through brine extraction, as well as to help to find cost-effective ways to treat extracted brines. From *Energy.gov* on June 3, 2016.

"NETL Launches a University Coalition for Fossil Energy Research at Pennsylvania State University." DOE's NETL selected Pennsylvania State University (PSU) as the lead institution for the University Coalition for Fossil Energy Research. The Coalition brings together a multi-disciplinary team of researchers from different universities to address the research challenges of fossil energy-based

technologies. In support of the Office of Fossil Energy's (FE) Coal Program and Oil and Gas Program, research conducted by the Coalition will focus on a variety of areas, including carbon capture and storage (CCS). The six-year initiative is expected to help accelerate the development and deployment of fossil fuel-based technologies in a cost-effective and environmentally safe manner. From *Energy.gov* on May 11, 2016.

July 2016

"DOE Announces $68.4 Million in Funding to Advance the Safe and Permanent Storage of CO_2." The U.S. Department of Energy (DOE) announced funding for cost-shared research and development (R&D) projects focused on the safe and permanent storage of carbon dioxide (CO_2) during carbon capture and storage (CCS) operations. The Carbon Storage Assurance and Facility Enterprise (CarbonSAFE) initiative is intended to develop integrated CCS storage complexes, constructed and permitted for operation in the 2025 timeframe following a series of developmental phases. Phase I CarbonSAFE: Integrated CCS Pre-Feasibility seeks R&D projects to provide pre-feasibility studies for a commercial-scale geologic storage site. Phase II CarbonSAFE: Storage Complex Feasibility seeks R&D projects to perform the initial characterization of a storage complex. From *energy.gov* on June 24, 2016.

August 2016

"DOE Investing $11.5 Million to Advance Geologic Carbon Storage and Geothermal Exploration." The U.S. Department of Energy (DOE) selected eight new research and development (R&D) projects to receive Federal funding under its Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) Crosscut initiative. The projects, which will be funded by the Office of Fossil Energy's (FE) Carbon Storage Program and the Office of Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office (GTO), will address two objectives. Projects selected under the first objective – to deploy and validate prototype carbon storage monitoring, verification, and accounting (MVA) technologies in an operational field environment – will deploy technologies or techniques associated with near-surface and/or subsurface monitoring at a large- or commercial-scale site for validation. Projects selected under the second objective – to identify and validate new subsurface signals to characterize and image the subsurface – will develop new approaches to characterize and image subsurface systems. From *energy.gov* on July 27, 2016.

"Texas CO_2 Capture Demonstration Project Hits Three Million Metric Ton Milestone." A carbon capture and storage (CCS) project sponsored by DOE and managed by the National Energy Technology Laboratory (NETL) has successfully captured and transported 3 million metric tons of carbon dioxide (CO_2) via pipeline. The project demonstrates the implementation of Air Products and Chemicals, Inc.'s vacuum swing adsorption technology into a hydrogen production facility in Port Arthur, Texas, USA. The gas separation technology captures 90 percent of the CO_2 from the product streams of two commercial-scale steam methane reformers. In addition, the project verifies the effective use of CO_2 enhanced oil recovery (EOR) for permanently storing CO_2, as the CO_2 captured from the Port Arthur facility is being used for EOR at the West Hastings Unit (oilfield) in southeast Texas, USA. The West Hastings Unit is estimated to have the potential to produce in the range of 60 to 90 million additional barrels of oil using CO_2 injection. The Air Products project is supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program. From *energy.gov* on June 30, 2016.

September 2016

"DOE's Carbon Storage Advances Featured in Special Issue of International Journal of Greenhouse Gas Control." Carbon storage research conducted under the U.S. Department of Energy's (DOE) National Risk Assessment Partnership (NRAP) was highlighted in a special August 2016 issue of

the *International Journal of Greenhouse Gas Control*, which is comprised of a compendium of research generated by the NRAP team over six years of collaboration. This is the first special issue focused on results from a research team, and the articles detail advancements in scientific understanding, risk assessment methodology, and computational tool development related to full geologic carbon dioxide (CO_2) storage system performance. Release of the special issue coincides with the completion of NRAP's first phase of research, which resulted in the generation of first-of-kind scientific data, methodologies, and simulation tools to support quantitative assessment of environmental risks associated with industrial-scale geologic CO_2 storage. NRAP is now transitioning into a second phase, in which the risk-assessment methodologies and tools developed during Phase I will be applied to real-world CO_2 storage sites, and new tools and findings will be generated to help effectively manage carbon storage operations. From *energy.gov* on August 18, 2016.

"DOE Seeks Projects to Advance Carbon Dioxide Utilization from Coal-Fired Power Plants." DOE released a Funding Opportunity Announcement (FOA) focused on securing applications for projects that will develop CO_2-utilization technologies that produce useful products, without generating additional greenhouse gas (GHG) emissions, at a lower cost than currently available technologies. The FOA has three areas of interest: (1) biological-based concepts for beneficial use of CO_2, (2) mineralization concepts utilizing CO_2 with industrial wastes, and (3) novel physical and chemical processes for beneficial use of carbon. More information on the FOA, titled "Applications for Technologies Directed at Utilizing Carbon Dioxide from Coal-Fired Power Plants," is available via FedConnect. The projects will be a part of DOE's Carbon Storage Program. From *energy.gov* on August 25, 2016.

Carbon Storage in the News

September 2015

"New Test Campaign Started at TCM, Mongstad." Technology Center Mongstad (TCM) will conduct new tests of the monoethanolamine (MEA) solvent in their amine plant in order to aid in the advancement of the CCS industry. The tests will result in lessons learned and reduce potential technology risks with the scale-up and operation of a full-scale capture plant. The results of the tests, which will include parameters such as energy consumption, emissions, degradation, and plant operability, will be made public, providing an MEA baseline for CCS applications. Based on TCM's previous MEA tests from November 2013 through February 2014, several other areas will be investigated further, such as CO_2 mass balances, optimized capture rates, and specific energy consumption; plant performance and effect of higher CO_2 concentrations in flue gas; and emission monitoring. From *TCM News Release* on August 12, 2015.

"UK Launches Free Access to National CO_2 Storage Database." The CO_2 Storage database, hosted by the Crown Estate and the British Geological Survey (BGS) and under license from the Energy Technologies Institute (ETI), has been made free for subscribers. The web-enabled database contains geologic data, storage estimates, and risk assessments of nearly 600 potential CO_2 storage units of depleted oil and gas reservoirs and saline formations in the United Kingdom (UK). The outcome of ETI's October 2009 UK CO_2 Storage Appraisal Project, the database went live in 2013 and provides stakeholders with information to enable more informed decisions related to CCS infrastructure in the UK, as well as to reduce the early-stage costs of offshore storage site selection. From *ClickGreen* on August 20, 2015.

"Australian Government Invests in CCS Research Fund." The Australian government launched a research fund designed to facilitate industry investment and research of CCS technologies. The CCS Research Development and Demonstration Fund, which will focus on transport and storage projects, will address research priorities in CCS, such as subsurface knowledge and mapping, transport infrastructure, whole of chain integration, and development of international collaboration and partnerships. While activities will primarily be based in Australia, support will also be provided to leverage international expertise. From *Carbon Capture Journal* on September 2, 2015.

October 2015

"BHP Billiton and SaskPower Partner to Accelerate Development of Carbon Capture & Storage." SaskPower will share data, information, and lessons learned from its Boundary Dam facility with BHP Billiton in a new partnership to accelerate the global development of CCS technology. Under the Memorandum of Understanding (MOU), BHP Billiton would contribute to the establishment of a global knowledge center focused on promoting research and reducing potential costs and risks associated with new CCS projects. From *BHP Billiton News Release* on September 10, 2015.

"Devon to Dedicate $100M CO_2 Oil Recovery Project." Devon Energy will invest approximately $100 million into a CO_2 injection facility to serve the Big Sand Draw in the Wind River Basin near Riverton, Wyoming, USA. The investment will be used for enhanced oil recovery (EOR). According to Devon officials, the company is currently producing 2,500 barrels of CO_2 per day at Big Sand Draw; the company expects production to peak beyond 5,000 barrels per day in the near future as more wells come online. From *Wyoming Business Report* on September 18, 2015.

"UK Government Awards [Approximately $2.6 Million] to CCS Projects." The United Kingdom (UK) government's Energy Entrepreneurs Fund awarded funding to three projects for the development and demonstration of CCS technologies to support cost reductions and innovation. In one project, Carbon

Clean Solutions, Ltd., will compare the performance of different solvents to remove CO_2 from flue gases. In another project, C-Capture, Ltd., will investigate amine-free solvents for suitability and scaling-up for industry use. In the final project, FET Engineering, Ltd., will aim to make their PureStream technology available for commercial deployment by 2017. From *Carbon Capture Journal* on October 2, 2015.

"British Study Finds New Potential for Carbon Storage." According to a case study on CCS in the North Sea, CO_2 storage in geologic formations could be optimized by injecting the CO_2 into two points simultaneously. The British Geological Survey (BGS) case study found that using the "dual-injection" method allowed for storing more CO_2 in less area. The BGS case study was conducted in the Captain Sandstone in the North Sea, which lies more than one mile beneath the sea surface off the northeast coast of Scotland. More information on the study is available via a Scottish Carbon Capture and Storage (SCCS) press release. From *UPI.com* on September 10, 2015.

"North Sea Carbon Storage Scheme Gets Support." The UK government announced plans to support a Royal Dutch Shell CCS program in the North Sea. With assistance from a UK energy company, Royal Dutch Shell is proposing to capture CO_2 released from an Aberdeen power station and store it in the Goldeneye reservoir in the North Sea. According to a study conducted by BGS, Royal Dutch Shell's Peterhead CCS project has the potential to store up to 20 million tons of CO_2. From *UPI.com* on September 14, 2015.

November 2015

"Southern Company Subsidiary and Korea Electric Power Corporation Sign MOU to Jointly Evaluate Clean Coal Technology Deployment Worldwide." Southern Company Services, a subsidiary of Southern Company, and Korea Electric Power Corporation (KEPCO) will jointly explore the deployment of clean coal power generation and CCS technologies through a recently signed Memorandum of Understanding (MOU). Through the agreement, the companies will explore CCS and other technologies in the United States, the Republic of Korea, as well as other developing nations. In addition, the agreement provides for the testing of KEPCO's carbon capture technologies at NCCC in Alabama, USA. Operated by Southern Company Services and aligned with U.S. and Korean efforts to cost-effectively reduce greenhouse gas (GHG) emissions, NCCC conducts research and development (R&D) to evaluate and advance emerging carbon capture technologies through integration with a coal-fired power plant and pilot gasification facility. From *Southern Company News Release* on October 15, 2015.

"GroundMetrics, Inc. Awarded Contract for CO_2 EOR Flood Monitoring." Electromagnetic survey company GroundMetrics Inc. was awarded a contract for a CO_2 enhanced oil recovery (EOR) flood monitoring survey in the Frio Sands Formation. The time-lapse electromagnetic survey of CO_2 will take place in an oil reservoir with sensors at the surface. With the depth greater than 5,000 feet, acquiring data from the surface allows for the entire field to be surveyed. From *GlobeNewswire* on October 12, 2015.

"Shell's Quest $1.35 Billion Carbon-Capture Project Near Edmonton on Target for Completion." More than 100,000 metric tons of compressed CO_2 have been stored during startup testing of Shell Canada's Quest CCS project. The oil sands CCS project is expected to reduce CO_2 emissions from the bitumen upgrader at Scotford by up to 35 percent (approximately 1 million metric tons per year). Construction was initiated in 2012, and was finished in March 2015; after the commissioning phase was completed in August 2015, testing began. The original plan called for approximately 25 to 28 million metric tons of CO_2 to be stored over the life of the project. However, according to officials, test results indicate the potential capacity of more than 30 million metric tons. From *Edmonton Journal* on October 20, 2015.

"Norway Renews Carbon Capture, Storage Pact with SA." The Norwegian and South African (SA) governments have renewed their long-term partnership on CCS research. According to the South African Center for Carbon Capture and Storage, the SA government carries out its CCS research in four phases. The first phase (completed in 2004) looked into CCS potential in SA, while the second (completed in 2010) was to identify potential sites for long-term storage in an atlas, with applications filed for permits. The currently underway third phase will build a pilot plant (10,000 metric tons of CO_2 per year) at Bongwana near Harding in KwaZulu-Natal. The fourth phase will be to scale that plant to 100,000 metric tons of CO_2 per year, and then to 1 million metric tons of CO_2 per year. From *Business Day Live* on October 20, 2015.

"$500 Million Oil Recovery Project Wraps Up First Phase in Hobbs." Occidental Petroleum Corporation (Oxy Permian) completed the first phase of its $500 million CO_2 EOR project in an oil field in South Hobbs, New Mexico, USA. According to the company, oil production has doubled since operations began more than a decade ago. The South Hobbs project replaces water-only recovery with CO_2 flooding, which is considered by Oxy Permian to be a third-stage oil recovery method. From *Albuquerque Business First* on October 21, 2015.

"JRI, MHI, and INPEX Enter Contract… for Feasibility Study on CCS-EOR Projects in Southern Mexico." A feasibility study consortium entered a contract in response to a public offer, titled "Feasibility Study on CCS-EOR projects in Southern Mexico – FY2015 Global Warming Mitigation Technology Promotion Project." The consortium, comprising of the Japan Research Institute, Limited (JRI); Mitsubishi Heavy Industries, Ltd. (MHI); and INPEX CORPORATION, would carry out the commissioned work from October 2015 to March 2016. The consortium would study the capability of CCS-EOR in Southern Mexico by implementing the evaluation of CO_2 sources at petrochemical plants and refineries, investigating the EOR targeted fields, estimating the overall business profitability, and conducting other studies as necessary. From *Mitsubishi Heavy Industries, Ltd. News Release* on October 23, 2015.

December 2015

"Shell Launches Quest Carbon Capture and Storage Project." Shell's Quest CCS project initiated commercial operations in Alberta, Canada. Designed to capture and safely store more than 1 million metric tons of CO_2 per year, Quest will capture one-third of the CO_2 emissions from Shells' Scotford Upgrader, transport it through an approximately 40-mile pipeline, and inject it more than 1 mile underground. Quest is now operating at commercial scale after successful testing that saw more than 200,000 metric tons of CO_2 captured and stored earlier in 2015. From *Shell Media Release* on November 6, 2015.

"CO_2 Solutions Completes Operation of Demonstration Plant." CO_2 Solutions, Inc., announced the completion of its demonstration plant in Valleyfield, near Montreal, Québec, Canada, after logging more than 2,500 operational hours since CO_2 capture began in June 2015. Data and results from the project, which are currently being validated and analyzed, will allow for the completion of detailed engineering and costing models for commercial units at various scales. From *CO_2 Solutions Press Release* on November 10, 2015.

"Saudi Pilot Carbon Storage Project May Boost Recovery Rates at Giant Oilfield." According to officials, Saudi Arabia's first CCS project has the potential to increase oil recovery rates by 20 percent. The CCS project is located at the Ghawar oilfield, which has been in operation since 1951 and produces more than 5 million barrels of oil per day. Under the project, 40 million cubic feet of CO_2 will be captured at the Hawiyah gas recovery plant and piped approximately 53 miles to the Uthmaniyah area, where it will be used in enhanced oil recovery (EOR) operations. Saudi Aramco, the national oil firm that developed the project, estimates it has the potential to store approximately 800,000 metric tons of CO_2 per year. From *Reuters* on November 5, 2015.

"Climeworks AG Builds First Commercial Scale CO_2 Capture Plant." Climeworks AG will operate an industrial-scale CO_2 capture plant in Hinwil (Canton of Zurich, Switzerland) with the capacity to capture 900 tons of CO_2 per year. The plant, which will be operational by mid-2016, is part of a three-year pilot and demonstration project supported by the Swiss Federal Office of Energy (SFOE). The project will utilize Climeworks' Direct Air Capture (DAC) technology and continuously operate an industrial-scale plant that captures CO_2 from ambient air. From *Climeworks' Press Release* on October 21, 2015.

"Test Begins to Store Carbon Dioxide Under Seabed Off Hokkaido." A Japanese government-backed trial operation for the capture and undersea storage of CO_2 emissions at a facility in Hokkaido, Japan, has been initiated. According to project officials, emissions will be transported via pipeline into a CO_2 separation and collection device, where they will be absorbed by a liquid solution that will raise the CO_2 concentration to more than 99 percent. The concentrated CO_2 will then be transported to two wells that are approximately 1.8 and 2.7 miles off the coast and 0.7 to 1.9 miles deep, respectively. Beginning in April 2016, the project will transfer in the range of 100,000 to 200,000 tons of CO_2 per year for three years, monitoring the temperature and pressure in the process. From *Japan Times* on November 20, 2015.

January 2016

"Statoil to Conduct CCS Feasibility Studies in North Sea Fields." At the request of the Norwegian government, Statoil will conduct new carbon storage studies on the Norwegian continental shelf. According to Statoil, the feasibility studies will be carried out at three locations in the Norwegian sector of the North Sea and are targeted for completion in 2016. The Norwegian government has previously stated a goal of at least one full-scale CCS demonstration plant by 2020. From *Reuters* on January 4, 2016.

"CO_2 Capture Technology Picked… for Commercial-Scale Use in Cement Production." Aker Solutions will use its advanced carbon capture technology to conduct a feasibility study on the development of a commercial-scale carbon capture facility for use in cement production. Picked by Norcem to conduct the study, Aker Solutions will look at capturing as much as 400,000 tons of CO_2 a year at Norcem's cement plant in Brevik, Norway. Aker Solutions' technology was successfully tested for 18 months at the cement plant and showed to be cost-effective, robust, and flexible during various operating conditions. The work is part of a feasibility study that will be submitted to Gassnova and the Norwegian Ministry of Petroleum and Energy. From *Aker Solutions' Press Release* on November 17, 2015.

"Seismos Announces… CO_2 EOR Surveillance Platform." Seismos, Inc., a provider of subsurface fluid-flow imaging technology for the oil and gas industry, announced a new surveillance platform for enhanced oil recovery (EOR) operations. The platform focuses on increasing CO_2-EOR production by providing continuous, real-time information on the subsurface movement of CO_2 and areas of unswept oil. The platform is currently installed in oilfields in Texas and New Mexico, USA. From *PR Newswire* on January 6, 2016.

February 2016

"PTRC and EERC Announce $2.5M in Funding." Funding was awarded to the Petroleum Technology Research Center (PTRC) and the Energy and Environmental Research Center (EERC) at the University of North Dakota to develop an "intelligent monitoring system" (IMS). Utilizing data from PTRC's Aquistore project, the IMS will allow future CO_2 storage site operators to more efficiently manage operations, data management, and monitoring. While current monitoring technologies require various project teams to manually acquire and process data, EERC will develop the IMS to automate the integration of the CO_2 monitoring and simulation data. PTRC will provide access to the data acquired from Aquistore. From *Aquistore News Release* on January 7, 2016.

"Research Could Slow Fuel Switching Trend in Electric Generation." A multi-national team, led by the University of Illinois, was selected to develop a proposal for retrofitting the university's Abbott Power Plant to capture CO_2 emissions. The Phase I award is for detailed engineering and planning and is expected to have a total value of $1.3 million. The retrofit project will also build a value chain and provide workforce training for operators from the coal and mining industries. From *Illinois Sustainable Technology Center* on January 21, 2016.

"Aker Solutions Starts Pioneering CO_2-Capture Project in Norway." Aker Solutions initiated a five-month test program to capture CO_2 emissions from a waste-to-energy plant in Oslo, Norway. The test will be conducted at the Klemetsrud plant, which emits approximately 300,000 tons of CO_2 per year. The test will be conducted using Aker's mobile test unit for carbon capture. From *Aker Solutions Press Release* on January 25, 2016.

"CO_2 Solutions Receives $15 Million to Advance Transformative Technology." CO_2 Solutions, Inc., will receive a grant from the Climate Change and Emissions Management Corporation (CCEMC), the company announced. CO_2 Solutions expects to use the grant towards the commercial deployment of their technology to capture CO_2 at an approximately 300 metric ton of CO_2/day scale from an industrial source in Alberta, Canada, with beneficial reuse of the captured CO_2. From *CO_2 Solutions Press Release* on February 1, 2016.

March 2016

"[Japan Plans Test of Carbon Capture]." Japan will inject CO_2 into saline formations off the coast of Hokkaido in a pilot project sponsored by the Ministry of Economy, Trade, and Industry (METI). Beginning in April 2016, CO_2 will be injected annually into two separate reservoirs under the seabed off the port of Tomakomai in Hokkaido at a site prepared by the Tokyo-based research company Japan CCS Co. From *Bloomberg* on February 28, 2016.

"Norway Examines Feasibility of CO_2 Shipping." Norwegian state operator Gassco has commissioned two companies to study the transport of CO_2 by ship. The study will analyze various ship-based solutions for CO_2 transport, with the companies, Knutsen OAS Shipping and Larvik Shipping, submitting their finding to Gassco by mid-April 2016. From *The Maritime Executive* on February 29, 2016.

"Project to Test CO_2 Monitoring from a Subsea [Release]." Carbon dioxide will be injected into the sea floor in the North Sea as part of a controlled experiment to test the safety of offshore CCS. The Strategies for the Environmental Monitoring of Marine CCS (STEMM-CCS) project, set to take place in 2018, will simulate emissions from a submerged CO_2 storage reservoir. The collaborative project will be led by the National Oceanographic Center (NOC) and will enable scientists to develop a system capable of detecting and quantifying the volume of CO_2 released. The technology will be installed at the site before the controlled release of the CO_2 in order to compare the natural changes from those resulting from the controlled release. From *Carbon Capture Journal* on March 2, 2016.

"ETI Studies Brine Removal from Subsea CO_2 Stores." The Energy Technology Institute (ETI) launched a project that will study the impact of removing brine from undersea storage reservoirs that have CO_2 storage potential. The "Impact of Brine Production on [Formation] Storage" project will build on earlier CCS research and aid in developing an understanding of potential CO_2 storage reservoirs located beneath UK waters. From *Carbon Capture Journal* on March 2, 2016.

"Kuwait's First CO_2 Plant Officially Opened." Kuwait's first CO_2 plant, with a design capacity of 280 metric tons of CO_2 per day, has officially opened. The plant is an international joint venture between Equate Petrochemical Company and Gulf Cryo. The Equate Petrochemical Company will provide raw

CO_2 from its industrial operations to Gulf Cryo for use in various commercial applications. From *Trade Arabia* on February 17, 2016.

April 2016

"15,000 Metric Tons of CO_2 Stored at Otway." CO2CRC and its Australian and international research partners injected 15,000 metric tons of CO_2 at the Otway research facility in Nirranda of South Western Victoria. Researchers remotely monitored the injected CO_2 by using fiber-optic cables and a high-resolution buried receiver fitted with automated communications facilities. The tested equipment provides options to reduce the surface monitoring activities required to verify the CO_2 plume movement. From *Carbon Capture Journal* on April 8, 2016.

"[NET Power Breaks Ground on Demonstration Plant]." NET Power, LLC, announced it has broken ground on a demonstration plant in La Porte, Texas, USA. The power plant will demonstrate NET Power's Allam Cycle technology, a natural gas power system that uses CO_2 to drive a combustion turbine and produces pipeline-quality CO_2 that can be stored or used in industrial processes, such as enhanced oil recovery (EOR). Commissioning of the plant is expected to begin in late 2016 and be completed in 2017. From *NET Power* on March 9, 2016.

"Tomakomai CCS Project [Now Online]." The Global CCS Institute announced a fully integrated CCS project came online in southwest Hokkaido, Japan. Carbon dioxide from a hydrogen production unit in an oil refinery will be captured and purified before compression and subsequent injection into offshore geological formations. From *Global CCS Institute Media Release* on March 18, 2016.

"[$15 Million Invested to Enhance Carbon Capture Technology]." A CO_2 Solutions enzyme-enabled carbon capture technology was studied at a demonstration project at Valleyfield in Québec, with the results validated through a third-party engineering firm. Québec, Canada, plans to reduce its greenhouse gas (GHG) emissions by 20 percent below 1990 levels by 2020, and 37.5 percent below the same level by 2030. From *CO_2 Solutions Release* on March 18, 2016.

May 2016

"[NIST Studying New CO_2 Monitoring Technique]." Scientists from the National Institute of Standards and Technology (NIST) are studying a CO_2 monitoring technique that may allow for more effective monitoring of storage sites under real-world conditions. Under a cooperative agreement with NETL, the NIST team, in collaboration with Harris Corporation and Atmospheric and Environmental Research (AER), built a laser-based measurement system that collected data from a mock storage site in Ft. Wayne, Indiana, USA. NIST developed a mathematical model based on the analysis of the data, the results of which allowed them to pinpoint potential releases from the ground ten times more accurately than previous monitoring techniques. From *NIST* on April 20, 2016.

"[Geologic] Carbon Dioxide Storage Technology Research Association Established in Japan." Japan's Ministry of Economy, Trade and Industry (METI) authorized the establishment of the "Geological Carbon Dioxide Storage Technology Research Association," which will promote the development of technologies related to large-scale CCS at storage sites in Japan. According to the press release, the "Geological Carbon Dioxide Storage Technology Research Association" will target the commercialization of CCS, the establishment of safety management technologies for large-scale CCS, the establishment of injection technologies for large-scale subsurface storage, and the development of criteria and standards for improved CCS awareness. From *Research Institute of Innovative Technology for the Earth (RITE) Press Release* on March 31, 2016.

"[Carbon Storage Tested with $1.5 Billion Project in Australia]." A CCS project will be conducted at Barrow Island in northwest Australia next year. The project will store as much as 4 million tons of CO_2 per year approximately 1.25 miles underground. Led by Chevron Corp., the project is part of the Gorgon liquified natural gas development, which began production earlier this year. From *Bloomberg* on April 19, 2016.

"Arup Appointed to Undertake Carbon Capture and Storage Study." Arup, a global firm of consulting engineers, has been awarded funding from the Scottish Government and the U.K. Department of Energy and Climate Change (DECC) to conduct a feasibility study for a CCS plant in Grangemouth, Scotland. Appointed by Summit Power Caledonia UK Ltd (Summit), Arup will provide environmental and permitting guidance for the Caledonia Clean Energy Project, conduct risk assessments, and assist with the development of a stakeholder and engagement strategy. From *Arup News* on April 20, 2016.

"[CCS Technology Paves Way...]." The European Commission's Horizon 2020 grant program will provide funding to the Low-Emissions Intensity Lime and Cement (LEILAC) consortium, whose project will focus on reducing the environmental impact of the construction industry through the cement sector. The technology will capture CO_2 released from limestone with potentially no additional energy costs. From *edie.net* on April 25, 2016.

"[MSU and CO_2 Storage Company Complete Phase I Algae Trial]." $PHYCO_2$, an algae growth and CO_2 storage company, and Michigan State University (MSU) have completed the first phase of their partnership to capture CO_2 and create renewable alternative energy feedstock. Phase I set out to prove $PHYCO_2$'s technology could capture CO_2 for algae cultivation with their patented algae photo bioreactor. According to their joint press release, the $PHYCO_2$ and MSU partnership's focus is to demonstrate the $PHYCO_2$-developed technology to store CO_2, reclaim water, and continuously grow multiple types of algae at an accelerated rate without sunlight. From *Carbon Capture Journal* on May 3, 2016.

June 2016

"UK CO_2 Storage Asset Reaffirmed." A 12-month CO_2 storage appraisal project conducted by the Energy Technologies Institute (ETI) confirmed there are a potential 579 CO_2 storage sites offshore in the United Kingdom (UK) and 20 were identified for potential future storage developers by the UK Department of Energy and Climate Change (DECC)-funded project. Five of the storage sites were then progressed towards readiness for "Final Investment Decisions" due to their potential contribution to mobilize commercial-scale CCS projects for power and industrial use in the UK. The Executive Summary of ETI's report, titled "Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource," is available in the Recent Publications section of this newsletter. From *Carbon Capture Journal* on May 12, 2016.

"PTRC and University of Alberta Sign Agreement to Collaborate on Carbon Capture Storage and Utilization (CCUS) Research in Mexico." The Petroleum Technology Research Center (PTRC) and the University of Alberta signed a Letter of Understanding (LOU) to collaborate on carbon capture, utilization, and storage (CCUS) in Mexico. The LOU, which was signed at the North American Energy Ministers Trilateral Meeting on CCUS in Mexico City, Mexico, allows the university to access research conducted at the PTRC-managed Aquistore CO_2 storage project in Saskatchewan, Canada. From *PTRC* on May 11, 2016.

"Scotland and Mexico Forge Links on Climate Action." Representatives from the Secretaria de Energia de Mexico (SENER), the Universidad Nacional Autonóma de México (UNAM), and the Scottish Carbon Capture and Storage (SCCS) Research Partnership held a meeting to explore future research collaborations to develop CCUS technologies. A Letter of Collaboration was signed between Mexican and Scottish scientists, laying the foundation to work jointly on CCUS research and to explore

international funding initiatives and potential academic opportunities. From *SCCS News Release* on May 30, 2016.

"Carbon Clean Solutions Announces Breakthrough Test Results from TCM Pilot." Carbon Clean Solutions Limited (CCSL) announced results of a pilot test designed to measure emissions, corrosion, and energy efficiency at Technology Center Mongstad (TCM). According to the results, plant availability levels were 100 percent and there was no loss of run time due to solvent issues. During the pilot project, which ran from November 2015 through the end of March 2016, more than 25,000 tons of CO_2 were captured. In addition, the pilot demonstrated parts per billion solvent emissions compared to parts per million for traditional solvents. A separate, independent test at the University of Kentucky also confirmed a 50 percent reduction in energy consumption over conventional solvents. From *Carbon Clean Solution Press Release* on May 10, 2016.

July 2016

"DOE Awards UND's EERC $15 Million to Continue Carbon Storage Research." The University of North Dakota's Energy and Environmental Research Center (UNDEERC) was awarded funding to continue its carbon storage research. UNDEERC was originally selected to study the benefits of active reservoir management (ARM) in CCS (Phase I), which consisted of feasibility studies and project designs. DOE's funding will be utilized for Phase II, which is expected to last approximately four years, beginning with the installation of infrastructure, such as wells and brine treatment and handling equipment, and continuing with active reservoir research and management testing and brine treatment technology demonstration. From *Prairie Business Magazine* on June 8, 2016.

"Iceland Carbon Capture Project Quickly Converts Carbon Dioxide Into Stone." According to scientists, tests have demonstrated that CO_2 emissions could be stored by turning them into rock. Conducted at the CarbFix project in Iceland, the tests indicated that most of the CO_2 injected into basalt turned into carbonate minerals in less than two years. Scientists' original estimates were that the process would take hundreds to thousands of years. The pilot project injected 230 tons of CO_2 into basalt rocks near the Hellisheidi geothermal plant east of Reykjavik, Iceland, in 2012; scientists also included a set of tracers to monitor the fate of the CO_2. The mineralogy of basalts is favorable for storing CO_2, as the rocks into which the gas is injected need calcium-, magnesium-, or iron-rich silicate materials; while sedimentary rocks do not have enough of those minerals, basalts do. From *Smithsonian Magazine* on June 9, 2016.

"BHP Billiton and Peking University to Accelerate CCUS Research." BHP Billiton and Peking University (PKU) announced an agreement to accelerate carbon capture, use, and storage (CCUS) research in China. The three-year agreement will identify key policy, technical, and economic barriers to CCUS deployment in the industrial sector. The agreement builds on the BHP Billiton SaskPower Carbon Capture Knowledge Center, which was established in February 2016 to share lessons learned on CCS. From *BHP Billiton News Release* on June 6, 2016.

August 2016

"Carbon Capture and Storage Pilot Planned for Rotterdam." Approximately 1 million metric tons of CO_2 will be captured at a coal-fired power station and injected into a gas field in the North Sea as part of a planned pilot project to be held in Rotterdam, Netherlands. An investment decision is expected by early next year. Once infrastructure is in place, the pilot project, called "ROAD," will operate for a three-year trial period. From *Digital Energy* on July 22, 2016.

"Scientists in Scotland Receive Funding for Offshore Carbon Dioxide Storage Investigation." Scientists from the University of Strathclyde in Scotland have received funding from the United

Kingdom's Natural Environment Research Council (NERC) for a four-year study of CO_2 storage solutions. The project, titled "Migration of CO_2 through North Sea Geological Carbon Storage Sites: Impact of Faults, Geological Heterogeneities and Dissolution," will explore the ability of complex rock strata beneath the North Sea to safely store CO_2 emissions. Specifically, the initiative will study how injected CO_2 could potentially migrate through overlying layers of underground rocks, while also examining the interaction of embedded faults and rock tiers with CO_2 flow. From *Gas World* on July 6, 2016.

September 2016

"Red Trail Energy, EERC Win Funding to Support CCS Study." Red Tail Energy, LLC, (RTE) and the University of North Dakota's Energy and Environmental Research Center (UNDEERC) have been awarded funding by the North Dakota Industrial Commission's Renewable Energy Program to examine CCS integration. The funding will be used to examine the integration of CCS by determining the technical and economic parameters of installing and operating a commercial CCS system at RTE's ethanol manufacturing facility in North Dakota, USA. The Broom Creek Formation, found below the RTE facility, has been identified as the location for potential geologic CO_2 storage. From *Ethanol Producer Magazine* on August 10, 2016.

"[CCS Demonstration Project in Japan Starts Up]." Commissioned by the Japan Ministry of Economy, Trade, and Industry (METI), Japan CCS (JCCS) is finalizing the commercialization of its CO_2 separation, capture, transportation, and storage technology and has constructed a demonstration plant in Tomakomai, Hokkaido. JCCS is conducting the METI scheme Tomakomai CCS Large-Scale Demonstration Project over a nine-year period, which began in 2012. JCCS completed preparatory work for the plant during its first four years of operation (2012 through 2015). METI initiated pressure injection and CO_2 monitoring in April 2016. Over the course of the demonstration project (a three-year period), more than 100,000 metric tons of CO_2 will be injected each year, stored at two different depths, and monitored. From *gasworld* on August 11, 2016.

"CO_2 Solutions [Finalizes] Commercial Agreement to Deploy CCS Unit in Canada." Fibrek General Partnership, CO_2 Solutions, and Serres Toundra, Inc. finalized an agreement to deploy a CCS unit at a pulp mill in Québec, Canada. The unit will be designed and constructed by CO_2 Solutions and is expected to capture approximately 30 metric tons of CO_2 per day from a pulp mill in Saint-Félicien, Québec, Canada; the CO_2 will then be transported for reuse in Serres Toundra's neighboring vegetable greenhouse. After a successful six-month demonstration period, Serres Toundra will purchase the captured CO_2 for the next 10 years. The site is expected to be commissioned by the end of 2017. From *gasworld* on August 19, 2016.

"[Australia Invests in CCS R&D]." The Australian CCS Research Development and Demonstration (RD&D) Fund, which provides funding for CCS projects with an emphasis on CO_2 transport and storage, awarded funding to seven applicants. In addition to supporting the Australian government's focus on reducing technical and commercial barriers to the deployment of large-scale CCS projects, the projects selected for funding are also expected to encourage industry investment in further deployment of CCS technologies. Details of the selected applicants, which include both industry- and institution-led projects, are available online. From *Carbon Capture Journal* on August 29, 2016.

Science

September 2015

"CU-Boulder Researchers Use Wastewater Treatment to Capture CO_2 Emissions and Produce Energy." Engineers from the University of Colorado Boulder have developed a wastewater treatment process that mitigates CO_2 emissions and captures GHGs. While purifying wastewater, the method, called microbial electrolytic carbon capture (MECC), uses an electrochemical reaction that absorbs more CO_2 than it releases, while also creating renewable energy. According to the research, which was funded by the National Science Foundation and recently published in the journal "Environmental Science and Technology," dissolved carbonates and bicarbonates produced by MECC may also have the long-term potential to counter the effects of absorbed CO_2 emissions on oceans. The Abstract of the study, titled "Microbial Electrolytic Carbon Capture for Carbon Negative and Energy Positive Wastewater Treatment," is available in the "Technology" section of this newsletter. From *University of Colorado Boulder News Release* on August 3, 2015.

"Climate Change Could Harm British Butterflies." According to a recent report, six species of butterflies located in the UK could face local extinction due to potential climate change. Researchers gathered their data by studying 129 sites in which 28 butterfly species are tracked in the United Kingdom Butterfly Monitoring Scheme, and incorporating historical weather data and climate model predictions from the Coupled Model Intercomparison Project. The data showed that, by 2050, populations in dry areas, such as southeastern England, have the potential to disappear. The study was published in the journal "Nature Climate Change." From *The Columbus Dispatch* on August 16, 2015.

October 2015

"Protected Areas Save Mangroves, Reduce Carbon Emissions." According to a study published in the journal "Ecological Economics," protected areas that keep Indonesia's mangrove habitats intact also prevent the release of CO_2 emissions. Mangroves are dense forests of trees and shrubs that grow in low-lying coastal areas. Using a detailed, country-wide dataset, the analysis states that keeping the mangroves "avoided release of approximately 13 million metric tons of CO_2 into the atmosphere." The Abstract of this study, titled "Do protected areas reduce blue carbon emissions? A quasi-experimental evaluation of mangroves in Indonesia," is available in the "Terrestrial" section of this newsletter. From *EurekAlert!* on September 14, 2015.

"Gas 'Fingerprinting' Could Help Energy Industry Manage Carbon Dioxide Storage." A new technique for monitoring CO_2, discovered by scientists from the Scottish Universities Environmental Research Center (SUERC), has the potential to contribute to the energy industry's efforts to reduce future greenhouse gas (GHG) emissions, a recently published study claims. Using gas samples collected from wells at the Cranfield CO_2-EOR field in Mississippi, USA, from 2009 and 2012, SUERC researchers used the unique signature from traces of noble gases (in this case, helium, neon, and argon) to monitor the fate of CO_2 stored underground. The study, titled "Tracing injected CO_2 in the Cranfield enhanced oil recovery field (MS, USA) using He, Ne and Ar isotopes," was published in the "International Journal of Greenhouse Gas Control." From *University of Glasgow* on October 5, 2015.

"BYU Technology Tackles Climate Change by Freezing Carbon." A scientist from Brigham Young University (BYU) has developed a system that prevents the release of CO_2 into the atmosphere by freezing it and capturing up to 99 percent of it in the process. The system freezes the CO_2 with -130 degrees Celsius (-202 degrees Fahrenheit) temperatures, separates the dry ice from the gas, and then heats everything back up. The CO_2 is then pressurized into liquid form for uses such as EOR. An overview of the technology was published in the "International Journal of Greenhouse Control." The Abstract of the paper, titled "Prediction and validation of external cooling loop cryogenic carbon capture

(CCC-ECL) for full-scale coal-fired power plant retrofit," is available in the "Technology" section of this newsletter. From *BYU News Release* on September 28, 2015.

November 2015

"Game-Changing Process Mitigates CO_2 Emissions Using Renewable Energy." DOE/NETL researchers conceived and developed a new process involving gold nanoparticles that can convert CO_2 into usable chemicals and fuels. The process, which has the potential to lead to an industrial-scale way to reduce CO_2 emissions, is a "carbon neutral" energy cycle, using renewable energy sources to recycle waste CO_2 into chemicals and fuels without generating new CO_2 emissions. In addition to limiting atmospheric CO_2 emissions, the process will also offer an environmentally friendly supplement to traditional energy sources and enable the sustainable use of current fossil fuel resources. The process was detailed in a peer-reviewed paper published in the American Chemical Society (ACS) "ACS Applied Materials & Interfaces" journal. Data from the study is also being used to inform critical performance estimates needed to move the carbon-neutral energy cycle into industrially relevant applications. The Abstract of the paper, titled "Efficient Electrochemical CO_2 Conversion Powered by Renewable Energy," is available in the "Technology" section of this newsletter. From *energy.gov* on October 21, 2015.

"New Crystal Captures Carbon from Humid Gas." Scientists have created a new material with micropores that is capable of more efficiently capturing CO_2 in the presence of water than previously known materials. The result of international cooperation between scientists from Stockholm University and Sogang University in Korea, the new material, a copper silicate crystal, is stable and recyclable, with the micropores within having different adsorption sites for CO_2 and water. Scientists believe the material, called SGU-29, could be used for capturing atmospheric CO_2. The research was published in a report titled "CO_2 capture from humid flue gases and humid atmosphere using a microporous coppersilicate," the Abstract of which is available in the "Technology" section of this newsletter. From *Stockholm University* on October 15, 2015.

December 2015

"DOE-Funded Research Yields U.S. Patent for Use of CO_2 in Concrete Curing." The United States Patent and Trademark Office issued a patent for a new process, funded by DOE's NETL, which uses CO_2 to cure pre-cast concrete. Developed by Solidia Technologies, Inc., the process uses CO_2 instead of water to cure pre-cast concrete, reducing curing time to less than 24 hours (water-based curing could take weeks). According to Solidia, the new process may reduce the carbon footprint of concrete curing by approximately 30 percent compared to traditional methods. In addition, Solidia's analysis claims that combining it with their patented CO_2-enriched cement process could reduce CO_2 emissions associated with concrete product fabrication by 60 percent, while slashing water use by 90 percent. Applied industry-wide, the two technologies combined have the potential to reduce CO_2 emissions by 1,920 million metric tons per year. For more information, visit NETL's Carbon Use and Reuse Webpage. From *energy.gov* on November 10, 2015.

"Halifax Firm Injects CO_2 into Concrete and Reduces Carbon Footprint." A company in Nova Scotia has developed a concrete technology in which captured CO_2 emissions are injected and stored into the concrete, lowering its carbon footprint by up to 15 percent. According to the developer, CarbonCure Technologies, the CO_2 mineralizes during the process, becoming limestone calcium carbonate, and creates a stronger, faster-setting concrete. From *CBC News* on November 30, 2015.

"Porous Liquid Holds Promise for CO_2 Capture." Scientists have created a porous liquid with the ability to dissolve large amounts of gas, which could potentially be used for carbon capture applications. Researchers from the School of Chemistry and Chemical Engineering at Queen's University Belfast led the three-year research project, which found that large amounts of gas can be absorbed into the "holes"

of their newly invented liquid. The study, titled "Liquids with permanent porosity" and published in the journal "Nature," also involved the University of Liverpool and universities in France, Germany, and Argentina. From *Carbon Capture Journal* on November 15, 2015.

January 2016

"Sea Plankton Rise Could be Due to Increased Carbon Dioxide: Research." According to researchers from John Hopkins University, rises in CO_2 levels in the Atlantic Ocean may have led to a nearly 10-times increase in the marine alga concentration during the last few decades. Published in the journal "Science," the study analyzed Continuous Plankton Recorder survey data from the North Atlantic Ocean and North Sea since the mid-1960s, finding that higher CO_2 levels in the oceans may be causing an increase in the population of single-celled coccolithophores. Previous studies believed that increased ocean acidity due to higher CO_2 levels would lead to a decline in the number of plankton species. The Abstract of the study, titled "Multidecadal increase in North Atlantic coccolithophores and the potential role of rising CO_2," is available below. From *Northern Californian* on November 29, 2015.

"Multidecadal increase in North Atlantic coccolithophores and the potential role of rising CO_2." The following is the Abstract of this article: "As anthropogenic CO_2 emissions acidify the oceans, calcifiers generally are expected to be negatively affected. However, using data from the Continuous Plankton Recorder, [the authors] show that coccolithophore occurrence in the North Atlantic increased from ~2 to more than 20 [percent] from 1965 through 2010. [The authors] used random forest models to examine more than 20 possible environmental drivers of this change, finding that CO_2 and the Atlantic Multidecadal Oscillation were the best predictors, leading [the authors] to hypothesize that higher CO_2 levels might be encouraging growth. A compilation of 41 independent laboratory studies supports [the authors'] hypothesis. [The authors'] study shows a long-term basin-scale increase in coccolithophores and suggests that increasing CO_2 and temperature have accelerated the growth of a phytoplankton group that is important for carbon cycling." **Sara Rivero-Calle, Anand Gnanadesikan, Carlos E. Del Castillo, William M. Balch, and Seth D. Guikema**, *Science*. (Subscription may be required.)

"Living Shorelines Blunt Effects of Climate Change, Study Shows." A National Oceanic and Atmospheric Administration (NOAA) study found that "living shorelines" may help reduce atmospheric CO_2. The study, published in the journal "PLOS One," measured carbon storage in the coastal wetlands and the fringing marshes of living shorelines in North Carolina, USA. Researchers found that the living shorelines stabilize shorelines using natural materials, such as plants, sand, and rock, which may reduce CO_2 emissions in the atmosphere and help to mitigate potential climate change. An Abstract of the study, titled "Living Shorelines: Coastal Resilience with a Blue Carbon Benefit," is available below. From *Environmental Protection* on December 23, 2015.

"Living Shorelines: Coastal Resilience with a Blue Carbon Benefit." The following is the Abstract of this article: "Living shorelines are a type of estuarine shoreline erosion control that incorporates native vegetation and preserves native habitats. Because they provide the ecosystem services associated with natural coastal wetlands while also increasing shoreline resilience, living shorelines are part of the natural and hybrid infrastructure approach to coastal resiliency. Marshes created as living shorelines are typically narrow (< 30 m) fringing marshes with sandy substrates that are well flushed by tides. These characteristics distinguish living shorelines from the larger meadow marshes in which most of the current knowledge about created marshes was developed. The value of living shorelines for providing both erosion control and habitat for estuarine organisms has been documented but their capacity for carbon [storage] has not. [The authors] measured carbon [storage] rates in living shorelines and sandy transplanted Spartina alterniflora marshes in the Newport River Estuary, North Carolina. The marshes sampled here range in age from 12 to 38 years and represent a continuum of soil development. Carbon [storage] rates ranged from 58 to 283 g C m^{-2} yr^{-1} and decreased with marsh age. The pattern of lower [storage] rates in older marshes is hypothesized to be the result of a relative enrichment of labile organic matter in younger sites and illustrates the importance of choosing mature marshes for determination of

long-term carbon [storage] potential. The data presented here are within the range of published carbon [storage] rates for S. alterniflora marshes and suggest that wide-scale use of the living shoreline approach to shoreline management may come with a substantial carbon benefit." **Jenny L. Davis, Carolyn A. Currin, Colleen O'Brien, Craig Raffenburg, and Amanda Davis**, *PLOS One*. (Subscription may be required.)

February 2016

"Breakthrough in Continuous Monitoring of CO_2 [Releases] from Storage Sites Could Assist CCS." A new study conducted by a team of Japanese researchers could potentially lead to conducting lower-cost monitoring of underground CO_2 storage sites. By using monitoring techniques more often associated with the study of earthquakes and volcanic eruptions, researchers from the Kyushu University International Institute for Carbon-Neutral Energy Research (I^2CNER) analyzed seismic waves to detect the movement of subterranean fluid and to identify CO_2 releases before they reach the surface. I^2CNER is currently testing the method to further improve its accuracy. The Abstract of the study, titled "Development of surface-wave monitoring system for [released] CO_2 using a continuous and controlled seismic source," is available below. From *Science Codex* on January 22, 2016.

"Development of surface-wave monitoring system for [released] CO_2 using a continuous and controlled seismic source." The following is the Abstract of this article: "To detect CO_2 [release] from CO_2 geological storage, [the authors] describe a seismic monitoring method using a continuous and controlled seismic source system, the Accurately Controlled Routinely Operated Signal System (ACROSS). The method applies surface-wave analysis to monitor the shallow subsurface from the temporal-variation (time-variation) of surface-wave phase velocity. [The authors'] numerical simulation study for CO_2 [release] through fault zones indicated that the spatial distribution of [released] CO_2 can be estimated from small temporal-variation of local phase velocities (~1–3 [percent]). To demonstrate the method in a field case, [the authors] analyzed continuous seismic records acquired with ACROSS. [The authors] clearly extracted a dispersion curve of surface waves in the frequency range excited by the ACROSS (5.015–15.015 Hz). In particular, [the authors] obtained reliable estimates of phase velocities in 10–15 Hz frequency range, in which the time-variation of phase velocities was better than [one percent] accuracy. This temporal stability was sufficient to allow [the authors] to detect changes in phase velocities associated with CO_2 [release] before [released] CO_2 reached the surface." **Tatsunori Ikeda, Takeshi Tsuji, Toshiki Watanabe, and Koshun Yamaoka**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Carbon Dioxide Captured from Air Can Be Directly Converted into Methane Fuel." Researchers from the University of Southern California have demonstrated that CO_2 captured from the air can be directly converted into methanol using a homogeneous catalyst. The conversion of CO_2 to methanol requires high temperatures, which can cause the catalysts to decompose. However, in the new study, published in the "Journal of the American Chemical Society," the researchers developed a stable catalyst that does not decompose in such conditions; the stability of the catalyst allows it to be reused numerous times for the continuous production of methanol, which can be used as an alternative fuel. According to the researchers, the new catalyst, along with additional compounds, allows for up to 79 percent of the CO_2 captured from the air to be converted into methanol. The Abstract of this study, titled "Conversion of CO_2 from Air into Methanol Using a Polyamine and a Homogeneous Ruthenium Catalyst," is available below. From *Phys.org* on January 27, 2016.

"Conversion of CO_2 from Air into Methanol Using a Polyamine and a Homogeneous Ruthenium Catalyst." The following is the Abstract of this article: "A highly efficient homogeneous catalyst system for the production of CH_3OH from CO_2 using pentaethylenehexamine and Ru-Macho-BH (1) at 125–165°C in an ethereal solvent has been developed (initial turnover frequency = 70 h^{-1} at 145°C). Ease of separation of CH_3OH is demonstrated by simple distillation from the reaction mixture. The robustness of the catalytic system was shown by recycling the catalyst over five runs without significant loss of activity

(turnover number > 2000). Various sources of CO_2 can be used for this reaction including air, despite its low CO_2 concentration (400 ppm). For the first time, [the authors] have demonstrated that CO_2 captured from air can be directly converted to CH_3OH in 79 [percent] yield using a homogeneous catalytic system." **Jotheeswari Kothandaraman, Alain Goeppert, Miklos Czaun, George A. Olah, and G.K. Surya Prakash**, *J. Am. Chem. Soc.* (Subscription may be required.)

March 2016

"Enhanced Levels of Carbon Dioxide are Likely Cause of Global Dryland Greening, Study Says." According to a study conducted by the School of Science at the Indiana University-Purdue University Indianapolis (IUPUI), enhanced levels of atmospheric CO_2 could be leading to global dryland greening. Researchers analyzed 45 studies from 8 countries, finding the that greening observed through satellite images may be a result of potentially rising levels of atmospheric CO_2 on plant water savings and the consequent increases in available soil water. Published in the journal "Scientific Reports," the study examined the sensitivity of soil water change to varying levels of CO_2, and discovered a positive change in soil water along the CO_2 enrichment gradient. The research also showed that elevated CO_2 enhanced soil water levels in drylands more than in non-drylands. From *Phys.org* on February 16, 2016.

April 2016

"Trees Deal With [Potential Climate Change] Better Than Expected." According to a new study, forests may release less atmospheric CO_2 during hotter temperatures than previously thought. While scientists originally hypothesized that plants would release more CO_2 into the atmosphere as global temperatures rose, new data showed that plants are able to adapt their respiration to increases in temperature over long periods. Researchers tested how respiration rates of 10 different species of trees were affected by temperature increases over a period of three to five years in two separate conditions: ambient and warmer. The results, published in the journal "Nature," showed trees that were acclimated to the warmer temperatures increased their CO_2 release by a smaller amount than those only exposed to a short-term temperature increase of the same magnitude. The Abstract of the study, titled "Boreal and temperate trees show strong acclimation of respiration to warming," is available below. From *The New York Times* on March 16, 2016.

"Boreal and temperate trees show strong acclimation of respiration to warming." The following is the Abstract of this article: "Plant respiration results in an annual flux of CO_2 to the atmosphere that is six times as large as that due to the emissions from fossil fuel burning, so changes in either will impact future climate. As plant respiration responds positively to temperature, a warming world may result in additional respiratory CO_2 release, and hence further atmospheric warming. Plant respiration can acclimate to altered temperatures, however, weakening the positive feedback of plant respiration to rising global air temperature, but a lack of evidence on long-term (weeks to years) acclimation to climate warming in field settings currently hinders realistic predictions of respiratory release of CO_2 under future climatic conditions. Here [the authors] demonstrate strong acclimation of leaf respiration to both experimental warming and seasonal temperature variation for juveniles of [10] North American tree species growing for several years in forest conditions. Plants grown and measured at 3.4°C above ambient temperature increased leaf respiration by an average of 5 [percent] compared to plants grown and measured at ambient temperature; without acclimation, these increases would have been 23 [percent]. Thus, acclimation eliminated 80 [percent] of the expected increase in leaf respiration of non-acclimated plants. Acclimation of leaf respiration per degree temperature change was similar for experimental warming and seasonal temperature variation. Moreover, the observed increase in leaf respiration per degree increase in temperature was less than half as large as the average reported for previous studies, which were conducted largely over shorter time scales in laboratory settings. If such dampening effects of leaf thermal acclimation occur generally, the increase in respiration rates of terrestrial plants in response to climate warming may be less than predicted, and thus may not raise

atmospheric CO_2 concentrations as much as anticipated." **Peter B. Reich, Kerrie M. Sendall, Artur Stefanski, Xiaorong Wei, Roy L. Rich, and Rebecca A. Montgomery**, *Nature*. (Subscription may be required.)

"Development of environmental impact monitoring protocol for offshore carbon capture and storage (CCS): A biological perspective." The following is the Abstract of this article: "Offshore geologic storage of CO_2, known as offshore CCS, has been under active investigation as a safe, effective mitigation option for reducing CO_2 levels from anthropogenic fossil fuel burning and climate change. Along with increasing trends in implementation plans and related logistics on offshore CCS, thorough risk assessment (i.e. environmental impact monitoring) needs to be conducted to evaluate potential risks, such as CO_2 gas [release] at injection sites. Gas [releases] from offshore CCS may affect the physiology of marine organisms and disrupt certain ecosystem functions, thereby posing an environmental risk. Here, [the authors] synthesize current knowledge on environmental impact monitoring of offshore CCS with an emphasis on biological aspects and provide suggestions for better practice. Based on [the authors'] critical review of preexisting literatures, this paper: (1) discusses key variables sensitive to or indicative of gas [release] by summarizing physico-chemical and ecological variables measured from previous monitoring cruises on offshore CCS; (2) lists ecosystem and organism responses to a similar environmental condition to CO_2 [release] and associated impacts, such as ocean acidification and hypercapnia, to predict how they serve as responsive indicators of short- and long-term gas exposure, and (3) discusses the designs of the artificial gas release experiments in fields and the best model simulation to produce realistic [release] scenarios in marine ecosystems. Based on [the authors'] analysis, [the authors] suggest that proper incorporation of biological aspects will provide successful and robust long-term monitoring strategies with earlier detection of gas [release], thus reducing the risks associated with offshore CCS." **Hyewon Kim, Yong Hoon Kim, Seong-Gil Kang, and Young-Gyu Park**, *Environmental Impact Assessment Review*. (Subscription may be required.)

May 2016

"Carbon Dioxide Fertilization Greening Earth, Study Finds." According to a study published in the journal "Nature," potential rising levels of CO_2 in the atmosphere may have led to greening of 25 to 50 percent of the Earth's vegetated lands over the last 35 years. The research involved the use of data from the National Aeronautics and Space Administration's (NASA) Moderate Resolution Imaging Spectrometer and the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer instruments to determine the amount of leaf cover over Earth's vegetated regions. The results showed that CO_2 fertilization explains 70 percent of the greening effect. The Abstract of the study, titled "Greening of the Earth and its drivers," appears below. From *ScienceDaily* on April 26, 2016.

"Greening of the Earth and its drivers." The following is the Abstract of this article: "Global environmental change is rapidly altering the dynamics of terrestrial vegetation, with consequences for the functioning of the Earth system and provision of ecosystem services. Yet how global vegetation is responding to the changing environment is not well established. Here [the authors] use three long-term satellite leaf area index (LAI) records and ten global ecosystem models to investigate four key drivers of LAI trends during 1982–2009. [The authors] show a persistent and widespread increase of growing season integrated LAI (greening) over 25 [percent] to 50 [percent] of the global vegetated area, whereas less than 4 [percent] of the globe shows decreasing LAI (browning). Factorial simulations with multiple global ecosystem models suggest that CO_2 fertilization effects explain 70 [percent] of the observed greening trend, followed by nitrogen deposition (9 [percent]), climate change (8 [percent]) and land cover change (LCC) (4 [percent]). [Carbon dioxide] fertilization effects explain most of the greening trends in the tropics, whereas climate change resulted in greening of the high latitudes and the Tibetan Plateau. LCC contributed most to the regional greening observed in southeast China and the eastern United States. The regional effects of unexplained factors suggest that the next generation of ecosystem models will need to explore the impacts of forest demography, differences in regional management intensities for

cropland and pastures, and other emerging productivity constraints such as phosphorus availability." **Zaichun Zhu, Shilong Piao, Ranga B. Myneni, Mengtian Huang, Zhenzhong Zeng, Josep G. Canadell, Philippe Ciais, Stephen Sitch, Pierre Friedlingstein, Almut Arneth, Chunxiang Cao, Lei Cheng, Etsushi Kato, Charles Koven, Yue Li, Xu Lian, Yongwen Liu, Ronggao Liu, Jiafu Mao, Yaozhong Pan, Shushi Peng, Josep Peñuelas, Benjamin Poulter, Thomas A. M. Pugh, Benjamin D. Stocker**, *Nature Climate Change*. (Subscription may be required.)

June 2016

"In Latin America, Forests May Rise to Challenge of Carbon Dioxide." According to a new study, recently established forests on abandoned Latin American farmland have the potential to store at least 31 billion tons of CO_2 if allowed to grow for another 40 years. The study, published in the journal *Science Advances*, also claims that the abandonment of additional pastures and allowing them to revert to tropical forest could store approximately 7 billion more tons of CO_2. The Abstract of the study, titled "Carbon [storage] potential of second-growth forest regeneration in the Latin American tropics," is available in the Terrestrial section of this newsletter. From *The New York Times* on May 16, 2016.

"Pacific Stores [CO_2] at Depths of Thousands of Meters." An international team of researchers, led by the Alfred Wegener Institute, has located a CO_2 reservoir in the South Pacific Ocean at an approximate depth of 2,000 to 4,300 meters. This region was selected for sampling due to large amounts of "old" CO_2 (from a reservoir that had not been in contact with the atmosphere for a long period of time) being released into the atmosphere at the end of the last ice age. The scientists concluded that, from a climate historical perspective, the most likely place where the CO_2 was hidden was in deep oceanic water. The Abstract of the study, titled "Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool," is available to the right. From *Alfred Wegener Institute Press Release* on May 10, 2016.

"Radiocarbon constraints on the extent and evolution of the South Pacific glacial carbon pool." The following is the Abstract of this article: "During the last deglaciation, the opposing patterns of atmospheric CO_2 and radiocarbon activities ($\Delta^{14}C$) suggest the release of ^{14}C-depleted CO_2 from old carbon reservoirs. Although evidences point to the deep Pacific as a major reservoir of this ^{14}C-depleted carbon, its extent and evolution still need to be constrained. Here [the authors] use sediment cores retrieved along a South Pacific transect to reconstruct the spatio-temporal evolution of $\Delta^{14}C$ over the last 30,000 years. In [approximately] 2,500–3,600 m water depth, [the authors] find ^{14}C-depleted deep waters with a maximum glacial offset to atmospheric ^{14}C ($\Delta\Delta^{14}C$=−1,000‰). Using a box model, [the authors] test the hypothesis that these low values might have been caused by an interaction of aging and hydrothermal CO_2 influx. [The authors] observe a rejuvenation of circumpolar deep waters synchronous and potentially contributing to the initial deglacial rise in atmospheric CO_2. These findings constrain parts of the glacial carbon pool to the deep South Pacific." **T.A. Ronge, R. Tiedemann, F. Lamy, P. Köhler, B.V. Alloway, R. De Pol-Holz, K. Pahnke, J. Southon, and L. Wacker**, *Nature Communications*. (Subscription may be required.)

July 2016

"New Study Helps Identify Criteria for Effective Greenhouse Gas Emissions Storage." A study on natural underground reservoirs of CO_2 has identified criteria for the effective storage of greenhouse gases (GHGs). Research conducted by scientists from Scotland's University of Edinburgh and the University of Strathclyde will be used to develop a new CCS technology to aid underground CO_2 storage. The data for the study was gathered through the evaluation of 76 natural reservoirs in Asia, America, Australia, and Europe. From *Power Technology* on June 22, 2016.

August 2016

"CO_2 Fingerprint Discovery Enables Safe Storage of Greenhouse Gas." Researchers from the University of Edinburgh found that CO_2 captured from power stations and industrial sites has a distinct chemical fingerprint that allows it to be distinguished from other CO_2 present near storage sites. The fingerprint, which is dependent on the fuel producing the gas and the technology being used for its capture, may aid in the storage and monitoring of underground CO_2. By comparing the chemical fingerprints in the captured CO_2 with those in geologic storage reservoirs and drinking water formations, the research shows that the fingerprints can be easily identified and distinguished from natural sources of CO_2. The study, titled "Inherent Tracers for Carbon Capture and Storage in Sedimentary Formations: Composition and Applications," was published in the journal *Environmental Science and Technology*. From *Scottish Carbon Capture and Storage News Release* on July 25, 2016.

"Polar Ice Reveals Secrets of Carbon-Climate Feedbacks." A team of international researchers has quantified the relationship of the Earth's land biosphere to changes in temperature, as well as how it affects the cycles of carbon between land, ocean, and the atmosphere. Published in the journal *Nature Geoscience*, the paper shows that the Earth's land biosphere takes up less carbon in a warmer climate. Scientists used air bubbles in polar ice from pre-industrial times, focusing on CO_2 changes preserved in ice before, during, and after the Little Ice Age. The study, titled "Low atmospheric CO_2 levels during the Little Ice Age due to cooling-induced terrestrial uptake," showed that for every degree Celsius of global temperature rise, the equivalent of 20 parts per million (ppm) less CO_2 is stored by the land biosphere. From *Phys.org* on July 26, 2016.

"Scientists Convert Carbon Dioxide, Create Electricity." Cornell University researchers have created an oxygen-assisted aluminum/CO_2 power cell capable of storing CO_2 while producing electrical energy. The proposed power cell would use aluminum as the anode and mixed streams of CO_2 and oxygen as the active ingredients of the cathode. The electrochemical reactions between the anode and the cathode would store the CO_2 while also producing electricity and an oxalate byproduct. The researchers' findings are detailed in a paper, titled "The O_2-assisted Al/CO_2 electrochemical cell: A system for CO_2 capture/conversion and electric power generation," published in the journal *Science Advances.* From *ScienceDaily* on August 4, 2016.

September 2016

"Blowing Bubbles to Catch Carbon Dioxide." Researchers from Sandia National Laboratory and the University of New Mexico developed a technology capable of capturing CO_2 from coal- and gas-fired electricity plants. The bubble-like membrane technology, called CO_2 Memzyme, is approximately 10 times thinner than a soap bubble and produces 99-percent pure CO_2. A video on CO_2 Memzyme, which has been tested successfully at the laboratory scale, is available online. From *Sandia National Laboratories News Release* on September 1, 2016.

"USGS Studies Groundwater Sampling for CO_2." Scientists at the U.S. Geological Survey (USGS), Electric Power Research Institute (EPRI), and Lawrence Berkeley National Laboratory (LBNL) completed a comparison study of deep-groundwater sampling techniques to provide guidance on the methods available to accurately reflect CO_2 storage effectiveness. The study, titled "Comparison of geochemical data obtained using four brine sampling methods at the SECARB Phase III Anthropogenic Test CO_2 injection site, Citronelle Oil Field, Alabama," was published in the *International Journal of Coal Geology* and included four sampling methods: gas lift, electric submersible pump, a down-hole vacuum sampler, and a U-tube. The research was carried out at the Citronelle injection site in Alabama, USA, which is part of the Southeast Regional Carbon Sequestration Partnership (SECARB) Anthropogenic Test project. SECARB is one of seven DOE RCSPs. From *Carbon Capture Journal* on September 1, 2016.

Policy

September 2015

"Korea to Develop Six New Technologies to Counter Climate Change." The Korean Ministry of Science, ICT, and Future Planning (MSIP) is investing approximately $44 million toward the development of six technologies, including CCS, to address potential climate change. MSIP will look to advance the commercialization of CCS by developing carbon capture technologies such as wet and dry processes and gas separation. In order to demonstrate the technologies, MSIP will construct an underground storage area at Pohang, South Korea, that can hold up to 10,000 tons of CO_2. From *Korea Bizwire* on August 7, 2015.

"State Grants Money for Local Climate Change Studies." Maine's Coastal Zone Management agency will help fund climate change studies through a joint grant to the Town of Essex, the National Wildlife Federation, the Ipswich River Watershed Association, and the Essex County Greenbelt Association. The grant is part of approximately $2 million given to coastal Massachusetts organizations as part of the state's effort to "advance local efforts to increase awareness and understanding of climate impacts." From *Newbury Port News* on August 22, 2015.

"Climate change policy in Brazil and Mexico: Results from the MIT EPPA model." The following is the Abstract of this article: "Based on an in-depth analysis of results from the MIT Economic Projection and Policy Analysis (EPPA) model of climate policies for Brazil and Mexico, [the authors] demonstrate that commitments by Mexico and Brazil for 2020—made during the UN climate meetings in Copenhagen and Cancun—are reachable, but they come at different costs for each country. [The authors] find that Brazil's commitments will be met through reduced deforestation, and at no additional cost; however, Mexico's pledges will cost [$4 billion] in terms of reduced GDP in 2020. [The authors] explore short- and long-term implications of several policy scenarios after 2020, considering current policy debates in both countries. The comparative analysis of these two economies underscores the need for climate policy designed for the specific characteristics of each country, accounting for variables such as natural resources and current economic structure. [The authors'] results also suggest that both Brazil and Mexico may face other environmental and economic impacts from stringent global climate policies, affecting variables such as the value of energy resources in international trade." **Claudia Octaviano, Sergey Paltsev, and Angelo Costa Gurgel**, *Energy Economics*. (Subscription may be required.)

October 2015

"Québec Sets New Greenhouse Gas Reduction Targets." The province of Québec, Canada, at the recommendation of its consultation committee on potential climate change, announced plans to cut its GHG emissions to 37.5 percent below 1990 levels by 2030. The Québec government will present its plans at the 21st Conference of the Parties (COP-21) to the United Nations Framework Convention on Climate Change (UNFCCC), scheduled to be held in Paris, France, in December 2015. More information is available in the Minister of Sustainable Development, Environment and the Fight Against Climate Change Press Release. From *CBC News* on September 17, 2015.

Washington to Set Carbon Emission Limits. The Washington Department of Ecology is drafting a rule that would require a portion of the state of Washington's CO_2 emitters to reduce their GHGs. Businesses and organizations responsible for producing 100,000 metric tons or more of GHGs could potentially be covered under the rule. Over the next year, public meetings and hearings will be held to gather input from stakeholders. More information is available on the Washington State Department of Ecology website.

"Economic evaluation on CO_2-EOR of onshore oil fields in China." The following is the Abstract of this article: "Carbon dioxide enhanced oil recovery (CO_2-EOR) and [storage] in depleted oil reservoirs is a plausible option for utilizing anthropogenic CO_2 to increase oil production while storing CO_2 underground. Evaluation of the storage resources and cost of potential CO_2-EOR projects is an essential step before the commencement of large-scale deployment of such activities. In this paper, a hybrid techno-economic evaluation method, including a performance model and cost model for onshore CO_2-EOR projects, has been developed based on previous studies. Total 296 onshore oil fields, accounting for about 70 [percent] of total mature onshore oil fields in China, were evaluated by the techno-economic method. The key findings of this study are summarized as follows: (1) deterministic analysis shows there are approximately 1.1 billion tons (7.7 billion barrels) of incremental crude oil and 2.2 billion tons CO_2 storage resource for onshore CO_2-EOR at net positive revenue within the Chinese oil fields reviewed under the given operating strategy and economic assumptions. (2) Sensitivity study highlights that the cumulative oil production and cumulative CO_2 storage resource are very sensitive to crude oil price, CO_2 cost, project lifetime, discount rate and tax policy. High oil price, short project lifetime, low discount rate, low CO_2 cost, and low tax policy can greatly increase the net income of the oil enterprise, incremental oil recovery and CO_2 storage resource. (3) From this techno-economic evaluation, the major barriers to large-scale deployment of CO_2-EOR include complex geological conditions, low API of crude oil, high tax policy, and lack of incentives for the CO_2-EOR project." **Ning Wei, Xiaochun Li, Robert T. Dahowski, Casie L. Davidson, Shengnan Liu, and Yongjin Zha**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

November 2015

"Expanding U.S.-Indonesia Cooperation for Energy Development and Energy Security." Building on the U.S.-Indonesia Comprehensive Partnership, the United States and Indonesia will further expand their partnership by promoting clean energy technologies and policies to help Indonesia's energy demands, improve energy access, and reduce energy-sector GHG emissions. Expanded cooperation includes support through the U.S. Agency for International Development (USAID) for clean energy development and to build Indonesian capacity to reduce carbon in land use and energy. For more information, view the "Joint Statement by the United States of America and the Republic of Indonesia," which includes a section on Energy Cooperation. From *The White House Fact Sheet* on October 26, 2015.

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

December 2015

"[The United States] and China Advance Policies to Limit Carbon Emissions." According to the U.S. Energy Information Administration (EIA), the United States and China have advanced policies to limit CO_2 emissions. In its intended nationally determined contributions (INDCs), the United States proposes to bring emissions 26 to 28 percent below 2005 levels by 2025. China's INDC proposes to peak its CO_2 emissions around 2030, furthermore proposing 20 percent non-fossil energy use, also by 2030. From *Energy Voice* on November 18, 2015.

"DNV GL Conducts Largest Ever Controlled Release of CO_2 from an Underwater Pipeline." DNV GL announced it will conduct a controlled release of CO_2 from an underwater pipeline at its full-scale Spadeadam Testing and Research Center in Cumbria, United Kingdom (UK). Scheduled in begin in January 2016, the planned underwater release is part of an international Joint Industry Project (JIP) called "Sub-C-O2," the goal of which is to develop safety guidelines on the use of offshore CO_2 pipelines. This marks the project's second experimental phase and is expected to run for three months and involve releases in an approximately 130-foot-diameter, 39-foot-deep pond at Spadeadam. From *DNV GL* on November 23, 2015.

"A benchmarking framework to evaluate business climate change risks: A practical tool suitable for investors decision-making process." The following is the Abstract of this article: "A fundamental concern for the investor community is to identify techniques which would allow them to evaluate and highlight the most probable financial risks that could affect the value of their asset portfolio. Traditional techniques primarily focus on estimating certain conventional social-economic factors and many fail to cover an array of climate change risks. A limited number of institutional documents present, to a somewhat limited extent, some general-defined types of business climate change risks, which are deemed most likely to influence the value of an investors' portfolio. However, it is crucial that stakeholders of businesses and scholars consider a wider range of information so as to assist investors in their decision making. This paper aims at establishing a new framework to operationalize and quantify an array of business climate change risks to provide more comprehensive and tangible information on non-traditional risks. This framework relies on the benchmarking – scoring systems and Global Reporting Initiative (GRI) guidelines, and is applied to various Greek businesses that are certified by Environmental Management and Audit Scheme (EMAS)." **Nikolaos Demertzidis, Thomas A. Tsalis, Glykeria Loupa, Ioannis E. Nikolaou**, *Climate Risk Management*. (Subscription may be required.)

January 2016

"New Zealand Meets Kyoto Climate Target." The New Zealand government released three reports indicating its target has been met for reducing emissions under the first commitment period of the Kyoto Protocol. The reports, which also show that the country is on track to meet its 2020 target, were published by the New Zealand Ministry for the Environment as part of their international climate change reporting obligations. The reports are available via the above link. From *New Zealand Government News Release* on December 17, 2015.

"Japan to Release New Climate Policy Plan..." The Japanese government announced plans to develop a new climate change policy plan by early 2016. The new climate plan, which will be developed by a panel from the Ministry of Economy, Trade, and Industry (METI) and a panel from the Ministry of Environment, will aim to meet Japan's target of reducing greenhouse gas (GHG) emissions to 26 percent below 2013 levels by 2030. Due for publication in 2016, the policy plan will also consider the possibility of implementing an emissions trading scheme (ETS). From *Carbon Pulse* on December 22, 2015.

"Recent advances in risk assessment and risk management of geologic CO_2 storage." The following is the Abstract of this article: "This paper gives an overview of the advances made in the field of

risk assessment and risk management of geologic CO_2 storage (GCS), since the publication of the IPCC Special Report on Carbon Capture and Storage in 2005. Development and operation of a wide range of demonstration projects coupled with development of new regulations for safe injection and storage of CO_2 have led to development and deployment of a range of risk assessment approaches. New methods and tools have been developed for quantitative and qualitative risk assessment. These methods have been integrated effectively with monitoring and mitigation techniques and deployed in the field for small-scale field tests as well as large-scale commercial projects. An important development has been improved definition of risks, which can be broadly classed as site performance risks, long-term containment risks, public perception risks and market risks. Considerable experience has now been gained on understanding and managing site performance risks. Targeted research on containment risks and induced seismicity risks has led to improved understanding of parameters and processes influencing these risks as well as identifying key uncertainties that need to be targeted. Finally, significant progress has been made to effectively integrate communication strategies with risk management approaches to increase stakeholder confidence in effectiveness of deployed risk management approaches to manage risks." **Rajesh J. Pawar, Grant S. Bromhal, J. William Carey, William Foxall, Anna Korre, Philip S. Ringrose, Owain Tucker, Maxwell N. Watson, and Joshua A. White**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

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

February 2016

"Historic Paris Agreement on Climate Change." An agreement was reached by 195 nations at the annual Conference of Parties (COP21) in Paris, France, to combat potential climate change by driving efforts to limit global temperature increase and invest in a low-carbon future. In addition to setting long-term direction, the Paris Agreement lays the foundation for countries to peak their GHG emissions as soon as possible while continuing to submit national climate action plans. Under the agreement, countries will submit their updated climate plans, called nationally determined contributions (NDCs), every five years. Following adoption of the Paris Agreement by the COP, it will be opened for one year for signature on April 22, 2016, and will become effective after 55 countries, accounting for at least 55 percent of global emissions, ratify the agreement. From *United Nations Press Release* on December 12, 2015.

"Canada to Consider CO_2 Emissions in Approving New Pipelines." Canada announced a new framework for approving the construction of pipelines that requires the consideration of the direct and upstream GHG emissions linked to the projects. The new requirements will be added to Canada's existing environmental assessment process and will apply to projects currently being analyzed by the national energy regulator. From *Phys.org* on January 28, 2016.

"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 Ratnatunda**, *Journal of Cleaner Production*. (Subscription may be required.)

"Climate policy modeling: An online SCI-E and SSCI based literature review." The following is the Abstract of this article: "This study utilizes the bibliometric method on climate policy modeling based on the online version of SCI-E from 1981 to 2013 and SSCI from 2002 to 2013, and summarizes several important research topics and methodologies in the field. Publications referring to climate policy modeling are assessed with respect to quantities, disciplines, most productive authors and institutes, and citations. Synthetic analysis of keyword frequency reveals six important research topics in climate policy modeling which are summarized and analyzed. The six topics include integrated assessment of climate policies, uncertainty in climate change, equity across time and space, endogeneity of technological change, greenhouse gases abatement mechanism, and enterprise risk in climate policy models. Additionally, twelve types of models employed in climate policy modeling are discussed. The most widely utilized climate policy models are optimization models, computable general equilibrium (CGE) models, and simulation models." **Yi-Ming Wei, Zhi-Fu Mi, and Zhimin Huang**, *Omega*. (Subscription may be required.)

March 2016

"Sweden Reveals Plan to Go 'Carbon Neutral' by 2045." The Swedish parliamentary committee responsible for environmental policy proposed a plan to go "carbon neutral" by reducing its emissions by at least 85 percent from 1990 levels. The country would then offset the remaining 15 percent by investing in projects to reduce CO_2 emissions abroad. The government is expected to release more details on the legislative proposals later this year. From *Business Green* on February 12, 2016.

"Japan to Target 80 [Percent] Emissions [Reduction] by 2050." According to a draft report, the Japanese government plans to reduce their greenhouse gas (GHG) emissions 80 percent from their current level by 2050. The draft states Japan will also set an official target of a 3.8 percent or more reduction in GHG emissions by 2020 compared to the 2005 level, as well as a target to reduce emissions by 26 percent by 2030 compared to 2013. Those targets, along with the long-term 2050 target, will be registered with the United Nations (UN) after the latest international framework on climate change takes effect. From *Nikkei Asian Review* on February 29, 2016.

"The European low-carbon mix for 2030: The role of renewable energy sources in an environmentally and socially efficient approach." The following is the Abstract of this article: "The

European Union's [EU] commitment to increase the presence of renewable energy sources in its portfolio has resulted in better levels of security of supply, competitiveness and environmental sustainability. This proposed work reviews European legislation regarding the promotion of renewable energy sources, as well as the bibliography that applies portfolio theory methodology to energy policy. This double revision gives rise to the question whether the share limits of renewable energy technologies anticipated for the European power mix in 2020 and 2030 are actually efficient. The optimization model corrects for the attractiveness of renewable energy sources as opposed to conventional sources in terms of costs, risks and pollutant gas emissions. This model successfully and explicitly identifies the positive effect on the environment that is represented by the inclusion of renewable energy sources in the portfolio. The goal is to minimize the cost and risk that society must bear to produce electricity, in addition to compliance with European pollutant gas (CO_2, SO_2, NO_x and PM) objectives. The results for 2020 indicate that the EU would not be able to reach its emissions reduction goals with the anticipated shares of renewable energy sources. In 2030, achieving a lower emissions portfolio would not mean taking on greater costs, although it would be necessary to assume a greater level of risk. The anticipated shares of renewable energy sources (+5 [percent]) and fossil fuel technologies (+15 [percent]) would be overdimensioned in the forecasts analyzed. In terms of technologies, both nuclear and wind energy stand out, both with shares above 20 [percent]. On the contrary, biomass and solar photovoltaic energies would be unnecessary in order to reach efficiency. In any case, one thing is clear: The EU would be the master of its energy future if it prioritizes the importance of renewable energy sources in its efficient portfolio." **Fernando deLlano-Paz, Anxo Calvo-Silvosa, Susana Iglesias Antelo, and Isabel Soares**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

"European Carbon Capture and Storage Project Network: Overview of the Status and Developments." The following is the Abstract of this article: "The European CCS Project Network [the 'Network'] is currently composed of projects located in the Netherlands, Norway, Spain, and the UK. The goal of the Network is to accelerate deployment of CCS by sharing project development experiences about technology integration, regulatory environment and financial structures. This paper aims to provide a review of some CCS experiences gained from developing the Network projects. Besides technology and project development, sharing knowledge and lessons learned on project-level basis, also gives valuable insights on how to create policies that would assist more effective deployment of technology and can enable development and implementation of regulatory frameworks. Hence, knowledge acquired in CCS aspects during the early development of this technology in Europe will be presented in this paper." **Zoe Kapetaki, Jelena Simjanović, and Jens Hetland**, *Energy Procedia*. (Subscription may be required.)

April 2016

"Malaysia Committed In Reducing CO_2 Emissions…" Malaysia will reduce its CO_2 emission intensity by 40 percent, government officials announced. To date, the country has reduced their emissions by 33 percent. According to the Eleventh Malaysian Plan, the Malaysian government has set aside funding to develop and implement technologies. From *Malaysian Digest* on March 20, 2016.

"A commentary on the [U.S.] policies for efficient large scale renewable energy storage systems: Focus on carbon storage cycles." The following is the Abstract of this article: "The inevitable depletion of fossil resources and increasing atmospheric [GHG] concentrations demonstrate the need for renewable energy conversion technologies for a sustainable economy. Intermittencies and variability in availability of renewable energy sources are the challenges for uninterrupted energy supply, which can be overcome by large scale energy storage facilities. Pumped hydroelectric energy storage is an efficient but a very low energy density energy storage method that dominates the current energy storage market with ~96 [percent] share. [The authors] first present a recently developed potential solution for large scale efficient and dense energy storage: closed loop carbon storage cycles and a specific example dimethyl ether storage cycle. [The authors] then discuss the relevant [U.S.] energy storage regulations, policy initiatives, their status, and potential modifications that will contribute to the invention and

implementation of novel energy storage systems." **Emre Gençer and Rakesh Agrawal**, *Energy Policy*. (Subscription may be required.)

"'Best practice' community dialogue: The promise of a small-scale deliberative engagement around the siting of a carbon dioxide capture and storage (CCS) facility." The following is the Abstract of this article: "In New Zealand the Taranaki region has been identified as a likely place for [CO_2 storage] as a result of its oil and gas industry, potential storage reservoirs and skilled local workforce. As yet there are no plans to deploy the CCS technology in this particular region but this presented an opportunity for pro-active engagement with local stakeholders, including the urban community, farmers and landowners, local iwi (Māori), local and regional councils and the oil/gas industry. As an alternative to a standard consultation technique, a small-scale dialogue-based method was used, based on the principles of deliberative engagement. In this context, the emphasis was on developing an informed understanding of different viewpoints and solution-focused decision-making. This method of engagement was found to be cost-effective, revealed some unexpected viewpoints and identified some important precursors to risk perception in New Zealand. The empowerment of participants, assisted by independent scientists and the opportunity for facilitated dialogue, were key success factors. Moreover, the approach was valued by the wider community and perceived as a means to open up dialogue around other regional energy issues. In summary, small-scale deliberative engagement processes are a viable alternative or complement to standard community consultation techniques for engagement around the siting of CCS facilities." **Fiona J. Coyle**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Persuasiveness, importance and novelty of arguments about Carbon Capture and Storage." The following is the Abstract of this article: "CCS is a promising technology for reducing carbon emissions, but the public is often reluctant to support it. To understand why public support is lacking, it is crucial to establish what citizens think about the arguments that are used by proponents and opponents of CCS. [The authors] determined the persuasiveness, importance and novelty of 32 arguments for and against CCS using a discrete choice experiment in which respondents made consecutive choices between pairs of pro or con arguments. [The authors] used latent class models to identify population segments with different preferences. The results show that citizens find arguments about climate protection, which is the primary goal of CCS, less persuasive than other arguments, such as normative arguments (for example 'a waste product such as CO_2 should be disposed of properly') or arguments about benefits of CCS for energy production and economic growth. This discrepancy complicates communication that aims to convince citizens of the benefits of CCS for climate protection." **Kevin P.F. Broecks, Sander van Egmond, Frank J. van Rijnsoever, Marlies Verlinde-van den Berg, and Marko P. Hekkert**, *Environmental Science & Policy*. (Subscription may be required.)

May 2016

"China's Hunan Province Sets Absolute CO_2 Target for 2020." According to the Hunan Provincial People's Government Office, the south-central China province will limit its 2020 CO_2 emissions to approximately 510 million metric tons. The target was outlined in the government's low-carbon implementation plan for 2016-2020. In addition, government officials announced plans to finalize work on a carbon emissions trading system (ETS) as part of preparations to join the national ETS. To meet the target, the provincial government will introduce advanced climate finance tools, increase international collaboration, and introduce a low-carbon building program. From *Carbon Pulse* on May 2, 2016.

"The political economy of carbon capture and storage: An analysis of two demonstration projects." The following is the Abstract of this article: "CCS technology is considered key to mitigating climate change by international institutions and governments around the world. The technology is considered advantageous because it may enable the continued utilization of fossil fuels while curbing carbon emissions. However, development of the technology remains slow on the ground. It is generally argued that large-scale, integrated demonstration projects are needed as a next step toward

commercialization. Despite government support in several countries, few projects exist so far worldwide. This paper asks why it is so difficult to get demonstration projects off the ground. The argument is that it is not only project-specific factors that determine the feasibility of demonstration, but given the need for government support, a variety of political economy factors influence decision-making processes by policy makers and companies. The paper introduces an analytical framework developed on the basis of the political economy literature that considers six sets of factors that influence outcomes. It discusses two specific projects, Longannet in the UK and Quest in Canada, and explains why one failed and the other one is under construction. The analysis shows that although climate change has been a more important policy concern in the UK compared to Canada, the specific political economy situation of fossil fuel rich provinces like Alberta has led to the Quest project going forward." **Florian Kern, James Gaede, James Meadowcroft, and Jim Watson**, *Technological Forecasting and Social Change*. (Subscription may be required.)

June 2016

"[South] Korea to Double Investment in Clean Energy by 2021." The South Korean government announced plans to spend more than $841 million on R&D of clean energy by 2021. In addition, the South Korean ministry also announced plans for detailed roadmaps for each of its six research areas, which include CCUS. From *The Korea Times* on June 3, 2016.

"Long-term abatement potential and current policy trajectories in Latin American countries." The following is the Abstract of this article: "This paper provides perspectives on the role of Latin American and Latin American countries in meeting global abatement goals, based on the scenarios developed through the CLIMACAP–LAMP modeling study. Abatement potential in Latin America, among other things, is influenced by its development status, the large contributions of non-CO_2 and land use change CO_2 emissions, and energy endowments. In most scenarios in this study, the economic potential to reduce fossil fuel CO_2 as well as non-CO_2 emissions in Latin America in 2050 is lower than in the rest of the world (in total) when measured against 2010 emissions, due largely to higher emission growth in Latin America than in the rest of the world in the absence of abatement. The potential to reduce land use change CO_2 emissions is complicated by a wide range of factors and is not addressed in this paper (land use emissions are largely addressed in a companion paper). The study confirms the results of previous research that the variation in abatement costs across models may vary by an order of magnitude or more, limiting the value of these assessments and supporting continued calls for research on the degree to which models are effectively representing key local circumstances that influence costs and available abatement options. Finally, a review of policies in place in several Latin American countries at the time of this writing finds that they would be of varying success in meeting the emission levels proposed by the most recent [Intergovernmental Panel on Climate Change (IPCC)] reports to limit global temperature change to 2°C." **Leon Clarke, et al.**, *Energy Economics*. (Subscription may be required.)

July 2016

"Leaders' Statement on a North American Climate, Clean Energy, and Environment Partnership." Representatives from the United States, Canada, and Mexico announced a commitment to the North American Climate, Clean Energy, and Environment Partnership, with a goal of achieving 50 percent clean power generation by 2025 through clean energy development and deployment, clean energy innovation, and energy efficiency. The partnership will include domestic initiatives and policies, cross-border projects, a joint study, trilateral collaborations on green government initiatives, aligning efficiency standards, and building on North American leadership in international forums. In addition, the collaboration will result in the identification of joint R&D initiatives to advance clean technologies in areas such as CCUS. From *The White House, Office of the Press Secretary* on June 29, 2016.

"Québec and Saskatchewan Join Forces for Carbon Capture and Storage Technologies." Officials from Québec, Canada, and Saskatchewan, Canada, agreed to expand their collaboration to accelerate the development of CCS-related technologies. According to Saskatchewan's Executive Council, the collaboration will contribute to the development of knowledge and best practices to reduce GHG emissions through CCS, while improving the economic return on projects by reusing the captured carbon for other purposes. In addition, officials from the two provinces will also exchange CCS project updates and information, and continue to work together to identify future collaboration possibilities. From *Canadian Underwriter* on June 17, 2016.

"CCS Feasible by 2022, Says [Norwegian Petroleum Directorate] Study." According to a feasibility study conducted by Norway's Ministry of Petroleum and Energy (MPE), full-scale CCS could be achieved in Norway by 2022. The study set out to identify a technically feasible CCS chain with corresponding cost estimates that include CO_2 capture, transport, and storage. The Norwegian government will present further plans for CCS in its state budget for 2017. More information is available via an MPE press release. Click here for a summary of the feasibility studies. From *Offshore Engineer* on July 4, 2016.

"[United Kingdom (UK)] Sets 2030 Climate Goal..." Britain has set a target to reduce its CO_2 emissions by 57 percent, based on 1990 levels, by 2032. Britain's overall target is to reduce emissions by 80 percent based on 1990 levels. Before it can become law, the carbon budget will need to be adopted by Parliament. By 2050, Britain has a legally binding target to cut emissions by 80 percent based on 1990 levels. From *Reuters* on June 30, 2016.

August 2016

"EU Commission Proposes Emissions Cuts for Member States." The European Commission has proposed country-specific emissions targets in a proposal known as the Effort Sharing Regulation. The proposal, which clarifies roles in helping the European Union (EU) reach a 40 percent reduction in greenhouse gas (GHG) emissions by 2030 compared to 1990 levels, targets sectors not included in the European Union Emissions Trading System (EU ETS). In addition, the proposal includes requirements for member states to report on their progress toward meeting goals, as well as sets annual interim targets from 2021 to 2030. The Effort Sharing Regulation builds upon the Effort Sharing Decision, which is the emissions roadmap for 2013 to 2020. From *International Centre for Trade and Sustainable Development* on July 28, 2016.

"The effects of fiscal policy on CO_2 emissions: Evidence from the U.S.A." The following is from the Abstract of this article: "This paper examines the effects of fiscal policy on CO_2 emissions using Vector Autoregressions on U.S. quarterly data from 1973 to 2013. In particular, [the authors] analyze the short- and mid-term interactions between fiscal policy and emissions by using sign restrictions to identify the policy shocks. [The authors] construct the impulse responses to linear combinations of fiscal shocks, corresponding to the scenarios of deficit-financed spending and deficit-financed tax-cuts. To consider possible variations of the effect of fiscal policy, [the authors] distinguish between production- and consumption-generated CO_2 emissions. The results point out that the implementation of expansionary fiscal spending provides an alleviating effect on emissions, whereas deficit-financed tax-cuts are associated with an increase on consumption-generated CO_2 emissions. The exact pattern of the effects depends on the source of emissions, the scenario of fiscal policy that is implemented and the functional class of government expenditure being increased." **George E. Halkos and Epameinondas A. Paizanos**, *Energy Policy*. (Subscription may be required.)

September 2016

"Canada Advances Mission Innovation with Establishment of Clean Energy Innovation Program." Natural Resources Canada (NRC) announced the Canadian government is seeking proposals for

projects as part of the Clean Energy Innovation Program, the goal of which is to advance the commercialization of clean energy technologies. In addition, the initiative will aid Canada in meeting its Mission Innovation goal of doubling its 2014 through 2015 funding for clean energy and clean technology R&D by 2020. Mission Innovation is a global initiative of 20 countries focused on accelerating clean energy development. From *Natural Resources Canada News Release* on August 18, 2016.

"Ontario, Québec Sign Climate Policy Deal with Mexico." The governments of Ontario and Québec, Canada, signed an agreement with the Mexican government to jointly develop carbon markets, allowing companies in the two Canadian provinces to purchase Mexican greenhouse gas (GHG) reduction credits. The memorandum was reached during the Climate Summit of the Americas in Guadalajara, Mexico, in August 2016. Under the agreement, Mexico plans to join the Western Climate Initiative (WCI), a non-profit corporation formed to support the implementation of state and provincial GHG emissions trading programs. Ontario and Québec are currently represented in WCI. From *The Globe and Mail* on August 31, 2016.

"Stakeholder and public perceptions of CO_2-EOR in the context of CCS – Results from UK focus groups and implications for policy." The following is the Abstract of this article: "Interest is growing in CO_2-EOR as an additional economic incentive for CO_2 injection and demonstration of storage feasibility. However, given increasing societal concern over fossil fuel energy, could CO_2-EOR unintentionally hinder conventional CCS by reducing support from neutral or cautiously supportive voices? This paper assesses how stakeholders and citizens respond to four scenarios for CCS with CO_2-EOR in the North Sea, and draws societal implications for deployment in other mature basins. Based on focus group data from Aberdeen, Edinburgh and London, [the authors] argue that scenarios [emphasizing maximizing] oil recovery may be met with [skepticism] or even opposition, and that there is an expectation for national governments to lead and ensure CO_2-EOR (and CCS more generally) are undertaken in the public interest. Nonetheless, [the authors'] data also suggest a certain degree of pragmatism as to the embeddedness of fossil fuels in society, and thus that there may be qualified support for CCS with CO_2-EOR as making best use of existing fields whilst [decarbonizing] the power and industrial sectors. However, for this support to emerge there is an imperative for coherent and credible policy that positions CO_2-EOR firmly within a managed transition towards a low-carbon economy." **Leslie Mabon and Chris Littlecott**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Geology

September 2015

"Impacts of CO_2 [release] into shallow formations on groundwater chemistry." The following is the Abstract of this article: "Geological storage of CO_2 is one option for mitigating atmospheric emissions of [CO_2]. However, the injected CO_2 has the possibility of [release]. The [released] CO_2 may move upward into shallow formations and thereby affects shallow groundwater. To investigate this effect, 27 tonnes of gaseous CO_2 was injected into [a formation] about 180 m below a surface. Periodic groundwater samples were studied to identify shift of hydro-chemical parameters, including pH, TDS, ORP, Ca, Mg, Na, HCO_3, Cl, SO_4, Pb, Fe, and F. The results indicated that CO_2 dissolution and reaction concurrently reduced aquifer pH levels and increased concentrations of TDS, Ca, Mg, HCO_3, and F. ORP level and SO_4 concentration remained static. Pb and Fe concentrations were lower than the detection limit 1 mg/L and 0.02 mg/L, respectively. After the CO_2 breakthrough, Cl concentration increased to a stable level slightly higher than the background concentration. The shift in groundwater levels of Ca and Mg was attributed to dolomite (or Mg-rich calcite) and calcite-dominant dissolution processes. Results indicated linear approximations between concentrations of F vs. HCO_3 (slope 0.0036) and F vs. Ca (slope 0.013). Additionally, the TDS and the total molar concentration of Ca and Mg showed linear correlations with increased levels of HCO_3." **Qianlin Zhu, Xiaochun Li, Zhenbo Jiang, and Ning Wei**, *Fuel Processing Technology*. (Subscription may be required.)

October 2015

"Capillarity and wetting of carbon dioxide and brine during drainage in Berea sandstone at reservoir conditions." The following is the Abstract of this article: "The wettability of CO_2-brine-rock systems will have a major impact on the management of carbon [storage] in subsurface geological formations. Recent contact angle measurement studies have reported sensitivity in wetting behavior of this system to pressure, temperature, and brine salinity. [The authors] report observations of the impact of reservoir conditions on the capillary pressure characteristic curve and relative permeability of a single Berea sandstone during drainage—CO_2 displacing brine—through effects on the wetting state. Eight reservoir condition drainage capillary pressure characteristic curves were measured using CO_2 and brine in a single fired Berea sandstone at pressures (5–20 MPa), temperatures (25–50°C), and ionic strengths (0–5 mol kg^{-1} NaCl). A ninth measurement using a N_2-water system provided a benchmark for capillarity with a strongly water wet system. The capillary pressure curves from each of the tests were found to be similar to the N_2-water curve when scaled by the interfacial tension. Reservoir conditions were not found to have a significant impact on the capillary strength of the CO_2-brine system during drainage through a variation in the wetting state. Two steady-state relative permeability measurements with CO_2 and brine and one with N_2 and brine similarly show little variation between conditions, consistent with the observation that the CO_2-brine-sandstone system is water wetting and multiphase flow properties invariant across a wide range of reservoir conditions." **Ali Al-Menhali, Ben Niu, and Samuel Krevor**, *Water Resources Research*. (Subscription may be required.)

"CO_2-induced mechanical [behavior] of Hawkesbury sandstone in the Gosford basin: An experimental study." The following is the Abstract of this article: "CO_2 [stored] in saline [formations] undergoes a variety of chemically-coupled mechanical effects, which may cause CO_2-induced mechanical changes and time-dependent reservoir deformation. This paper investigates the mineralogical and microstructural changes that occur in reservoir rocks following injection of CO_2 in deep saline [formations] and the manner in which these changes influence the mechanical properties of the reservoir rocks. In this study, cylindrical sandstone specimens, 38 mm in diameter and 76 mm high, obtained from the Gosford basin, were used to perform a series of unconfined compressive strength (UCS) tests. Different saturation conditions: dry, water- and brine-saturated sandstone samples with and without $scCO_2$ (super-critical carbon dioxide) injection, were considered in the study to obtain a

comprehensive understanding of the impact of $scCO_2$ injection during the CO_2 [storage] process on saline [formation] mechanical properties. An acoustic emission (AE) system was employed to identify the stress threshold values of crack closure, crack initiation and crack damage for each testing condition during the whole deformation process of the specimens. Finally, scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses were performed to evaluate the chemical and mineralogical changes that occur in reservoir rocks during CO_2 injection. From the test results, it is clear that the CO_2-saturated samples possessed a lower peak strength compared to non-CO_2 saturated samples. According to SEM, XRD and XRF analyses, considerable quartz mineral corrosion and dissolution of calcite and siderite were observed during the interactions of the CO_2/water/rock and CO_2/brine/rock systems, which implies that mineralogical and geochemical rock alterations affect rock mechanical properties by accelerating the collapse mechanisms of the pore matrix. AE results also reveal the weakening effect of rock pore structure with CO_2 injection, which suggests a significant effect of CO_2 on failure mechanisms of the reservoir rock, with CO_2 saturation showing a significant influence on crack initiation and crack damage stages." **T.D. Rathnaweera, P.G. Ranjith, M.S.A. Perera, A. Haque, A. Lashin, N. Al Arifi, D Chandrasekharam, SQ Yang, T Xu, SH Wang, and E Yasar**, *Materials Science and Engineering A*. (Subscription may be required.)

November 2015

"Opportunities and obstacles for CO_2 mineralization: CO_2 mineralization specific frames in the interviews of Finnish carbon capture and storage (CCS) experts." The following is from the Abstract of this article: "CCS is expected to significantly reduce CO_2 emissions for climate change mitigation purposes. Currently, the EU CCS Directive contains only geological storage as the storage option for CO_2 – excluding CO_2 mineralization as a storage option. Since all CCS technologies are currently in a relatively early stage of development, this exclusion seems unreasonable. Opportunities for the use of CO_2 mineralization and the main uncertainties that can potentially prevent the use of these opportunities are investigated in this paper. The analysis is done by means of framing methodology that enables the extraction of CCS experts' mental models concerning CO_2 mineralization from the interview data." **Laura Kainiemi, Sanni Eloneva, Arho Toikka, Jarkko Levänen, and Mika Järvinen**, *Journal of Cleaner Production*. (Subscription may be required.)

December 2015

"Eocene atmospheric CO_2 from the nahcolite proxy." The following is the Abstract of this article: "Estimates of the atmospheric concentration of CO_2, $[CO_2]_{atm}$, for the 'hothouse' climate of the early Eocene climatic optimum (EECO) vary for different proxies. Extensive beds of the mineral nahcolite ($NaHCO_3$) in evaporite deposits of the Green River Formation, Piceance Creek Basin, Colorado, USA, previously established $[CO_2]_{atm}$ for the EECO to be >1125 ppm by volume (ppm). Here, [the authors] present experimental data that revise the sodium carbonate mineral equilibria as a function of $[CO_2]$ and temperature. Co-precipitation of nahcolite and halite (NaCl) now establishes a well-constrained lower $[CO_2]_{atm}$ limit of 680 ppm for the EECO. Paleotemperature estimates from leaf fossils and fluid inclusions in halite suggest an upper limit for $[CO_2]_{atm}$ in the EECO from the nahcolite proxy of ~1260 ppm. These data support a causal connection between elevated $[CO_2]_{atm}$ and early Eocene global warmth, but at significantly lower $[CO_2]_{atm}$ than previously thought, which suggests that ancient climates on Earth may have been more sensitive to a doubling of $[CO_2]_{atm}$ than is currently assumed." **Elliot A. Jagniecki, Tim K. Lowenstein, David M. Jenkins, and Robert V. Demicco**, *Geology*. (Subscription may be required.)

"Analysis of CO_2 trapping capacities and long-term migration for geological formations in the Norwegian North Sea using MRST-co2lab." The following is the Abstract of this article: "MRST-co2lab is a collection of open-source computational tools for modeling large-scale and long-time migration of CO_2 in conductive [formations], combining ideas from basin modeling, computational geometry, hydrology, and reservoir simulation. Herein, [the authors] employ the methods of MRST-co2lab to study

long-term CO_2 storage on the scale of hundreds of [million tons]. [The authors] consider public data sets of two [formations] from the Norwegian North Sea and use geometrical methods for identifying structural traps, percolation-type methods for identifying potential spill paths, and vertical-equilibrium methods for efficient simulation of structural, residual, and solubility trapping in a thousand-year perspective. In particular, [the authors] investigate how data resolution affects estimates of storage capacity and discuss workflows for identifying good injection sites and optimizing injection strategies." **Halvor Møll Nilsen, Knut-Andreas Lie, and Odd Andersen**, *Computers & Geosciences*. (Subscription may be required.)

January 2016

"Capillary trapping for geologic carbon dioxide storage – From pore scale physics to field scale implications." The following is the Abstract of this article: "A significant amount of theoretical, numerical and observational work has been published focused on various aspects of capillary trapping in CO_2 storage since the IPCC Special Report on Carbon Dioxide Capture and Storage (2005). This research has placed capillary trapping in a central role in nearly every aspect of the geologic storage of CO_2. Capillary, or residual, trapping – where CO_2 is rendered immobile in the pore space as disconnected ganglia, surrounded by brine in a storage [formation] – is controlled by fluid and interfacial physics at the size scale of rock pores. These processes have been observed at the pore scale in situ using X-ray microtomography at reservoir conditions. A large database of conventional centimetre core scale observations for flow modelling are now available for a range of rock types and reservoir conditions. These along with the pore scale observations confirm that trapped saturations will be at least 10 [percent] and more typically 30 [percent] of the pore volume of the rock, stable against subsequent displacement by brine and characteristic of water-wet systems. Capillary trapping is pervasive over the extent of a migrating CO_2 plume and both theoretical and numerical investigations have demonstrated the first order impacts of capillary trapping on plume migration, [immobilization] and CO_2 storage security. Engineering strategies to [maximize] capillary trapping have been proposed that make use of injection schemes that [maximize] sweep or enhance imbibition. National assessments of CO_2 storage capacity now incorporate modelling of residual trapping where it can account for up to 95 [percent] of the storage resource. Field scale observations of capillary trapping have confirmed the formation and stability of residually trapped CO_2 at masses up to 10,000 tons and over time scales of years. Significant outstanding uncertainties include the impact of heterogeneity on capillary [immobilization] and capillary trapping in mixed-wet systems. Overall capillary trapping is well constrained by laboratory and field scale observations, effectively modelled in theoretical and numerical models and significantly enhances storage integrity, both increasing storage capacity and limiting the rate and extent of plume migration." **Samuel Krevor, Martin J. Blunt, Sally M. Benson, Christopher H. Pentland, Catriona Reynolds, Ali Al-Menhali, and Ben Niu**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Petrological characterization and reactive transport simulation of a high-water-cut oil reservoir in the Southern Songliao Basin, Eastern China for CO_2 [storage]." The following is from the Abstract of this article: "[Carbon dioxide] geological [storage] (CGS) in depleted or high-water-cut oil reservoirs is a viable option for reducing anthropogenic CO_2 emissions and [EOR]. The Upper Cretaceous Qingshankou Formation in the central Changling (fault) Depression, Songliao Basin, East China is the selected site for a pilot injection of the CO_2 INJECTION project. The target reservoir depth is about 2400–2500 m. Lithologic features and diagenetic minerals of the reservoir and [caprocks] have been investigated by optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD). In the Qingshankou Formation, the reservoir rock is a typical arkose with moderately to good sorting, and very fine to fine grain sizes. Minerallogically it is dominated by quartz (19–31 vol.%), plagioclase (19–28 vol.%), and K-feldspar (2–26 vol.%). Calcite and ankerite constitute the most common diagenetic minerals. The lithology of the [caprock] is mainly silty mudstone and composed of quartz (average of 12.9–27.0 wt.%), albite (14.2–35.5 wt.%), K-feldspar (1.3–2.7 wt.%), mixed-layer illite/smectite (24.9–68.8 wt.%), chlorite (3.15–14.7 wt.%) and some kaolinite. The main antigenic minerals in the CO_2 INJECTION well are made up of albite (average of 29.7 wt.%), K-feldspar (average of 4.5 wt.%), calcite

(average of 7.5 wt.%) and ankerite (average of 9.1 wt.%)." **Zhichao Yu, Li Liu, Keyu Liu, Siyu Yang, and Yongzhi Yang**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Carbon dioxide storage in subsurface geologic medium: A review on capillary trapping mechanism." The following is the Abstract of this article: "Carbon dioxide (CO_2) storage in subsurface geologic medium is presently the most promising option for mitigating the anthropogenic CO_2 emissions. To have an effective storage in immobile phase, however, it is necessary to determine the distribution of CO_2 in a medium, which mainly depends on three trapping mechanisms known as capillary, dissolution and mineral mechanisms. Previous studies have emphasized on these mechanisms individually in different aspects, particularly by considering the [formation] system. The purpose of this review is to give a comprehensive discussion on the advancement made toward capillary trapping in terms of effective and non-effective factors. It also throws light into the importance of capillary trapping in depleted hydrocarbon reservoir. Considering various factors and their impacts on capillary trapping, it is suggested to carry out an integrated study for the assessment of the major and minor influential parameters for better modeling and understanding of capillary trapping in any storage medium." **Arshad Raza, Reza Rezaee, Chua Han Bing, Raoof Gholami, Mohamed Ali Hamid, and Ramasamy Nagarajan**, *Egyptian Journal of Petroleum*. (Subscription may be required.)

February 2016

"Impact of pressure and temperature on CO_2–brine–mica contact angles and CO_2–brine interfacial tension: Implications for carbon geo-[storage]." The following is the Abstract of this article: "Precise characterization of wettability of CO_2–brine–rock system and CO_2–brine interfacial tension at reservoir conditions is essential as they influence capillary sealing efficiency of caprocks, which in turn, impacts the structural and residual trapping during CO_2 geo-[storage]. In this context, [the authors] have experimentally measured advancing and receding contact angles for brine–CO_2–mica system (surface roughness ~12 nm) at different pressures (0.1 MPa, 5 MPa, 7 MPa, 10 MPa, 15 MPa, 20 MPa), temperatures (308 K, 323 K, and 343 K), and salinities (0 wt%, 5 wt%, 10 wt%, 20 wt% and 30 wt% NaCl). For the same experimental matrix, CO_2–brine interfacial tensions have also been measured using the pendant drop technique. The results indicate that both advancing and receding contact angles increase with pressure and salinity, but decrease with temperature. On the contrary, CO_2–brine interfacial tension decrease with pressure and increase with temperature. At 20 MPa and 308 K, the advancing angle is measured to be ~110°, indicating CO_2-wetting. The results have been compared with various published literature data and probable factors responsible for deviations have been highlighted. Finally, [the authors] demonstrate the implications of measured data by evaluating CO_2 storage heights under various operating conditions. [The authors] conclude that for a given storage depth, reservoirs with lower pressures and high temperatures can store larger volumes and thus exhibit better sealing efficiency." **Muhammad Arif, Ahmed Z. Al-Yaseri, Ahmed Barifcani, Maxim Lebedev, and Stefan Iglauer**, *Journal of Colloid and Interface Science*. (Subscription may be required.)

"Analysis of a time dependent injection strategy to accelerate the residual trapping of [stored] CO_2 in the geologic subsurface." The following is the Abstract of this article: "A time dependent injection strategy for greatly accelerating the immobilization of geologically [stored] CO_2 is proposed and analyzed. The injection of high density CO_2 into a brine [formation] is followed by brine flooding facilitating residual trapping and dissolution of the CO_2 on time scales much shorter than those that would occur by natural processes. One-dimensional kinematic wave equations are derived for the two-phase flow of brine and CO_2 and for the transport of dissolved CO_2. A solution of these equations using the method of characteristics reveals that brine flooding is most effective when the kinematic wave speed of CO_2 saturation is higher than the propagation velocity of a shock wave separating the two-phase flow from the native brine. Finite volume simulation using the reservoir simulator TOUGH2 with PetraSIM interface are generally in good agreement with the one-dimensional model, but show that gravitational overriding of the CO_2 can become important if the duration of the injection process is too long. Both methods show that brine flooding is able to reduce the mass fraction of mobile CO_2 to less than 10

[percent] using a volume ratio brine:CO_2 of less than 2.75 on time scales comparable to that of the CO_2 injection." **Erik J. Huber, Abraham D. Stroock, and Donald L. Kock**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

March 2016

"Effects of rate law formulation on predicting CO_2 [storage] in sandstone formations." The following is the Summary of this article: "Injection of CO_2 into confined geological formations, given their massive carbon storage capacity and widespread geographic distribution, represents one of the most promising options for CO_2 [storage]. Reactive transport models have been constructed to understand the process of carbon storage and predict the fate of injected CO_2. Model results, however, differ dramatically because of the large uncertainties attributed to reaction kinetics. The root of this problem is partly related to the one of the biggest challenges in modern geochemistry: The persistent two to five orders of magnitude discrepancy between laboratory-measured and field-derived feldspar dissolution rates. Recently, advances in reaction kinetics research suggest that the slow precipitation of secondary minerals produces negative feedback in the dissolution–precipitation loop, which reduces the overall feldspar dissolution rates by orders of magnitude. In this study, [the authors] focused on how the coupling between feldspar dissolution and secondary mineral precipitation, as well as mineral carbonation, is affected by rate law uncertainties. Reactive transport models with four different rate law scenarios were used for CO_2 [storage] in a sandstone formation resembling the Mt. Simon saline reservoir in the Midwest, USA. The results indicate that (1) long-term mineral trapping is more sensitive to rate laws for feldspar dissolution than to rate laws for carbonate mineral precipitation and (2) negligence of the sigmoidal shape of rate – ΔGr relationships and the mitigating effects of secondary mineral precipitation can overestimate both the extent of feldspar dissolution during CO_2 injection and in turn mineral trapping." **Guanru Zhang, Peng Lu, Yilun Zhang, Xiaomei Wei, and Chen Zhu**, *International Journal of Energy Research*. (Subscription may be required.)

"Reduced order models of transient CO_2 and brine [release] along abandoned wellbores from geologic carbon [storage] reservoirs." The following is the Abstract of this article: "[The authors] have developed reduced order models (ROMs) for CO_2 and brine [release] rates along wellbores including abandoned wells at geologic CO_2 storage sites using a Multivariate Adaptive Regression Splines (MARS) algorithm. The ROMs were developed for use within systems level performance assessment models such as Los Alamos National Laboratory's CO_2-PENS model. The ROMs are used to compute [release] rates as a function of wellbore properties including effective permeability, depth as well as pressures and saturations in the reservoir where the wellbore intercepts the reservoir. The ROMs were created using results of complex, 3-D multi-phase numerical simulations of large-scale CO_2 injection at a generic CO_2 storage site with an abandoned wellbore. The generic site included not only the primary storage reservoir but also a groundwater [formation] and an intermediate permeable zone. Two sets of simulations were performed, one with and one without an abandoned wellbore in order to capture the effect of coupling between the storage reservoir and wellbore in a system level model where it is assumed that they are decoupled. Cross-validation against the complex, multi-phase numerical simulation results were used to evaluate the ability of the ROMs to reproduce numerical simulation results. Further, [the authors'] ROM development approach effectively captures transient CO_2 and brine [release] during and after CO_2 injection as well as the effects of an intermediate permeable zone on [release] to a shallow groundwater [formation] and to the atmosphere. Ultimately, the ROM is a computationally efficient model that effectively captures many of the complex underlying processes taking place during CO_2 and brine [release] along a wellbore at a geologic CO_2 storage site." **Dylan R. Harp, Rajesh Pawar, J. William Carey, and Carl W. Gable**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Integration of reservoir simulation, history matching, and 4D seismic for CO_2-EOR and storage at Cranfield, Mississippi, USA." The following is the Abstract of this article: "In this paper, [the authors] compare 4D seismic interpretations of CO_2 plume evolution with fluid-flow numerical simulation results

for Cranfield, Mississippi. Historic pressure trends, oil and gas production rates, and current CO_2-[enhanced oil recovery (EOR)] production data from the field were history matched, and a tuned model was used for predictive simulations. For CO_2-EOR operations, numerical simulation results of the CO_2 plume distribution and CO_2 first arrival (breakthrough) times in production wells were compared to the available field data. Three interpretations of 4D seismic data show discrepancies on the edges of the seismic survey, and along the sealing fault, where numerical simulations show high CO_2 saturations. In areas between these two limits, the match between simulation and 4D seismic interpretation improves. In addition, for most of the production wells, comparison of the breakthrough time of CO_2 showed a reasonable match. The tuned model was then used to predict reservoir response and storage capacity in different field development scenarios under CO_2 injection. [The authors] compared hypothetical scenarios where the operator transitions from CO_2-EOR to CO_2 injection without oil production (CO_2-EORT) when oil production is not economical anymore, to a scenario of continuing with CO_2-EOR. [The authors'] results show that CO_2-EOR can store more CO_2 and operations will last longer, whereas if switched to CO_2-EORT, the field must be abandoned earlier because of spillover of the CO_2 plume. However, the amount of CO_2 stored per year is larger for CO_2-EORT as compared to CO_2-EOR." **Masoud Alfi and Seyyed A. Hosseini**, *Fuel*. (Subscription may be required.)

April 2016

"Palaeogeographic mapping to understand the hydrocarbon and CO_2 storage potential of the post-rift Warnbro Group, offshore Vlaming Sub-basin, southern Perth Basin, Australia*."*** The following is from the Abstract of this article: "The Lower Cretaceous Gage Sandstone and South Perth Shale are a prospective reservoir-seal pair in the Warnbro Group, offshore Vlaming Sub-basin, Western Australia. Plays include post-breakup pinch-outs and [four]-way dip closures. A sequence stratigraphic analysis incorporating seismic interpretation, well log analysis and new biostratigraphic data characterised the reservoir-seal pair. Palaeogeographic mapping reveals multiple regressive-transgressive cycles which infilled the central palaeodepression on the Valanginian Unconformity. Within the deltaic South Perth Supersequence, the Gage Lowstand Fan (lithostratigraphically referred to as the Gage Sandstone) is a sand-rich submarine fan system and ranges from canyon-confined inner fan to basin-plain middle fan deposits. Major sediment contributions were from north–south-trending canyons adjacent to the Mandurah Terrace. Detailed seismic facies mapping and well log analysis of the Gage Lowstand Fan show that distal middle fan sand sheets and stacked channelised sands in the inner fan may provide an extensive reservoir of good to excellent quality. Seal quality varies greatly and may explain the lack of exploration success at some structural closures. A re-evaluation of the regional seal determined the extent of deepwater shale facies that provides an effective seal for the underlying submarine fans. 3D geological modelling confirms that the reservoir is suitable for hydrocarbon entrapment and CO_2 storage. Migration path analysis identified the presence of multiple structural and stratigraphic closures at the top of the reservoir. Previous petroleum systems modelling concluded that some source rock maturation probably post-dates deposition of the effective seal thereby allowing structural closures to be charged with hydrocarbons. Uncertainties potentially comprising hydrocarbon preservation and CO_2 storage include reactivation of large syn-rift faults that may breach top seal, the potential absence of base seal, effective seal thickness, and reservoir thickness and quality." **Megan E. Lech, Diane C. Jorgensen, Chris Southby, Liuqi Wang, Victor Nguyen, Irina Borissova, and David Lescinsky**, *Marine and Petroleum Geology*. (Subscription may be required.)

"Isothermal adsorption kinetics properties of carbon dioxide in crushed coal." The following is the Abstract of this article: "Understanding the dynamic response of coal to [CO_2] sorption is crucial for optimizing [CO_2 storage] in unmineable coal seams and enhanced coalbed methane recovery. In order to explore the adsorption kinetics of [CO_2] in coal, 15 isothermal adsorption tests were conducted on bituminous and sub-bituminous coals at 50°C for increasing equilibrium pressures (up to 4 MPa). The pseudo-second order (PSO) model is introduced to approximate the [CO_2] sorption kinetics in coal, and the kinetics properties are then investigated via the PSO model. The linear relationship between (t/q) and (t) is validated and confirmed with a high correlation coefficient (>99 [percent]). The kinetics parameter,

k_2, decreases with both increasing equilibrium sorption pressure and increasing pressure difference. The sorption equilibrium content, Q_e, in each sorption stage depends on both the final equilibrium pressure and the pressure difference. Based on the relationship between sorption content and time, the sorption content for different pressure ranges is predicted using different time intervals. The analysis indicates that the adsorption process for [CO_2] in coal is a combination of both bulk diffusion-controlled and surface interaction-controlled processes; the former dominates the initial stage while the latter controls the majority of the overall process." **Xu Tang, Nino Ripepi, and Ellen Gilliland**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"CO_2 Storage Potential of Basaltic Rocks Offshore Iceland." The following is the Abstract of this article: "Injection of CO_2 into basaltic formations provides significant benefits including permanent storage by [mineralization] and large storage volume. The largest geological storage potential lies offshore and in the case of basalt, along the mid-oceanic ridges where CO_2 could be stored as carbonate minerals for thousands of years. Most of the bedrock, both on land and offshore Iceland consists of basalt that could theoretically be used for injection of CO_2, fully dissolved in water. The most feasible formations are the youngest formations located within the active rift zone. It is estimated that up to 7000 $GtCO_2$ could be stored offshore Iceland within the Exclusive Economic Zone. Site specific geological research and pilot studies are required for refining the concept and offshore pilot scale projects should be considered as the next steps in evolving the method." **Sandra Ó. Snæbjörnsdóttir and Sigurdur R. Gislason**, *Energy Procedia*. (Subscription may be required.)

May 2016

"Wettability, hysteresis and fracture-matrix interaction during CO_2 EOR and storage in fractured carbonate reservoirs." The following is the Abstract of this article: "Relative permeabilities show significant dependence on the saturation path during CO_2 enhanced oil recovery (EOR) and storage. This dependence (or hysteresis) is particularly important for water-alternating-gas (WAG) injection, a successful CO_2 EOR and storage method for clastic and carbonate reservoirs. WAG injection is characterized by an alternating sequence of drainage and imbibition cycles. Hysteresis is hence common and results in residual trapping of the CO_2 phase, which impacts the volume of CO_2 stored and the incremental oil recovery. The competition between hysteresis and geological heterogeneity during CO_2 EOR and storage, particularly in carbonate reservoirs, is not yet fully understood. In this study, [the authors] use a high-resolution simulation model of a Jurassic Carbonate ramp, which is an analogue for the highly prolific reservoirs of the Arab D formation in Qatar, to investigate the impact of hysteresis during CO_2 EOR and storage in heterogeneous carbonate formations. [The authors] then compare the impact of residual trapping (due to hysteresis) on recovery to the impact of heterogeneity in wettability and reservoir structure. End-member wettability scenarios and multiple wettability distribution approaches are tested, while, effective fracture permeabilities are computed using discrete fracture networks (DFN), ranging from sparsely distributed background fractures to fracture networks where intensity varies with proximity to faults. The results enable [the authors] to analyze the efficiency of oil recovery and CO_2 [storage] in carbonate reservoirs by comparing the impact of physical displacement processes (e.g., imbibition, drainage, residual trapping) and heterogeneous rock properties (e.g., wettability, faults, fractures, layering) that are typical in carbonate reservoirs. [The authors] show that although the fracture network properties have the greatest impact on the fluid flow, the effect of wettability and hysteresis is nontrivial. [The authors'] results emphasize the need for wettability to be accurately measured and appropriately distributed in a reservoir simulation model. Similarly, [the authors'] results indicate that hysteresis effects in cyclic displacement processes must be accounted for in detail to ensure that simulation models give accurate predictions." **Simeon Agada, Sebastian Geiger, and Florian Doster**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Molecular dynamics study of CO_2 sorption and transport properties in coal." The following is the Abstract of this article: "An understanding of gas transport in nano-scale porous media is crucial for many industrial applications, for example, processes associated with CO_2 injection, storage and enhanced

coalbed methane (ECBM) production. In this study, [the authors] carried out combined molecular dynamics (MD) and Grand Canonical Monte Carlo (GCMC) simulations on the transport properties (i.e. self- and transport diffusivities and permeability) of CO_2, in a realistic intermediate rank bituminous coal (flexible coal model) at a temperature of 328 K (55°C) and a range of pressures up to 25 MPa. Self-diffusivity and sorption isotherms of CO_2 are obtained directly from the MD and GCMC simulations. The Maxwell–Stefan diffusion model was then applied to correlate the self- and transport diffusivities. The permeability was computed through an integration of the transport diffusivity over the sorption concentration obtained from the simulations. The results show that CO_2 self-diffusivity decreases with increasing reservoir gas pressure up to 8 MPa, then increases with pressure due to the interaction between coal and CO_2. The transport diffusivity increases with the reservoir gas pressure as a result of an enhanced thermodynamic factor. The simulation results reveal a negative correlation between the sorption-induced coal swelling and CO_2 self-diffusivity due to the interaction between CO_2 and coal. Rigorous modeling of gas recovery and production thus requires consideration of specific interaction of the gas and coal matrix. Permeability of CO_2 exponentially increases with the decreasing reservoir gas pressure, which is comparable with published field data." **Junfang Zhang, Michael B. Clennell, Keyu Liu, David N. Dewhurst, Marina Pervukhina, and Neil Sherwood**, *Fuel.* (Subscription may be required.)

"Comparison of relative permeability-saturation-capillary pressure models for simulation of reservoir CO_2 injection." The following is the Abstract of this article: "Constitutive relations between relative permeability (k_r), fluid saturation (S), and capillary pressure (P_c) determine to a large extent the distribution of brine and supercritical CO_2 ($scCO_2$) during subsurface injection operations. Published numerical multiphase simulations for brine–$scCO_2$ systems so far have primarily used four $k_r - S - P_c$ models. For the $S - P_c$ relations, either the Brooks–Corey (BC) or Van Genuchten (VG) equations are used. The $k_r - S$ relations are based on Mualem, Burdine, or Corey equations without the consideration of experimental data. Recently, two additional models have been proposed where the $k_r - S$ relations are obtained by fitting to experimental data using either an endpoint power law or a modified Corey approach. The six models were tested using data from four well-characterized sandstones (Berea, Paaratte, Tuscaloosa, Mt. Simon) for two radial injection test cases. The results show a large variation in plume extent and saturation distribution for each of the sandstones, depending on the used model. The VG–Mualem model predicts plumes that are considerably larger than for the other models due to the overestimation of the gas relative permeability. The predicted plume sizes are the smallest for the VG–Corey model due to the underestimation of the aqueous phase relative permeability. Of the four models that do not use fits to experimental relative permeability data, the hybrid model with Mualem aqueous phase and Corey gas phase relative permeabilities provide the best fits to the experimental data and produce results close to the model with fits to the capillary pressure and relative permeability data. The model with the endpoint power law resulted in very low, uniform gas saturations outside the dry-out zone for the Tuscaloosa sandstone, as the result of a rapidly declining aqueous phase relative permeability. This observed behavior illustrates the need to obtain reliable relative permeability relations for a potential reservoir, beyond permeability and porosity data." **M. Oostrom, M.D. White, S.L. Porse, S.C.M. Krevor, and S.A. Mathias**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

June 2016

"Impacts of Mineral Reaction Kinetics and Regional Groundwater Flow on Long-Term CO_2 Fate at Sleipner." The following is the Abstract of this article: "[The authors] conducted coupled reactive mass transport modeling of CO_2 storage in a sandy [formation] resembling the uppermost layer in the Utsira Sand, Sleipner, North Sea, in order to investigate the general effects of rate laws and regional groundwater flow on long-term CO_2 fate in saline [formations]. The temporal and spatial evolution of CO_2 plume and the fate of injected CO_2 were simulated with a series of scenarios with different rate law formulations for dissolution and precipitation reactions and different flow regimes. The results indicated the following: (1) Changing the dissolution rate laws of the main soluble silicate minerals can influence the silicate reactions and mineral trapping by impacting the sensitivity of the relevant coupled reaction's

rate to the acidification of brine. The steeper the slope of rate−ΔG_r (Gibbs free energy of reaction) relationships, the more sensitive the coupled reaction rate and the mineral trapping are to the acidification of brine. The predicted fraction of CO_2 mineral trapping when using the linear rate law for feldspar dissolution is twice as much as when using the nonlinear rate law. (2) Mineral trapping is more significant when regional groundwater flow is taken into consideration. Under the influence of regional groundwater flow, the replenishment of fresh brine from upstream continuously dissolves CO_2 at the tail of CO_2 plume, generating a larger acidified area where mineral trapping takes place. In a Sleipner-like [formation], the upstream replenishment of groundwater results in ∼22 [percent] mineral trapping at year 10 000, compared to ∼4 [percent] when the effects of regional groundwater are ignored. (3) Using linear rate law for silicate dissolution reactions can exaggerate the effect of groundwater flow on the reaction rates and mineral trapping and can overestimate the theoretical mineral trapping capacity, compared to using the nonlinear rate law." **Guanru Zhang, Peng Lu, Xiaomei Wei, and Chen Zhu**, *Energy Fuels*. (Subscription may be required.)

"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.)

"Influence of relative permeability on injection pressure and plume configuration during CO_2 injections in a mafic reservoir." The following is the Abstract of this article: "[CCS] projects have traditionally targeted deep sedimentary basins; however, mafic reservoirs may also be attractive targets for CO_2 disposal on the basis of permanent mineral trapping over relatively short time scales (101 to 102 yr). Nevertheless, CCS development in mafic reservoirs is hampered by substantial uncertainty in fracture-controlled reservoir characteristics, particularly with respect to the effects of multi-phase fluid flow, e.g., relative permeability and capillary pressure. The present study quantifies uncertainty surrounding relative permeability effects in a basalt reservoir by developing a numerical modeling experiment on the basis of site characterization data from the Slack Canyon #2 flow top, which is one of three flow tops comprising the injection zone at the Wallula Basalt Sequestration Pilot Project in southeast Washington State. This numerical modeling experiment controls for the effects of curvature in the relative permeability models by performing an ensemble of 399 CO_2 injection simulations with constant geometry and reservoir properties, while systematically varying the phase interference parameter (λ) and residual CO_2 saturation (S_{gr}), which govern wetting and non-wetting phase relative permeability, respectively. The relative permeability parameter space is defined by selecting combinations of λ and Sgr that cover a wide range of experimental laboratory measurements. For each simulation, CO_2 is injected into the reservoir for 10 years at a constant rate of 2.78 kg s^{-1} (87,856 metric tons [MT] yr^{-1}), which is 10 [percent] of the annual injection rate proposed for one injection scenario at the Wallula Site. Results from the ensemble of simulations show that relative permeability alone can account for >50 MPa of variability in the injection pressure and a two-fold difference in lateral CO_2 plume migration. Additionally, this work shows that curvature in the wetting phase relative permeability model is the stronger influence on reservoir pressure accumulation, while curvature in the non-wetting phase

relative permeability model strongly governs CO_2 plume geometry." **Ryan M. Pollyea**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

July 2016

"Mechano-chemical interactions in sedimentary rocks in the context of CO_2 storage: Weak acid, weak effects?" The following is the Abstract of this article: "Due to the corrosive nature of dissolved CO_2, the potential short or long term alteration of rock properties, represents a major issue in several sites where natural CO_2 circulation is observed, as well as in reservoirs targeted for storage of anthropogenic CO_2. To date, this has been primarily studied from a transport-chemical perspective, with laboratory evidence of microstructural modifications together with the consequences for flow properties. Compared to the transport-chemical aspects, the mechanical-chemical aspects have been less investigated, though it is to be expected that mechanical properties (e.g. elastic properties, failure parameters, and time-dependent mechanical [behavior]) could potentially be affected in a similar manner to hydraulic parameters. Yet, since CO_2 is a weak acid, the pH drop is expected to be moderate with a likely lower limit close to 4.0. The buffering of pH by calcite minerals present in most reservoirs targeted for storage may further limit the pH drop, as well as confining it to a localized rock volume around the injection well. This leads to the question of the magnitude and time/spatial scales of chemically-mediated mechanical processes during CO_2 [storage]. The authors propose to address this issue by reviewing recent laboratory-based studies restricted to sedimentary rocks, namely: reservoir rocks (carbonate or sandstone), intact or fractured caprocks and fault rocks. Key findings include the following: [1.] the short-term impact on the elastic and inelastic [behavior] of intact caprocks remains limited; [2.] shear strength weakening is likely to be respectively low and low-to-moderate for shale/clay-rich and anhydrite-rich faults, but without modifying slip stability in either case; [3.] the largest impact is located within carbonate reservoirs, but with a broad range of reported responses depending on hydrodynamic conditions (closed or open) and on dissolution regime (uniform or channelling); and [4.] creep experiments confirm that CO_2-induced dissolution may enhance long-term compaction of carbonate reservoirs, but the magnitude of acceleration (varying from non-significant to 50 times) depends to a large extent on site-specific conditions (grain size, pH, temperature, effective stress state, etc.), which renders any direct extrapolation from laboratory to reservoir scale difficult. Finally, some directions for future research studies are discussed." **J. Rohmer, A. Pluymakers, and F. Renard**, *Earth-Science Reviews*. (Subscription may be required.)

"An integrated core-based analysis for the characterization of flow, transport and mineralogical parameters of the Heletz pilot CO_2 storage site reservoir." The following is the Abstract of this article: "Heletz, Israel is the location for an onshore deep saline CO_2 storage pilot site. The '*Heletz sandstone*' is the building unit of the deep saline reservoir. Based on core samples of sandstone and caprock taken from the newly drilled injection (H18A) and monitoring wells (H18B), this article examines and reports the petrophysical properties of the Heletz Formation reservoir important for the short and long term trapping of CO_2. A suite of laboratory and pore-scale CT-based modeling techniques are employed to determine the flow and transport parameters used by the continuum-scale numerical simulators and the mineral composition necessary for the understanding of mineral trapping processes. The effect of diagenesis on the reservoir parameters was determined in the laboratory using sedimentological, petrological, and petrophysical analyses. Variations in $^{87}Sr/^{86}Sr$ isotope composition and fluid inclusion analysis bring additional information about the diagenetic development and define the status quo of fluid–mineral reactions before CO_2 injection. Cathodoluminescence microscopy and SEM/XRD revealed the amounts of minerals in the sandstone samples and caprock and explained the poor binding of the sandstone which may lead to mobilized material during injection. Digital image analysis on thin sections, cathodoluminescence, and SEM were integrated with attributes derived from mercury intrusion porosimetry, steady state gas permeametry or nuclear magnetic resonance to form an essential outline for the Heletz Formation reservoir. This relates storage space, injectivity and storage efficiency to features such as grain size, pore size distribution, effective porosity, intrinsic permeability, or tortuosity. Furthermore, the laboratory and numerical CT-based investigation techniques are compared and

discussed. The benefit of combining experimental methods and numerical simulations on pore-scale models is the increase in confidence of the parameter accuracy, fundamental for the success of the planned activities at Heletz." **Alexandru Bogdan Tatomir, Matthias Halisch, Florian Duschl, Aaron Peche, Bettina Wiegand, Mario Schaffer, Tobias Licha, Auli Niemi, Jacob Bensabat, and Martin Sauter**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

August 2016

"Heletz experimental site overview, characterization and data analysis for CO_2 injection and geological storage." The following is the Abstract of this article: "This paper provides an overview of the site characterization work at the Heletz site, in preparation to scientifically motivated CO_2 injection experiments. The outcomes are geological and hydrogeological models with associated medium properties and baseline conditions. The work has consisted on first re-analyzing the existing data base from ~40 wells from the previous oil exploration studies, based on which a 3-dimensional structural model was constructed along with first estimates of the properties. The CO_2 injection site is located on the saline edges of the Heletz depleted oil field. Two new deep (>1600 m) wells were drilled within the injection site and from these wells a detailed characterization program was carried out, including coring, core analyses, fluid sampling, geophysical logging, seismic survey, in situ hydraulic testing and measurement of the baseline pressure and temperature. The results are presented and discussed in terms of characteristics of the reservoir and [caprock], the mineralogy, water composition and other baseline conditions, porosity, permeability, capillary pressure and relative permeability. Special emphasis is given to petrophysical properties of the reservoir and the seal, such as comparing the estimates determined by different methods, looking at their geostatistical distributions as well as changes in them when exposed to CO_2." **Auli Niemi, Jacob Bensabat, Vladimir Shtivelman, Katriona Edlmann, Philippe Gouze, Linda Luquot, Ferdinand Hingerl, Sally M. Benson, Philippe A. Pezard, Kristina Rasmusson, Tian Liang, Fritjof Fagerlund, Michael Gendler, Igor Goldberg, Alexandru Tatomir, Torsten Lange, Martin Sauter, and Barry Freifeld**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

September 2016

"Pore-scale supercritical CO_2 dissolution and mass transfer under imbibition conditions." The following is the Abstract of this article: "In modeling of geological carbon storage, dissolution of supercritical CO_2 ($scCO_2$) is often assumed to be instantaneous with equilibrium phase partitioning. In contrast, recent core-scale imbibition experiments have shown a prolonged depletion of residual $scCO_2$ by dissolution, implying a non-equilibrium mechanism. In this study, eight pore-scale $scCO_2$ dissolution experiments in a 2D heterogeneous, sandstone-analog micromodel were conducted at supercritical conditions (9 MPa and 40°C). The micromodel was first saturated with deionized (DI) water and drained by injecting $scCO_2$ to establish a stable $scCO_2$ saturation. DI water was then injected at constant flow rates after $scCO_2$ drainage was completed. High resolution time-lapse images of $scCO_2$ and water distributions were obtained during imbibition and dissolution, aided by a $scCO_2$-soluble fluorescent dye introduced with $scCO_2$ during drainage. These images were used to estimate $scCO_2$ saturations and $scCO_2$ depletion rates. Experimental results show that (1) a time-independent, varying number of water-flow channels are created during imbibition and later dominant dissolution by the random nature of water flow at the micromodel inlet, and (2) a time-dependent number of water-flow channels are created by coupled imbibition and dissolution following completion of dominant imbibition. The number of water-flow paths, constant or transient in nature, greatly affects the overall depletion rate of $scCO_2$ by dissolution. The average mass fraction of dissolved CO_2 ($dsCO_2$) in water effluent varies from 0.38 [percent] to 2.72 [percent] of CO_2 solubility, indicating non-equilibrium $scCO_2$ dissolution in the millimeter-scale pore network. In general, the transient depletion rate decreases as trapped, discontinuous $scCO_2$ bubbles and clusters within water-flow paths dissolve, then remains low with dissolution of large bypassed $scCO_2$ clusters at their interfaces with longitudinal water flow, and finally increases with coupled transverse

water flow and enhanced dissolution of large $scCO_2$ clusters. The three stages of $scCO_2$ depletion, common to experiments with time-independent water-flow paths, are revealed by zoom-in image analysis of individual $scCO_2$ bubbles and clusters. The measured relative permeability of water, affected by $scCO_2$ dissolution and bi-modal permeability, shows a non-monotonic dependence on saturation. The results for experiments with different injection rates imply that the non-equilibrium nature of $scCO_2$ dissolution becomes less important when water flow is relatively low and the time scale for dissolution is large, and more pronounced when heterogeneity is strong." **Chun Chang, Quanlin Zhou, Timothy J. Kneafsey, Mart Oostrom, Thomas W. Wietsma, and Qingchun Yu**, *Advances in Water Resources*. (Subscription may be required.)

Technology

September 2015

"CO_2 storage associated with CO_2 enhanced oil recovery: A statistical analysis of historical operations." The following is the Abstract of this article: "This work analyzes a database of 31 existing CO_2 enhanced oil recovery (EOR) projects that was compiled for the estimation of oil reserves to better understand the CO_2 retention, incremental oil recovery, and net CO_2 utilization for these oil fields. The measured data begin at the start date of the CO_2 flood and extend through the year 2007. Cumulative CO_2 retention (in the formation), incremental oil recovery factors, and net CO_2 utilization factors were calculated for each of the sites. To express all site data on a common dimensionless scale, the data were extrapolated to 300 [percent] cumulative hydrocarbon pore volume (HCPV) by fitting nonlinear functions. Summary statistics were then calculated from 0 [percent] to 300 [percent] HCPV. Across all 31 sites, the 10th, 50th (median), and 90th percentile values for the three factors at 300 [percent] HCPV were: CO_2 retention: 23.1 [percent], 48.3 [percent], and 61.8 [percent] retained; incremental oil recovery: 5.3 [percent], 12.2 [percent], and 21.5 [percent] of OOIP (original oil in place); and net CO_2 utilization: 4.8, 8.7, and 10.5 Mscf/STB (stock-tank barrel). This work employs a novel approach that incorporates nonlinear functions to quantify uncertainty in the estimated values as a function of HCPV and to describe the shape of the CO_2 retention or incremental oil recovery response with a handful of parameters, providing insight into the behavior of the reservoir across the entire timeline of the CO_2 flood. These nonlinear curve fits are focused on statistical inference – i.e., what is the likely outcome and uncertainty ranges for CO_2 retention, incremental oil recovery, and net CO_2 utilization given the historical data from the 31 CO_2 EOR sites? However, the approach described in this work also provides useful information for prediction – i.e., given a set of inputs from another site with similar geology, what are plausible ranges in outcomes for each of these factors? Consequently, the results of this work can be used to estimate the potential range of expected performance for similar candidate oil fields that are not currently undergoing CO_2 injection, including estimates of the associated CO_2 storage potential of these candidate fields. The results of this work allow estimation of CO_2 storage capacity in CO_2-EOR operations with various degrees of confidence. The sites in the dataset reflect water – alternating gas CO_2 floods – all within the continental United States and heavily dominated by the West Texas carbonate floods. Other floods outside of this region, where the data were available, are also included in this study (i.e., the Rocky Mountain region and the State of Oklahoma)." **Nicholas A. Azzolina, David V. Nakles, Charles D. Gorecki, Wesley D. Peck, Scott C. Ayash, L. Stephen Melzer, and Sumon Chatterjee**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Microbial Electrolytic Carbon Capture for Carbon Negative and Energy Positive Wastewater Treatment." The following is the Abstract of this article: "Energy and carbon neutral wastewater management is a major goal for environmental sustainability, but current progress has only reduced emission rather than using wastewater for active CO_2 capture and utilization. [The authors] present here a new microbial electrolytic carbon capture (MECC) approach to potentially transform wastewater treatment to a carbon negative and energy positive process. Wastewater was used as an electrolyte for microbially assisted electrolytic production of H_2 and OH^- at the cathode and protons at the anode. The acidity dissolved silicate and liberated metal ions that balanced OH^-, producing metal hydroxide, which transformed CO_2 in situ into (bi)carbonate. Results using both artificial and industrial wastewater show 80–93 [percent] of the CO_2 was recovered from both CO_2 derived from organic oxidation and additional CO_2 injected into the headspace, making the process carbon-negative. High rates and yields of H_2 were produced with 91–95 [percent] recovery efficiency, resulting in a net energy gain of 57–62 kJ/mol-CO_2 captured. The pH remained stable without buffer addition and no toxic chlorine-containing compounds were detected. The produced (bi)carbonate alkalinity is valuable for wastewater treatment and long-term carbon storage in the ocean. Preliminary evaluation shows promising economic and environmental benefits for different industries." **Lu Lu, Zhe Huang, Greg H. Rau, and Zhiyong Jason Ren**, *Environmental Science and Technology*. (Subscription may be required.)

"Fracture-based modeling of complex flow and CO_2 migration in three-dimensional fractured rocks." The following is the Abstract of this article: "The fractures and pores in rock formations are the fundamental units for flow and contaminant-transport simulations. Modeling and meshing a fractured rock system are challenging tasks because mesh generations of fractured networks typically involve complex procedures in conducting topological transformations, and the modeling of such a complex mesh system is computationally expensive. The objective of this study was to develop a three-dimensional (3D) discrete fracture network (DFN) model and an associated unstructured mesh generation (UMG) model to simulate flow and transport for fractured rock systems. This study employed coupled multicomponent, multiphase fluids in a 3D porous and fractured media simulator (the TOUGH2/ECO2N model) to analyze flow and CO_2 migration in fracture formations. The developed DFN and UMG models were first tested using a single and horizontal fracture plate to evaluate the results based on various mesh types. The models were then implemented in multiple DFN realizations to assess the behavior of equivalent permeability of a rock block influenced by various fracture intensities. By exploiting the well-developed TOUGH2/ECO2N model, the developed DFN and UMG models were applied to problems of flow and CO_2 migration in fracture formations. The simulation results showed that the developed models can capture behaviors of the flow and transport in fractured formations. Different types of mesh led to slight variations in pressure distribution near injection wells. However, such pressure variations can be reduced with refined mesh around the injection wells. The results based on 52 DFN realizations indicated that the value of equivalent permeability for the simulated rock block shows three to four orders of magnitudes lower than the value of the specified fracture permeability. The injection of supercritical CO_2 exhibited a rapid migration of gaseous and aqueous phase CO_2 along connected fractures." **I-Hsein Lee and Chuen-Fa Ni**, *Computers & Geosciences*. (Subscription may be required.)

October 2015

"Reducing uncertainty associated with CO_2 injection and brine production in heterogeneous formations." The following is the Abstract of this article: "Spatial heterogeneity and variability across many orders of magnitude are two properties of formation permeability that are challenging to effectively capture in subsurface flow models. With regard to geological CO_2 storage, heterogeneity affects storage capacity, plume migration, pressure build-up around injection wells and, if utilized, the possibility of early breakthrough at brine extraction wells. Faced with under-characterized heterogeneity and an information-poor environment, the challenge is to make as much use as possible of the available data in reducing uncertainty associated with model prediction of a CO_2 injection operation. The two types of data used here to inform models are point permeability measurements from each well and interference tests between wells; these are both obtained from a synthetic permeability distribution approximating a hypothetical CO_2 storage formation. These data are used to reduce uncertainty in predictions of CO_2 injection, brine and CO_2 production rates, and CO_2 breakthrough times obtained from simulations of five-spot CO_2 injection/brine production performed on >600 conditional permeability realizations. First, assuming the underlying permeability field exhibits long-range correlation and a log-normal permeability distribution, a Bayesian analysis was undertaken using the point permeability measurements to reduce the likely magnitude of permeability heterogeneity. Comparison of realizations drawn from the prior and posterior indicate that the data were sufficient to exclude extreme scenarios with very rapid or very slow CO_2 transport and breakthrough at brine production wells. Thirty-year prediction envelopes for net CO_2 retention, brine and CO_2 production were reduced by 40, 45 and 72 [percent], respectively. In the second stage, simulated interference tests for each of the posterior realizations were compared against interference tests simulated for the synthetic 'true' permeability field. Weighting functions derived from these comparisons are used to further refine predictions, providing additional reductions of uncertainty by 38 and 69 [percent] for brine and CO_2 production rates, respectively. Predictions of CO_2 breakthrough are especially sensitive to analysis of interference tests, with a good estimate of the correct time obtained in three out of four cases." **David Dempsey, Daniel O'Malley, and Rajesh Pawar**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Assessing the usefulness of the isotopic composition of CO_2 for [release] monitoring at CO_2 storage sites: A review." The following is the Abstract of this article: "[Geologic] storage of injected CO_2 is a promising technology to reduce CO_2 emissions into the atmosphere. Tracer methods are an essential tool to monitor CO_2 plume distribution in the target formation and to enable tracking potential [release] of CO_2 outside the storage reservoir. Here, [the authors] demonstrate that the isotopic composition of CO_2 can serve as a suitable tracer at large CO_2 injection sites provided that the injected CO_2 is isotopically distinct from background CO_2 sources that are usually composed of dissolved inorganic carbon, bedrock-derived carbon, and soil CO_2. Very [favorable] conditions for this tracer approach exist if $\delta^{13}C$ values of injected CO_2 are more than 10‰ different from those of baseline CO_2 and other dissolved inorganic carbon species at the CCS site. In this case, changes in $\delta^{13}C$ values accompanied with increasing concentrations of CO_2 or DIC in samples obtained regularly at monitoring sites within or above the storage reservoir indicate arrival of injected CO_2. The proportion of injected CO_2 contributing to the obtained samples can be quantified when carbon isotope fractionation effects are either negligible or thoroughly known. [The authors] point out several areas where additional detailed information on carbon isotope effects during phase change, transport and geochemical reactions is desirable to refine this tracer approach for temperature, pressure and salinity conditions relevant for CO_2 storage sites. Oxygen isotope ratios of injected CO_2 were not found to be a conservative tracer due to oxygen isotope exchange between CO_2 and water on time scales of hours to a few days. $\delta^{18}O$ measurements on CO_2 and H_2O have, however, revealed pore space saturation with CO_2 and hence indicate the presence of injected CO_2 within CO_2 storage reservoirs. [The authors] suggest that the stable isotopic composition of injected CO_2 is a suitable tracer for assessing the movement and fate of injected CO_2 in the target reservoir and for [release] detection at CO_2 storage sites, provided that the injected CO_2 is isotopically distinct from background CO_2 sources. A key advantage is that this tracer approach does not depend on the co-injection of additional tracers and hence can be continuously used in large-scale commercial storage projects with CO_2 injection rates exceeding 1 million [metric tons] per year at reasonable cost." **B. Mayer, P. Humez, V. Becker, C. Dalkhaa, L. Rock, A. Myrttinen, and J.A.C. Barth**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Prediction and validation of external cooling loop cryogenic carbon capture (CCC-ECL) for full-scale coal-fired power plant retrofit." The following is the Abstract of this article: "Bench-scale experiments and Aspen Plus™ simulations document full-scale, steady-state performance of the external cooling loop cryogenic carbon capture (CCC-ECL) process for a 550 MWe coal-fired power plant. The baseline CCC-ECL process achieves 90 [percent] CO_2 capture, and has the potential to capture 99+ [percent] of CO_2, SO_2, PM, NO_2, Hg, and most other noxious species. The CCC-ECL process cools power plant flue gas to 175 K, at which point solid CO_2 particles desublimate as the flue gas further cools to 154 K. Desublimating flue gas cools in a staged column in direct contact with a cryogenic liquid and produces a CO_2-lean flue gas that warms against the incoming flue gas before venting. The CO_2/contacting liquid slurry separates through a filter to produce a CO_2 stream that warms to 233 K and partially flashes to provide a CO_2-rich product. The CO_2–rich product (99.2 [percent]) liquefies under pressure to form a product for EOR or [storage]. All contacting liquid streams cool and cycle back to the staged column. An internal CF_4 refrigeration cycle transfers heat from melting CO_2 to desublimating CO_2 by cooling contact liquid. An external cooling loop of natural gas or other refrigerant provides the additional heat duty to operate the cryogenic process. The nominal parasitic power loss of operating CCC-ECL is 82.6 MWe or about 15 [percent] of the coal-fired power plant's rated capacity. In different units, the energy penalty of CCC-ECL is 0.74 MJe/kg CO_2 captured and the resulting net power output is decreased to 467 MWe. Lab- and skid-scale measurements validate the basic operation of the process along with the thermodynamics of CO_2 solids formation." **Mark J. Jensen, Christopher S. Russell, David Bergeson, Christopher D. Hoeger, David J. Frankman, Christopher S. Bence, and Larry L. Baxter**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

November 2015

"Efficient Electrochemical CO_2 Conversion Powered by Renewable Energy." The following is the Abstract of this article: "The catalytic conversion of CO_2 into industrially relevant chemicals is one strategy for mitigating [GHG] emissions. Along these lines, electrochemical CO_2 conversion technologies are attractive because they can operate with high reaction rates at ambient conditions. However, electrochemical systems require electricity, and CO_2 conversion processes must integrate with carbon-free, renewable-energy sources to be viable on larger scales. [The authors] utilize Au_{25} nanoclusters as renewably powered CO_2 conversion electrocatalysts with $CO_2 \rightarrow CO$ reaction rates between 400 and 800 L of CO_2 per gram of catalytic metal per hour and product selectivities between 80 and 95 [percent]. These performance metrics correspond to conversion rates approaching 0.8–1.6 kg of CO_2 per gram of catalytic metal per hour. [The authors] also present data showing CO_2 conversion rates and product selectivity strongly depend on catalyst loading. Optimized systems demonstrate stable operation and reaction turnover numbers (TONs) approaching 6×10^6 mol_{CO2} $mol_{catalyst}^{-1}$ during a multiday (36 h total hours) CO_2 electrolysis experiment containing multiple start/stop cycles. TONs between 1×10^6 and 4×10^6 mol_{CO2} $mol_{catalyst}^{-1}$ were obtained when [the authors'] system was powered by consumer-grade renewable-energy sources. Daytime photovoltaic-powered CO_2 conversion was demonstrated for 12 h and [the authors] mimicked low-light or nighttime operation for 24 h with a solar-rechargeable battery. This proof-of-principle study provides some of the initial performance data necessary for assessing the scalability and technical viability of electrochemical CO_2 conversion technologies. Specifically, [the authors] show the following: (1) all electrochemical CO_2 conversion systems will produce a net increase in CO_2 emissions if they do not integrate with renewable-energy sources, (2) catalyst loading vs activity trends can be used to tune process rates and product distributions, and (3) state-of-the-art renewable-energy technologies are sufficient to power larger-scale, [metric ton] per day CO_2 conversion systems." **Douglas R. Kauffman, Jay Thakkar, Rajan Siva, Christopher Matranga, Paul R. Ohodnicki, Chenjie Zeng, and Rongchao Jin**, *ACS Appl. Mater. Interfaces*. (Subscription may be required.)

"CO_2 capture from humid flue gases and humid atmosphere using a microporous coppersilicate." The following is the Abstract of this article: "Capturing CO_2 from humid flue gases and atmosphere with porous materials remains costly because prior dehydration of the gases is required. A large number of microporous materials with physical adsorption capacity have been developed as CO_2-capturing materials. However, most of them suffer from CO_2 sorption capacity reduction or structure decomposition that is caused by co-adsorbed H_2O when exposed to humid flue gases and atmosphere. [The authors] report a highly stable microporous coppersilicate. It has H_2O-specific and CO_2-specific adsorption sites but does not have H_2O/CO_2-sharing sites. Therefore, it readily adsorbs both H_2O and CO_2 from the humid flue gases and atmosphere, but the adsorbing H_2O does not interfere with the adsorption of CO_2. It is also highly stable after adsorption of H_2O and CO_2 because it was synthesized hydrothermally." **Shuvo Jit Datta, Chutharat Khumnoon, Zhen Hao Lee, Won Kyung Moon, Son Docao, Thanh Huu Nguyen, In Chul Hwang, Dohyun Moon, Peter Oleynikov, Osamu Terasaki, and Kyung Byung Yoon**, *Science*. (Subscription may be required.)

"A meta-analysis of carbon capture and storage technology assessments: Understanding the driving factors of variability in cost estimates." The following is the Abstract of this article: "The estimated cost of reducing carbon emissions through the deployment of CCS in power systems vary by a factor of five or more across studies published over the past [eight] years. The objective of this paper is to understand the contribution of techno-economic variables and modeling assumptions to explain the large variability in the published international literature on cost of avoided CO_2 ($CACO_2$) using statistical methods. [The authors] carry out a meta-analysis of the variations in reported $CACO_2$ for coal and natural gas power plants with CCS. [The authors] use regression and correlation analysis to explain the variation in reported $CACO_2$. The regression models built in [the authors'] analysis have strong predictive power ($R^2 > 0.90$) for all power plant types. [The authors] find that the parameters that have high variability and large influence on the value of $CACO_2$ estimated are levelized cost of electricity (LCOE) penalty, capital cost of CCS, and efficiency penalty. In addition, the selection of baseline technologies

and more attention and transparency around the calculation of capital costs will reduce the variability across studies to better reflect technology uncertainty and improve comparability across studies." **Oguz Akbilgic, Ganesh Doluweera, Maryam Mahmoudkhani, and Joule Bergerson**, *Applied Energy*. (Subscription may be required.)

December 2015

"Geomechanical stability of CO_2 containment at the South West Hub Western Australia: A coupled geomechanical-fluid flow modelling approach." The following is the Abstract of this article: "An area in the Southern Perth Basin has been selected as a potentially suitable site for CO_2 injection and storage as a part of the South West Hub Project (SW Hub), due to its proximity to major CO_2 emission sources and the presence of potentially suitable geology. This 3D modelling study attempts to assess the geomechanical stability of faults and intact host rocks during CO_2 injection at the SW Hub. The stratigraphy and fault structure of the 3D model are based on the architecture of an E–W cross section in a pre-existing 3D geological model that represents a comprehensive synthesis of seismic, stratigraphic and structural data. In the models, the rocks and faults are simulated as Mohr–Coulomb elastic–plastic materials, and their geomechanical and hydrological properties are based on experimental data from the Harvey-1 drill core samples and also information from literature. A series of models are performed to assess five injection scenarios with injection rates of 1–5 million tonnes per year over a period of 20 years. The results show that the simulated CO_2 injection scenarios would not lead to fault reactivation or breach the overlying Yalgorup or Eneabba Shale formations in the area. Some small smooth uplifts are recorded as a result of injection. In the models assuming weak faults, average ground surface uplifts are 0.4–1.8 cm for the injection rates of 1–5 million tonnes per year, over an area of approximately 2.5 km radius around the hypothetical injection site. Uplifts are marginally smaller when assuming strong faults." **Y. Zhang, L. Langhi, P.M. Schaubs, C. Delle Piane, D.N. Dewhurst, L. Stalker, and K. Michael**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Modelling CO_2 migration in [formations]; considering 3D seismic property data and the effect of site-typical depositional heterogeneities." The following is the Abstract of this article: "Geological [storage] is one proposed measure for [GHG] mitigation; and deep, saline [formations] are considered to hold large storage potentials for CO_2. The Johansen Formation has been suggested by Norwegian authorities as a potential reservoir candidate due to its relative proximity to land and point sources for CO_2. Reservoir evaluations must consider the given premise of zero interference with ongoing gas production in the Troll Field, providing geographical constraints. Recent data contributions; new 3D seismic data, attribute analyses, and revision of the depositional model form the basis of this modelling study. Porosity distributions were generated from quantified relations with acoustic impedance. The reservoir quality varies according to sedimentary facies, and differentiated relative permeability curves were assigned accordingly. Effects of directional anisotropy and site-typical geological heterogeneities were considered through scenario-modelling. The potential for dissolution and residual trapping of CO_2 varies according to migration paths; and was estimated to 50–80 [percent] of injected CO_2 after 150 years. [Immobilization] was more efficient with increased sweep through reservoir zones with high irreducible gas fractions, and in scenarios where plume separation occurred. The main determinant, however, for improving trapping efficiency is the well location and injection scheme." **Anja Sundal, Rohaldin Miri, Trude Ravn, and Per Aagaard**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

January 2016

"Numerical analyses of the effects of nitrogen on the dissolution trapping mechanism of carbon dioxide geological storage." The following is the Abstract of this article: "Numerical simulations are carried out to investigate the effects of impurity on geological storage of CO_2, in the context of [CCS]

which has been considered as one of the primary options for significantly reducing anthropogenic emissions of [GHGs] into the atmosphere. The CO_2 streams captured from power plants or other large industrial processes contain a variety of impurities. This study investigates the effects of nitrogen (N_2) on the dissolution trapping mechanism, which occurs when the injected CO_2 mixture dissolves into the formation fluids. The density of the formation water/brine at the two-phase interface would increase in response to the dissolution of CO_2. At favorable conditions, convection would be triggered and could greatly accelerate the dissolution rate of CO_2. This density-driven convection process is beneficial for both storage security and permanence. However, N_2 would lead to a density reduction of the aqueous phase when dissolved into the formation water/brine. The onset of convection would be delayed and the dissolution rate may be affected when co-injecting CO_2 with N_2. In addition, the spatial distribution of CO_2 in the aqueous phase would also be different with varying amounts of N_2 in the CO_2 streams." **Didi Li, Xi Jiang, Qingliang Meng, and Qiyuan Xie**, *Computers & Fluids*. (Subscription may be required.)

"Geochemical modeling of a sustained shallow [formation] CO_2 [release] field study and implications for [release] and site monitoring." The following is the Abstract of this article: "A geochemical numerical modeling study was conducted to constrain processes occurring in field and laboratory experiments, simulating CO_2 [release] from geological storage on shallow potable [formations]. A [release] was previously physically simulated in a shallow potable [formation] at Vrøgum plantation, Western Denmark by injection of 1600 kg of gas phase CO_2 over 72 days. Here, a 1-dimensional reactive transport model was constructed based on field and laboratory results and subsequently used to explore the contributions of various geochemical processes to explain observed results from the carbonate free system. Finite gibbsite derived Al^{3+} driven cation exchange is able to explain the majority of water chemistry change observed at Vrøgum including: a pulse like effect showing a fast peak and return toward background levels for alkalinity and dissolved ion concentrations; and increasing and persistent acidification via buffering exhaustion. Model processes were supported further by simulation of a batch experiment conducted on the Vrøgum glacial sand, employing the same processes and sediment parameters. The fitted reactive transport model was subsequently used to extend predictions and explore various scenarios. Extended predictions suggest the pulse of elevated ions travels with advective flow succeeded by a zone of increasing acidification. Model runs at higher P_{CO2} (implying greater depths) suggest amplification of effects, i.e., greater peaks and more rapid and severe acidification. Calcite limits acidification, however, induces additional Ca driven ion exchange giving rise to more significant chemistry change. Although a site specific model, results have significant implications for risks posed to water resources from CCS [release] and implementation of [MVA] programs." **Aaron G. Cahill and Rasmus Jakobsen**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

February 2016

"Impact of wettability alteration on 3D nonwetting phase trapping and transport." The following is the Abstract of this article: "[The authors] investigate capillary trapping and fluid migration via x-ray computed microtomography (x-ray CMT) of nonwetting phase (air) and wetting phase (brine) in Bentheimer sandstone cores which have been treated to exhibit different degrees of uniform wettability. x-Ray CMT scans were acquired at multiple steps during drainage and imbibition processes, as well as at the endpoints; allowing for assessment of the impact of wettability on nonwetting phase saturation and cluster size distribution, connectivity, topology and efficiency of trapping. Compared with untreated (water-wet) Bentheimer sandstone, cores treated with tetramethoxylsilane (TMS) were rendered weakly water-wet, and cores treated with octadecyltrichlorosilane (OTS) demonstrate intermediate-wet characteristics. As apparent contact angle increases, drainage flow patterns deviate from those derived for water-wet systems, total residual trapping and trapping efficiency decrease, and buoyancy plays a larger role during nonwetting phase mobilization; this has significant implications for CO_2 migration and trapping during CO_2 [storage] operations." **Anna L. Herring, Adrian Sheppard, Linnéa Andersson, and Dorthe Wildenschild**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

March 2016

"Solving the [CO_2] buoyancy challenge: The design and field testing of a dissolved CO_2 injection system." The following is the Abstract of this article: "Long-term security is critical to the success and public acceptance of geologic carbon storage. Much of the security risk associated with geologic carbon storage stems from CO_2 buoyancy. Gaseous and supercritical CO_2 are less dense than formation waters providing a driving force for it to escape back to the surface via fractures, or abandoned wells. This buoyancy can be eradicated by the dissolution of CO_2 into water prior to, or during its injection into the subsurface. Here [the authors] demonstrate the dissolution of CO_2 into water during its injection into basalts leading directly to its geologic solubility storage. This process was verified via the successful injection of over 175 t of CO_2 dissolved in 5000 t of water into porous rocks located 400–800 m below the surface at the Hellisheidi, Iceland CarbFix injection site. Although larger volumes are required for CO_2 storage via this method, because the dissolved CO_2 is no longer buoyant, the storage formation does not have to be as deep as for supercritical CO_2 and the [caprock] integrity is less important. This increases the potential storage resource substantially compared to the current estimated storage potential of supercritical CO_2." **Bergur Sigfusson, Sigurdur R. Gislason, Juerg M. Matter, Martin Stute, Einar Gunnlaugsson, Ingvi Gunnarsson, Edda S. Aradottir, Holmfridur Sigurdardottir, Kiflom Mesfin, Helgi A. Alfredsson, Domenik Wolff-Boenisch, Magnus T. Arnarsson, and Eric H. Oelkers**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Density Measurement and Modeling of CO_2−Brine System at Temperature and Pressure Corresponding to Storage Conditions." The following is the Abstract of this article: "The densities of CO_2 solution of the brine from Teikoku Oil Field located at Niigata Prefecture in Japan are measured by a magnetic suspension balance at temperatures from 303.15 to 323.15 K, pressures from 10 to 20 MPa, and CO_2 mole fractions of 0, 0.0038, 0.0040, 0.0087, 0.0100, and 0.0160. Results show that the densities of CO_2–brine solution increase to 0.86 [percent] from that of brine and linearly increases with pressure at a gradient of 0.411 $kg \cdot m^{-3} \cdot MPa^{-1}$ and with CO_2 mole fraction at an average gradient of 514 $kg \cdot m^{-3} \cdot mol^{-1}$ at a temperature of 303.15 K. On the other hand, the density of CO_2–brine solution decreases with increasing temperature at an average rate of −0.377 $kg \cdot m^{-3} \cdot K^{-1}$ under [the authors'] experimental conditions. The ePC-PSAFT model is applied to predict the data obtained from this study and those from literature. It is demonstrated that the model works well with average relative deviation (ARD) of 0.27 [percent]. A correlation of density ratio of CO_2–brine solution to brine is provided and validated by data used in the ePC-PSAFT model, which is convenient for engineering application in comparison with that by the ePC-PSAFT. The ARDs for density ratio predicted by ePC-PSAFT and correlation are 0.075 [percent] and 0.019 [percent] for this work, respectively." **Yi Zhang, Tongtong Li, Baixin Chen, Masahiro Nishio, and Yongchen Song**, *J. Chem. Eng. Data*. (Subscription may be required.)

April 2016

"Integration of SNG plants with Carbon Capture and Storage Technologies modeling." The following is the Abstract of this article: "Several power plant configurations have been recently studied as an alternative to conventional technologies in the field of energetic conversion of coal. The price of natural gas shows a volatile trend and when at its maximum promotes a renewed interest in technologies converting coal into synthetic natural gas (SNG). Moreover, in an low-carbon economy these processes include the capture of CO_2 in the base plant configuration. This paper analyzes the possible integration of SNG plants with [CCS] Technologies. The studied SNG facilities are based on commercial coal gasification and methanation technologies currently available worldwide. The major problem in optimizing the methanation reaction, one of the most important stages of the whole process, is to achieve an efficient removal of the reaction heat to avoid catalyst sintering and prevent carbon particle formation. For this reason, in this study two different process configurations were compared. In the first configuration (case A), the removal of CO_2 is operated before the methanation section and the reaction is

carried out in a series of adiabatic fixed bed reactors with inter-cooling and product recycle. In the second configuration (case B) the dilution of the methanation feed with CO_2 and steam controls the heat of reaction, being CO_2 captured downstream the process. For both the plant configurations, performance is analyzed and the energy penalty caused by the introduction of CCS is evaluated. Particular attention is devoted to heat integration between different sections of the plant. Results show similar efficiency in both the cases and that more than 50 [percent] of the input energy can be converted to [SNG]. The CCS integration leads to a slight efficiency reduction of about [one] percentage point. The selected plant configurations were tested and performance evaluated and compared in the Aspen Plus v. 8 simulation environment." **Claudia Bassano, Paolo Deiana, Lorenza Pacetti, and Nicola Verdone**, *Fuel*. (Subscription may be required.)

"A model to calculate effects of atmospheric deposition on soil acidification, eutrophication and carbon [storage]." The following is the Abstract of this article: "Triggered by the steep decline in sulphur deposition in Europe and North America over the last decades, research and emission reduction policies have shifted from acidification to the effects of nitrogen (N) deposition and climate change on plant species diversity and carbon (C) [storage] in soils and biomass. Consequently, soil-ecosystem models need to include detailed descriptions of C and N processes, and ideally provide output that link to plant species diversity models. [The authors] describe an extension of the Very Simple Dynamic (VSD) model, called VSD+, which includes an explicit description of C and N turnover. Model simulations for three forest stands, which differ in N deposition and soil C/N ratios, show that VSD+ can well predict both trends and absolute values of NO_3 and NH_4 concentrations in soil and stream waters, soil C/N ratios and pH, which makes VSD+ suitable for providing input for plant species diversity models." **Luc T.C. Bonten, Gert Jan Reinds, and Maximilian Posch**, *Environmental Modelling & Software*. (Subscription may be required.)

"An integrated site characterization-to-optimization study for commercial-scale carbon dioxide storage." The following is the Abstract of this article: "Injection of supercritical carbon dioxide ($scCO_2$) into deep saline [formations] is considered a promising option to mitigate global climate change. At a storage site, the main objectives of [CO_2 storage] are to maximize the volume of $scCO_2$ injected and minimize the [release] risk, while effectively managing formation fluid pressure buildup and the brine displaced by $scCO_2$. An integrated characterization-to-optimization study is carried out for potential commercial-scale deep saline [formation CO_2] storage proposed in western Wyoming. A three-dimensional heterogeneous reservoir model is built for which petrophysical and fluid flow parameters are populated using field characterization data and state-of-the-art laboratory measurements. The measured $scCO_2$ relative permeability end point is low compared to previous measurements on similar sandstones, which poses a challenge for CO_2 flow, formation pressure control, and storage efficiency. By carefully selecting a set of optimal well locations, perforation intervals, and bottomhole pressure constraints that lead to maximum CO_2-in-place and minimal CO_2 breakthrough at the producers, an injection rate ranging from 10.8 to 15.1 Mt/year is achieved for a duration of 50 years. After $scCO_2$ injection ceases, up to 62 [percent] of the total injected $scCO_2$ can be immobilized as residual $scCO_2$ in 1000 years. Because of the low $scCO_2$ relative permeability end point, post-$scCO_2$-injection chase brine operation is not found to be an effective means of enhancing residual trapping. Instead, by modulating reservoir fluid pressure, boundary conditions of the reservoir exert a more significant impact on flow. Given the same well configuration and bottomhole pressure constraints, an open reservoir with lateral background flow allows 40 [percent] additional $scCO_2$ injection compared to a compartmentalized system without background flow. However, background flow leads to a lower trapping efficiency – after 1000 years post-$scCO_2$-injection, only 54 [percent] of the total injected $scCO_2$ is immobilized as residual $scCO_2$. This research suggests that a careful engineering design can contribute to significant CO_2 storage at commercial scales while enhancing storage security. Site-specific multi-phase flow data should be measured for such a design, since for the study site, chase-brine operation is not effective when $scCO_2$ relative permeability is low." **Shuiquan Li, Morteza Akbarabadi, Ye Zhang, and Mohammad Piri**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

May 2016

"Using pulse testing for [release] detection in carbon storage reservoirs: A field demonstration." The following is the Abstract of this article: "Monitoring techniques capable of deep subsurface detection are desirable for early warning and [release] pathway identification in geologic carbon storage formations. This work demonstrates the feasibility of a pulse-testing-based [release] detection procedure, in which the storage reservoir is stimulated using periodic injection patterns and the acquired pressure perturbation signals are analyzed in the frequency domain to detect potential deviations in the reservoir's frequency domain responses. Unlike the traditional well testing and associated time domain analyses, pulse testing aims to minimize the interference of reservoir operations and other ambient noise by selecting appropriate pulsing frequencies such that reservoir responses to coded injection patterns can be uniquely determined in frequency domain. Field demonstration of this pulse-testing [release] detection technique was carried out at a CO_2 [EOR] site—the Cranfield site located in Mississippi, USA, which has long been used as a carbon storage research site. During the demonstration, two sets of pulsing experiments (baseline and [release] tests) were performed using 90-min and 150-min pulsing periods to demonstrate feasibility of time-lapse [release] detection. For [release] tests, an artificial [release] source was created through rate-controlled venting of CO_2 from one of the monitoring wells because of the lack of known [release] pathways at the site. [The authors'] results show that [release] events caused a significant deviation in the amplitude of the frequency response function, indicating that pulse testing may be deployed as a cost-effective active monitoring technique, with a great potential for site-wide automated monitoring." **Alexander Y. Sun, Jiemin Lu, Barry M. Freifeld, Susan D. Hovorka, and Akand Islam**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"A review on well integrity issues for CO_2 geological storage and enhanced gas recovery." The following is the Abstract of this article: "The world's rapid economic growth has contributed to the ever increasing demand for energy which results in the increase of fossil fuels usage. On the other hand, renewable energies, which are considered environmentally friendly, cannot replace the fossil fuels in the short term. For this, CCS technologies could work as transitional technology. To ensure a meaningful underground storage, well integrity is potentially the greatest challenge. On one hand, the injected CO_2 may cause severe corrosion to metallic tubulars and cement in the wellbore. Identification, quantification and mitigation of this corrosion are the key to achieve satisfactory well conditions. On the other hand, the mechanical integrity loss due to cyclic and thermal loading in the well life will also occur, so to investigate and evaluate well integrity is of paramount importance to ensure a safe operation and storage. This paper presents a definition of well integrity in the scope of CSEGR as well as the mechanisms of well integrity loss. Overview on corrosion issues of metallic and cement corrosion along with the remedial measures is discussed. Through a thorough literature review, well integrity criteria for new and old wells are introduced to provide a guidance for material selection for the usage in CSEGR. Moreover, in order to evaluate the integrity of operational and abandoned wells, this paper provides a review on the existing monitoring methods, as well as risk based methods such as FEPs analysis, Performance and Risk Management, CO_2-PENS, and put forward a new concept of well integrity evaluation." **Mingxing Bai, Zhichao Zhang, and Xiaofei Fu**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

"A novel sub-seabed CO_2 release experiment informing monitoring and impact assessment for geological carbon storage." The following is the Abstract of this article: "[CCS] is a mitigation strategy that can be used to aid the reduction of anthropogenic CO_2 emissions. This process aims to capture CO_2 from large point-source emitters and transport it to a long-term storage site. For much of Europe, these deep storage sites are anticipated to be sited below the [seabed] on continental shelves. A key operational requirement is an understanding of best practice of monitoring for potential [release] and of the environmental impact that could result from a diffusive [release] from a storage complex. Here [the authors] describe a controlled CO_2 release experiment beneath the seabed, which overcomes the limitations of laboratory simulations and natural analogues. The complex processes involved in setting up the experimental facility and ensuring its successful operation are discussed, including site selection,

permissions, communications and facility construction. The experimental design and observational strategy are reviewed with respect to scientific outcomes along with lessons learnt in order to facilitate any similar future." **Peter Taylor, Henrik Stahl, Mark E. Vardy, Jonathon M. Bull, Maxine Akhurst, Chris Hauton, Rachel H. James, Anna Lichtschlag, Dave Long, Dmitry Aleynik, Matthew Toberman, Mark Naylor, Douglas Connelly, Dave Smith, Martin D.J. Sayer, Steve Widdicombe, Ian C. Wright, and Jerry Blackford**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

June 2016

"Baking Soda 'Sponge' Could Capture Carbon Emissions." Scientists at the Lawrence Livermore National Laboratory (LLNL) in California, USA, are testing sponges filled with baking soda as a way to capture CO_2 emissions. According to the researchers, who have trialed microcapsules, the "baking soda approach" could be less expensive than currently available technology. The trailed microcapsules were created with a liquid solution of sodium carbonate at their core, surrounded by a polymer shell through which the CO_2 can flow. From *BBC News* on May 31, 2016.

"Evaluation of hydraulic controls for [release] intervention in carbon storage reservoirs." The following is the Abstract of this article: "Assuring the storage security of geologically [stored] CO_2 is essential for proper project management and long-term emissions reductions. Storage security relies not only on comprehensive site characterization prior to injection and careful reservoir management, but also on having a suite of intervention and remediation strategies available to implement if [release] occurs. In this study sequential stages of intervention are analyzed and evaluated. The first step in halting [release] is likely to be stopping CO_2 injection in the vicinity of the [release] (also termed passive remediation). Results indicate that while passive remediation can reduce the [release] rate by an order of magnitude, completely stopping [release] may often require implementation of additional measures. Additional measures evaluated here focus largely on hydraulic controls, whereby water is injected or produced in or above the CO_2 injection reservoir in order to terminate [release]. The degree of residual trapping determines the extent to which [release] is ultimately reduced. For example, water injection into the overlying [formation] directly above a fault was able to completely terminate [release] for as long as water injection continues. Remediation was even more effective when water injection above the fault was combined with reservoir fluid production. [The authors] also show that in addition to hydraulic control methods, extracting 15–25 [percent] of the injected CO_2 can lead to permanent [release] termination. The role of reservoir heterogeneity on remediation efficacy was also examined and found to reduce the total amount of CO_2 [released] compared to a homogeneous reservoir. Overall this study demonstrates that temporally limited, multi-stage intervention strategies such as hydraulic barriers can permanently stop CO_2 [release] from storage reservoirs into overlying [formations]." **Christopher Zahasky and Sally M. Benson**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"CO_2 solubility measurements in brine under reservoir conditions: A comparison of experimental and geochemical modeling methods." The following is the Abstract of this article: "The dissolution of CO_2 in brine (solubility trapping) is one of the most secure and permanent trapping mechanisms when considering CO_2 [geologic] storage. In addition, CO_2 dissolution in brine is an important mechanism of CO_2 enhanced oil recovery [(EOR)] as it improves sweep efficiency and increases oil displacement. Currently, there is a range of experimental methods that has been used to measure CO_2 solubility in brine and a critical review of these methods is presented here. Several different geochemical models that can be used to calculate CO_2 solubility in brine are also reviewed and the importance of selecting the correct equation of state (EoS) is addressed. Furthermore, the validity of the experimental results was ascertained through a comparison of the published experimental results with those produced through geochemical modeling. The geochemical modeling software, HydraFLASH, can be used to accurately calculate CO_2 solubilities under a number of conditions provided the correct EoS is selected. For the purpose of CO_2-water systems, the Valderrama-Patel-Teja EoS is the most accurate as it is designed to be used for systems containing polar and non-polar compounds. The published experimental results

were compared with those obtained through the geochemical modeling, to ascertain the most accurate means of measuring CO_2 solubility." **Luc Steel, Qi Liu, Eric Mackay, M. Mercedes Maroto-Valer**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

July 2016

"The CO_2 storage and EOR evaluation in Daqing Oilfield." The following is the Abstract of this article: "Injecting CO_2 into oil reservoirs could improve recovery and facilitate the storage of CO_2. For developing countries, especially China, coupling enhanced oil recovery (EOR) and CO_2 storage becomes an economical and environmentally safe method. Daqing Oilfield is the biggest oilfield in China. It has been operational for 50 years, and has faced many EOR challenges. In this study, a CO_2 storage and EOR evaluation method is introduced to calculate the CO_2 storage potential in the Daqing Oilfield. The stream tube simulation method and the mixed cell mesh method are adopted to determine the storage coefficient, recovery factor, and MMP (minimum miscible pressure). The evaluation results of the Daqing Oilfield show that most of the oilfields in Daqing can carry out CO_2 immiscible flooding. For EOR effects, the CO_2 miscible flooding can improve oil recovery by about [nine percent]. The average CO_2 storage factors are 0.4 for miscible flooding while the immiscible flooding is 0.28; miscible flooding has better CO_2 storage capacity and EOR potential. The results show that injecting CO_2 into the reservoirs in Daqing Oilfield is a win-win technology." **Xiaoliang Zhao, Yuedong Yao, and Heng Ye**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

"Optimization of miscible CO_2 EOR and storage using heuristic methods combined with capacitance/resistance and Gentil fractional flow models." The following is the Abstract of this article: "Ongoing increase in worldwide oil demand and emission of [GHGs] persuades engineers to utilize new approaches to optimize enhanced hydrocarbon recovery operations so that the concentration of such gases in atmosphere is reduced, simultaneously. CO_2 injection into geological formations could be a promising alternative for [EOR] and lessening anthropogenic CO_2 emissions. It is [the authors]' objective to employ Capacitance-Resistance Model (CRM) for characterization of inter-well interactions in two reservoir models, which experience miscible CO_2 injection for combined EOR and storage purposes. Then, an efficient model is developed, on the basis of Gentil fractional flow model, coupled with CRM. The introduced strategy is applied to optimize miscible CO_2 injection scenarios. The main goal in this research work is to minimize the fraction of cumulatively produced CO_2 to cumulatively produced oil by varying injection rates pattern with the same total injection as history. Minimizing the produced CO_2 ensures the increase of stored CO_2 through the formation. The developed methodology is validated through comparison with the results obtained from reservoir production history. Three heuristic optimization methods utilized in this work are Artificial-Bee-Colony (ABC), Particle-Swarm-Optimization (PSO), and Genetic-Algorithm (GA). According to results of several simulations and optimizations and compared to reservoir history, amounts of stored CO_2 and recovered oil increased, remarkably, for a real geological formation. In general, all optimization techniques result in favorable outcomes; however, ABC exhibits better performance, followed by PSO and GA. It was also found that well transmissibility is a vital factor to satisfy desired conditions for optimization process." **S. Ehsan Eshraghi, M. Reza Rasaei, and Sohrab Zendehboudi**, *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

August 2016

"Geochemical impact of O_2 impurity in CO_2 stream on carbonate carbon-storage reservoirs." The following is the Abstract of this article: "Carbon capture and storage (CCS) is regarded as an effective, large-scale mitigation technology for reducing CO_2 atmospheric emissions from the use of fossil fuels. One of the major barriers for widespread deployment of the technology is the high cost of CO_2 capture from the flue gas of fossil-fuel power plants and other industrial emitters. In general, the purer the desired captured CO_2 stream, the more expensive the capture process. Coinjecting some of these impurities with CO_2 can reduce the operational cost of CCS. Potential detrimental effects, if any, of impurities on storage

formations need to be identified and evaluated. Previous studies on the effects of impurities have focused on sandstone reservoir rocks and mudstone caprock, but little work has been done to evaluate potential impacts on carbonate reservoirs, which are major storage candidates. [The authors] conducted a series of autoclave experiments on Redwater Leduc limestone (Alberta, Canada) and SACROC dolostone (Texas, United States) to investigate the effect of O_2 impurity on CO_2–brine–rock interactions. A total of eight reaction experiments were conducted with or without O_2 for ~3 weeks each at 200 bar and 70°C or 100°C. Chemical analyses of the reaction fluids show that carbonate dissolution is the major mineral reaction caused by injection of CO_2. The addition of 3.5 [percent] O_2 had no significant impact on the limestone, whereas it led to precipitation of iron hydroxides in dolostone experiments that contained ankerite and a small amount of siderite. Porosity and permeability increased when CO_2 was added, but the addition of O_2 did not lead to notable changes. The results suggest that the addition of O_2 impurity into the CO_2 stream will not cause significant damage to carbonate formations, which potentially allows significant cost reduction by retaining a small O_2 content in the injection gas stream." **Jiemin Lu, Patrick J. Mickler, Jean-Philippe Nicot, Changbing Yang, and Roxana Darvari**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"CO_2 huff and puff for heavy oil recovery after primary production." The following is the Abstract of this article: "In this study, micromodel tests were performed to investigate the microscopic flow behavior during primary production and the subsequent CO_2 huff and puff. A series of 12 tests was conducted in sandpacks to evaluate the effects of the injection and production parameters on the displacement efficiency of the CO_2 huff and puff. The micromodel tests and sandpack tests showed that the flow characteristics of CO_2 huff-and-puff process was significantly affected by the pressure of converting the solution gas drive to the subsequent CO_2 huff and puff. A foamy oil flow could be more easily formed in the production period of the CO_2 huff and puff with a higher conversion pressure. Foamy oil can reduce the mobility of gas and provide tremendous energy to the system, thereby improving the performance of the CO_2 huff and puff. The sandpack flood results show that the oil recovery of the solution gas drive decreased as the conversion pressure increased, whereas the oil recovery of the CO_2 huff and puff increased as the conversion pressure increased. The highest total oil recovery was obtained at the pseudo-bubblepoint pressure. The oil recovery of the CO_2 huff and puff increased as the CO_2 injection pressure and pressure decline rate increased. The oil recovery of CO_2 huff and puff increased with the soaking time, and it exhibits a significant change when the soaking time ranges from 10 h to 24 h; above this value, the increase become slight." **Teng Lu, Zhaomin Li, Weiyu Fan, and Songyan Li**, *Greenhouse Gas Sci Technol*. (Subscription may be required.)

"Integration of reservoir simulation, history matching, and 4D seismic for CO_2-EOR and storage at Cranfield, Mississippi, USA." The following is the Abstract of this article: "In this paper, [the authors] compare 4D seismic interpretations of CO_2 plume evolution with fluid-flow numerical simulation results for Cranfield, Mississippi. Historic pressure trends, oil and gas production rates, and current CO_2-EOR production data from the field were history matched, and a tuned model was used for predictive simulations. For CO_2-EOR operations, numerical simulation results of the CO_2 plume distribution and CO_2 first arrival (breakthrough) times in production wells were compared to the available field data. Three interpretations of 4D seismic data show discrepancies on the edges of the seismic survey, and along the sealing fault, where numerical simulations show high CO_2 saturations. In areas between these two limits, the match between simulation and 4D seismic interpretation improves. In addition, for most of the production wells, comparison of the breakthrough time of CO_2 showed a reasonable match. The tuned model was then used to predict reservoir response and storage capacity in different field development scenarios under CO_2 injection. [The authors] compared hypothetical scenarios where the operator transitions from CO_2-EOR to CO_2 injection without oil production (CO_2-EORT) when oil production is not economical anymore, to a scenario of continuing with CO_2-EOR. [The authors'] results show that CO_2-EOR can store more CO_2 and operations will last longer, whereas if switched to CO_2-EORT, the field must be abandoned earlier because of spillover of the CO_2 plume. However, the amount of CO_2 stored per year is larger for CO_2-EORT as compared to CO_2-EOR." **Masoud Alfi and Seyyed A. Hosseini**, *Fuel*. (Subscription may be required.)

"Design of CO_2 Injection Pilot in Offshore Middle East Carbonate Reservoir." The following is the Abstract of this article: "Carbon dioxide injection is considered to be a viable option for EOR and has already been implemented commercially for more than 40 years. However, the applications are limited to onshore and offshore application for EOR activities have not yet been implemented. This paper presents the subsurface evaluation using laboratory experiments (PVT and corefloods) and compositional modeling, the design and surveillance program of a CO_2 pilot project planned in a carbonate reservoir located offshore Abu Dhabi. PVT and coreflood experiments demonstrate the local displacement efficiency of CO_2 in tertiary mode due to gas-oil miscibility, swelling of oil and reduction in oil viscosity. The screening study performed using a tuned equation of state (EOS) predicts significant additional recovery in a previously waterflooded area. A pilot is planned in one of the reservoirs of the field, which has 40 years of peripheral seawater injection history. The pilot design is influenced by existing peripheral pressure gradient, and is located down-dip in the field that covers approximately 80 acres. The pilot location is selected based on geology, reservoir quality, maturity to waterflood and surface facility constraints. A comprehensive reservoir surveillance plan, including one to two observers well, is developed to monitor pilot performance. The planned pilot will reduce uncertainties and risk associated with CO_2 injection and address bottleneck uncertainties in an offshore environment before large-scale application. The first offshore CO_2 injection pilot is designed for implementation in a tertiary mode in a giant carbonate field, which is still under secondary recovery production, to minimize interaction with current production and impact on surface facility. The paper also presents the possible mitigation for various challenges identified like asphaltene, scaling, corrosion, impact on existing carbon steel well completion, etc. associated with CO_2 injection. The methodology and technical analysis used to evaluate and design the CO_2 pilot are applicable to other potential fields in the region." **Jitendra Kumar, Elyes Draoui, and Satoru Takahashi**, *Society of Petroleum Engineers*. (Subscription may be required.)

September 2016

"Reducing costs of carbon capture and storage by shared reuse of existing pipeline—Case study of a CO_2 capture cluster for industry and power in Scotland." The following is the Abstract of this article: "The deployment of CCS is [recognized] as critical to delivering deep decarbonisation of energy and industrial processes. CCS clusters, where multiple CO_2 emitting sources share CO_2 transport and storage infrastructures, offer cost savings and enable smaller sources to undertake CCS, which are unlikely to be capable of justifying a stand-alone transport and storage system. Scotland has a legacy of onshore and offshore pipelines, which transported methane from producing regions. These can be re-used to connect CO_2 emitters to storage. Approximately 80 [percent] of large [stationary]-source CO_2 emissions in Scotland are within 40 km of the Feeder 10 pipeline. Thirteen selected emitters are evaluated for potential CO_2 capture volume, estimated capture project cost and cost of connection. Scenarios for sequential deployment show that Feeder 10 has capacity through known expansion potential for developments allowing capture volumes rising from 2 to 8 Mt yr^{-1} CO_2." **Peter A. Brownsort, Vivian Scott, and R. Stuart Haszeldine**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

"Comparison of geochemical data obtained using four brine sampling methods at the SECARB Phase III Anthropogenic Test CO_2 injection site, Citronelle Oil Field, Alabama." The following is the Abstract of this article: "The chemical composition of formation water and associated gases from the lower Cretaceous Paluxy Formation was determined using four different sampling methods at a characterization well in the Citronelle Oil Field, Alabama, as part of the SECARB Phase III Anthropogenic Test, which is an integrated [CCS] project. In this study, formation water and gas samples were obtained from well D-9-8 #2 at Citronelle using gas lift, electric submersible pump, U-tube, and a downhole vacuum sampler (VS) and subjected to both field and laboratory analyses. Field chemical analyses included electrical conductivity, dissolved sulfide concentration, alkalinity, and pH; laboratory analyses included major, minor and trace elements, dissolved carbon, volatile fatty acids, free and dissolved gas species. The formation water obtained from this well is a Na–Ca–Cl-type brine with a salinity of about

200,000 mg/L total dissolved solids. Differences were evident between sampling methodologies, particularly in pH, Fe and alkalinity. There was little gas in samples, and gas composition results were strongly influenced by sampling methods. The results of the comparison demonstrate the difficulty and importance of preserving volatile analytes in samples, with the VS and U-tube system performing most favorably in this aspect." **Christopher H. Conaway, James J. Thordsen, Michael A. Manning, Paul J. Cook, Robert C. Trautz, Burt Thomas, and Yousif K. Kharaka**, *International Journal of Coal Geology*. (Subscription may be required.)

"Seismic monitoring of CO_2 [geostorage]: CO2CRC Otway case study using full 4D FDTD approach." The following is the Abstract of this article: "Stage 2C of the Otway project by CO2CRC Limited was designed as a feasibility study of seismic monitoring to detect and [characterize] small-scale [release] of CO_2-rich gas into a saline [formation]. Design of the monitoring program is based on a series of simulations conducted in 2007–2014. The gas plume is likely to be small in size and the contrast in elastic properties is also predicted to be relatively low. To [maximize] the chances of detecting the low-amplitude time-lapse signal [the authors optimize] the current time-lapse processing workflow using synthetic datasets for the entire baseline and monitor surveys. The datasets were obtained by an elastic 3D FDTD modelling approach for the actual field acquisition geometry and the most realistic model of the subsurface and distribution of elastic properties in the gas plume. To this end [the authors] built a full-earth static geological model of the Otway site with resolution typical for reservoirs in petroleum exploration. Distributions of the seismic properties were obtained from geostatistical interpolation between wells within the static model. The analysis of the synthetic datasets gives an estimate of the magnitude of the time-lapse signal and illustrates effects of the conventional processing procedures on the signal in the presence of the band limited random noise. [The authors] have found that the anticipated intensity of the time-lapse signal is comparable to the average intensity of the reflections observed within the target interval, and hence should be sufficient for the detection of the signal. [The authors] believe that the proposed modelling workflow is of methodological value since it provides a reliable basis for seismic feasibility studies and development of modelling-driven processing workflows." **Stas Glubokovskikh, Roman Pevzner, Tess Dance, Eva Caspari, Dmitry Popik, Valeriya Shulakova, and Boris Gurevich**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Terrestrial

September 2015

"Effects of Greenhouse Gas Mitigation on Drought Impacts in the United States." The following is the Abstract of this article: "The authors present a method for analyzing the economic benefits to the United States resulting from changes in drought frequency and severity due to global GHG mitigation. The method begins by constructing reduced-form models of the effect of drought on agriculture and reservoir recreation in the contiguous United States. These relationships are then applied to drought projections based on two climate stabilization scenarios and two twenty-first-century time periods. Drought indices are sector specific and include both the standardized precipitation index and the Palmer drought severity index. It is found that the modeled regional effects of drought on each sector are negative, almost always statistically significant, and often large in magnitude. These results confirm that drought has been an important driver of historical reductions in economic activity in these sectors. Comparing a reference climate scenario to two GHG mitigation scenarios in 2050 and 2100, the authors find that, for the agricultural sector, mitigation reduces both drought incidence and damages through its effects on temperature and precipitation, despite regional differences in the sign and magnitude of effects under certain model scenarios. The current annual damages of drought across all sectors have been estimated at $6–$8 billion (U.S. dollars), but this analysis shows that average annual benefits of GHG mitigation to the U.S. agricultural sector alone reach $980 million by 2050 and upward of $2.2 billion by 2100. Benefits to reservoir recreation depend on reservoir location and data availability. Economic benefits of GHG mitigation are highest in the southwestern United States, where drought frequency is projected to increase most dramatically in the absence of GHG mitigation policies." **Brent Boehlert, Ellen Fitzgerald, James E. Neumann, Kenneth M. Strzepek, and Jeremy Martinich**, *Weather, Climate, and Society*. (Subscription may be required.)

October 2015

"Do protected areas reduce blue carbon emissions? A quasi-experimental evaluation of mangroves in Indonesia." The following is the Abstract of this article: "Mangroves provide multiple ecosystem services such as blue carbon [storage], storm protection, and unique habitat for species. Despite these services, mangroves are being lost at rapid rates around the world. Using the best available biophysical and socio-economic data, [the authors] present the first rigorous large-scale evaluation of the effectiveness of protected areas (PAs) at conserving mangroves and reducing blue carbon emissions. [The authors] focus on Indonesia as it has the largest absolute area of mangroves (about 22.6 [percent] of the world's mangroves), is one of the most diverse in terms of mangrove species and has been losing its mangroves at a very fast rate. Specifically, [the authors] apply quasi-experimental techniques (combining propensity score and covariate matching, differences-in-differences, and post-matching bias adjustments) to assess whether PAs prevented mangrove loss between 2000 and 2010. [The authors'] results show that marine protected areas reduced mangrove loss by about 14,000 ha and avoided blue carbon emissions of approximately 13 million metric tons (CO_2 equivalent). However, [the authors] find no evidence that species management PAs stalled the loss of mangroves. [The authors] conclude by providing illustrative estimates of the blue carbon benefits of establishing PAs, which can be cost-effective policies for mitigating climate change and biodiversity loss." **Daniela A. Miteva, Brian C. Murray, and Subhrendu K. Pattanayak**, *Ecological Economics*. (Subscription may be required.)

November 2015

"The dynamic soil organic carbon mitigation potential of European cropland." The following is the Abstract of this article: "Changes in soil organic carbon stocks depend on the management regime and a

variety of environmental factors including climatic conditions and soil properties. So far, the dynamics of soil organic carbon have not been explicitly represented in global economic land use optimization models. Here, [the authors] apply an approach to represent soil organic carbon dynamics explicitly in a global bottom-up recursive dynamic partial equilibrium model using carbon response functions simulated with a biophysical process-based model. [The authors] project soil organic carbon emissions from European cropland to decrease by 40 [percent] from 64 $MtCO_2$ in 2010 to about 39 $MtCO_2$ in 2050 mainly due to saturation effect when soils converge toward their equilibrium after management, crop rotation, or land use change. Moreover, [the authors] estimate a soil organic carbon mitigation potential for European cropland between 9 and 38 $MtCO_2$ per year until 2050 for carbon prices between 10 and 100 USD/tCO_2. The total European mitigation potential including co-benefits from the crop and livestock sector due to the carbon price is even higher with 60 $MtCO_2$ equivalents (eq) per year. Thus carbon [storage] in soils could compensate 7 [percent] of total emissions from agriculture within the EU, 10 [percent] when including co-benefits from the crop and livestock sector. However, as production is reallocated outside Europe with increasing carbon prices, emissions decrease in Europe but increase in the rest of the world (20 $MtCO_2$ eq). Preventing GHG emission [release] to the rest of the world would decrease the European soil organic carbon mitigation potential by around 9 [percent] and the total European mitigation potential including co-benefits by 16 [percent]. Nevertheless, the net global mitigation potential would still increase. [The authors] conclude that no significant contributions to emission reduction targets should be expected from the European cropland carbon [storage] options considered in this study." **Stefan Frank, Erwin Schmid, Petr Havlík, Uwe A. Schneider, Hannes Böttcher, Juraj Balkovič, and Michael Obersteiner**, *Global Environmental Change*. (Subscription may be required.)

"Evolution and variation of atmospheric carbon dioxide concentration over terrestrial ecosystems as derived from eddy covariance measurements." The following is the Abstract of this article: "Carbon dioxide (CO_2) is the most important anthropogenic [GHG] contributing to global climate change. Understanding the temporal and spatial variations of CO_2 concentration over terrestrial ecosystems provides additional insight into global atmospheric variability of CO_2 concentration. Using 355 site-years of CO_2 concentration observations at 104 eddy-covariance flux tower sites in Northern Hemisphere, [the authors] presented a comprehensive analysis of evolution and variation of atmospheric CO_2 concentration over terrestrial ecosystem (ACTE) for the period of 1997–2006. [The authors'] results showed that ACTE exhibited a strong seasonal variations, with an average [seasonal] amplitude (peak-trough difference) of 14.8 ppm, which was approximately threefold that global mean CO_2 observed in Mauna Loa in the United States (MLO). The seasonal variation of CO_2 were mostly dominant by terrestrial carbon fluxes, i.e., net ecosystem procution (NEP) and gross primary production (GPP), with correlation coefficient(r) were −0.55 and −0.60 for NEP and GPP, respectively. However, the influence of carbon fluxes on CO_2 were not significant at interannual scale, which implied that the inter-annual changing trends of atmospheric CO_2 in Northern Hemisphere were likely to depend more on anthropogenic CO_2 emissions sources than on ecosystem change. It was estimated, by fitting a harmonic model to monthly-mean ACTE, that both annual mean and seasonal amplitude of ACTE increased over the 10-year period at rates of 2.04 and 0.60 ppm yr^{-1}, respectively. The uptrend of annual ACTE could be attributed to the dramatic global increase of CO_2 emissions during the study period, whereas the increasing amplitude could be related to the increases in Northern Hemisphere biospheric activity. This study also found that the annual CO_2 concentration showed large variation among ecosystems, with the high value appeared in deciduous broadleaf forest, evergreen broadleaf forest and cropland. [The authors] attribute these discrepancies to both differential local anthropogenic impacts and carbon [storage] abilities across ecosystem types." **Min Liu, Jiabing Wu, Xudong Zhu, Honglin He, Wenxiao Jia, and Weining Xiang**, *Atmospheric Environment*. (Subscription may be required.)

December 2015

"Hydraulics are a first-order control on CO_2 efflux from fluvial systems." The following is the Abstract of this article: "Evasion of CO_2 from fluvial systems is now recognized as a significant

component of the global carbon cycle. However, the magnitude of, and controls on, this flux remains uncertain, and improved understanding of both is required to refine global estimates of fluvial CO_2 efflux. [Carbon dioxide] efflux data show no pattern with latitude suggesting that catchment biological productivity is not a primary control and that an alternative explanation for intersite variability is required. It has been suggested that increased flow velocity and turbulence enhance CO_2 efflux, but this is not confirmed. Here using contemporaneous measurements of efflux (range: 0.07–107 μmol CO_2 m^{-2} s^{-1}), flow hydraulics (mean velocity range: 0.03–1.39 m s^{-1}), and pCO_2 (range: 174–10712 μatm) at six sites, [the authors] find that flow intensity is a primary control on efflux across two climatically different locations (where pH is not a limiting factor) and that the relationship is refined by incorporating the partial pressure of CO_2 (pCO_2) of the water. A remaining challenge is how to upscale from point to reach or river basin level. Remote imaging or river surface may be worth exploring if subjectivity in interpreting surface state can be overcome." **Hazel Long, Leena Vihermaa, Susan Waldron, Trevor Hoey, Simon Quemin, and Jason Newton**, *Journal of Geophysical Research*. (Subscription may be required.)

January 2016

"Freshwater Sources Allow Escape for Terrestrial Carbon." A new study published in the "Proceedings of the National Academy of Sciences" claims large amounts of CO_2 may be escaping from forest soil to freshwater sources. According to researchers, freshwater rivers and streams transport more than 220 billion pounds of CO_2 per year, which based on previous approximations may indicate that the current assessments of carbon storage in terrestrial landscapes may be overestimated by almost 30 percent. The data used for the study, titled "Aquatic carbon cycling in the conterminous United States and implications for terrestrial carbon accounting," was the result of four years' worth of countrywide carbon assessment, where researchers gathered carbon data from freshwater rivers, lakes, and reservoirs around the United States. From *R&D Magazine* on December 28, 2015.

February 2016

"Economic value of carbon storage in U.S. National Wildlife Refuge wetland ecosystems." The following is the Abstract of this article: "The *Third National Climate Assessment* released in 2014 provides further evidence of global warming and mitigation options [including carbon storage]. In this paper, [the authors] report on the quantity and economic value of carbon stored in wetlands ecosystems found in four U.S. National Wildlife Refuges. [The authors'] results suggest that wetlands in National Wildlife Refuges provide substantial carbon storage benefits to the [United States] and world." **Douglas Patton, John C. Bergstrom, Rebecca Moore, and Alan P. Covich**, *Ecosystem Services*. (Subscription may be required.)

"Land use, land use change and soil carbon [storage] in the St. Johns River Basin, Florida, USA." The following is the Abstract of this article: "Land use change is widely recognized as a net source of [GHG] emissions at the global scale. Most of these emissions are attributed to losses from aboveground terrestrial pools such as deforestation. However, much less is known about the effects of land use change on soil carbon pools at regional scales. To address this problem, relationships between soil organic carbon (SOC), land use/land cover (LULC) classes, and LULC change were investigated at the regional scale. A legacy soil survey was used in conjunction with a new, contemporary sampling campaign to determine SOC change through time. Together, the two datasets cover an approximate 40-year time period (1965 to 2009). The greatest densities of SOC were documented in wetland classes. Specifically, soils of Hardwood Swamp, Cypress Swamp, and Mixed Urban consisted of both residential Wetland Forest contained 9.8, 9.5, and 7.8 g C m^{-2}. In regard to absolute storage, or SOC stocks, Hardwood Swamp, Pineland, and Urban ranked highest and contained 14.4, 13.3, and 9.9 Tg C, respectively. The effect of LULC change was mixed, and resulted in both gains and losses of SOC at the field scale. At the regional scale, median SOC increased by 16.9 g C m^{-2} yr^{-1}. Urbanization of natural landscapes resulted in the largest rate of [storage], which increased SOC by 37.1 g C m^{-2} yr^{-1}. The

largest losses were documented in LULC classes converted from Improved Pasture to Rangeland, which decreased SOC by 8.5 g m^{-2} yr^{-1}." **C. Wade Ross, Sabine Grunwald, David Brenton Myers, and Xiong**, *Geoderma Regional*. (Subscription may be required.)

March 2016

"Villagers and Scientists [Collaborate in Mangrove Project]." A research project exploring mangroves on the coasts of Kenya found that mangrove forests are being impacted by coastal development. Mangrove forests filter pollutants and can reduce the impact of CO_2 emissions. The research, led by Edinburgh Napier University (UK) and the Kenya Marine and Fisheries Research Institute, has led to the conservation and restoration training of scientists, provided data for the Kenyan government's conservation policies, and led to the creation of a Community Forest Association. Since it was initiated in 2010, the project has led to the restoration of 20 hectares of degraded land. From *The Star* on February 26, 2016.

"Aquatic carbon cycling in the conterminous United States and implications for terrestrial carbon accounting." The following is the Abstract of this article: "Inland water ecosystems dynamically process, transport, and [store] carbon. However, the transport of carbon through aquatic environments has not been quantitatively integrated in the context of terrestrial ecosystems. Here, [the authors] present the first integrated assessment, to [their] knowledge, of freshwater carbon fluxes for the conterminous United States, where 106 (range: 71–149) teragrams of carbon per year ($TgC \cdot y^{-1}$) is exported downstream or emitted to the atmosphere and sedimentation stores 21 (range: 9–65) $TgC \cdot y^{-1}$ in lakes and reservoirs. [The authors] show that there is significant regional variation in aquatic carbon flux, but verify that emission across stream and river surfaces represents the dominant flux at 69 (range: 36–110) $TgC \cdot y^{-1}$ or 65 [percent] of the total aquatic carbon flux for the conterminous United States. Comparing [the authors'] results with the output of a suite of terrestrial biosphere models (TBMs), [the authors] suggest that within the current modeling framework, calculations of net ecosystem production (NEP) defined as terrestrial only may be overestimated by as much as 27 [percent]. However, the internal production and mineralization of carbon in freshwaters remain to be quantified and would reduce the effect of including aquatic carbon fluxes within calculations of terrestrial NEP. Reconciliation of carbon mass–flux interactions between terrestrial and aquatic carbon sources and sinks will require significant additional research and modeling capacity." **David Butman, Sarah Stackpoole, Edward Stets, Cory P. McDonald, David W. Clow, and Robert G. Striegl**, *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required.)

April 2016

"Carbon storage in a bamboo (Bambusa vulgaris) plantation in the degraded tropical forests: Implications for policy development." The following is the Abstract of this article: "Tropical forests potentially contribute to global climate change mitigation through carbon [storage], hence a global carbon pool. In order to mitigate the global climate change impact, the Kyoto protocol developed the clean development mechanism (CDM) which supports carbon credits for plantation activities in developing countries. Unfortunately, none of the CDM forestry projects included bamboo as a carbon reservoir. Although bamboo is an integrating part of tropical forest ecosystems, it was overlooked in the initial negotiating process. The present study, therefore, investigated the carbon storage potential of a common bamboo species, *Bambusa vulgaris* at Lawachara forest reserve of Bangladesh. Results showed that five-year-old *B. vulgaris* stand stored in total 77.67 t C ha^{-1} of which 50.44 t C ha^{-1} were stored in the above ground biomass (culms, branches and leaves), 2.52 t C ha^{-1} in the below ground biomass and 24.71 t C ha^{-1} in the soils. This amount of carbon storage is much more promising than the carbon storage of many other tree species considered in the CDM projects. These findings demonstrate the potential of *B. vulgaris* to be considered in CDM projects as a plantation species and thereby mitigate

climate change impact more efficiently." **Md. Shawkat Islam Sohel, Mohammed Alamgir, Sayma Akhter, and Mizanur Rahman**, *Land Use Policy*. (Subscription may be required.)

"Carbon storage and nutrient mobilization from soil minerals by deep roots and rhizospheres." The following is the Abstract of this article: "Roots mobilize nutrients via deep soil penetration and rhizosphere processes inducing weathering of primary minerals. These processes contribute to C transfer to soils and to tree nutrition. Assessments of these characteristics and processes of root systems are important for understanding long-term supplies of nutrient elements essential for forest growth and resilience. Research and techniques have significantly advanced since Olof Tamm's 1934 'base mineral index' for Swedish forest soils, and the basic nutrient budget estimates for whole-tree harvesting systems of the 1970s. Recent research in areas that include some of the world's most productive and intensively managed forests, including Brazil and the USA, has shown that root systems are often several meters in depth, and often extend deeper than soil is sampled. Large amounts of carbon are also sometimes stored at depth. Other recent studies on potential release of nutrients due to chemical weathering indicate the importance of root access to deep soil layers. Nutrient release profiles clearly indicate depletion in the top layers and a much higher potential in B and C horizons. Reviewing potential sustainability of nutrient supplies for biomass harvesting and other intensive forest management systems will advance understanding of these important ecosystem properties, processes and services relevant for management." **Ingeborg Callesen, Robert Harrison, Inge Stupak, Jeff Hatten, Karsten Raulund-Rasmussen, James Boyle, Nicholas Clarke, and Darlene Zabowski**, *Forest Ecology and Management*. (Subscription may be required.)

May 2016

"Global zero emissions scenarios: The role of biomass energy with carbon capture and storage by forested land use." The following is the Abstract of this article: "[The authors] investigate the prospects of three zero-emission scenarios for achieving the target of limiting global mean temperature rise to 2°C or below, and compare them with the business-as-usual (BAU) scenario involving no climate policy intervention. The '2100 zero' emissions scenario requires zero emissions after 2100 until 2150. The '350 ppm zero' emissions scenario entails zero emissions in the latter half of this century, which can be achieved by the cumulative emissions constraints of the Wigley–Richels–Edmonds (WRE) 350 from 2010 to 2150. Finally, the 'net zero' scenario requires zero cumulative emissions from 2010 to 2150, allowing positive emissions over the coming several decades that would be balanced-out by negative emissions in the latter half of the century. The role of biomass energy carbon capture and storage (BECCS) with forested land is also assessed with these scenarios. The results indicate that the 2°C target can be achieved in the 'net zero' scenario, while the '350 ppm zero' scenario would result in a temperature rise of 2.4°C. The '2100 zero' scenario achieved a 4.1°C increase, while the BAU reached about 5.2°C. BECCS contributed to achieving zero-emission requirements while providing a limited contribution to energy supply. The findings indicate substantial future challenges for the management of forested land." **Koji Tokimatsu, Rieko Yasuoka, and Masahiro Nishio**, *Applied Energy*. (Subscription may be required.)

"Long-term effects of crop rotation, manure and mineral fertilization on carbon [storage] and soil fertility." The following is the Abstract of this article: "Carbon [storage], recently advocated to mitigate climate change, needs a thorough knowledge of the dynamics of soil organic carbon (SOC), whose study requires long-term experiments. A field trial started in 1967 is still in progress in the Southeast Po valley (Italy). It compares a [nine]-year rotation (corn–wheat–corn–wheat–corn–wheat–alfalfa–alfalfa–alfalfa), two [two]-year successions (corn–wheat and sugarbeet–wheat), continuous corn and continuous wheat. During the first 18 years (up to 1984) wheat crops were always followed by catch crops of silage corn. Within each rotation, three rates of cattle manure have been factorially combined with three mineral NP rates. In 1984 the highest manure application was stopped. Wheat straw and corn stalks have always been removed from the field. Since 1972 up to now every year [the authors] have determined the organic C and total N contents in soil samples collected from 0.40-m depth. During the first 18 years (in the

presence of the catch crop) SOC exponentially declined, probably as a consequence of the intensification of tillage depth and crop succession with respect to the previous conventional agriculture. The intensification regarded ploughing, which became deeper, the number of cropped species that in most treatments was reduced, and mineral N application, which, on average, increased. The drop was faster in the sugarbeet–wheat succession than in the [nine]-yr rotation and continuous wheat. After 1985, without the catch crop, SOC linearly increased, faster in the [nine]-yr rotation and continuous wheat than in sugarbeet–wheat. The results can be ascribed to the amount and C/N ratio of debris remaining in the field after each crop, even after having taken away wheat straw and corn stalks. The debris consisted of sugarbeet tops, with a low C/N ratio, and of roots and basal culms of the two cereal crops with higher C/N ratio. Mineral fertilizers significantly increased SOC, probably for the greater amount of cereal roots and sugarbeet tops in more fertilized plots. The influence of manure was less intense, but its benefits lasted longer than 18 years after its interruption. Soil N content was more related to accumulated organic matter than to mineral N fertilisation. In conclusion the highest C [storage] was obtained with manure addition, with the highest rate of mineral fertilizers, and in the rotation containing the alfalfa ley. The effects of these factors were not additive." **Loretta Triberti, Anna Nastri, and Guido Baldoni**, *European Journal of Agronomy*. (Subscription may be required.)

June 2016

"Carbon [storage] potential of second-growth forest regeneration in the Latin American tropics." The following is the Abstract of this article: "Regrowth of tropical secondary forests following complete or nearly complete removal of forest vegetation actively stores carbon in aboveground biomass, partially counterbalancing carbon emissions from deforestation, forest degradation, burning of fossil fuels, and other anthropogenic sources. [The authors] estimate the age and spatial extent of lowland second-growth forests in the Latin American tropics and model their potential aboveground carbon accumulation over four decades. [The authors'] model shows that, in 2008, second-growth forests (1 to 60 years old) covered 2.4 million km^2 of land (28.1 [percent] of the total study area). Over 40 years, these lands can potentially accumulate a total aboveground carbon stock of 8.48 Pg C (petagrams of carbon) in aboveground biomass via low-cost natural regeneration or assisted regeneration, corresponding to a total CO_2 [storage] of 31.09 Pg CO_2. This total is equivalent to carbon emissions from fossil fuel use and industrial processes in all of Latin America and the Caribbean from 1993 to 2014. Ten countries account for 95 [percent] of this carbon storage potential, led by Brazil, Colombia, Mexico, and Venezuela. [The authors] model future land-use scenarios to guide national carbon mitigation policies. Permitting natural regeneration on 40 [percent] of lowland pastures potentially stores an additional 2.0 Pg C over 40 years. [The authors'] study provides information and maps to guide national-level forest-based carbon mitigation plans on the basis of estimated rates of natural regeneration and pasture abandonment. Coupled with avoided deforestation and sustainable forest management, natural regeneration of second-growth forests provides a low-cost mechanism that yields a high carbon [storage] potential with multiple benefits for biodiversity and ecosystem services." **Robin L. Chazdon, et al.**, *Science Advances*. (Subscription may be required.)

"CO_2 emission and structural characteristics of two calcareous soils amended with municipal solid waste and plant residue." The following is the Abstract of this article: "This investigation examines the effect of different amendments on selected soil physical and biological properties over a 24-month period in two cropland fields. Urban municipal solid waste (MSW) compost and alfalfa residue (AR) were used as different organic amendments at the rates of 0 (control), 10 and 30 Mg ha^{-1} to a clay loam soil and a loamy sand soil in a semiarid region. Results showed that the soil improvement was controlled by the application rate and decomposability of amendments and soil type. The addition of organic amendments to the soils improved aggregate stability and consequently enhanced total porosity, especially macropore fraction. The increased soil organic carbon (SOC) and total porosity values as compared to the control treatment were greater in the loamy sand soil than in the clay loam soil. Moreover, compared to the microbial respiration of control plots, the application of MSW resulted in higher values of microbial respiration in the clay loam soil than in the loamy sand soil, whereas the

reverse was found for AR. Linear and power functions were provided for the relationships between microbial respiration and SOC in the loamy sand and clay loam soils, respectively. Also, CO_2 emission was stimulated significantly as power functions of the total porosity and the ratio of macroporosity to microporosity. However, the soil microbial respiration and carbon storage improved aggregate stability and pore size distribution, and as a response, soil porosity, especially the macropore fraction, controlled CO_2 flux." **N. Yazdanpanah**, *Solid Earth.* (Subscription may be required.)

"Carbon [Storage] and Carbon Markets for Tree-Based Intercropping Systems in Southern Québec, Canada." The following is from the Abstract of this article: "Since agriculture directly contributes to global anthropogenic greenhouse gas (GHG) emissions, integrating trees into agricultural landscapes through agroforestry systems is a viable adaptive strategy for climate change mitigation. The objective of this study was to evaluate the carbon (C) [storage] and financial benefits of C [storage] according to Québec's Cap-and-Trade System for Greenhouse Gas Emissions Allowances (C & T System) or two experimental 10-year-old tree-based intercropping (TBI) systems in southern Québec, Canada. [The authors] estimated total C stored in the two TBI systems with hybrid poplar and hardwoods and adjacent non-TBI systems under agricultural production, considering soil, crop and crop roots, litterfall, tree and tree roots as C stocks. The C [storage] of the TBI and adjacent non-TBI systems were compared and the market value of the C payment was evaluated using the net present value (NPV) approach. The TBI systems had 33 [percent] to 36 [percent] more C storage than adjacent non-TBI systems. The financial benefits of C [storage] after 10 years of TBI practices amounted to of [$1,763.88-$2,153.51] ha^{-1} and [$1,224.33–$1,493.71] ha^{-1} for St. Edouard and St. Paulin sites, respectively. [The authors] conclude that valorizing the C [storage] of TBI systems could be an incentive to promote the establishment of TBI for the purpose of GHG mitigation in Québec, Canada." **Kiara S. Winans, Joann K. Whalen, David Rivest, Alain Cogliastro, and Robert L. Bradley**, *Atmosphere*. (Subscription may be required.)

July 2016

"Researchers to Study How to Reduce Carbon Dioxide in Ranch Soil." The U.S. Department of Agriculture is funding research to reduce GHG emissions emanating from soil. The three-year study will also offer the potential for cattle ranchers to receive credit for storing CO_2. Scientists from the University of Florida Institute of Food and Agricultural Sciences will conduct the research, using lab and field studies to investigate how pasture management affects soil microbes, which produce CO_2 when they eat plant litter and soil organic matter. From *ScienceDaily* on June 22, 2016.

"Assessing the carbon [storage] potential of poplar and black locust short rotation coppices on mine reclamation sites in Eastern Germany – Model development and application." The following is the Abstract of this article: "In the temperate zone short rotation coppice systems for the production of woody biomass (SRC) have gained great interest as they offer a pathway to both sustainable bioenergy production and the potential [storage] of CO_2 within the biomass and the soil. This study used the carbon model SHORTCAR to assess the carbon cycle of a poplar (*Populus suaveolens* Fisch. x *Populus trichocarpa* Torr. et Gray cv. Androscoggin) and a black locust (*Robinia pseudoacacia* L.) SRC. The model was calibrated using data from established SRC plantations on reclaimed mine sites in northeast Germany and validated through the determination of uncertainty ranges of selected model parameters and a sensitivity analysis. In addition to a 'reference scenario', representing the actual site conditions, [seven] hypothetical scenarios, which varied in climate conditions, rotation intervals, runtimes, and initial soil organic carbon (SOC) stocks, were defined for each species. Estimates of carbon accumulation within the biomass, the litter layer, and the soil were compared to field data and previously published results. The model was sensitive to annual stem growth and initial soil organic carbon stocks. In the reference scenario net biome production for SRC on reclaimed sites in Lusatia, Germany amounted to 64.5 Mg C ha^{-1} for *R. pseudoacacia* and 8.9 Mg C ha^{-1} for poplar, over a period of 36 years. These results suggest a considerable potential of SRC for carbon [storage] at least on marginal sites." **A.**

Quinkenstein and H. Jochheim, *Journal of Environmental Management*. (Subscription may be required.)

August 2016

"Spatio-Temporal Variation and Impact Factors for Vegetation Carbon Sequestration and Oxygen Production Based on Rocky Desertification Control in the Karst Region of Southwest China." The following is the Abstract of this article: "The Grain to Green Program (GTGP) and eco-environmental emigration have been employed to alleviate poverty and control rocky desertification in the Southwest China Karst region. Carbon [storage] and oxygen production (CSOP) is used to indicate major ecological changes, because they involve complex processes of material circulation and energy flow. Using remote sensing images and weather records, the spatiotemporal variation of CSOP was analyzed in a typical karst region of northwest Guangxi, China, during 2000–2010 to determine the effects of the Chinese government's ecological rehabilitation initiatives implemented in 1999. An increase with substantial annual change and a significant increase (20.94 [percent], $p < 0.05$) in variation were found from 2000 to 2010. CSOP had a highly clustered distribution in 2010 and was correlated with precipitation and temperature (9.18 [percent] and 8.96 [percent], respectively, $p < 0.05$). CSOP was significantly suppressed by human activities ($p < 0.01$, $r = -0.102$) but was consistent with the intensity of GTGP (43.80 [percent] positive). The power spectrum of CSOP was consistent with that of the gross domestic product. These results indicate that ecological services were improved by rocky desertification control in a typical karst region. The results may provide information to evaluate the efficiency of ecological reconstruction projects." **Mingyang Zhang, Kelin Wang, Huiyu Liu, Jing Wang, Chunhua Zhang, Yuemin Yue, and Xiangkun Qi**, *Remote Sensing*. (Subscription may be required.)

September 2016

The Terrestrial section was removed from the Carbon Storage Newsletter in September 2016.

Trading

September 2015

"Trading Program Linked to Significant Emissions Reductions." According to a new study, the RGGI emissions trading program in the northeastern United States that limits CO_2 emissions is responsible for approximately half of the region's emissions reductions. The study, led by Duke University and published online in the journal "Energy Economics," examined how RGGI performed once it was introduced in 2009 through 2012. The researchers then used various data from the 48 continental U.S. states from 1990 onward, allowing them to separate emissions reduction factors in RGGI states after the program went into effect from factors that affected emissions in other states and time periods. The study found that RGGI was responsible for the largest emissions drop. The Abstract of the study, titled "Why Have Greenhouse Gas Emissions in RGGI States Declined? An Econometric Attribution to Economic, Energy Market, and Policy Factors," is available below. From *The Nicholas Institute for Environmental Policy Solutions at Duke University* on August 21, 2015.

"Why Have Greenhouse Emissions in RGGI States Declined? An Econometric Attribution to Economic, Energy Market, and Policy Factors." The following is the Abstract of this article: "RGGI is a consortium of northeastern U.S. states that limit [CO_2] emissions from electricity generation through a regional emissions trading program. Since RGGI started in 2009, regional emissions have sharply dropped. [The authors] use econometric models to quantify the emissions reductions due to RGGI and those due to other factors such as the recession, complementary environmental programs and lowered natural gas prices. The analysis shows that after the introduction of RGGI in 2009 the region's emissions would have been 24 percent higher without the program, accounting for about half of the region's emissions reductions during that time, which were far greater than those achieved in the rest of the United States." **Brian C. Murray and Peter T. Maniloff**, *Energy Economics*. (Subscription may be required.)

"China Hubei Carbon Market Reports 100 [Percent] Compliance Rate." All 138 companies obligated to reduce their CO_2 emissions under the first year of Hubei's carbon market complied in full. According to the China Hubei Emissions Exchange, participants reduced their CO_2 emissions by 7.8 million metric tons during the trading year. China's three-year pilot trading phase is set to expire in mid-2016; however, work is ongoing on preparing unified trading rules for the launch of a nationwide scheme (under the current phase, China's seven pilot carbon markets operate independently). From *Economic Times* on August 21, 2015.

"China's carbon-emissions trading: Overview, challenges and future." The following is the Abstract of this article: "Because China has emerged as the largest GHG emitter in total annual emissions, to accelerate the pace of GHG emission reduction in China is important to the success of global efforts in addressing climate change. Carbon trading is a market mechanism and key instrument in the mitigation of climate change. This paper explores the policy process and development state to date of China's carbon-trade market to understand the emergence and development of that market and to understand what barriers are hampering China's carbon-trade market development. To achieve this goal, this paper introduces and analyzes China's status in the international market, examines the factors driving carbon-market launching by the Chinese government, and traces the development of mandatory carbon-emission trading and voluntary emission trading. It is argued that China's carbon-trading market is confronted with challenges such as the absence of a functional carbon-trading market, inaccuracy of the quota allocation, an imperfect trading mechanism, and lagging legislation. At the present stage, shortcomings such as having no real-time carbon price and dominated spot transactions differentiate China's trade market substantially from a functional system. A quick market integration of China's carbon market appears remote. It is suggested that specific measures be taken to promote the development of

the Chinese carbon-trading market." **Liwei Liu, Chuxiang Chen, Yufei Zhao, and Erdong Zhao**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

October 2015

"CO_2 Allowances Sold for $6.02 in 29th RGGI Auction." The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced that 25,374,294 CO_2 allowances sold in their 29th auction of CO_2 allowances were sold at a clearing price of $6.02. The total allowances sold included both the initial offering of 15,374,294 CO_2 allowances, as well as the 10 million additional Cost Containment Reserve (CCR) allowances. The CCR is a fixed supply of 10 million allowances only available for sale if CO_2 allowance prices exceed certain price levels; there are no more CCR allowances available for 2015 (the CCR will be replenished in 2016). In addition, the Auction Notice and application materials for the 30th quarterly auction, to be held on December 2, 2015, were released. The Auction Notice for CO_2 Allowance Auction 30 provides the information needed to submit a Qualification Application and indicate intent to bid. The RGGI states will offer 15,374,274 CO_2 allowances for sale using a reserve price of $2.05. This will be the last quarterly auction in which states will offer CO_2 allowances for purchase to meet CO_2 interim compliance obligations for the 2015 interim control period, which began on January 1, 2015. To date, RGGI CO_2 allowance auctions have generated a total of more than $2.2 billion for reinvestment in strategic programs, such as GHG abatement and renewable energy programs. From *RGGI* on September 11, 2015, and October 5, 2015.

November 2015

"Government to Raise $22 Billion from Carbon Pricing in 2015: Report." According to a new report from the Climate Markets and Investment Association (CMIA), carbon pricing schemes, such as taxes and emissions trading systems (ETS), will generate approximately $22 billion for their governments. The figure is up 46 percent from the estimated $15 billion raised in 2014, according to CMIA. The report, titled "Carbon Pricing Revenues," is available on the CMIA website. From *Reuters* on October 28, 2015.

"[Vietnam] Approves Plan for $3.6M Carbon Market." Vietnam has approved a project to create a carbon market. Funded by the World Bank and Vietnamese government, the project would help to set up a database of GHG emissions throughout the country; issue policies and state management tools related to the carbon market; implement the Nationally Appropriate Mitigation Action (NAMA) to create carbon credits; and assist Vietnam in building a roadmap to participate in the global carbon market. From *Vietnam News* on October 28, 2015.

"Carbon emissions and stock returns: Evidence from the EU Emissions Trading Scheme." The following is the Abstract of this article: "This paper provides an empirical investigation of the effect of the European Union's Emissions Trading Scheme on German stock returns. [The authors] find that, during the first few years of the scheme, firms that received free carbon emission allowances on average significantly outperformed firms that did not. This suggests the presence of a large and statistically significant 'carbon premium,' which is mainly explained by the higher cash flows due to the free allocation of carbon emission allowances. A carbon risk factor can also explain part of the cross-sectional variation of stock returns as firms with high carbon emissions have higher exposure to carbon risk and exhibit higher expected returns." **A. Marcel Oestreich and Ilias Tsiakas**, *Journal of Banking & Finance*. (Subscription may be required.)

December 2015

"First California Cap-and-Trade Compliance Period Ends with 99 Percent Compliance." The California Air Resources Board announced a 99 percent compliance rate for the first compliance period of the state's cap-and-trade program. The program was initiated under the California Global Warming

Solutions Act of 2009 (AB 32), which aims to reduce greenhouse gas (GHG) emissions back to 1990 levels by 2020. From *California Environmental Protection Agency Air Resource Board News Release* on November 4, 2015.

"World Bank Launches $500 [Million] Carbon Market Scheme." The World Bank, with pledges from Germany, Norway, Sweden, and Switzerland, has launched a $500 million carbon market scheme designed to help developing countries pay for CO_2 emission reductions and address potential climate change. According to the bank, the scheme will reward countries for reducing emissions by paying a fee for each ton of CO_2 reduced. The price-per-ton paid to the countries will be set on a case-by-case basis. From *Reuters* on November 30, 2015.

"China to Start Nationwide Emissions Trading Market in 2017." Following the successful operation of seven pilot-scale schemes across the country, Chinese officials announced intentions to start a nationwide CO_2 emissions trading market in 2017. According to China's INDCs, the country is looking to cut CO_2 emissions per unit of gross domestic product (GDP) by 60 to 65 percent from the 2005 level by 2030. From *Xinhua News* on November 19, 2015.

"Modeling the impacts of alternative emission trading schemes on international shipping." The following is the Abstract of this article: "Various market-based measures have been proposed to reduce CO_2 emissions from international shipping. One promising mechanism under consideration is the Emission Trading Scheme (ETS). This study analyzes and benchmarks the economic implications of two alternative ETS mechanisms, namely, an open ETS compared to a Maritime only ETS (METS). The analytical solutions and model calibration results allow [the authors] to quantify the impacts of alternative ETS schemes on the container shipping sector and the dry bulk shipping sector. It is found that an ETS, whether open or maritime only, will decrease shipping speed, carrier outputs and fuel consumption for both the container and dry bulk sectors, even in the presence of a 'wind-fall' profit to shipping companies. Under an open ETS, the dry bulk sector will suffer from a higher proportional reduction in output than the container sector, and will thus sell more emission permits or purchase fewer permits. Under an METS, container carriers will buy emission permits from the dry bulk side. In addition, under an METS the degree of competition within one sector will have spill-over effects on the other sector. Specifically, when the sector that sells (buys) permits is more collusive (competitive), the equilibrium permit price will rise. This study provides a framework for identifying the moderating effects of market structure and competition between firms on emission reduction schemes, and emphasizes the importance of understanding the differential impacts of ETS schemes on individual sectors within an industry when considering alternative policies." **Kun Wang, Xiaowen Fu, and Meifeng Luo**, *Transportation Research Part A: Policy and Practice*. (Subscription may be required.)

January 2016

"China Sets CO_2 Reporting Standards Ahead of Market Launch." As part of their plan to launch a national carbon market by 2017, China has issued national standards for industrial firms to report their GHG emissions. Issued by the National Development and Reform Commission (NDRC), the standards will enable China to create a statistical system for GHG emissions and support the establishment of a national carbon trading scheme. The reporting rules cover 10 industries, including power generation and grids. By approximately 2030, China has pledged to reduce its carbon intensity from the 2005 level. From *The Business Times* on December 23, 2015.

"S. Korea, China Agree to Expand Cooperation in Carbon Trading." Seoul's carbon trading market operator announced plans for South Korea and China to expand their cooperation on emissions trading, including joint efforts to link their carbon trading markets. Under the Memorandum of Understanding (MOU) signed by the Korea Exchange (KRX) and the China Beijing Environment Exchange (CBEEX), the sides will exchange market information and share their experiences. The KRX launched their carbon

trading system in 2015; China, which currently has seven operators of regional carbon trading markets, plans to launch their nationwide scheme in 2017. From *Yonhap News* on December 21, 2015.

February 2016

"Beijing Carbon Market to Extend Pilot Trading." Beijing's carbon market will continue to trade local CO_2 permits after their three-year pilot phase expires in June 2016, according to a statement released by the Beijing market regulator. In addition, the Beijing Development and Reform Commission has submitted plans to convert local permits into ones tradable on the nationwide exchange. To date, Beijing has traded approximately 5.7 million permits. From *Reuters* on January 27, 2016.

"EU and Switzerland Set to Link Carbon Markets…" The European Union (EU) and Switzerland announced plans to link their respective emissions trading schemes, allowing covered entities in both systems to trade emissions permits. The Swiss scheme was set up in 2008, includes approximately 55 companies, and covered 5.5 million metric tons of carbon emissions in 2015. EU's Emission Trading Scheme (ETS) was initiated in 2005 and regulates approximately 11,000 power stations and manufacturing plants representing approximately 2 billion metric tons of carbon emissions. From *International Center for Trade and Sustainable Development* on January 26, 2016.

"Adjusting the CO_2 cap to subsidized RES generation: Can CO_2 prices be decoupled from renewable policy?" The following is the Abstract of this article: "The low prices in the EU ETS have triggered discussions of various possible reforms. One option is to decouple the CO_2 prices from renewable energy policy by adjusting the emission cap to renewable energy investment overshoots. [The authors] introduce two ways of reducing the CO_2 cap in response to overshoots of renewable policy investment over previously announced targets. [The authors] investigate these options with the agent-based model EMLab-generation. [The authors] find that both policy implementations are successful in restoring prices. They also ensure that making public investments that exceed policy targets contribute to carbon emission reduction, and that renewable policy does not benefit the most emission-intensive power plants. However, neither policy is suitable for achieving [specific] levels of prices or price volatility." **Jörn C. Richstein, Émile J.L. Chappin, and Laurens J. de Vries**, *Applied Energy*. (Subscription may be required.)

March 2016

"[Ontario Releases Draft Cap-and-Trade Regulations]." The Ontario government proposed annual emissions cuts of more than four percent for its cap-and-trade system in recently released draft regulations. Amendments to the regulations, which will undergo a period of public consultation, will allow for Ontario's program to be connected to the cap-and-trade programs in California and Québec (once a linking deal has been agreed upon). The draft proposed to cap CO_2 emissions for included sectors at 142.332 million metric tons in 2017, when the scheme starts, falling more than four percent per year to 124.668 million metric tons in 2020. From *Carbon Pulse* on February 26, 2016.

"Guangdong Becomes China's First Carbon Market to Green-Light OTC Forward Trading." The Guangdong emissions exchange became China's first carbon market to release rules for forward trading in carbon. Under the rules, published in a bid to formalize the practice, parties may negotiate forward trades of Guangdong Emissions Allowances (GDAs) and Chinese Certified Emissions Reductions (CCERs). From *Carbon Pulse* on February 3, 2016.

"An optimal control model for reducing and trading of carbon emissions." The following is the Abstract of this article: "A stochastic optimal control model of reducing and trading for carbon emissions is established in this paper. With considerations of reducing the carbon emission growth and the price of the allowances in the market, an optimal policy is searched to have the minimum total costs to achieve

the agreement of emission reduction targets. The model turns to a two-dimension HJB equation problem. By the methods of reducing dimension and Cole–Hopf transformation, a semi-closed form solution of the corresponding HJB problem under some assumptions is obtained. For more general cases, the numerical calculations, analysis and comparisons are presented." **Huaying Guo and Jin Liang**, *Physica A: Statistical Mechanics and its Applications*. (Subscription may be required.)

April 2016

"[Results of 31st RGGI Auction Announced]." The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of the 31st auction of CO_2 allowances. A total of 14,838,732 CO_2 allowances were sold at a clearing price of $5.25. None of the 10 million cost containment reserve (CCR) allowances, a fixed additional supply of allowances that are only available for sale if CO_2 allowance prices exceed certain price levels, were sold. The auction generated $77.9 million for reinvestment in strategic programs; to date, cumulative proceeds from all RGGI auctions exceeds $2.4 billion. More information is available in the Market Monitor Report for Auction 31. In addition, the RGGI states also released the Auction Notice and application materials for their 32nd auction to be held June 1, 2016, in which 15,089,652 CO_2 allowances will be offered for sale at a reserve price of $2.10. The notice and materials provide potential auction participants with the information needed to submit a Qualification Application indicating their intent to bid. More information on CO_2 Allowance Auction 32 is available on the RGGI website. From *RGGI News Release* on March 11, 2016.

"Role of carbon swap trading and energy prices in price correlations and volatilities between carbon markets." The following is the Abstract of this article: "The present paper theoretically and empirically examines the role of carbon swap trading and energy prices in volatilities and price correlations between the [European Union (EU)] and Kyoto Protocol emissions trading schemes. A supply and demand based correlation model between [EU allowance (EUA)] and [secondary certified emissions reduction (sCER)] price returns is proposed in detail using inverse Box–Cox type marginal abatement cost (MAC) curves and simple emission reduction volume processes. The model includes financial players' EUA–sCER swap transaction in boom periods of carbon prices using the logit model for EUA and EUA–sCER swap volume correlations, and stronger energy price impacts on EUA prices than sCER prices using a mean-reverting lognormal process for energy prices. The empirical studies using EUA and sCER prices estimate the model parameters, resulting in a positive EUA volume impact on EUA–sCER swap transactions and a positive energy price impact on EUA prices. It is shown that high EUA–sCER price correlations during high EUA price periods stemmed from EUA–sCER swap transactions, whereas high EUA–sCER price correlations during the period of financial turmoil with low EUA prices came from the drop in energy prices. [The authors] also show that the leverage effects often observed in security markets exist in both the EUA and sCER markets according to the price–volatility relation." **Takashi Kanamura**, *Energy Economics*. (Subscription may be required.)

May 2016

"Washington State Readies Revised CO_2 Market Plan." Washington State plans to unveil a revised CO_2 market plan that could potentially limit out-of-state carbon credits and set new targets for industry. Once the plan is announced, the Washington State Department of Ecology will open a consultation and host webinars before adopting the measure. The revised scheme is designed to aid the state in reducing its greenhouse gas (GHG) emissions in half from 1990 levels by 2050. From *Carbon Pulse* on April 28, 2016.

"How to improve the market efficiency of carbon trading: A perspective of China." The following is the Abstract of this article: "Emissions trading scheme (ETS) is one of the effective measures to realize energy conservation and emission reduction. In order to set up a nationwide carbon emissions trading mechanism, seven ETS pilots have been launched in China. Firstly, based on empirical investigation and

research of seven pilots, this paper analyzed the market efficiency of ETS pilots from four aspects: carbon price, trading volume, market liquidity, and information transparency. The result showed that the market efficiency of ETS pilots is not satisfactory in spite of the fact that system designs of ETS have achieved preliminary result. Then, the reason for low market efficiency of ETS pilots was discussed from some factors such as institutional arrangements, market participants, the supply and demand, etc. Finally, this paper puts forward some policy suggestions to improve the market efficiency of China's carbon trading market." **Xin-gang Zhao, Gui-wu Jiang, Dan Nie, and Hao Chen**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

June 2016

"CO_2 Allowances Sold for $4.53 in 32nd RGGI Auction." The nine states participating in RGGI, the Nation's first market-based regulatory program to reduce greenhouse gas (GHG) emissions, released results of their 32nd auction of CO_2 allowances. A total of 15,089,652 CO_2 allowances were sold at a clearing price of $4.53, with bids ranging from $2.10 to $12.65 per allowance. None of the 10 million cost containment reserve (CCR) allowances available were sold (CCR is a fixed additional supply of allowances only made available if allowance prices exceed certain levels). More information on Auction 32, which generated a total of $68.3 million for reinvestment in strategic programs, such as energy efficiency and GHG abatement programs, is available in the "Market Monitor Report for Auction 32." From *RGGI News Release* on June 3, 2016.

July 2016

"S. Korea, EU Join Hands to Promote Emissions Trading System." South Korea and the European Union (EU) announced bilateral cooperation on potential climate change with the Seoul-Brussels joint emissions trading system cooperation project. According to Seoul's finance ministry, the cooperation with EU's cap-and-trade system will help South Korea further develop its emissions trading system (ETS) and reach its plan to reduce GHG emissions by 37 percent from the 2030 business-as-usual levels. From *Yonhap News Agency* on July 8, 2016.

"An optimal control model for reducing and trading of carbon emissions." The following is the Abstract of this article: "A stochastic optimal control model of reducing and trading for carbon emissions is established in this paper. With considerations of reducing the carbon emission growth and the price of the allowances in the market, an optimal policy is searched to have the minimum total costs to achieve the agreement of emission reduction targets. The model turns to a two-dimension HJB equation problem. By the methods of reducing dimension and Cole–Hopf transformation, a semi-closed form solution of the corresponding HJB problem under some assumptions is obtained. For more general cases, the numerical calculations, analysis and comparisons are presented." **Huaying Guo and Jin Liang**, *Physica A: Statistical Mechanics and its Applications*. (Subscription may be required.)

"The effects of allowance price on energy demand under a personal carbon trading scheme." The following is the Abstract of this article: "Personal carbon trading (PCT) is a downstream cap-and-trade scheme which could be used to reduce carbon emissions from the household sector. To explore the effectiveness of this scheme, it is necessary to investigate how consumers respond to allowance price change. In this paper, a general utility optimization (GUO) model and a constant elasticity of substitution (CES) utility function are proposed to examine the price, substitution and income effects of carbon allowance price changes. It is shown that higher income consumers are more sensitive to the allowance price changes than lower income consumers. Moreover, the short-run adjustment in consumers' consumption of electricity in response to a change in allowance price would be lower than the long-run value. According to the sensitivity analysis, downward (upward) adjustments in the elasticity of substitution result in a positive (negative) effect on price effect. The findings in this study are used to

draw policy implications. Suggestions for future research are also provided." **Jin Fan, Jun Li, Yanrui Wu, Shanyong Wang, and Dingtao Zhao**, *Applied Energy*. (Subscription may be required.)

August 2016

"[RGGI States Initiate Auction Process for Auction 33]." The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their third-party quarterly CO_2 allowance auction. The CO_2 Allowance Auction 33 Auction Notice provides potential auction participants with the information needed to submit a Qualification Application and indicate their intent to bid. Auction 33, scheduled for September 7, 2016, will offer 14,911,315 CO_2 allowances for sale at a reserve price of $2.10. In addition, a 10 million CO_2 allowance cost containment reserve (CCR) is available for this auction, which will be accessed if the interim clearing price exceeds the CCR trigger price of $8.00. From *Regional Greenhouse Gas Initiative* on July 11, 2016.

"Limited trading of emissions permits as a climate cooperation mechanism? US–China and EU–China examples." The following is the Abstract of this article: "Recent multilateral climate negotiations have underlined the importance of international cooperation and the need for support from developed to developing countries to address climate change. This raises the question of whether carbon market linkages could be used as a cooperation mechanism. Policy discussions surrounding such linkages have indicated that, should they operate, a limit would be set on the amount of carbon permits that could be imported by developed regions from developing countries. This paper analyzes the impact of limited carbon trading between an ETS in the EU or the US and a carbon market covering Chinese electricity and energy intensive sectors using a global economy-wide model. [The authors] find that the limit results in different carbon prices between China and Europe or the US. Although the impact on low-carbon technologies in China is moderate, global emission reductions are deeper than in the absence of international trading due to reduced carbon [release]. If China captures the rents associated with limited permit trading, [the authors] show that it is possible to find a limit threshold that makes both regions better off relative to carbon markets operating in isolation." **Claire Gavard, Niven Winchester, and Sergey Paltsev**, *Energy Economics*. (Subscription may be required.)

September 2016

"Mexico Announces Launch of Cap-and-Trade Pilot Program." Mexican officials announced the launch of a cap-and-trade simulation program as a test run for a national carbon market expected to launch in 2018. The pilot program, which will commence in November 2016, will provide up to 60 voluntary companies the opportunity to adapt to a forthcoming carbon credit system. As part of the Paris climate agreement, Mexico expects to implement measures to reduce GHG emissions by 22 percent by 2030. From *Reuters* on August 15, 2016.

"CO_2 Allowances Sold for $4.54 in 33rd RGGI Auction." The Northeastern and Mid-Atlantic states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of their 33rd auction, in which 14,911,315 CO_2 allowances were sold at a clearing price of $4.54. None of the 10 million cost containment reserve (CCR) allowances available were sold; the CCR is a fixed additional supply of allowances offered only if CO_2 allowance prices exceed certain price levels ($8.00 in 2016). The third auction of 2016, Auction 33 generated $67.7 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement. To date, total proceeds from all RGGI CO_2 allowance auctions exceeds $2.58 billion. From *RGGI News Release* on September 9, 2016.

"The impact of verified emissions announcements on the European Union emissions trading scheme: A bilaterally modified dummy variable modelling analysis." The following is the Abstract of this article: "Carbon trading scheme is easily subject to the shocks from vital information announcements or regulations modification due to its vulnerability as a man-made market. This paper investigates the

impact of verified emissions announcements, which are released annually by the European Commission and span three phases (2006–2013), on carbon price returns and volatility in the European Union emissions trading scheme (EU ETS), by constructing econometric model with bilaterally modified dummy variables of high adaptability. The results show that on average, verified emissions announcements have significant impact on carbon expected returns but show a week effect on price volatility; the separate examination for each announcement event indicates heterogeneous ex-ante and ex-post impacts over time in different market contexts, but the ex-post impact dominates obviously. The verified emissions announcement remarkably causes shocks to the market and the risk of prior information leakage although it facilitates the price discovery. Meanwhile, there is an obvious asymmetry between ex-ante and ex-post impacts that is triggered by market characteristics, and it generally takes more than seven days to absorb the ex-post impacts due to the intrinsic characteristics of the EU ETS. These findings could provide reference for market traders and regulators to make robust allowance management strategy and system design." **Jun-Jun Jia, Jin-Hua Xu, and Ying Fan**, *Applied Energy*. (Subscription may be required.)

Recent Publications

September 2015

"CCS Deployment in the Context of Regional Developments in Meeting Long-Term Climate Change Objectives." The following is from the Executive Summary of this document: "According to the most recent assessment of the Intergovernmental Panel on Climate Change (IPCC), without additional efforts to reduce emissions, global mean surface temperatures are likely to increase between 3.7 and 4.8°C by 2100 compared to pre-industrial levels. Scenarios that keep the atmospheric concentration of CO_2 to around 450 ppm by 2100 (66 percent chance) are consistent with holding a rise in global temperatures to below 2°C – the long-term goal of the United Nations Framework Convention on Climate Change (UNFCCC). Such scenarios involve deep cuts in GHG emissions over the coming decades, requiring radical changes to energy systems and a step-change in the uptake of low carbon technologies. CCS represents a potentially important technology within a portfolio of abatement options available to help achieve the 2°C goal. The technology represents a key mitigation option in most of the emission reduction pathways described by the IPCC – as well as in other scenarios of global GHG mitigation such as the 2DS (2°C Scenario) developed by the International Energy Agency (IEA). Studies also show that both the total investment cost and the cost of emissions reduction are higher for scenarios that exclude CCS from the list of mitigation options. As alternative mitigation options are deployed over the coming decades, CCS will be increasingly needed to meet climate goals. Current forecasts assume fossil-based power generation and industrial output from major emitting sectors such as cement, and iron and steel to rise globally, driven by economic growth in emerging economies. CCS is the only technology available that can achieve deep cuts in CO_2 emissions across fossil-fired power generation and many carbon-intensive industries - for example those where there are no realistic alternatives to using fossil fuels, or to producing CO_2 as part of the industrial process. Furthermore, CCS can be deployed with other low carbon technologies to achieve significant emissions reductions, including the potential for achieving so-called 'negative emissions', for example through the use of bioenergy combined with carbon capture and storage (BECCS or Bio-CCS). CCS projects are technically feasible at scale and have costs that are comparable with other mitigation technologies. A number of industries routinely capture and transport CO_2 worldwide as part of their commercial activities. In North America for example, injection of CO_2 into geological formations has successfully taken place over several decades, principally for the purposes of EOR. CCS involves integrating the separate components of the CCS chain (capture; transport; storage) into projects deployed at scale to move beyond the technical demonstration phase. There are currently 22 large-scale CCS projects in operation worldwide, capturing up to 40 million tonnes of CO_2 per year across a range of sectors."

"Projected emissions of non-CO_2 greenhouse gases." The following is the Executive Summary of this document: "This report presents the 2015 update to [the U.K.'s Department of Energy and Climate Change's (DECC)] projections of non-CO_2 [GHG] emissions for the UK, as well as the methodologies used to derive them and the associated uncertainties. The non-CO_2 gases are methane (CH_4), nitrous oxide (N_2O) and the fluorinated gases (HFCs, PFCs, SF_6 and NF_3). The projections are a best estimate of future emissions, accounting for expected technological developments, key drivers such as population and known policy commitments. It is important to note that policies affecting these projected emissions are still being developed and will be incorporated in future updates. All non-CO_2 emissions sources are covered, with the exception of some non-CO_2 emissions produced as a result of combustion activities. These projections feed into DECC's Energy and Emissions Projections, which cover all UK GHG emissions and will be published later in the year. Total non-CO_2 GHG emissions within the scope of this report were 95.8 million tonnes CO_2 equivalent ($MtCO_2e$) in 2013, which represented 17 [percent] of all GHG emissions. They are projected to reduce to 71.1 $MtCO_2e$ in 2035; a projected 26 [percent] decrease between 2013 and 2035, or a 65 [percent] reduction on 1990 levels… Most of the projected reduction in emissions from 2013 to 2035 comes from decreases in CH_4 emissions from gas network [release], CH_4 emissions from landfill and hydrofluorocarbon (HFC) emissions from refrigeration and air-

conditioning. Since last year's projections there have been significant changes to both the emissions baseline, following the introduction of updated guidelines from the Intergovernmental Panel on Climate Change (IPCC), and also to the projection methodologies used… The 2015 projections start from a higher baseline, but decrease more rapidly. The most significant changes to emissions projections since 2014 have been to the agriculture, waste and F-gas projections."

"Applying carbon capture and storage to a Chinese steel plant." The following is description of this document: "The Global CCS Institute presents a feasibility study report on applying CCS to a steel plant in China. Toshiba was commissioned to conduct the study through its business partner Tongfang Environment in collaboration with Shougang Jingtang United Iron & Steel of China. The study examined the application of CCS onto the Caofeidian steel plant. The report covers the concept of capturing CO_2 from a Chinese steel plant, transportation and potential storage in an oilfield for EOR. The study suggests that carbon capture in Chinese steel plants is a cost effective means of reducing carbon emissions compared with similar plants around the world. This report is authored by Toshiba for the Global CCS Institute."

October 2015

"An Executable Plan for enabling CCS in Europe." The following is from the Executive Summary of this document: "Emitting CO_2 to the atmosphere is currently much cheaper than storing it safely underground. Emitters can pay an 'ETS wergild' and are divorced from all the consequences of their actions, yet if they try to [store] CO_2 they risk taking on liability for decades under the CO_2 Storage Directive. Those factors serve, along with the lack of a near-term business case, to prolong the current inertia on CCS in the [European Union (EU)]. Urgent action is now required to deliver CO_2 storage projects and enabling infrastructure in preparation for commercial deployment. This requires an Executable Plan, owned by the European Commission. This note sketches the contours of such a plan, describing how the Commission can effectively and rapidly aid wide uptake of CCS in Europe; delivering additional CCS projects in power and industry; progressing the development of CCS hubs in Europe; and supporting the appraisal of storage capacity required for commercial CCS deployment. The Executable Plan has been prepared in response to discussion of the 5 Point Action Plan (ANNEX 1) for CCS […] It draws solely on existing policies and public financing opportunities, with the aim to enable their most efficient and effective use. It is designed to feed into the SET Plan preparation and next steps on the Energy Union Strategy. The proposed plan builds on [Zero Emissions Platform's (ZEP's)] insights into the principles for development of CCS in Europe, in particular the need to: decouple the capture of CO_2 from transport and storage (T&S); develop CCS in phases through (expanding) infrastructure hubs; optimize available funding and create mechanisms to [commercialize] CCS; and engage [Member State (MS)] though 2050 decarbonisation plans to enable the development of T&S infrastructure."

"[Optimizing] CO_2 storage in geological formations; a case study offshore Scotland." The following is from the Executive Summary of this document: "CCS is considered a key technology to provide a secure, low-carbon energy supply and reduce the [GHG] emissions that contribute to the adverse effects of climatic change. [Commercialization] projects for the permanent storage of CO_2 captured at power plants are currently in the design stage for the Peterhead, White Rose, Caledonia Clean Energy and Don Valley projects. Storage of the CO_2 captured by these projects is planned in strata deep beneath the North Sea in depleted hydrocarbon fields or regionally extensive sandstones containing brine (saline [formation] sandstones). The vast majority of the UK and Scotland's potential storage resource, which is of European significance, is within brine-saturated sandstone formations. The sandstone formations are each hundreds to thousands of square [kilometers] in extent and underlie all sectors of the North Sea. The immense potential to store CO_2 in these rocks can only be fully achieved by the operation of more than one injection site within each formation. Government, university and research institutes, industry, and stakeholder [organizations] have anticipated the need to inform a second phase of CCS developments following on from a [commercialization] project in Scotland. The CO_2 MultiStore study, led by SCCS, investigates the operation of more than one injection site within a

storage formation using a North Sea case study. The Captain Sandstone, within the mature oil and gas province offshore Scotland, contains the Goldeneye Field, which is the planned storage site for the Peterhead CCS project. Previous research was augmented by data from offshore hydrocarbon exploration and detailed investigation of the Goldeneye Field for CO_2 storage…"

"CarbonNet storage site selection and certification: challenges and successes." The following is from the Abstract of this document: "The CarbonNet Project is seeking CO_2 storage sites in the nearshore area of the Gippsland Basin that provide permanent and safe storage for 25 to 125 Mt of CO_2. The process used by CarbonNet for site selection follows international best practice, aligned to DNV GL Recommended Practice (DNV-RP-J203) to provide decision makers and stakeholders with independent expert assurance of environmentally safe, long-term [geologic] storage. The DNV-RP-J203 requires a systematic approach, based on understanding and minimizing storage risks and analysis of diverse geoscience and environmental factors. The main areas of investigation include: [selection and qualification of storage sites; documentation of site [characterization] and site development plans; risk management throughout the life cycle of CO_2 [geologic] storage projects; monitoring and storage performance verification; well assessment and management planning; and planning for site closure and subsequent stewardship]. The CarbonNet Project reviewed more than twenty five storage concepts at fourteen locations, within 25km of the coastline. These were quantified for prospective storage volume and risk for capacity, containment, and injectivity. A portfolio of three sites was shortlisted. CarbonNet has had its storage site selection process endorsed by an Independent Scientific Peer Review and the site selection process was assessed by DNV GL and a Statement of Feasibility issued for the portfolio in January 2013. Detailed site-specific risk analyses and data gap analyses of key elements were prepared for each site. As a result, a [prioritized] site was selected for further analysis and the development of a site appraisal plan…"

"Pathways to Deep Decarbonization in Canada." The following is from the Executive Summary of this document: "In this second Deep Decarbonization Pathways Project (DDPP) Canada report [the authors] look outside of Canada's borders to identify global decarbonization trends that will affect Canada and [its] ability to achieve deep decarbonization. [The authors] focus on identifying resilient pathways that policy can target regardless of eventual ambition, whether it is tentative, short-term steps or longer-term shifts towards deeper reductions. Complementing this domestic focus is [the authors'] interactions with the 16 other project teams in the DDPP. Through a series of meetings and working groups, [the authors] have collectively begun to coalesce around deep decarbonization pathways that are resilient across countries but also mitigation ambition. [The authors] observe that in virtually every country there are clean energy policies and technology drivers that are pushing global decarbonization trends, notably decarbonization of electricity production and energy-efficiency improvements in buildings and transport. Despite global trends towards progress in reducing the emission intensity of electricity production, buildings and transport, however, significant gaps in global technology exist that pose a challenge for Canadian deep decarbonization efforts, especially in primary extraction but also for emission intensive heavy industries. It is these twin themes that Canadian climate policy must now address: how to deepen and broaden current Canadian policy signals and technology deployment, and where policy attention will be required to push next generation decarbonisation technologies forward, particularly in liquid fossil fuels and industrial processes. [The authors'] analysis identifies six decarbonization pathways under three main themes that emerge from [their] analysis and modelling…"

November 2015

"Assessing the Social Costs and Benefits of Regulating Carbon Emissions." The following is the Executive Summary of this document: "U.S. government agencies are required to quantify the costs and benefits of regulations they propose. In the context of regulations pertaining to carbon emissions, the various agencies had been using differing (often implicit) estimates of the net social cost of carbon. In response, an Interagency Working Group was created in order to establish a consistent and objective

'social cost of carbon' (SCC). Although wide, the range of estimates of the social cost of carbon produced by the Interagency Working Group is both too narrow and almost certainly biased upwards. This is a consequence of using only three rather simplistic models, all of which use estimates of climate sensitivity that are likely too high and two of which likely overestimate the economic impact of climate change. Taking into account a wider range of climate models, impact evaluations, economic forecasts and discount rates, as well as the most recent evidence on climate sensitivity, this study finds that the range of social cost of carbon should be revised downwards. At the low end, carbon emissions may have a net beneficial effect (i.e. carbon should be priced negatively), while even at the high end carbon emissions are very unlikely to be catastrophic. Given this range of possible 'damage functions,' combined with significant uncertainty concerning the costs of limiting emissions of [CO_2] and other [GHGs]—costs which may, among other things, slow down the rate at which poor countries develop, thereby making the inhabitants of those countries more susceptible to climate and other changes—the social cost of carbon should be set at zero."

"Global CCS Institute CSS Legal and Regulatory Indicator." The following is from the Executive Summary of this document: "The development of law and regulation to support the deployment of CCS has proven an important aspect of a national policy response to the technology. National regulators and regional legislatures in a number of jurisdictions globally have, in recent years, amended legislation or enacted legal and regulatory frameworks to address the technology. The Institute's CCS Legal and Regulatory Indicator ('the Indicator') offers a more detailed examination and assessment of national legal and regulatory frameworks, by considering a broad range of legal and regulatory factors, which are likely critical in the regulation of the technology. A broad spectrum of administrative and permitting arrangements across the project lifecycle, including issues related to environmental assessments, public consultation and long-term liability, have been considered. The resulting Indicator therefore represents a detailed assessment of each individual jurisdiction's legal and regulatory frameworks for the technology, as well as offering a comprehensive model for tracking progress and opportunities for the development of legal frameworks worldwide."

"Carbon Capture and Storage: The Lacq pilot – Project and injection period 2006-2013." The following is from the Introduction of this document: "This book presents the results of a pilot project implementing for the first time the complete CCS chain in an industrial environment. This pilot was designed, built and operated by Total for more than three years. The CCS pilot project entailed the conversion of an existing air-gas combustion boiler into an oxygen-gas combustion boiler, using oxygen delivered by an air separation unit (ASU) to obtain a more CO_2 concentrated (and easier to capture) flue gas stream. The 30 MWth oxy-boiler was able to deliver up to 38 t/h of steam to the high pressure (HP) steam network of the Lacq sour gas production and treatment plant. After quenching of the flue gas stream, the CO_2 stream was compressed (to 27 barg), dried and transported in a gaseous phase via existing pipelines to the Rousse depleted gas field, 29 kilometers away, where it was injected. Over the injection period of 39 months, 51,340 metric tons of CO_2 were injected. Total's main objectives in this experiment were: [1] To demonstrate the technical feasibility and reliability of an integrated chain comprising CO_2 capture, transportation and injection into a depleted gas reservoir; [2] To acquire operating experience and data to upscale the oxy-combustion technology from pilot (30 MWth) to industrial scale (200 MWth) while downscaling the 'oxy-combustion' capture cost compared to classical post capture technologies; [3] To develop and apply geological storage qualification methodologies, monitoring methodologies and technologies on site to serve in future onshore storage monitoring programs that will be larger in scale, longer in time and economically and technically viable; [4] To promote CCS knowledge sharing among a range of stakeholders, from governments, public institutions, industry, academia, non-governmental organizations, to the local communities and the broader public, through an outreach and communication program of activities including face-to-face meetings, workshops and technical meetings, site visits, informative videos, open days with site tours and press releases. This book shares the project's scientific results as well as the major achievements and lessons learnt."

"Prospects for CO_2-EOR in the UKCS." The following is from the Executive Summary of this document: "The UK's oil and gas industry has made a significant contribution to UK GDP over the last fifty years. However, the North Sea basin is mature and is expected to see major decommissioning over the next 10-15 years. Recovery of remaining oil reserves could be significantly improved by greater use of [EOR] techniques. One option involves injecting CO_2 into the oil reservoirs to [mobilize] the remaining oil (CO_2-EOR). It is a mature technology that has been used onshore in the USA for 40 years, where it has benefited from large natural sources of CO_2. It has the additional benefit of providing low-cost storage space for CO_2 emissions. An un-risked screening of technical EOR potential across the oil fields in the UK Continental Shelf (UKCS) identified a resource of up to 6 billion barrels of additional oil, with storage for [more than 1 billion metric tons] of CO_2. However, CO_2-EOR is untested at scale offshore, as yet, and therefore faces technical, commercial and economic risks. Less than a tenth of the un-risked potential is likely to be [realizable] when economic, commercial and operational risks are taken into account. Developing CO_2-EOR could extend the life of the oil fields for up to 15 years, delivering a range of benefits including additional taxable oil revenues, delaying of decommissioning and sustaining the wider UK oil industry. By providing secure, low-cost CO_2 storage, CO_2-EOR will benefit the development of CCS, which, in turn, will reduce the cost of achieving the UK's energy and carbon targets. Furthermore, developing the CO_2 transport infrastructure in the North Sea to supply CO_2-EOR could help open up the best and largest CO_2 storage assets in Europe. A new industry could be developed in the UK North Sea storing CO_2 and providing opportunities to manage emissions from [neighboring] EU member states."

"Methodology for Greenhouse Gas Emission Reductions from Carbon Capture and Storage Projects." The following is the Background and Applicability section of this document: "CCS is the separation and capture of CO_2 from the atmospheric emissions of industrial processes or the direct air capture (DAC) of atmospheric CO_2 and the transport and safe, permanent storage of the CO_2 in deep underground geologic formations. In CCS, CO_2 that would otherwise have been emitted into the atmosphere or that currently resides in the atmosphere is captured and disposed of underground. By preventing CO_2 from large-scale industrial facilities from entering the atmosphere or by removing the CO_2 that currently resides in the atmosphere, CCS is a powerful tool for addressing potential climate change. Geologic storage is defined as the placement of CO_2 into a subsurface formation so that it will remain safely and permanently stored. Examples of subsurface formations include deep saline [formations] and oil and gas producing reservoirs. The CO_2 for geologic storage comes either from industrial facilities that emit large amounts of CO_2, particularly those that burn coal, oil, or natural gas; or potentially directly from the atmosphere via large-scale chemical DAC facilities. Industrial facilities include power plants, petroleum refineries, oil and gas production facilities, iron and steel mills, cement plants, and various chemical plants. This methodology outlines the requirements and process for CCS Project Proponents that store CO_2 in oil and gas reservoirs to qualify their projects for carbon credits under the American Carbon Registry® (ACR) program. The methodology is based on the accounting framework developed by the Center for Climate and Energy Solutions (formerly the Pew Center on Global Climate Change)."

December 2015

"Leveling the Playing Field: Policy Parity for Carbon Capture and Storage Technologies." The following is from the Executive Summary of this document: "Federal energy and environmental policy has severely tilted the energy playing field. Secretary Moniz has requested the National Coal Council (NCC) make recommendations to level the playing field for CCS and provide 'policy parity.' Existing incentives for CCS are simply too small to 'bridge the chasm' – as the NCC put it earlier this year – between the cost and risk of promising but immature CCS technologies and other technology alternatives. While CCS is commercially deployed in some industrial sectors and technically demonstrated at electric power plants, power generation with CCS remains expensive today compared to other technologies such as natural gas combined cycle (NGCC) or heavily subsidized renewables. DOE has stewarded a successful research and development program to spur early development of CCS technologies, but without sufficient government support and incentives, commercial CCS deployment has lagged. Absent

commercial-scale deployment, developers have no history to understand technical risks, frequency and duration of down time, and other critical factors that become known only with operation. Today, the world's first and only operating commercial-scale power plant with CCS has successfully achieved a capture rate of 80 [percent] of the plant's CO_2, but has been unable to maintain that level of performance and has been operational just 40 [percent] of the time because of technical complications. With broad deployment, technological experience and confidence will rise, and costs will decline. Policy parity is essential to this progress. Coal and other fossil fuel use will keep rising globally as the world adds, per the United Nations, three billion more people to cities in the next 40 – 50 years. To achieve climate goals and address fossil emissions, the world must have CCS. Commercializing CCS requires a level playing field. Cross-functional experts within the NCC's working groups have rigorously assessed the incentives and policies needed to level the playing field. There is consensus among them that the recommendations in this report will bring needed advances to development and deployment of CCS technologies…"

"Power sector scenarios for the fifth carbon budget." The following is from the Executive Summary of this document: "This report sets out scenarios for the power sector in 2030 as an input to [the authors] advice on the fifth carbon budget, which [will be published] in November. The fifth carbon budget will set a limit on UK emissions of [GHGs] over the period 2028 to 2032. It marks the halfway point from the first carbon budget (2008-12) to the UK's statutory target for 2050 to reduce emissions by at least 80 [percent] across the economy relative to 1990, as set out in the Climate Change Act. [The authors] are publishing these scenarios ahead of [their] November advice given the importance of the power sector to meeting the economy-wide emissions targets. It has been a common finding of [the authors'] previous work that meeting the 2050 target will require that emissions from energy use – power, heat and transport – are almost eliminated. To achieve this it is important to have low-carbon sources of energy that are low cost, secure, acceptable to the public and attractive to investors. A [decarbonized] power sector can provide that low-carbon energy source. [The authors'] scenarios set out possible futures for the UK power sector. They are not intended to set out a prescriptive path. The scenarios provide a tool for the Committee to verify that its advice can be achieved with manageable impacts for the criteria in the Climate Change Act, including competitiveness, affordability and energy security. [The authors] welcome comments and input on this analysis."

"The Global Status of CCS: 2015 Summary Report." The following is a description of this document: "The Global Status of CCS: 2015 Summary Report provides an overview of the key findings contained in the package of Volumes and Reports that comprises The Global Status of CCS: 2015 release, as well as a set of actions that can accelerate the deployment of CCS globally."

"World Energy Outlook 2015." The following is a description of this document: "The precipitous fall in oil prices, continued geopolitical instability and the ongoing climate negotiations are witness to the dynamic nature of energy markets. In a time of so much uncertainty, understanding the implications of the shifting energy landscape for economic and environmental goals and for energy security is vital. The World Energy Outlook 2015 (WEO-2015) presents updated projections for the evolution of the global energy system to 2040, based on the latest data and market developments, as well as detailed insights on the prospects for fossil fuels, renewables, the power sector and energy efficiency and analysis on trends in CO_2 emissions and fossil-fuel and renewable energy subsidies."

"The CarbonNet Project: integrity of wells in the near-shore area Gippsland Basin Victoria." The following is the Abstract of this document: "The CarbonNet Project is investigating CO_2 storage sites in the nearshore area of the Gippsland Basin of Victoria, Australia. The project objective is to provide permanent and safe storage for 25 to 125 Mt of CO_2. The integrity of legacy or existing wells (which includes abandoned, production, injection, mineral/water bores and Measurement, Monitoring and Verification [MMV] wells) is [recognized] around the world as one of the most significant operational risks to CO_2 storage projects. The number of wells and quality of completions can vary significantly in different basins and jurisdictions. Furthermore, the drilling and completion requirements for onshore and offshore wells are subject to various regulatory, industry and operator standards and practices. The Gippsland

Basin has been an active oil and gas production province since the 1960's and there is a reasonable database of well data and parameters to assess well integrity. In the nearshore area of the Gippsland Basin, the integrity of fourteen wells has been assessed by CarbonNet and risks were identified. The assessment was based on existing documentation lodged with the regulator under Australia's comprehensive offshore petroleum legislation. The assessment concludes that the risk of [release] to surface from the fourteen legacy wells reviewed is very low. At an intraformational level, some wells are less securely completed and therefore appropriate mitigation measures are proposed – generally, to avoid intraformational storage concepts at these sites and locations. Ultimately for any CO_2 storage project, there is a requirement to demonstrate how to safely monitor legacy wells. In an Australian regulatory context, the requirement is to demonstrate they are not active [release] pathways and to outline plans for remediation of wells if they are shown to have problems. Options are discussed for completion and monitoring of future petroleum wells and other boreholes to avoid any new risks."

January 2016

"Carbon Capture and Storage – The vital role of CCS in an effective COP21 agreement." The following is a description of this document: "The report 'Carbon Capture and Storage – the vital role of CCS in an effective COP21 agreement' provides an overview of the road so far and calls for key policy initiatives to support the greater global deployment of CCS technology. Key [World Coal Association (WCA)] policy recommendations include: [1] Policy parity - CCS must receive the same policy support that has benefitted renewable technologies in recent decades. This is vital to facilitate the lowest cost pathway to [decarbonization]. [2] Governments must articulate how they plan to drive CCS deployment beyond the demonstration phase towards [commercialization]. [3] Solutions to reducing emissions will require global action, CCS deployment requires international incentives."

"Carbon Capture and Storage: A vital low carbon technology that can deliver on economic development, energy security, and climate goals." The following is from the Executive Summary of this document: "The global energy landscape is changing and policy makers have important choices to make. Energy markets are in transition with technology innovations tapping unconventional oil supplies, improving efficiency, and generating lower carbon electricity, but not at a rate fast enough to seriously address climate concerns. Energy investments are shifting from developed countries to emerging economies with rapid energy demand growth. Yet, reliance on fossil fuels continues. At present, around 80 [percent] of the world's primary energy and 65 [percent] of global electricity generation is supplied from fossil fuels and they are projected to dominate for decades. As part of a portfolio of low carbon emissions technologies, CCS, a vital technology that can address large-scale cuts in CO_2 emissions from fossil fuel power plants and industrial facilities, can deliver on climate goals and in many countries simultaneously meet energy security and sustainable economic development goals. Given these potential benefits, policy makers must take urgent action to accelerate commercial deployment and build on the successes of the past two decades."

"North Sea to the Rescue: The commercial and industrial opportunities of CO_2 storage in the North Sea." The following is from the Introduction of this document: "CCS delivers very substantial CO_2 reductions from large industrial and energy facilities. CCS is not a peripheral [decarbonization] technology. CCS is an indispensable component of national and global [decarbonization] pathways as [recognized] by the IPCC, the IEA, and the European Commission. The EU 2050 Energy Roadmap relies heavily on the deployment of CCS to meet EU wide [decarbonization] goals. CCS deployment provides a huge opportunity for Europe to meet its energy, climate and societal goals, in particular to achieve its GHG emissions reduction targets at lower cost while satisfying energy security. The North Sea has a critical role in the permanent storage of CO_2 from many of Europe's emitters. The North Sea has immense secure CO_2 storage capacity and indigenous offshore industries with the capability to develop and operate CO_2 storage complexes. The development and operation of transport and storage infrastructure has the potential to become a new industry for the North Sea, eclipsing declining hydrocarbon production. Countries that act now to remove commercial barriers and [incentivize] the

sectors development will foster highly skilled employment attract industrial activity and enable the development of technology and service sectors. Using estimates of the CO_2 required to be stored in the North Sea for Europe to reach its 2050 [decarbonization] objectives, Bellona has estimated the size of the future North Sea CO_2 storage sector. [Carbon dioxide] storage will require the characterization of storage sites, the drilling of appraisal and injection wells, the emplacement of CO_2 platforms, along with engineering, fabrication and logistics. [Carbon dioxide] storage requires many of the same skills and infrastructure now underemployed or to be decommissioned. The CO_2 storage sector has the potential to become a major North Sea enterprise, employing 22,000 people by 2030. Countries surrounding the North Sea basin must act to encourage the sectors development and to enable Europe to [decarbonize] effectively."

February 2016

"No-Impact Threshold Values for Groundwater Reduced-Order Models." The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP; an initiative within DOE/NETL) document: "The purpose of this study was to examine methodologies for establishing baseline data sets and statistical protocols for determining statistically significant changes between background concentrations and predicted concentrations that would be used to represent a contamination plume from geologic storage of CO_2 in the second-generation hydrologic models being developed by the National Risk Assessment Partnership's (NRAP) Groundwater Protection Working Group. This could then be used to help quantitatively evaluate the impact of [releasing] fluids on a groundwater system. The initial effort examined selected portions of two [formation] systems: the urban shallow-unconfined [formation] system of the Edwards-Trinity [Formation] System (being used to develop the reduced-order model for carbonate-rock [formations]), and a portion of the High Plains [Formation] (an unconsolidated and semi-consolidated sand and gravel [formation] being used to develop the reduced-order model for sandstone [formations]). No-impact threshold values were determined for cadmium, lead, arsenic, pH, and total dissolved solids that could be used to identify potential areas of contamination in overlying [formations] predicted by numerical models of [CO_2] storage reservoirs. No-impact threshold values were later determined for chromium specifically to support the reduced-order model being developed by Lawrence Livermore National Laboratory (LLNL) for the High Plains [Formation]. These threshold values are based on an interwell approach for determining background groundwater concentrations as recommended in the U.S. Environmental Protection Agency's Unified Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities…"

"Roadmap for carbon capture and storage demonstration and deployment in the People's Republic of China." The following is from the Introduction of this Global CCS Institute document: "Carbon dioxide (CO_2) emissions from fossil fuel combustion account for the largest share of [GHG] emissions by far. In the People's Republic of China (PRC), CO_2 emissions have risen in tandem with its rapid economic growth for the past three decades due to its carbon-intensive coal dominated energy mix. Accelerated efforts to reign in growing CO_2 emissions in the PRC, the world's largest energy consumer and largest emitter of CO_2, are of paramount importance to global climate change mitigation efforts. Consistent with its aim to peak out CO_2 emissions by 2030, the Government of the PRC is implementing strong measures to transform its energy to a lowcarbon mix. But coal is expected to remain a pillar of its energy security even in the long-term, with a large share in the energy mix. As a result, for the PRC to move from its current CO_2 emission reduction trajectory to a more ambitious one, CO_2 abatement from coal-based industrial production and power generation is crucial. CCS is the only currently available technology that can cut up to 90 [percent] of CO_2 emissions from coal-fired power plants and industries. Many studies have highlighted CCS as an essential part of a portfolio of technologies that are required to achieve cost-effective long-term CO_2 mitigation. Yet, many perceived and real risks and barriers are delaying CCS demonstration and deployment, risking the attainment of CO_2 mitigation objectives…"

"Scottish CO_2 Hub – A unique opportunity for the United Kingdom." The following is from this Scottish Carbon Capture & Storage (SCCS) document: "The unique importance of a Scottish CO_2 Hub is

as the 'downstream' component of a Europe-wide CO_2 capture, transport and storage system, complementing the 'upstream' collection and dispatch hubs envisaged for mainland Europe, Scandinavia and England by providing access to low risk, high capacity and cost-effective CO_2 storage. This can be achieved economically and rapidly by re-use of existing on- and offshore transport and storage infrastructure to reduce costs, and potentially through value generation from CO_2 [utilization] in CO_2-EOR. A flexible shipping solution can transport CO_2 from eastern England and Europe with low initial capital investment and allow sequential, project-by-project expansion of the system. A CO_2 capture cluster in central and eastern Scotland involving both power and industrial emitters can be established using existing transport and storage infrastructure allowing rapid deployment of the whole-chain CCS system for sequential expansion as import volumes from European and other UK CO_2 hubs become available. Although small by European standards, this capture cluster would be significant for Scottish emissions, realistically able to halve Scottish industrial emissions and reduce total Scottish emissions from all sources by c.20 [percent]."

March 2016

"A User's Guide to DFNGen." The following is the Executive Summary of this NRAP document (NRAP is an initiative within DOE's National Energy Technology Laboratory [NETL]): "This report is the user manual for the initial release of the computer code [Discrete Fracture Network Generator Interface (DFNGen)]. DFNGen is a graphical user interface for the computer code FracGen and several supplementary ('ancillary') programs developed at NETL in Morgantown, West Virginia. The intent of DFNGen is to facilitate use of FracGen, to increase the understanding of FracGen's input options and to reduce errors in input. DFNGen is a Windows-based interface, which allows for the generation and control of input files using specially-created forms (windows). DFNGen runs FracGen as a background process and can analyze the resulting output using a range of options. The code also allows the import of input files from prior versions of FracGen. The analysis options in DFNGen allow the user to examine fracture length, fracture orientation, scanline spacing, and the spatial distribution of fracture center points. DFNGen implements a special version of FracGen, termed version 14M (i.e., FracGen version 2014, modified for current application), which has a revised input format. FracGen 14M, as with other versions of FracGen, incorporates three fracture "models" (Model1, Model2, Model3) to simulate randomly located fractures, randomly-located swarms or clusters of fractures and regularly-distributed cluster zones. Another option (termed Model0) permits the input of fracture data collected along boreholes, cores or outcrop scans by the user. Of importance for flow modeling, the generated fractures of the network can be subsequently adjusted for varying connectivity by several approaches, including synthetic annealing, to facilitate flow modeling with a network with a sparse number of fractures. This user guide provides an essential, but directed summary of DFNGen operation. For more details on FracGen, NFflow, or the ancillary codes, the user is referred to the user guide for these codes."

"*Key Factors for Assessing Potential Groundwater Impacts Due to [Release] from Geologic Carbon [Storage] Reservoirs*." The following is from the Executive Summary of this NRAP document: "NRAP is developing a science-based toolset for the analysis of potential impacts to groundwater chemistry from CO_2 injection should [release] from a deep storage reservoir occur. The toolset adopts a stochastic approach in which predictions address uncertainties in shallow groundwater and [release] scenarios. It is derived from detailed physics and chemistry simulation results that are used to train more computationally efficient models, referred to here as reduced-order models (ROMs), for each component system. In particular, these tools can be used to help regulators and operators understand the expected sizes and longevity of plumes in pH, [total dissolved solids (TDS)], and dissolved metals that could result from a [release] of brine and/or CO_2 from a storage reservoir into [formations]. This information can inform, for example, decisions on monitoring strategies that are both effective and efficient. This approach was used to develop predictive ROM for two common types of [formations], but the approach could be used to develop a model for a specific [formation] and/or other common types of [formations]."

"Coupled Inversion of Hydrological and Geophysical Data for Improved Prediction of Subsurface CO_2 Migration." The following is from the Executive Summary of this NRAP document: "This report is one of two deliverables resulting from a Lawrence Berkeley National Laboratory (LBNL) NRAP project that aimed at developing, testing, and applying novel methods for modeling geologic storage of CO_2 and jointly inverting monitoring data for [release] detection. This first NRAP report summarizes the method for jointly inverting hydrological and geophysical monitoring data. The ability to identify potential [release] pathways with monitoring data and continually monitor localized [release] of CO_2 and/or brine is essential for the science-based quantitative risk assessment at the core of the mission of NRAP. The second NRAP report describes the development, demonstration, and application of an inversion-based methodology for early [release] detection using pressure and surface deformation monitoring data."

"Future of carbon capture and storage in the UK." The following is from the Summary of this UK Energy and Climate Change Committee document: "Meeting the UK's climate change commitments will be challenging if [CCS is not applied] to new gas-fired power stations and to energy intensive industries. Building the transport and storage infrastructure needed for CCS requires large upfront investments, but costs of later projects are expected to fall rapidly once this primary infrastructure is in place. Without CCS it may be necessary to find large and potentially more expensive carbon savings to meet the legally binding targets set out in the Climate Change Act as well as the more recent challenging ambitions set out at the Paris climate summit."

April 2016

"NETL's ARRA Site Characterization Initiative: Accomplishments." The following is from the Executive Summary of this NETL document: "NETL's Storage Program received approximately $100 million from the American Recovery and Reinvestment Act of 2009 (ARRA). These funds were distributed among nine projects with a focus on characterizing high-priority formations that have potential for future commercial-scale geologic CO_2 storage. The formations studied are representative of different depositional environments and geologic settings that have significant potential for carbon storage. The projects targeted not only the development of individual sites for carbon storage, but also the regional characterization of distinct high-potential geologic formations. Characterizing these formations provides greater insight into the capabilities of similar geologic formations across the United States to safely and permanently store CO_2. Knowledge gained from these efforts may be applied to similar settings with potential for carbon storage and, thus, contribute valuable information for future commercial-scale carbon storage projects within the study areas. In addition, baseline subsurface conditions must be characterized and subsurface response to injection of large quantities of CO_2 must be assessed as part of the U.S. Environmental Protection Agency's (EPA) Underground Injection Control (UIC) Class VI regulatory framework. Class VI permits are required prior to any CO_2 injection in the United States that is part of a carbon storage project. These characterization data contribute to the development of best practices for safe, long-term storage of CO_2."

"Parameter Sensitivity Analysis with the Seismicity Simulation Program RSQSim." The following is the Abstract of this NRAP document (NRAP is an initiative within DOE/NETL): "Earthquake simulations performed using the program RSQSim as part of the NRAP probabilistic seismic risk analyses depend on several parameters that are subject to degrees of uncertainty. In the current study, the sensitivity of simulation outputs to uncertainty in key RSQSim input parameters was analyzed using the Lawrence Livermore National Laboratory (LLNL) code PSUADE (Computer Code of Problem Solving Environment for Uncertainty Analysis and Design Exploration). A total sensitivity analysis was first performed to rank the parameters in terms of sensitivity, and then a detailed individual sensitivity analyses of the top-ranked parameters was conducted. The metric used to assess sensitivity is the Gutenberg-Richter b-value."

"Induced Seismicity and Carbon Storage: Risk Assessment and Mitigation Strategies." The following is the Abstract of this NRAP document (NRAP is an initiative within DOE/NETL): "Geologic carbon storage (GCS) is widely recognized as an important strategy to reduce atmospheric CO_2

emissions. Like all technologies, however, [storage] projects create a number of potential environmental and safety hazards that must be addressed. These include earthquakes—from microseismicity to large, damaging events—that can be triggered by altering pore-pressure conditions in the subsurface. To date, measured seismicity due to CO_2 injection has been limited to a few modest events, but the hazard exists and must be considered. There are important similarities between CO_2 injection and fluid injection from other applications that have induced significant events—e.g. geothermal systems, waste-fluid injection, hydrocarbon extraction, and others. There are also important distinctions among these technologies that should be considered in a discussion of seismic hazard. This report focuses on strategies for assessing and mitigating risk during each phase of a CO_2 storage project. Four key risks related to fault reactivation and induced seismicity were considered. Induced slip on faults could potentially lead to: (1) infrastructure damage, (2) a public nuisance, (3) brine-contaminated drinking water, and (4) CO_2-contaminated drinking water. These scenarios lead to different types of damage—to property, to drinking water quality, or to the public welfare. Given these four risks, this report focuses on strategies for assessing (and altering) their likelihoods of occurrence and the damage that may result…"

"Global storage portfolio: a global assessment of the geological CO_2 storage resource potential." The following is a summary of this document: "The primary purpose of the Institute's Global Storage Portfolio is to collate and [summarize] published regional assessments of key nations. The Portfolio also [summarizes] key data on a nation's readiness to host a commercial, large-scale project. For this reason, only proven storage scenarios including deep saline formations (DSF), depleted/depleting oil and gas fields (DGOF) and enhanced oil recovery using CO_2 (CO_2-EOR) are considered. The analysis has found that: [1] Substantial storage resources are present in most key regions of the world. [2] Reliable methodologies to determine and classify regional storage resources are available and have been widely applied, although there is no formally [recognized] international standard. [3] The level of resource assessment undertaken and the availability of [characterization] data is highly variable across regions. [4] The level of detail a regional resource assessment has progressed as well as the policy, legal and regulatory frameworks are key criteria that can be used to gauge the readiness of any given nation to deploy a CCS project. The storage resources are grouped into five regions: [(1) Asia-Pacific (fourteen countries); (2) Americas (five countries); (3) Middle East (three countries); (4) Europe and Russia (EU plus three countries); and (5) Africa (four countries)]. The resulting portfolio will enable the reader to rapidly establish a snapshot of a country's storage resource and potential to deploy a large-scale project."

May 2016

"Modeling the Impact of Carbon Dioxide [Release] into an Unconfined, Oxidizing Carbonate [Formation]." The following is the Abstract of this Pacific Northwest National Laboratory (PNNL) document: "Multiphase, reactive transport modeling was used to identify the mechanisms controlling trace metal release under elevated CO_2 conditions from a well-characterized carbonate [formation]. Modeling was conducted for two experimental scenarios: batch experiments to simulate sudden, fast, and short-lived release of CO_2 as would occur in the case of well failure during injection, and column experiments to simulate more gradual [releases] such as those occurring along undetected faults, fractures, or well linings. Observed and predicted trace metal concentrations are compared to groundwater concentrations from this [formation] to determine the potential for [releasing] CO_2 to adversely impact drinking water quality. Finally, a three-dimensional multiphase flow and reactive-transport simulation of CO_2 [release] from an abandoned wellbore into a generalized model of the shallow, unconfined portion of the [formation] is used to determine potential impacts on groundwater quality. As a measure of adverse impacts on groundwater quality, both the EPA's MCL limits and the maximum trace metal concentration observed in the [formation] were used as threshold values."

"Analysis Of Options For Funding Large Pilot Scale Testing Of Advanced Fossil-Based Power Generation Technologies With Carbon Capture And Storage." The following is a description of this document: "[The Coal Utilization Research Council (CURC)] and Japan's New Energy and Industrial

Technology Development Organization (NEDO) released a study titled Analysis of Options for Funding Large Pilot Scale Testing of Advanced Fossil-Based Power Generation Technologies with Carbon Capture. The paper is the product of an effort led by CURC pursuant to a contract with NEDO of Japan and as a component of the continuing collaboration between NEDO and [DOE]. Other participants to the study include Natural Resources Canada and the Korean Institute of Energy Research of the Republic of Korea."

"Carbon Capturing & Storage Technology Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2014 – 2020." The following is from a description of this document: "Governmental agencies of developed economies are accelerating their drive to combat climatic changes, specifically focusing on the power sector as it is a major source of CO_2 emissions. [CCS] technology might play an essential role in establishing the emission reduction targets set by different countries. This technology is designed to capture the [CO_2] emissions which are primarily produced from the use of fossil fuels in industrial process and electricity generation. The captured [CO_2] can then be transported by ships and pipelines for safe storage enclosures. The stored [CO_2] can also be utilized for several commercial purposes such as [EOR] techniques. The [CCS] technology is still in the stages of development and the European Union has planned to implement this technology in large scale in 2015. Though this method has been technologically proven to work, it is not yet commercially viable on a large scale in several circumstances. The market for [CCS] technology is expected to grow at a considerable rate in future years owing to increasing investment in emission reduction technologies."

June 2016

"Annual Energy Outlook 2016 Early Release: Annotated Summary of Two Cases." The following is a description of this U.S. Energy Information Administration (EIS) document: "The Annual Energy Outlook 2016 (AEO2016) Early Release features two cases: the Reference case and a case excluding implementation of the Clean Power Plan (CPP). [1] Reference case: A business-as-usual trend estimate, given known technology and technological and demographic trends. The Reference case assumes CPP compliance through mass-based standards that establish caps on CO_2 emissions from fossil-fired generators covered by the CPP. The mass-based standards are modeled using allowances with cooperation across states at the regional level, with all allowance revenues rebated to ratepayers. [2] No CPP case: A business-as-usual trend estimate, but assumes that CPP is not implemented."

"Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource." The following is from the Executive Summary of this ETI document: "CCS is widely recognized as a critical technology to meet the 1.5/2°C ambitions agreed at the Paris COP 21 meeting. Much progress is being made on carbon capture technologies, with mature industrial scale projects having been in operation for many years. Whilst the use of CO_2 for [EOR] is commonplace in some parts of the North America, CO_2 storage at industrial scale has only been demonstrated at a small number of sites around the world. Two of these sites are located offshore in the Norwegian sector of the North Sea at Sleipner and Snøhvit, with Sleipner reaching a key milestone in 2016 of 20 years of offshore CO_2 storage operations. The UK is fortunate to have completed three large [front-end engineering design (FEED)] study projects for offshore CO_2 storage, all of which are already or will be placed in the public domain. These were for storage sites called Hewett, Goldeneye and Endurance. Enabling CCS in the UK requires the rapid assembly of mature plans for further offshore CO_2 storage sites around the UK Continental Shelf (UKCS). Collectively, these plans will contribute towards supporting investor confidence around large energy and industrial CCS systems by assuring the presence, location and cost base of high quality offshore CO_2 storage site development options. This will support the early industrial [mobilization] of full chain CCS technology."

"Can technology unlock unburnable carbon?" The following is a description of this white paper: "To stay within the 2°C carbon budget, a very significant reduction in fossil fuel consumption is required. [If the carbon budget is to be met,] the majority of global fossil fuel reserves cannot be combusted: the

unburnable carbon. The role of technologies such as CCS may be critical in enabling a greater quantity of fossil fuel to be combusted within a low-carbon framework. However, the potential for CCS to alleviate the carbon constraint is still controversial and uncertain, with a number of studies reaching different conclusions. This extensive review paper will assess the current state of knowledge regarding the 'unburnable carbon' issue, and attempt to provide clarity by quantitatively defining the potential role of CCS in unlocking the unburnable carbon over the next 85 years."

July 2016

"Clean Energy Resource Options for Massachusetts to Meet GHG Reduction Goals under the Global Warming Solutions Act (GWSA)." The following is the Introduction of this white paper: "The long-term energy policy of the Commonwealth of Massachusetts has been hotly debated for the past few years. During the current legislative session, Massachusetts policymakers will be deciding how the Commonwealth will enact policies to guide the development of clean energy resources to meet the near-term and long-term GHG emissions reductions of the 2008 Global Warming Solutions Act ('GWSA') while providing reliable electricity at a reasonable cost. The purpose of this paper is to inform the Massachusetts policy makers of the resource options and the key policy considerations."

"Energy Technology Perspectives 2016." The following is the Executive Summary of this International Energy Agency (IEA) document: "The agreement reached at the 21st Conference of the Parties (COP21) in Paris could prove to be a historic turning point for reversing the currently unsustainable trends in the global energy system, provided that this heightened low-carbon ambition is translated into fast, radical and effective policy action. Even in the context of low fossil fuel prices, policy support for low-carbon technologies should [mobilize] all levers available to accelerate research, development, demonstration and deployment (RDD&D) to make decarbonisation the preferred development path. Chief among such levers is governments' support for urban energy transitions, a conclusion that is supported by the analysis of Energy Technology Perspectives 2016 (ETP 2016), which shows the vast number and size of cost-effective, sustainable energy opportunities available in cities. [Realizing] this potential, and the multiple non-climate benefits it presents, will require national and local governments to work together effectively."

"Tees Valley: Opportunity Unlimited." The following is a description of this Independent Report from the UK Department for Communities and Local Government: "This is Lord Heseltine's independent review of the Tees Valley following a range of discussions with local private and [public] sector leaders and businesses to identify opportunities to unlock, promote and support economic growth. Building on the momentum provided by the Tees Valley devolution deal and the new Combined Authority, the report makes recommendations to further develop the Tees Valley area with the emphasis on creating the conditions for a sustainable prosperous future. Lord Heseltine worked closely with local leaders to bring forward the creation of the new South Tees Development Corporation, which will set the future vision for the SSI site and surrounding area. This will be the first Mayoral Development Corporation outside of London."

"Achieving a low-carbon society: CCS expertise and opportunity in the UK." The following is a description of this Scottish Carbon Capture and Storage (SCCS) document: "This report, published on 23 March 2016, derives from the SCCS 2015 Conference, which brought together policymakers, industry, academia and representatives from Scottish, UK and European governments. It presents the UK's unique set of assets and opportunities that can create a viable route to a zero-carbon economy. These include: [1] Retaining skilled jobs and creating new industries at clusters of industrial emitters around the UK coastline, with plans already developed for shared-cost CCS 'hubs' [2] A globally significant and exceptional North Sea geological asset for CO_2 storage [3] An oil and gas workforce that routinely delivers high-quality infrastructure and could build a new offshore CCS industry serving the UK and Europe [4] An enviable [R&D] community with its amassed knowledge and strategic international collaborations [5] Large-scale CCS projects poised to [decarbonize] industry and power generation."

"Lessons Learned – Lessons and Evidence Derived from the UK CCS [Program], 2008 – 2015." The following is from the Executive Summary of this Carbon Capture and Storage Association (CCSA) document: "Following the decision of the UK Government (HMG) to cancel the UK CCS [Commercialization Program] in November 2015, it became clear that there was a need to identify and collate the key lessons learned by those who have sought to develop CCS. It is hoped that making these lessons available will help to inform the future development and deployment of CCS in the UK… Interviews were conducted with CCS project developers and a selection of other CCS stakeholders between January and April 2016. Views were sought on the recent UK CCS [Commercialization Program] (2012 – 2015); and more generally around experiences with developing CCS projects in the UK and Europe over the last decade. This exercise was evidence-based. The document identifies 36 key lessons based on evidence provided by participants. This document aims to avoid advocacy, and does not provide any specific recommendations; however readers should be able to draw a number of important conclusions from the evidence."

August 2016

"Carbon Dioxide Incubator Market - Global Trends, Market Share, Industry Size, Growth, Opportunities, and Market Forecast - 2015 – 2022." The following is a description of this document: "Research Corridor recently added new report titled 'Carbon Dioxide Incubator Market - Global Trends, Market Share, Industry Size, Growth, Opportunities, and Market Forecast - 2015 – 2022' to its repertoire. This latest industry research study scrutinizes the Carbon Dioxide Incubator market by different segments, companies, regions and countries over the forecast period 2015 to 2022. The report titled 'Carbon Dioxide Incubator Market - Global Trends, Market Share, Industry Size, Growth, Opportunities, and Market Forecast - 2015 – 2022' offers a primary overview of the Carbon Dioxide Incubator industry covering different product definitions, classifications, and participants in the industry chain structure. The quantitative and qualitative analysis is provided for the global Carbon Dioxide Incubator market considering competitive landscape, development trends, and key critical success factors (CSFs) prevailing in the Carbon Dioxide Incubator industry."

"Developing the Public Engagement Strategy for the Guangdong CCUS Demonstration Program." The following is from the Introduction of this document: "The China Resources Power (Haifeng) and China National Offshore Oil Corporation (CNOOC) Integrated Carbon Capture and Sequestration Demonstration Project (CRP Power Project) and the UK-China (Guangdong) CCUS Centre are committed to understanding and implementing CCS public engagement best practice throughout the lifecycle of the CRP Power Project as well as sharing the experience with the wider CCS community. This report presents an analysis of work undertaken by the CRP Power Project and the UK-China (Guangdong) CCUS Centre which will help guide the project's future work program. It may also be useful to other CCS project proponents in China who are considering the development of a public engagement strategy. This undertaking is the first of its kind in China and is an ongoing process. To date, the majority of CCS public engagement project case studies have [analyzed] activity that has taken place in Europe, North America and Australia. An important next step is to reflect on how current best practice may apply in other regional contexts. The UK-China (Guangdong) CCUS Centre is actively investigating this topic and this report seeks to capture the processes and analysis that have occurred so far."

"Approaches to Address Potential CO_2 Emissions [Release] to New Sources under the Clean Power Plan." The following is from the Introduction and Summary of this document: "To guide state implementation of the Clean Power Plan, [the U.S. Environmental Protection Agency (EPA)] has proposed a model rule for states that regulates only existing affected generating units on a mass basis. The model rule also is expected to form the basis for a [Federal] plan. The model rule, when finalized, would be presumptively approvable for states. [The authors'] comments are presented as 10 recommendations that are organized in three groups: [(1) Allowance Allocation; (2) Requirements for State Compliance Plans; and (3) EPA Implementation of the Clean Power Plan. The authors'] summarize

the recommendations in this introduction. [The authors'] comments focus on the emissions outcome that can be achieved under the mass-based proposed model rule and the cost of achieving those emissions reductions. A state's choosing an emissions cap that covers only existing sources raises generation costs relative to costs of new sources that are excluded from the cap. This may cause generation to shift from existing to new sources with an associated increase in emissions outside the emissions cap. This emissions [release] can be reduced by lowering the costs for existing sources so they are more competitive with new sources. Greater utilization of existing sources will reduce the use of new sources and help reduce [release]."

"Effective enforcement of underground storage of carbon dioxide." The following is from the Executive Summary of this Global CCS Institute Document: "The perception of an effective enforcement regime that ensures the secure and safe storage of CO_2 in underground geologic formations will be crucial in increasing public and industry confidence in CCS as a viable low-carbon technology. An effective enforcement regime for underground storage of CO_2 has the following key features: [1] comprehensive obligations that address the key risks of underground storage of CO_2; [2] comprehensive monitoring and verification (M&V) requirements, including baseline monitoring, M&V obligations during the injection phase and M&V obligations post-injection; [3] enforcement mechanisms that are risk-based, layered and flexible, grounded in science and fact-based decision-making, and include the ability to deal with 'serious situations' (such as unintended releases and CO_2 not behaving as predicted); and [4] a clear allocation of roles and responsibilities for enforcement."

September 2016

"CCS Forum Report." The following is from the Executive Summary of this document: "The three-day CCS Forum, held in London, hosted delegates from academia, industry, and government to discuss the future of CCS and, in particular, to identify the key research challenges to be addressed in the near-to-medium term. In all sectors pertaining to CCS, it was agreed that translating major research findings to the market often takes many years and that developing a systematic procedure for the acceleration of the transition of academic research to pilot- and demonstration-scales is essential. Over the course of the three days, the applications of CO_2 capture technologies to the power and industrial sectors were discussed in detail, as was the subsequent geological storage of the CO_2. In addition to the [utilization] of the CO_2 in enhanced hydrocarbon recovery, the mineral carbonation of industrial wastes and also the potential for the further conversion of CO_2 into chemicals was discussed. Furthermore, the role of policy measures to enable the deployment of CO_2 to the power and industry sectors was discussed. The critical needs identified have been summarized in the Executive Summary and the detailed insights are included in each section throughout the remainder of the document."

"Carbon Capture and Storage (CCS) Market Analysis: By Technology (Post Combustion, Pre Combustion, Oxy Fuel Technology); By Storage (Geological, Ocean and Mineral); By End User (Chemical, Fertilizer, Iron and Steel, Oil & Gas) – Forecast (2016 – 2021)." The following is a description of this report: "CCS technology has emerged as critical technical component in the combined efforts of various nations to combat climate change. [CCS] refers to the capturing of [CO_2] from different sources of emission, separating it from other gases and transporting to a suitable location for storage. Considering the cumulative commitment of disparate industrial stakeholders in curbing CO_2 emissions coupled with ongoing dominant role of fossil fuels in energy generation, the [CCS] technology is being adopted and employed across the globe. The report explains that global [CCS] market is segmented on the basis of type of capture technology, storage technology and geography. Based on capture technology, market is classified into: [Post Combustion Capture, Pre Combustion Capture, Oxy Fuel Technology and Others.] Also, based on the storage methods, the market has been categorized into: [Geological Storage, Mineral Storage, Ocean Storage and Others. CCS] technology finds its applications into a variety of end user industries which include: [Chemical Production, Fertilizer Production, Iron and Steel, Oil & Gas, Power generation and Others.] Each of these segments is further broken down to give an in-depth analysis of the market. The [CCS] market report analyses the applications in disparate end

user industries coupled with market demand from across the regions. The growth in [CCS] market is driven from Non Organization for Economic Corporation and Development (OECD) countries with a strong economic growth and industrialization. The increase of energy consumption is projected from renewable energy and nuclear power, presently contributing 2.5 [percent] growth to the market per year. Policies and regulations governing usage of fossil fuels and [CO_2] emissions fuel are set to increase the market growth. The increase in usage of biofuels resulted in the increase of energy consumption."

"A need unsatisfied: Blueprint for enabling investment in CO_2 storage." The following is the Executive Summary of this Deloitte LLP document: "The Crown Estate commissioned Deloitte LLP to project manage and participate in a collaborative study that investigated the risks of offshore CO_2 storage development and identified potential commercial models for public and private investment in CO_2 transport and offshore storage infrastructure. Storage rights on the UK continental shelf are owned by The Crown Estate… The conclusions and recommendation in this report are intended to: move forward discussion between policy makers and industry participants form full-chain CCS projects [and] provide a suitable framework that enable CO_2 storage projects to be developed and which can serve the needs of both power stations and industrial emitters."

Legislative

September 2015

"Carbon Tax Bill Introduced Into Assembly." A bill that would tax carbon emissions in New York State was entered into the Assembly. The carbon tax bill would implement a tax starting at $40 per metric ton of CO_2, increasing in $10 annual increments up to $180 per metric ton. In addition, the bill proposed to refund approximately 60 percent of its revenue to lower-income classes; the remaining 40 percent would be utilized to support the transition to clean energy within the state. From *PR Newswire* on August 28, 2015.

October 2015

"[Senators] Offer Pathway to a Cleaner Energy Future and Economy." A group of Senators released a national energy bill, the American Energy Innovation Act of 2015, that addresses the creation of new jobs, updated infrastructure, and technological innovation through programs in the energy sector that modernize infrastructure, reduce CO_2 emissions, invest in clean energy, and support research and development (R&D). Specifically, the bill includes provisions such as: reducing GHG emissions and securing CO_2 reduction targets from other countries; investing in energy storage; implementing recommendations from DOE's Quadrennial Energy Review; and investing in clean energy technologies. For more information, view the bill text and the bill summary. From *U.S. Senate Committee on Energy & Natural Resources* on September 22, 2015.

November 2015

"South Africa Consults On Carbon Tax Legislation." South Africa's National Treasury has published draft carbon tax legislation for public comment. The South African government has committed to reduce its GHG emissions below current levels by 34 percent by 2020, and by 42 percent by 2025. The carbon offsets are expected to enable firms to cost-effectively lower their carbon tax liability while incentivizing investment in GHG emission-reduction projects. From *Tax-News* on November 5, 2015.

December 2015

"[Senators] Introduce Bill to Help Finance Carbon Capture and Storage Projects." The Carbon Capture Improvement Act of 2015 was introduced to help power plants and industrial facilities finance the purchase of CCS equipment by allowing businesses to use tax-exempt private activity bonds (PABs) to finance the upfront capital costs associated with installation of the equipment. In addition to making CCS projects more economically feasible through the use of PABs, the bill will also look to boost oil production through EOR operations. From *U.S. Senator Rob Portman Press Release* on November 19, 2015.

"[Irish] Government to Introduce Legislation to Combat Climate Change – Taoiseach." The Irish government announced it will introduce legislation to combat potential climate change. According to government officials, the climate bill would set out plans in four areas (agriculture, energy, buildings, and transport), as well as increase financial contributions to developing nations. From *independent.ie* on November 30, 2015.

"Russia Lays Foundations for Carbon Regulation…" Russia's Ministry of Natural Resources and Environment has published a draft law that introduces a baseline for controlling CO_2 emissions by creating a legal definition of GHGs and setting rules on how to measure, regulate, and report CO_2 emissions. From *Reuters* on November 5, 2015.

"The political economy of passing climate change legislation: Evidence from a survey." The following is from the Abstract of this article: "Climate change is now a major aspect of public policy. There are almost 500 identified climate change laws in the world's leading economies. This paper reviews the main domestic factors that drive this legislation. The analysis is based on a unique dataset of climate legislation in 66 national jurisdictions for the period 1990–2013. [The authors] find that the passage of new climate laws is influenced by several factors. One important factor is the quantity and quality of previous legislation: the propensity to pass more laws decreases non-linearly with the stock of existing legislation, but increases in the presence of a strategic 'flagship law' that sets an overall framework for climate policy. Contrary to widespread belief, political orientation is not a decisive factor…" **Sam Fankhauser, Caterina Gennaioli, and Murray Collins**, *Global Environmental Change*. (Subscription may be required.)

January 2016

"[California Announces Climate Legislation at COP21]." At the 21st Conference of Parties (COP21) meeting in Paris, France, the California delegation announced a climate change proposal that will set targets to achieve, among other targets, a 50 percent reduction in black carbon emissions in the state of California by 2030. The "Short-Lived Climate Pollutant Reduction Act of 2016" will require the California Air Resources Board (CARB) to approve and implement, by January 1, 2018, a strategy to reduce statewide emissions of short-lived climate pollutants to achieve a reduction in emissions of methane by 40 percent, F-gases by 40 percent, and black carbon by 50 percent below 2013 levels by the year 2030. The legislation is expected to be formally introduced in early 2016. From *U.S. Senator Ricardo Lara Press Release* on December 8, 2015.

February 2016

"[CO_2 Capture Technology Amendment Included in Energy Bill]." The U.S. Senate passed the clean air technology amendment (S.A. 3017) to the Energy Policy Modernization Act. The program, established by a Federal commission under DOE, will award public and private entities that design technology to remove CO_2 from the atmosphere and permanently store CO_2. Once the technology is developed, the intellectual property rights would be shared by the United States and the inventor. From *U.S. Senator John Barrasso News Release* on January 28, 2016.

"Climate Change Package Passes Massachusetts Senate." The Massachusetts State Senate passed legislation requiring the state to develop a climate change mitigation plan and to meet long-term carbon emissions reduction benchmarks. The bill, S. 2092, would set new targets between the goal of reducing Massachusetts' emissions 25 percent below 1990 levels by 2020, and reducing it to 80 percent below 1990 levels in 2050. In addition, the bill, which was sent to the Massachusetts House for consideration, would establish benchmarks of 35 to 40 percent below 1990 levels in 2030, and 55 to 65 percent below 1990 levels in 2040. From *NewBostonPost* on January 28, 2016.

March 2016

"[Carbon Capture Bill Introduced]." A group of lawmakers proposed a bill supporting deployment of carbon capture equipment at coal facilities for EOR. The measure would make permanent the existing CCS incentive (known as the 45Q tax credit), which is set to expire once reaching 75 million tons of CO_2. Under the proposal, the credit value for CO_2 storage through EOR or other types of geologic storage would be gradually increased from $10 and $20 per ton, respectively, to $30 per ton by 2025. From *Utility Dive* on February 26, 2016.

April 2016

"[Maryland Governor Signs Bills to Reduce GHG Emissions]." The Governor of Maryland signed an environmental bill that reauthorizes and sets new targets for the Greenhouse Gas Reduction Act, which was originally passed in 2009 and required Maryland to reduce GHG emissions to 25 percent below 2006 levels by 2020. The new target aims for a GHG emissions reduction to 40 percent below 2006 levels by 2030. More information is available via the Governor's press release. From *The Washington Post* on April 4, 2016.

May 2016

"[U.S.] Senate OKs Bill to Promote Wide Variety of Energy Sources." The U.S. Senate approved a wide-ranging energy bill that encourages clean coal technology, including coal-fired power plant carbon capture projects, and a variety of energy sources (e.g., solar, wind, natural gas, hydropower, geothermal). The measure would cost approximately $32 billion over five years. From *The Pittsburgh Post-Gazette* on April 20, 2016.

June 2016

"Ontario Passes Landmark Climate Change Legislation." The government of Ontario passed the Climate Change Mitigation and Low-Carbon Economy Act, which lays the groundwork for the province to link its program to a carbon cap-and-trade market set up by Québec and California. Under the legislation, Ontario will deposit allowances under its cap-and-trade program into the "Greenhouse Gas Reduction Account," which invests in initiatives that reduce GHG emissions. From *Government of Ontario News Release* on May 18, 2016.

July 2016

"South Africa Proposes Carbon Tax Relief in Draft Law." The South African National Treasury has published draft regulations on a potential carbon offset in a step to implement their government's carbon tax into law by January 2017. The carbon offset regulations, if enacted, will set procedures for taxpayers to use carbon offsets to reduce liability and reinvest in areas such as energy efficiency and renewable energy. From *International Tax Review* on June 27, 2016.

"Effectiveness of greenhouse-gas Emission Trading Schemes implementation: a review on legislations." The following is the Abstract of this article: "[Due to potentially rising global temperatures], controlling [GHG] emissions has become an emerging topic around the world. This situation has led to the implementation of legislations, forcing companies to implement innovations and strategies to prevent and reduce carbon emissions. Nevertheless, the effectiveness of implementing these strategies and the estimation to fulfill Kyoto Protocol's 2020 target Emission Trading Schemes needs to be further [analyzed] and discussed. This paper reviews the existing [GHG]-emission legislations, as well as carbon offset programs worldwide. A detailed analysis on carbon emissions trends related to emissions penalties is shown for six major countries. The optimal penalty for emissions trading schemes is also analyzed and discussed. Future changes that could be made to the existing programs for enhancing their effectiveness are also suggested. It was found that carbon emissions decreased around 1.58 [percent] per year since Emission Trading Schemes implementation. Around 23.43 [percent] of CO_2 reduction can be reached after 10 years of Emission Trading Schemes implementation, compared to the trend when Emission Trading Schemes was not implemented. Despite Emission Trading Schemes implementation is extremely recent, based on the existing data a first estimation of the optimal penalty in achieving the maximum carbon reduction it was found around US$90.22 per [metric ton]. However, as the implementation period of Emission Trading Schemes is still limited for most countries, it is necessary to explore similar analysis as future work." **Paola Villoria-Sáez, Vivian W.Y. Tam, Mercedes del Río**

Merino, Carmen Viñas Arrebola, Xiangyu Wang, *Journal of Cleaner Production*. (Subscription may be required.)

August 2016

"[Senators] Introduce Bill to Support Carbon Capture Utilization [and] Storage." Two U.S. Senators introduced a bill to incentivize development and use of carbon capture, utilization, and storage (CCUS) technologies and processes. The bill would promote carbon capture technologies by extending the 45Q tax credit, which encourages investment in carbon capture, utilization, and storage. In addition, the bill would also utilize the credit system to encourage innovation and the use of CO_2 in EOR. For more information, refer to the press release, or read the bill, titled "Carbon Capture and Utilization Act of 2016." From *U.S. Senator Heidi Heitkamp Press Release* on July 13, 2016.

September 2016

"California Legislature Passes Climate Change Bills." The California Senate voted to extend the state's climate change efforts, setting a target of reducing emissions 40 percent below 1990 levels by 2030. California is currently on track to meet its 2020 goal of reducing emissions to 1990 levels. The bill, which extends the current efforts through 2030, was passed following a linked bill that increases legislative oversight of the climate change programs managed by the California Air Resources Board. From *Reuters* on August 24, 2016.

Announcements

September 2015

U.S., China Sign Memorandum of Understanding. At the U.S.-China Clean Coal Industry Forum (CCIF) in Billings, Montana, USA, DOE and China's National Energy Administration (NEA) finalized a Memorandum of Understanding (MOU) to continue ongoing collaboration on fossil energy technologies, including CCS. U.S. and Chinese partners are currently advancing six CCS pilot projects in China and Chinese companies have invested in CCS projects in the United States.

DOE/NETL Funding Announcements. The Carbon Capture Program will fund 8 projects for reducing the cost of CO_2 capture and compression, 16 projects for the development and testing of transformational CO_2 capture systems, and 4 projects to assess the geologic storage potential of offshore subsurface depleted oil and natural gas reservoirs and saline formations. Furthermore, six projects will receive funding through NETL's University Coal Research Program, administered by the Crosscutting Technology Research Program, and 12 projects will receive funding through DOE/NETL's Crosscutting Research Program's Transitional Technology Development to Enable Highly Efficient Power Systems with Carbon Management initiative. Project descriptions are available via the above links.

New Zealand Emissions Trading Scheme Reports Released. New Zealand's Environmental Protection Authority issued their annual data reports on the New Zealand Emissions Trading Scheme (ETS), providing information on the businesses involved in the ETS, including greenhouse gases (GHGs) emitted and reduced, as well as year-by-year comparisons. The three ETS reports issued are available for download.

Report Released on Secondary Market for RGGI CO_2 Allowances. On behalf of the states participating in the Regional Greenhouse Gas Initiative (RGGI), independent marketing monitor Potomac Economics released the "Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2015."

Pact Signed to Cut Greenhouse Gas Emissions. Six New England governors and five premiers of Eastern Canadian Provinces agreed to set a new goal for reducing GHG emissions by 2030. According to the agreement, the respective governments will look to reduce CO_2 emissions in the range of 35 to 45 percent below 1990 levels by 2030.

October 2015

DOE/NETL Funding Announcement. DOE/NETL's Carbon Storage Program will fund nine projects to research new CO_2 storage technologies devoted to intelligent monitoring systems and advanced well integrity and mitigation approaches. The selected projects focus on the following three research priorities: (1) CCS-specific intelligent systems for monitoring, controlling, and optimizing CO_2 injection operations; (2) diagnostic tools and methods capable of characterizing borehole release pathways or fluid flow in existing wells; and (3) next-generation materials and methods for mitigating wellbore release.

Quest CCS Project Set to Launch. Shell announced that its Quest CCS project, which is expected to store approximately 1 million metric tons of CO_2 per year from the Scotford Upgrader, will officially launch in November 2015. The Quest project will capture and compress the CO_2 produced by the Upgrader, then transport it via underground pipeline to three injection wells. Quest's underground CO_2 storage will be monitored through a measurement, monitoring, and verification program.

November 2015

NETL's 2015 Carbon Storage Atlas Shows Increase in U.S. CO_2 Storage Potential. DOE/NETL released the fifth edition of the Carbon Storage Atlas (Atlas V), which shows prospective CO_2 storage resources of at least 2,600 billion metric tons – an increase over the findings of the 2012 Atlas. Atlas V highlights potential CO_2 storage resources in saline formations, oil and natural gas reservoirs, and unmineable coal seams. This edition also presents a detailed look at the RCSP Initiative's large-scale field projects, which are uniquely tailored to address technical and non-technical challenges within their respective regions.

DOE Selects Five Projects to Produce Fresh Water from CO_2 Storage Sites. DOE/NETL selected five projects to develop and validate strategies to manage pressure and the flow of CO_2 in saline formations through a Brine Extraction Storage Test (BEST). The projects will be managed under the Carbon Storage Program and will support the clean energy and climate goals announced by the U.S. and Chinese governments in November 2014.

ION Engineering Successfully Completes Pilot-Scale Testing of Carbon Capture Technology. ION Engineering announced the successful completion of the first pilot-scale testing of its solvent and process technology for the removal of CO_2 from large stationary sources. The project involved 1,200 hours of continuous testing at the 0.6-Megawatt equivalent (MWe) Pilot Solvent Test Unit (PSTU), located at the National Carbon Capture Center (NCCC) in Wilsonville, Alabama, USA. More than 99 percent of the CO_2 was captured from the facility's flue gas.

Cambridge Draft Climate Change Strategy Open for Consultation. Cambridge City Council (in the United Kingdom) produced a draft "Climate Change Strategy 2016 to 2021," providing a framework for addressing potential climate change from April 2016 through March 2021. Public consultation on the draft strategy is being accepted, via survey, through January 12, 2016.

December 2015

Underground CO_2 Storage, Natural Gas Recovery Targeted by Virginia Tech/NETL Researchers. Researchers from DOE's National Energy Technology Laboratory (NETL) and Virginia Polytechnic Institute and State University (Virginia Tech) are investigating the feasibility of permanently and safely storing CO_2 underground while simultaneously recovering natural gas. Virginia Tech's Virginia Center for Coal and Energy Research (VCCER) initiated the injection of up to 20,000 tons of CO_2 into a coalbed methane field in Buchanan County, Virginia, USA, in July 2015. Researchers will use a state-of-the-art monitoring, verification, and accounting (MVA) program to monitor and collect data as the CO_2 is injected into the coal seams.

RGGI Completes 30th Auction of CO_2 Allowances. The Regional Greenhouse Gas Initiative's (RGGI) 30th auction of CO_2 allowances was completed, with 15,374,274 CO_2 allowances selling at the clearing price of $7.50. This was the fourth and final auction of 2015 and generated $115.3 million for reinvestment in strategic programs, such energy efficiency and greenhouse gas (GHG) abatement programs. In addition, the states participating in RGGI also released the "Report on the Secondary Market for RGGI CO_2 Allowances: Third Quarter 2015."

6th Carbon Sequestration Leadership Forum Minister's Meeting Held in Saudi Arabia. The 6th CSLF Ministerial Meeting, co-hosted by the United States and Saudi Arabia, was held in Riyadh, Saudi Arabia. The meeting focused on the role of CCS technologies.

CSLF Recognizes CO_2 Capture Project for Work in CCS. CSLF recognition for the CO_2 Capture Project (CCP) includes a Global Achievement Award for the third phase of the CCP Program (CCP3 –

2009-2014), as well as Recognized Project Status for its current, fourth phase of the program (CCP4 – 2014-2018).

Sembcorp Joins Industrial CCS Scheme. Sembcorp Utilities UK, an industrial energy and water services provider, has joined the Teesside Collective, an industrial CCS scheme. The first phase of the scheme could be up and running by 2024.

January 2016

Underground CO_2 Storage, Natural Gas Recovery Targeted by Virginia Tech/NETL Researchers. Researchers from DOE's National Energy Technology Laboratory (NETL) and Virginia Polytechnic Institute and State University (Virginia Tech) are investigating the feasibility of permanently and safely storing CO_2 underground while simultaneously recovering natural gas. Virginia Tech's Virginia Center for Coal and Energy Research (VCCER) initiated the injection of up to 20,000 tons of CO_2 into a coalbed methane field in Virginia, USA. Researchers will use a state-of-the-art monitoring, verification, and accounting (MVA) program to monitor and collect data as the CO_2 is injected into the coal seams.

DOE-Funded Research Yields U.S. Patent for Use of CO_2 in Concrete Curing. The United States Patent and Trademark Office issued a patent for a new process, funded by DOE's NETL, which uses CO_2 to cure pre-cast concrete. The process uses CO_2 instead of water to cure pre-cast concrete, reducing curing time to less than 24 hours. For more information, visit NETL's Carbon Use and Reuse Webpage.

February 2016

DOE Co-Sponsors Workshop. DOE and the UAE Ministry of Energy co-sponsored a CO_2 utilization workshop examining the technological and economic factors for CO_2 utilization to recover oil and water in the Gulf Region. The workshop, which took place at the World Future Energy Summit in Abu Dhabi, brought together government and industry technical experts from the Middle East and the United States to discuss the full lifecycle of carbon capture, utilization, and storage. The workshop furthers ongoing collaboration under the U.S.-UAE Strategic Energy Dialogue and in the Carbon Sequestration Leadership Forum (CSLF).

RGGI Auction 31. The states participating in the Regional Greenhouse Gas Initiative's (RGGI) 2016 auctions released the Auction Notice and application materials for their upcoming quarterly CO_2 allowance auction. The CO_2 Allowance Auction 31 will be held March 9, 2016.

Canada Pledges Funds to Reduce Carbon Emissions. The Government of Canada announced funding to reduce short-lived climate pollutants (SLCPs), which have a shorter lifespan compared to greenhouse gases (GHGs). A portion of the funding will be used for projects that aim to reduce black carbon emissions to benefit the Arctic.

World Bank to Buy Carbon Credits. The World Bank announced it has committed to buy carbon credits from the Philippines, potentially purchasing approximately 1.7 million carbon credits until 2020.

GCCSI Introduces CCS Fellowship Program. The Global CCS Institute (GCCSI) appointed the first legal Fellow to their CCS Fellowship Program. The Institute, whose mission is to accelerate the development, demonstration, and deployment of carbon capture and storage (CCS), introduced the CCS Fellowship Program to recruit international experts to help advance CCS in Asia Pacific.

March 2016

RGGI Releases Reports. The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "Report on the Secondary market for RGGI CO_2 Allowances: Fourth Quarter 2015" and the "2015 Interim Compliance Summary Report." The Secondary Market Report contains information on the secondary market for RGGI carbon dioxide (CO_2) allowances from October through December 2015. The Interim Compliance Report contains CO_2 allowance data to meet 2015 interim control period compliance.

Scientists Collaborate on CCS Research. The University of Edinburgh (UK) and the University of Regina (Canada) signed a Memorandum of Understating (MOU) focused on strategic international research on CCS. The MOU will establish up to three scholarships each year; successful students will be accepted as visiting graduate students at Regina following the completion of two semesters for the University of Edinburgh's Master of Science (MSc) in CCS.

MITEI Announces Partnership to Support Low-Carbon Future. The Massachusetts Institute of Technology's Energy Initiative (MITEI) will partner with national energy provider Exelon to advance technologies to address potential climate change through MITEI's eight Low-Carbon Energy Centers. Each center focuses on advancing research in a specific technology area, such as carbon capture, utilization, and storage.

CCS Technical Advisor Named to Gassnova. AGR, a well construction and engineering project management company, will act as technical advisor to the Norwegian state-owned Gassnova, which focuses on the research, development, and implementation of CCS technology in Norway. As part of the agreement, AGR will offer technical expertise across geoscience, reservoir, and drilling disciplines, as well as facilities and cost engineering.

April 2016

Tools to Monitor Carbon Storage Released. Simulation tools developed by the DOE-led National Risk Assessment Partnership (NRAP) are under review by members of industry, regulatory agencies, universities, and other organizations, such as the Regional Carbon Sequestration Partnerships (RCSPs). The successful deployment of the tools will enable users to predict the safety and permanence of carbon storage systems. Following review, the NRAP project team will implement improvements based on the feedback, with the final tool release expected in late 2016. For more information on NRAP and the new tool set, visit the NRAP website.

U.S. to Lead International Carbon Capture Test Network. The International Test Center Network (ITCN), a global consortium of facilities conducting research and development (R&D) on carbon capture technologies, will be led by the United States (represented by FE). The ITCN was formed by the DOE-sponsored National Carbon Capture Center (NCCC) and Norway's Technology Centre Mongstad (TCM) to facilitate knowledge transfer from carbon capture test facilities around the world.

Global CCS Institute Releases Global Storage Portfolio. The Global CCS Institute published a new report summarizing regional storage resource assessments. Designed as a regularly updated reference containing the latest assessment of geological storage in regions around the world, the Global Storage Portfolio summarizes storage resource potential of nations that have published regional assessments. A summary of the portfolio is available in the Recent Publications section of this newsletter.

Western Australia Project Releases Well Data. The South West Hub Carbon Capture and Storage (CCS) project released new well data to aid research in the feasibility of storing carbon dioxide (CO_2) in underground formations. More information is available via the Government of Western Australia's Department of Mines and Petroleum (DMP) website.

May 2016

DOE-Supported Research Has Potential to Reduce CO_2 Emissions. Research under a National Energy Technology Laboratory (NETL)-sponsored Small Business Technology Transfer Project has led to a discovery that may reduce CO_2 emissions from power plants through a new process called "solution precursor plasma spray" (SPPS). The process provides a thermal barrier coating (TBC) with a potential for use at 1,500°C, which is a 300°C temperature advantage compared to current state-of-the-art air plasma-sprayed TBCs.

Wyoming Integrated Test Center Groundbreaking. Construction has begun on Wyoming's Integrated Test Center, a laboratory where researchers will test new carbon-conversion technologies on a coal-fired power plant. Wyoming has pledged $15 million toward construction of the laboratory. Construction of the Integrated Test Center, located at Basin Electric's Dry Fork Station coal-fired power plant near Gillette, Wyoming, USA, is expected to be completed in 2017.

Shell Publishes 2015 Sustainability Report. Royal Dutch Shell published its Sustainability Report for 2015, detailing its focus on energy transitions, such as carbon capture and storage (CCS), as well as other investments in low-carbon technologies.

June 2016

U.S., Saudi Arabia Announce International Collaboration. The United States and the Kingdom of Saudi Arabia announced plans to establish an international consortium to promote research, development, and demonstration (RD&D) of supercritical carbon dioxide (sCO_2) power cycles. The collaboration between the United States and Saudi Arabia builds on actions by both nations to advance sCO_2 technologies to reduce technical barriers and risks to commercialization of the sCO_2 power cycle. Other countries that are pursuing sCO_2 research and development (R&D), including the Republic of Korea, will be invited to join the new consortium.

UK Center for Applied Energy Research Receives Grant for U.S.-China Clean Energy Research Center. DOE selected the University of Kentucky's Center for Applied Energy Research (CAER) for a renewal of its U.S.-China Clean Energy Research Center (CERC) grant. The five-year DOE grant will support CAER efforts to develop advanced coal technologies. CERC, created in 2009 by DOE, the China Ministry of Science and Technology, and the China National Energy Administration, facilitates joint R&D on clean energy by research teams from the United States and China.

DOE-Supported Research Has Potential to Reduce CO_2 Emissions. Research under an NETL-sponsored project has led to a discovery that may reduce CO_2 emissions from power plants through a new process called "solution precursor plasma spray" (SPPS). The process provides a thermal barrier coating (TBC) with a potential for use at 1,500°C, which is a 300°C temperature advantage compared to current state-of-the-art air plasma-sprayed TBCs.

NETL Researchers Develop New CO_2 Conversion Process. A new process developed by an NETL-led research team uses gold nanoparticles to convert CO_2 into usable chemicals and fuels. If implemented on a commercial scale, the new process has the potential to reduce atmospheric CO_2 emissions. The research team estimates that renewable energy sources can efficiently power large-scale CO_2 conversion systems to convert CO_2.

Annual Report on Market for RGGI CO_2 Allowances Released. In reviewing the four Regional Greenhouse Gas Initiative (RGGI) CO_2 allowance auctions held in 2015, an independent market monitor found no material concerns regarding the auction process, barriers to participation, or competitiveness.

According to the report, titled "Annual Report on the Market for RGGI CO_2 Allowances: 2015," the average auction clearing price increased 29 percent ($4.72 in 2014 to $6.10 in 2015), and the volume-weighted average prices in the secondary market increased to an average of $6.48 in 2015. In addition, the average number of auction participants increased from 45 in 2014 to 50 in 2015.

July 2016

DOE Awards $10 Million to Small Businesses for Fossil Energy Research and Technology Transfer. DOE selected 10 research projects to be funded under the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) Programs through DOE's Office of Science. Of the 10 selected projects, 8 were made under Topic Area 1: Clean Coal and Carbon Management, and include key R&D programs, such as carbon storage technologies in the area of wellbore release pathway detection techniques.

DOE Selects Projects to Demonstrate Feasibility of Producing Usable Water from CO_2 Storage Sites. DOE selected two projects to test enhanced water recovery (EWR) technologies for their potential to produce useable water from CO_2 storage sites. The two projects, which will be managed by DOE's National Energy Technology Laboratory (NETL), were selected from the five Brine Extraction Storage Test (BEST) projects awarded in September 2015.

NETL Launches University Coalition for Fossil Energy Research. Pennsylvania State University (PSU) will serve as the lead institution for DOE/NETL's University Coalition for Fossil Energy Research. The Coalition brings together a multi-disciplinary team of researchers from different universities to address the research challenges of fossil energy-based technologies, including CCS. The six-year initiative is expected to help accelerate the development and deployment of fossil fuel-based technologies in a cost-effective and environmentally safe manner.

Reports Highlight CCS Technology. The Global CCS Institute released two public information reports that highlight the long-term application of CCS technology in a variety of industrial sectors. The first report, titled "Introduction to Industrial Carbon Capture and Storage," summarizes 17 CCS projects across multiple sectors. The second report, titled "Understanding Industrial CCS Hubs and Clusters," explores the economic benefits of building shared infrastructure.

August 2016

NETL Technologies Named Finalists for Awards. The Carbon Capture Simulation Initiative (CCSI) Toolset was one of four NETL-developed technologies named finalists for this year's R&D 100 Awards, presented annually by R&D Magazine in recognition of the top technologies and services across multiple categories. The CCSI Toolset is a suite of computational tools and models tailored to help maximize learning and reduce potential risk during scale-up of carbon capture technologies.

NETL Releases CCS Education Videos. NETL released two educational videos on the safe and permanent storage of CO_2. The first video describes the National Risk Assessment Partnership (NRAP), an NETL-led initiative within DOE's FE that applies science-based prediction for engineered-natural systems to the long-term storage of CO_2. The second video discusses NETL's advances and innovation in cost-effective and safe CCS strategies.

DOE Announces Funding to Advance Safe and Permanent Storage of CO_2. DOE announced funding for cost-shared R&D projects focused on the safe and permanent storage of CO_2 during CCS operations. The Carbon Storage Assurance and Facility Enterprise (CarbonSAFE) initiative is intended to develop integrated CCS storage complexes, which will be constructed and permitted for operation in the 2025 timeframe following a series of developmental phases.

DOE to Invest in Advanced Turbine and Supercritical CO_2-Based Power Cycles. DOE's NETL selected six Phase II projects to further develop innovative technologies for advanced gas turbine components and supercritical carbon dioxide (sCO_2) power cycles.

PTRC and CO2CRC Agree to Collaborate on Carbon Management. The Petroleum Technology Research Center (PTRC) and the CO_2 Commonwealth Research Center (CO2CRC) signed a Memorandum of Understanding (MOU) on Aquistore, an integrated CO_2 storage project associated with an industrial-scale coal-fired power plant. The MOU represents efforts to prepare and execute joint research; facilitate the exchange of scientists and technical personnel; and encourage dedicated CO_2 storage on regional, national, and international scales.

September 2016

NETL's 2016 Carbon Storage and Oil and Natural Gas Technologies Review Meeting Materials Available Online. Proceedings of the 2016 Carbon Storage and Oil and Natural Gas Technologies Review Meeting, held August 16-18, 2016, in Pittsburgh, Pennsylvania, USA, are available. Plenary sessions included an international offshore carbon storage panel discussion and updates on Regional Carbon Sequestration Partnership (RCSP) projects. Poster presentations are also available for download.

DOE Announces Funding to Advance Cleaner Fossil Fuel-Based Power Generation. DOE selected 14 research and development (R&D) projects to advance energy systems that will enable cost-competitive, fossil fuel-based power generation with near-zero emissions. The National Energy Technology Laboratory (NETL)-managed projects will accelerate the scale-up of coal-based advanced combustion power systems; advance coal gasification processes; and improve the cost, reliability, and endurance of solid oxide fuel cells (SOFCs). DOE's Office of Fossil Energy (FE) will fund the projects.

DOE Investing in Advanced Geologic Carbon Storage and Geothermal Exploration. DOE selected eight R&D projects to receive federal funding under its Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) Crosscut initiative. The projects will be funded by FE's Carbon Storage Program and the Office of Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office (GTO).

Texas CO_2 Capture Demonstration Project Hits Milestone. A CCS project sponsored by DOE and managed by NETL successfully captured and transported 3 million metric tons of CO_2 via pipeline. The project demonstrates the implementation of Air Products and Chemicals, Inc.'s vacuum swing adsorption technology into a hydrogen production facility, and verifies the effective use of CO_2 enhanced oil recovery (EOR) for permanently storing CO_2. The project is supported through DOE's Industrial Carbon Capture and Storage (ICCS) Program.

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DOE's Carbon Storage Program

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