NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON STORAGE NEWSLETTER

ANNUAL INDEX – FY 2017

October 2016 – September 2017

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This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters (CSN) published from October 2016 to September 2017. The CSN 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. Outdated information (e.g., conference dates, paper submittals, etc.) and duplicative stories have been removed.

Note that all links were active at the time of publication.

A comprehensive archive of the CSN is available on the NETL website.

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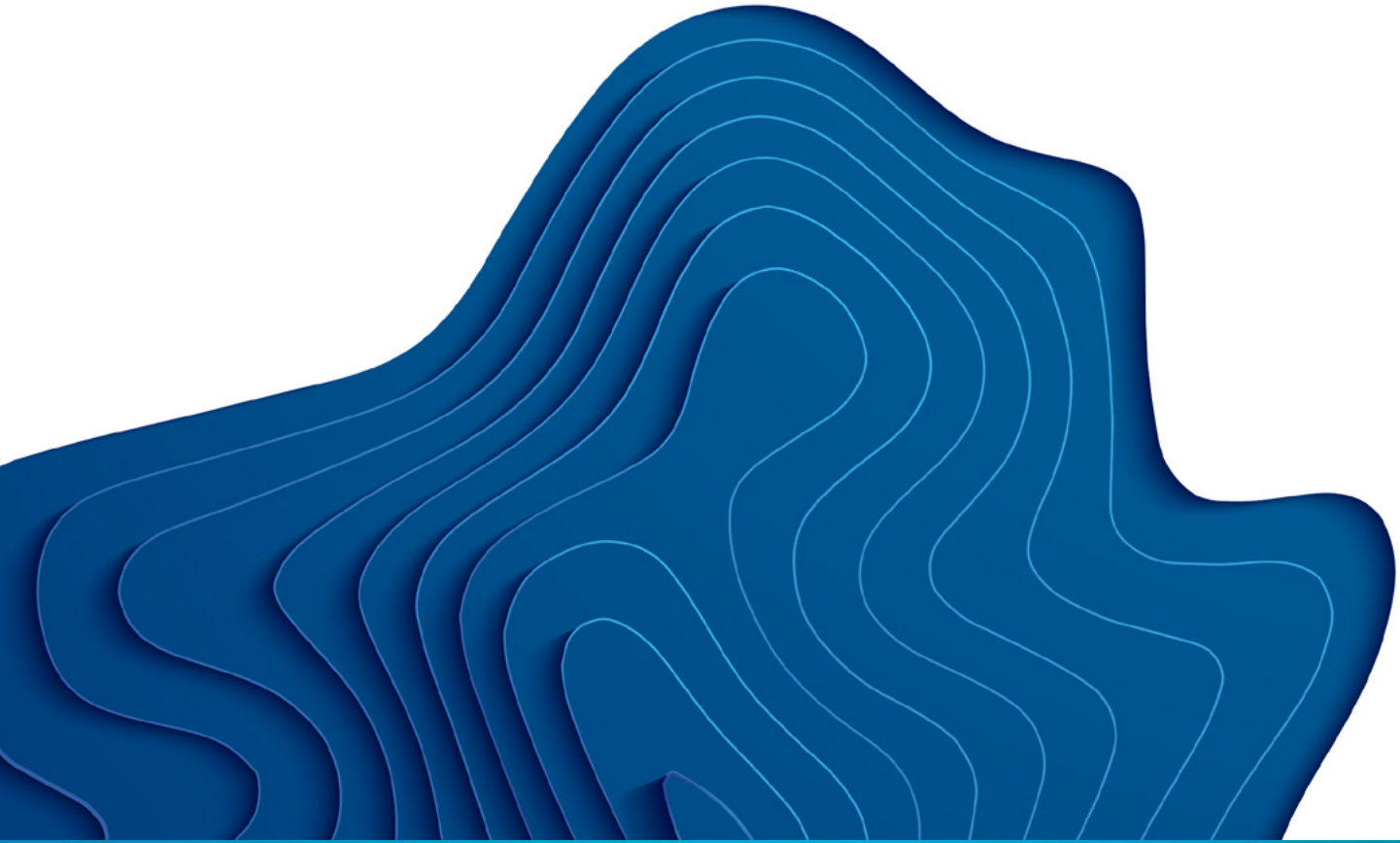

DOE/NETL HIGHLIGHTS

OCTOBER 2016

DOE-Funded Carbon Capture Technology Moves Forward to Large-Scale Testing.

A *second-generation carbon dioxide (CO_2) solvent technology project* funded by the U.S. Department of Energy (DOE) will begin testing at the *Technology Centre Mongstad (TCM)* in western Norway, DOE announced. DOE has a bilateral Memorandum of Understanding (MOU) with the Royal Norwegian Ministry of Petroleum and Energy that covers fossil energy-related research to leverage each countries' investments in carbon capture, utilization, and storage (CCUS). The ION Engineering project is the first project from *DOE's Carbon Capture Program* to be located at an international host site. From *energy.gov* on October 12, 2016.

DOE Invests $6 Million to Accelerate Next-Generation Advanced Energy Systems.

DOE selected two projects to advance key technologies that enable development of next-generation advanced energy systems. The two projects, which will receive Phase II research funding from DOE with an approximate three-year performance period, were selected from five DOE-funded Phase I projects. Next-generation advanced energy systems include advanced combustion, chemical looping, gasification, turbines, fuel cells, gas cleaning and separation technologies, and CO_2 separation technologies. Research and development (R&D) in these areas is supported by the Office of Fossil Energy's (FE) *Crosscutting Research Program*, which aims to advance early stage R&D for innovative FE solutions to improve availability, efficiency, and environmental performance of advanced energy systems integrated with carbon capture and storage (CCS). From *energy.gov* on October 5, 2016.

NOVEMBER 2016

DOE, Natural Resources Canada Announce Pilot Plant to Advance Oxy-Combustion Carbon Capture.

The U.S. Department of Energy (DOE) and Canada's Natural Resources Canada (NRCan) will open a new facility to test oxy-fired pressurized fluidized bed combustion (oxy-PFBC) to capture carbon dioxide (CO_2) emissions from a coal-fired power plant. The *1-megawatt thermal (MWth) facility*, located in Canoga Park, California, USA, will test oxy-PFBC as a means to more efficiently and economically capture CO_2 and help advance the commercialization of carbon capture, utilization, and storage (CCUS). The test plant is part of an ongoing collaboration between DOE, NRCan, and CametEnergy (NRCan's research and development [R&D] lab). The National Energy Technology Laboratory (NETL)-managed project, which is being led by the Gas Technologies Institute (GTI), received funding from *DOE's Office of Fossil Energy's* (FE) *Advanced Combustion Program*. From *energy.gov* on October 18, 2016.

DECEMBER 2016

Energy Department Announces More Than $44 Million for CO_2 Storage Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) announced the selection of 16 carbon storage projects to receive funding for cost-shared research and development (R&D) as part of DOE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative, which seeks to help mitigate carbon dioxide (CO_2) emissions from the burning of fossil fuels. The selected projects will address key research gaps in the deployment of carbon capture and storage (CCS) technologies, as well as look to develop integrated CCS complexes that are constructed and permitted for operation in the 2025 timeframe over a series of sequential phases of development: Integrated CCS Pre-Feasibility, Storage Complex Feasibility, Site Characterization, Permitting, and Construction. The 16 selected projects, which apply to the first two of those phases, will build on lessons learned from the *Regional Carbon Sequestration Partnerships' (RCSPs)* large-scale field projects. From *energy.gov* on November 30, 2016.

JANUARY 2017

DOE Offers Conditional Commitment to Facility.

The U.S. Department of Energy (DOE) offered a conditional commitment to guarantee loans up to $2 billion for the construction of a methanol production facility in Lake Charles, Louisiana, USA, that will employ carbon capture technology. The carbon dioxide (CO_2) captured at the facility, which will be constructed by Lake Charles Methanol, LLC, will be transported, via pipeline, to oilfields in Texas, USA, where it will be utilized for enhanced oil recovery (EOR). The project is expected to result in the storage of approximately 4.2 million metric tons of CO_2 annually. DOE's loan guarantee was made under the *Advanced Fossil Energy* Project solicitation issued by *DOE's Loan Programs Office (LPO)*. From *energy.gov* on December 21, 2016.

FEBRUARY 2017

Post-Combustion Carbon Capture Project Begins Commercial Operation.

The post-combustion carbon capture *Petra Nova project* began commercial operation at the W.A. Parish Plant in Thompsons, Texas, USA, officials announced. The U.S. Department of Energy (DOE) provided funding and the National Energy Technology Laboratory (NETL) provided project management support for the project, which demonstrates how carbon capture technologies can support the flexibility and sustainability of fossil fuels at a commercial scale. The Petra Nova project has the potential to capture 1.6 million tons of carbon dioxide (CO_2) per year from an existing coal-fired power plant. From *energy.gov* on January 11, 2017.

MARCH 2017

Department of Energy Invests in Projects to Advance Novel CO_2 Utilization Strategies.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) selected seven projects to receive funding to focus on novel ways to use carbon dioxide (CO_2) captured from coal-fired power plants. The selected research projects, which directly support the National Energy Technology Laboratory's (NETL) *Carbon Storage Program's Carbon Use and Reuse* research and development (R&D) portfolio, fall under three technical 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 CO_2. The portfolio will develop and test novel approaches that convert the captured CO_2 to useable products, as well as explore ways to use the captured CO_2 in areas where high-volume uses may not be optimal, such as enhanced oil recovery (EOR). Each project will also include non-federal cost share of at least 20 percent. From *energy.gov* on February 22, 2017.

APRIL 2017

DOE Announces Milestone for Industrial CCS Project.

The U.S. Department of Energy (DOE) announced that the Illinois Industrial Carbon Capture and Storage (ICCS) project has begun operation by injecting carbon dioxide (CO_2) into a saline reservoir. Based in Decatur, Illinois, USA, and led by the Archer Daniels Midland Company (ADM), the DOE-funded, large-scale demonstration project is demonstrating an integrated system for collecting CO_2 from an ethanol production plant and storing the CO_2 in an underground reservoir. The CO_2 will be stored in the Mt. Simon Sandstone in the Illinois Basin, and the project can store approximately 1 million tons of CO_2 per year at depths of approximately 7,000 feet; however, researchers estimate the sandstone formation has the potential to store more than 250 million tons of produced CO_2 each year. From *energy.gov* on April 7, 2017.

MAY 2017

Successful Completion of Carbon Capture Project Celebrated.

The U.S. Department of Energy (DOE)-funded Petra Nova Carbon Capture project located at the W.A. Parish power plant in Thompsons, Texas, USA, opened after being completed on-schedule and on-budget. The large-scale demonstration project was originally conceived as a 60-megawatt electric (MW_e) capture project, but was expanded to a 240-MW_e project without the need of additional federal investment. Performance testing of the project, which is a joint venture between NRG Energy and JX Nippon Oil and Gas Exploration Corporation, demonstrated a carbon dioxide (CO_2) capture rate of more than 90 percent. The CO_2 captured from the project will be used for enhanced oil recovery (EOR). From *energy.gov* on April 13, 2017.

JUNE 2017

Successful Demonstration of NETL-Supported Project.

A National Energy Technology Laboratory (NETL)-supported project successfully concluded a six-month testing campaign at the Technology Centre Mongstad (TCM) in western Norway, a facility for testing and improving carbon dioxide (CO_2) capture. The testing involved ION Engineering's novel carbon capture system, which achieved all research objectives and represents progress toward commercialization. The system successfully captured more than 90 percent of CO_2 from the flue gas during steady-state testing, with CO_2 product purity greater than 99 percent. Approximately 14,000 metric tons of CO_2 were captured during testing. The U.S. Department of Energy (DOE) and the Royal Norwegian Ministry of Petroleum and Energy have a bilateral Memorandum of Understanding (MOU) covering fossil energy-related research to leverage each country's investments in carbon capture, utilization, and storage (CCUS). From *energy.gov* on June 7, 2017.

JULY 2017

NETL's Geologic Carbon Storage Risk Assessment Tools Recognized.

The Carbon Sequestration Leadership Forum (CSLF) recognized the U.S. Department of Energy's (DOE) National Risk Assessment Partnership (NRAP) as a project that contributes to the advancement of carbon capture and storage (CCS) technology deployment. NRAP is one of approximately 50 such projects worldwide to be recognized over the past decade by CSLF, an international, ministerial-level organization focused on the development of CCS technology. Led by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), NRAP is a multi-lab partnership developing a defensible, science-based methodology and platform for quantifying risk at carbon dioxide (CO_2) storage sites to guide decision-making and risk management. A reason NRAP was selected as a CSLF-recognized project is the internationally used NRAP toolset, which comprises simulation tools designed to help evaluate the performance of geologic carbon storage sites related to potential risks. For more information, visit the *NRAP website*. From *energy.gov* on June 13, 2017.

DOE Investment in Carbon Storage.

DOE's FE announced the availability of funds to advance new carbon storage projects that enable safe, cost-effective, and permanent geologic storage of CO_2. Specifically, two Funding Opportunity Announcements (FOAs) under FE's *Carbon Storage Program* will look to advance the development and validation of storage technologies associated with enhanced oil recovery (EOR) operations or injection into a saline reservoir. The FOA "*Partnership for Offshore Carbon Storage Resources and Technology Development in the Gulf Mexico*" will look to facilitate offshore geologic CO_2 storage in the Gulf of Mexico by combining the capabilities and experience of industry, academia, and government. The FOA "*Technology Development to Ensure Environmentally Sustainable CO_2 Injection Operations*" will look to advance capabilities to assess CO_2 stored in the deep subsurface by addressing key knowledge and experience gaps in carbon storage technology. From *energy.gov* on June 16, 2017.

AUGUST 2017

NETL Releases Latest Best Practice Manuals for Geological Storage.

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) released three 2017 revised edition Best Practice Manuals (BPMs) for geologic storage projects ("*Public Outreach and Education for Geologic Storage Projects*"; "*Risk Management and Simulation for Geologic Storage Projects*"; and "*Site Screening, Site Selection, and Site Characterization for Geologic Storage Projects*"). The BPMs provide a holistic approach to carrying out a geologic storage project from inception to completion. The revised BPMs were developed in conjunction with the *Regional Carbon Sequestration Partnerships (RCSPs)*, an initiative launched by DOE's Office of Fossil Energy (FE) and NETL in 2003 to develop and test the best technologies for safe and permanent storage of carbon dioxide (CO_2). RCSP experts worked with DOE on the latest updates by incorporating knowledge gained in their respective partnership projects. The 2017 revisions include new information learned as the RCSPs progressed to large-scale Development Phase field projects, as well as a variety of carbon storage scenarios at different geologic and geographic settings across the United States. From *DOE/NETL News Release* on July 17, 2017.

SEPTEMBER 2017

DOE Invests in Projects to Advance Beneficial Use of CO_2.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) selected five projects to receive funding to investigate novel uses of carbon dioxide (CO_2) captured from coal-fired power plants. The newly selected projects fall under three technical 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. The five projects join *seven previously selected projects* under the "Applications for Technologies Directed at Utilizing Carbon Dioxide from Coal-Fired Power Plants" Funding Opportunity Announcement (FOA). All 12 projects selected under the FOA support FE's *Carbon Storage Program's Carbon Use and Reuse* research and development (R&D) portfolio. From *energy.gov* on August 10, 2017.

NETL Releases Updated BPMs for Geologic Carbon Storage.

DOE's National Energy Technology Laboratory (NETL) announced the release of the final two of five 2017 revised edition best practice manuals (BPMs) for geologic carbon storage projects. The final two BPMs ("*Operations for Geologic Storage Projects*" and "*Monitoring, Verification, and Accounting (MVA) for Geologic Storage Projects*") join the three *BPMs released in July 2017* to provide a holistic approach to carrying out a geologic storage project from inception to completion. The revised BPMs were developed in conjunction with the *Regional Carbon Sequestration Partnerships (RCSPs)* and include new information learned as the RCSPs progressed to large-scale Development Phase field projects, as well as a variety of carbon storage scenarios at different geologic and geographic settings across the United States. From *energy.gov* on September 1, 2017.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2016

Quest Carbon Capture and Storage Project Reaches Significant One-Year Milestone.

Shell Canada's Quest carbon capture and storage (CCS) project successfully captured and stored 1 million metric tons of carbon dioxide (CO_2) after one year of operation, the company announced. In collaboration with the Alberta and Canadian governments, the intellectual property and data generated (including the detailed engineering plans) have been made publicly available to reduce future CCS implementation costs and spur interest across the industry. One of the lessons learned was the achievement of cost savings through joint transportation and storage facilities. From *Shell Canada News Release* on September 14, 2016.

Canadian Government Invests in Carbon Reduction Research.

The Canadian government announced funding for the University of Calgary to research the reduction of CO_2 emissions during unconventional oil and gas operations. The funding will be used to develop more efficient ways of extracting oil and gas, as well as to potentially improve the efficiency of carbon capture and conversion and eliminate the release of CO_2 by developing new means of extracting energy from carbon fuels. The research will be conducted in partnership with researchers from Mexico, China, and Israel. From *CBC News* on September 6, 2016.

CO2CRC Limited Opens New CCS Laboratories.

CO2CRC Limited announced the opening of new CCS laboratories, funded through the Australian Government's Education Investment Fund (EIF), as part of the Australian CCS Research Laboratories Network (CCSNet). One of the laboratories, *located at Federation University Australia's Gippsland campus*, will conduct research on various CCS technologies with the aim of reducing the cost of implementation. CO2CRC *also collaborated with The University of Melbourne* on emissions reduction laboratories that aim to provide clean, efficient, and cost-effective energy for Australia. From CO2CRC *Media Releases* on September 20 and September 28, 2016.

NOVEMBER 2016

Norway Unveils Plan to Develop Industrial CCS Portfolio.

The *Norwegian government unveiled plans* to develop its industrial carbon capture and storage (CCS) portfolio by supporting three large-scale industrial CCS demonstration projects. According to officials, if all three projects proceed to a final investment decision, they would have the potential to reduce Norway's carbon emissions by five percent. The Norwegian government also announced the approval of a three-year extension of the TCM CCS test facility, with a new agreement on the ownership and operation expected before the end of 2016. From *BusinessGreen* on October 6, 2016. (Subscription may be required.)

First Fully Commercial CCSU Plant Launches Capturing CO_2 at $30 Per [Metric Ton].

Carbon Clean Solutions Limited (CCSL) announced the launching of a new project that will capture more than 60,000 metric tons of CO_2 from a 10-megawatt coal-fired power station in India. Post start-up, the project is expected to capture carbon dioxide (CO_2) at a lower cost than is currently observed per metric ton of CO_2. CCSL successfully completed a pilot-testing program at TCM in May 2016, in which the results showed that use of CCSL's solvent reduced emission levels, lowered corrosion, and improved system reliability. From *Carbon Clean Solutions* on October 11, 2016.

Funding Awarded for Test Program on CO_2 Pipelines.

DNV GL and Energy Pipelines CRC (EPCRC) were awarded funding for a CO_2 pipelines test program. Funded by the Norwegian CLIMIT Programme and the Australian Department of Industry, Innovation, and Science, the test program will address the existing knowledge gaps in the fracture control of high-pressure pipelines by conducting large-scale, fracture-propagation testing of dense-phase CO_2 pipelines at *DNV GL's Spadeadam test site* in the United Kingdom (UK). Scheduled to run from late 2016 to early 2019, the test program, titled "Improving the safety and efficiency of CO_2 pipelines by developing and validating predictive models for CO_2 pipeline design," will look to reduce future costs of CO_2 pipelines while also ensuring the required safety level. From *DNV GL Press Release* on October 20, 2016.

MENA's First CCUS Project Now on Stream.

The first commercial-scale CCUS facility in the Middle East and North Africa (MENA) is operational and capable of storing up to 800,000 metric tons of CO_2 per year, according to officials. Developed by a joint venture between Abu Dhabi National Oil Company (ADNOC) and Masdar, the project captures CO_2 emissions from Emirates Steel Industries (ESI), compresses and dehydrates it, and then transports the CO_2 via underground pipeline for enhanced oil recovery (EOR) injection into ADNOC onshore oilfields. Construction on the project began in July 2013. From *Masdar Press Release* on November 5, 2016.

Lab Upgrade to Help Store Carbon Dioxide Underground.

An X-ray microscopy laboratory at Australian National University (ANU) received a $5 million upgrade. Funded by CO2CRC Limited and the Australian Government's Education Investment Fund, the renovated laboratory is part of the Australian CCS Research Laboratories Network (CCSNET). According to officials, the new facilities enable the building of large-scale computer models that help explain the influence of complex layers of sedimentary rock on the effectiveness of CO_2 storage. From *Australian National University* on November 7, 2016.

DECEMBER 2016

Washington Carbon Capture Project Says it has Permanently Stored CO_2.

The Wallula Basalt Pilot Project in Washington state completed the injection of nearly 1,000 tons of carbon dioxide (CO_2) into the Grande Ronde basalt formation. According to *post-injection findings*, the injected CO_2 remains within the targeted formation and at a depth in the range of 2,720 to 2,786 feet. As part of the project, the CO_2 was injected into underground lava flows where it solidified into a mineral called ankerite. The project is being conducted by the *Big Sky Carbon Sequestration Partnership*, one of *the U.S. Department of Energy's (DOE) Regional Carbon Sequestration Projects (RCSPs)*. From *Utility Dive* on November 22, 2016.

Results Released from CO_2 Monitoring Project.

New data has been released from three subsurface release experiments at the Ginninderra Controlled Release Facility in Canberra, Australia. The datasets, released by Geoscience Australia and CO2CRC Limited, will inform monitoring strategies. The research enabled scientists to simulate the release of atmospheric CO_2 under controlled experiment conditions and assess the performance of different monitoring technologies. The results of the controlled release experiment – which involved releasing a known amount of CO_2 into soil and monitoring how it moves into the atmosphere – found horizontal movement in the near surface. More than 20 monitoring techniques were trialed. The datasets are available for download via *Geoscience Australia's website*. From *Geoscience Australia News Release* on November 16, 2016.

JANUARY 2017

Indian Firm Advances Carbon Capture and Utilization Processes.

An industrial plant in India is capturing carbon dioxide (CO_2) for carbon capture and utilization (CCU) processes. The CO_2 captured from the plant, located at the industrial port of Tuticorin, India, is being used to make baking soda. According to plant officials, approximately 60,000 metric tons of CO_2 per year will be captured at the plant with the use of Carbonclean's technology. From *The Guardian* on January 3, 2017.

Elk Petroleum Acquires Gas Field and Plant.

Elk Petroleum entered an agreement to acquire interest in a gas field and plant located in Wyoming, USA, approximately 60 miles from Elk's Grieve CO_2-enhanced oil recovery (EOR) plant. The Madden Gas Field and Lost Cabin Gas Plant is the second largest supplier of CO_2 into the Northern Rockies CO_2 Gas Transmission and Supply Pipeline Network. The amount of the currently available supply of CO_2 from the Lost Cabin Gas Plant, according to an Elk Petroleum Media Release, is capable of supporting the development of a CO_2-EOR project similar in size to that of *Elk's Grieve project*. From *Proactive Investors* on January 4, 2017.

FEBRUARY 2017

CCS Membrane Technology Licensed.

Air Products and Chemicals, Inc. licensed carbon dioxide (CO_2) membrane technology developed by the Norwegian University of Science and Technology (NTNU). The fixed site carrier membrane will be used by Air Products as part of its PRISM gas-separation membrane technology offerings. According to Air Products' officials, the new technology is expected to benefit coal-fired power plants and the cement industry. From *The Chemical Engineer* on January 16, 2017. (Subscription may be required.)

Enhanced Oil Recovery Joint Industry Project Announced.

The development of work flows and methodology for simulating field-wide CO_2-enhanced oil recovery (EOR) projects will be the focus of Petronas' recent Joint Industry Project (JIP) Agreement. The research and development (R&D) project will include collaboration with researchers from Heriot-Watt University, Petronas Research, and UZMA Berhad, an international oil and gas service company. The study will concentrate on minimizing uncertainties affecting the predictions of hydrocarbon recovery and supporting simulation studies through the acquisition of physical data. Upon completion, the lessons learned will be applied to real field scenarios. From *The Star Online* on February 2, 2017.

MARCH 2017

Pale Blue Dot Energy to Review CO_2 Transport and Storage Business Models.

Pale Blue Dot Energy, energy transition management consultants, were awarded a contract to review business models for carbon dioxide (CO_2) transport and storage. The project will examine models that have been successfully used overseas and for other types of infrastructure, as well as those that have been proposed for the delivery and operation of CO_2 infrastructure in the United Kingdom (UK). Pale Blue Dot Energy, which provides support in CCS, oil and gas transition, and emerging energy systems, was awarded the contract from HMG Department for Business, Energy, and Industrial Strategy (BEIS). From *Pale Blue Dot* on February 8, 2017.

CCS Facility Captures More than 63,000 Metric Tons of CO_2.

The Boundary Dam Power Station's carbon capture and storage (CCS) facility located in Saskatchewan, Canada, captured more than 63,000 metric tons of CO_2 during January 2017, according to a release from SaskPower. The amount captured was 63 percent of the capacity; the 12-month average for the facility was 64 percent. Since start-up, the CCS facility has captured more than 1.3 million metric tons of CO_2. From *Estevan Mercury* on February 10, 2017.

APRIL 2017

CCUS Project Approved in China.

A carbon capture utilization and storage (CCUS) facility has been given final investment approval to begin construction at Xi-an (Shaanxi Province) in China. Yanchang Petroleum CCUS's gasification facility will capture 50,000 metric tons of carbon dioxide (CO_2) per year from Yanchang's chemical plants. When fully operational in 2018, the facility is expected to capture more than 360,000 metric tons of CO_2 per year. From *Global CCS* Institute on March 14, 2017.

Development of CCS Project in Norway.

Norway's EFTA Surveillance Authority (ESA) approved public financing of studies for full-scale carbon capture and storage (CCS) demonstration projects. The Norwegian government presented its CCS strategy in 2014, the goal of which was to realize at least one full-scale CCS demonstration project by 2020. Depending on the results of concept and front-end engineering design (FEED) studies, authorities will decide whether to proceed with a full-scale project. From *EFTA Surveillance Authority Press Release* on March 16, 2017.

Carnegie Mellon University Launches Carbon Emissions Index.

Carnegie Mellon University (CMU), along with Mitsubishi Hitachi Power Systems (MHPS), launched an index that measures CO_2 emissions from the U.S. electrical power generation sector. The Carnegie Mellon Power Sector Carbon Index will track the performance of U.S. power producers, comparing current emissions to historical data collected nationwide for more than two decades. CMU will provide an online resource for a wide variety of power sector emissions data and forecasts. From *Phys.org* on March 20, 2017.

Partnerships Formed for CO_2 Capture and Reuse.

Two separate agreements have been reached that involve CO_2 capture and reuse on a large-scale level. As part of an agreement between CO_2 Solutions Inc. and global engineering firm Hatch Ltd. to deliver carbon capture systems, both companies will also collaborate on the Valorisation Carbone Québec (VCQ) project, which aims to demonstrate CO_2 capture and beneficial reuse on a large-scale level in an industrial facility. In addition, Carbon Clean Solutions Limited (CCSL) and the resource management company Veolia *have formed a partnership* to reduce the greenhouse effect of industrial processes and rollout large-scale CO_2 capture and industrial re-use. From *Gasworld* on March 28 and March 29, 2017.

MAY 2017

Research Institutes Join Forces in CO_2 Storage Project.

European research institutes have joined forces on a project to increase field experience relevant to the geologic storage of carbon dioxide (CO_2). The project, named ENabling ONshore CO_2 storage in Europe (ENOS), will also look to refine techniques and tools used for site selection and to monitor and advance communication between science and society on CO_2 geologic storage. Launched in September 2016 and expected to run through August 2020, ENOS plans to enhance the development of onshore CO_2 storage, and several field pilots in various geologic settings will be studied. Financed by the European Union's (EU) Horizon 2020 Program, ENOS is an initiative of CO_2GeoNet, the European Network of Excellence on the geologic storage of CO_2, and unites 29 organizations across 17 countries. From *Carbon Capture Journal* on April 25, 2017.

CCS Research Center Receives Funding.

The UK Carbon Capture and Storage Research Center (UKCCSRC) announced it will receive funding from the Engineering and Physical Sciences Research Council (EPSRC). The funding will help UKCCSRC ensure CCS plays an effective role in reducing net CO_2 emissions while securing affordable and controllable electricity supplies, low carbon heat, and competitive industries for the UK. The UKCCSRC core activities are delivered by the British Geological Survey, the University of Cambridge, the University of Edinburgh, Imperial College London, the University of Nottingham, and the University of Sheffield. From *UKCCS Research Center* on April 11, 2017.

Contracts Awarded for Carbon Capture.

Gassnova has awarded contracts for three companies to continue CO_2 capture studies with the plan of storing CO_2 from at least one of the facilities under a seabed in the North Sea. The full-scale carbon capture studies will be conducted at facilities located in Oslo, Norway. Statoil conducted a feasibility study and identified the Smeaheia area to the east of the Troll gas field and approximately 30 miles offshore as the storage site. From *Gassnova* on April 19, 2017.

Project Uses Carbon Dioxide Removal Technology.

Petronas launched its Terengganu Gas Terminal in Malaysia, which uses CO_2-removal technology. The terminal, according to Petronas officials, is capable of processing up to 700 million standard cubic feet per day of gas from the Malaysia-Thailand joint development area and from the North Malay Basin offshore Terengganu. Completed ahead of schedule, the project is part of the company's clean energy commitment in support of Malaysia's environmental agenda to reduce its carbon footprint by 2030. From *The Edge Markets* on April 21, 2017.

JUNE 2017

Newly Launched Commercial Plant to Capture Atmospheric CO_2.

Climeworks has launched a commercial plant that captures atmospheric carbon dioxide (CO_2) for supply and sale to customers. The Swiss direct air capture (DAC) company launched the plant, which features technology that filters CO_2 from ambient air. Currently, the plant supplies 900 metric tons of CO_2 a year to a nearby greenhouse. In the coming months, Climeworks will look to launch additional commercial pilot projects to test its technology's potential to be combined with CO_2 storage. From *Climeworks Press Release* on May 31, 2017.

North Dakota Ethanol Plant May Store CO_2 Underground.

An ethanol plant in North Dakota, USA, may store CO_2 underground after recent state government approval allowed ethanol plants to capture and store CO_2. Red Trail Energy is located near the center of the Broom Creek Formation, which is conducive to storing CO_2. According to the Energy and Environmental Research Center (EERC), the geologic formation has the potential to store from 10 billion to 40 billion tons of captured CO_2. The plant is capable of producing approximately 4 million tons of CO_2 over a 20-year span, and approximately 20 million tons of CO_2 over a 100-year span. There is a window for public comment before the primacy to oversee the capture and storage of CO_2 will be passed from the federal government to North Dakota. From *Grand Forks Herald* on June 2, 2017.

CO_2 Capture and Reuse Project Launched.

Officials from CO_2 Solutions Inc. and the Québec government officially launched the Valorisation Carbone Québec project (VCQ), the objective of which is to promote the development and demonstration of commercially viable solutions to capture and reuse CO_2 in applications. CO_2 Solutions announced the formation of the VCQ Scientific Committee, which is made up of scientists from university and private sectors to assess the merits of the CO_2 reuse technologies being considered by VCQ. In addition, the following steps have been taken in the deployment of the program: the 10-ton-per-day capture unit will be moved from its Valleyfield location to the new VCQ testing center located at the Parachem facilities in Montreal and a technology to convert CO_2 into acetic acid has been selected to become part of the VCQ project. From *CO_2 Solutions Press Release* on May 18, 2017.

United Kingdom (UK) and Australian Researchers Sign MOU to Reduce CO_2 Emissions.

The UK Carbon Capture and Storage Research Center (UKCCSRC) and CO2CRC Limited signed a Memorandum of Understanding (MOU) continuing their carbon capture and storage (CCS) collaboration. Signed at the Carbon Sequestration Leadership Forum (CSLF) meeting in Abu Dhabi, the five-year MOU formalizes the two organizations' commitment to share knowledge, collaborate on research, bring research communities together through joint events, and provide researcher exchange opportunities. The new MOU between CO2CRC and UKCCSRC, which recently secured funding to continue its work through 2022, will build upon the achievements under the previous MOU that expired in March 2017. From *UKCCS Research Center News* on May 1, 2017.

JULY 2017

DOE Contract Awarded for Subsurface CO_2 Monitoring.

The U.S. Department of Energy (DOE) awarded a contract to GroundMetrics, Inc. to monitor carbon dioxide (CO_2) in the subsurface in a new project in which the company will develop a continuous monitoring system to measure resistivity changes. While GroundMetrics uses its proprietary resistivity sensors and software for applications such as enhanced oil recovery (EOR), the technology can also be used for mapping CO_2 injection for carbon capture and storage (CCS). If successful, the test will enable companies to better monitor CO_2 saturation, allowing them to improve operational efficiency and efficacy; verify monitoring, verification, and accounting (MVA); and maximize oilfield productivity. From *PR Web* on June 8, 2017.

Statoil Evaluating New CO_2 Storage Project.

Statoil will evaluate the development of carbon storage on the Norwegian continental shelf (NCS). The storage project, which is part of Norway's efforts to develop full-scale CCS, will capture CO_2 from three onshore industrial facilities in Eastern Norway, transporting the CO_2 by ship to a nearby receiving plant. The CO_2 will then be pumped to onshore tanks prior to being sent via pipeline to several injection wells east of the Troll field on the NCS. The final choice for the receiving plant will be based on criteria such as safety, cost, and expansion flexibility. Gassnova assigned Statoil to evaluate the storage solution, which will have the potential to receive CO_2 from Norwegian and European emission sources. From *Carbon Capture Journal* on July 3, 2017.

Grant Signed to Develop CCS Demonstration Project.

The Asian Development Bank (ADB) signed a Memorandum of Understanding (MOU) for a technical assistance grant to develop a large-scale CCS demonstration project. The National Development and Reform Commission (NDRC) of the People's Republic of China (PRC), who signed the MOU along with Yanchang Petroleum Group and Northwest University, had requested ADB to support the development of a Roadmap for CCS Demonstration and Deployment that identified potential early demonstration projects. The Yanchang CCS project was ranked as the closest to being ready and is being considered for a commercial-scale demonstration project by the Shaanxi provincial government. ADB's technical assistance project will address key barriers to large-scale CCS demonstration in the PRC by supporting the front-end engineering design of the Yanchang CCS project, including a feasibility study, environmental and social impact assessments, and monitoring. From *The Financial* on June 6, 2017.

AUGUST 2017

Husky Energy Investing in Pilot Plant.

Husky Energy Inc. is increasing investment in carbon capture and storage (CCS) technology by aiming to develop a plant larger than its current CCS plant at its Pikes Peak South operation. The new plant will be located at the same site as the smaller CCS plant, which was developed by clean energy company Inventys Inc. The carbon dioxide (CO_2) captured from the new project will be used alongside CO_2 recovered from other facilities for enhanced oil recovery (EOR) operations. Expected to be commissioned in late 2018, the plant will utilize Inventys' second-generation CCS technology that captures CO_2 in a solid material rather than a solvent. From *Saskatoon StarPhoenix* on July 14, 2017.

Power Plant Evaluation MOU Includes CCS.

Statoil, Vattenfall, and Gasunie signed an MOU to evaluate converting Vattenfall's gas-powered Magnum plant, located in the Netherlands, into a hydrogen-powered plant. The scope of the MOU also includes the exploration of designing a large-scale value chain where the production of hydrogen is combined with CO_2 capture, transport, and permanent storage. According to a *Statoil press release*, the conversion has a potential CO_2 emission reduction of 4 million tons of CO_2 per year. From *Carbon Capture Journal* on July 17, 2017.

SEPTEMBER 2017

Ultra-High-Resolution 3D Seismic Technology Deployed in DOE/NETL Offshore CO_2 Storage Monitoring Project.

Researchers from the Gulf Coast Carbon Center at the Texas Bureau of Economic Geology conducted an ultra-high-resolution 3D seismic data collection survey off Japan's north island of Hokkaido. The location offshore the industrial port of Tomakomai is the site of an extensive carbon dioxide (CO_2) capture, transport, and offshore injection demonstration project operated by the Japanese Ministry of Economy, Trade, and Industry and an industrial consortium, JCCS Co., Ltd. At the time of the survey, approximately 65,000 tons of CO_2 had been injected into a geologic formation 1,100 meters below the seafloor. Funded through the U.S. Department of Energy (DOE)/National Energy Technology Laboratory's (NETL) Carbon Storage Research Program, the seismic data were collected using technology designed to provide high-resolution 3D data that can be used to characterize the geology above potential CO_2 storage sites. According to the researchers, a high-resolution 3D seismic survey using novel technology at an active offshore CO_2 injection site contributes to national CO_2 storage needs by validating monitoring technologies and reducing potential storage risks. From *DOE Project "Field Validation of MVA Technology for Offshore CCS: Novel Ultra-High-Resolution 3D Marine Seismic Technology (P-Cable)."*

NETL Research Studies CO_2 Interaction with Shale.

NETL researchers are using complex experiments to determine if shale formations can serve as a storage reservoir for CO_2 captured from fossil fuel-burning power plants and other industries. Initial NETL research has shown that injected CO_2 may change the rock's porosity and permeability; understanding these and other effects is key to developing successful carbon storage techniques and achieving more accurate predictions of the formation's storage potential. The research supports DOE's goal to increase the ability to predict CO_2 storage capacity in geologic formations to within ± 30 percent. From *NETL News Release* on September 5, 2017.

Researchers Study Potential Leakage and Related Cost.

A study conducted by researchers from Princeton University shows that CO_2 storage would not be prone to leakage or high costs related to fixing leaks. Based on the levels of leakage at simulated hypothetical subsurface CO_2 storage locations, the researchers found that the cost of the technology, even in worst case scenarios, was not prohibitive. The study, *published in the online journal Climatic Change*, was conducted with modeling based on both the geophysical aspects of CCS (e.g., flow through subsurface geologic formations) and economic modeling of the global energy market, using an integrated assessment model. From *Carbon Capture Journal* on September 1, 2017.

Forest Conservation Project to Benefit Carbon Storage.

The California Department of Forestry and Fire Protection (CAL FIRE) awarded a California Climate Investment grant to Pacific Forest Trust (PFT) for a project that will, among other objectives, promote carbon storage. As part of the multi-partner forest health and conservation project, PFT officials say the project will include higher levels of carbon storage in forests. The California Climate Investment Program reinvests revenue generated by California's cap-and-trade program to reduce greenhouse gas (GHG) emissions. From *Mount Shasta News* on August 17, 2017.

LEGISLATION and POLICY

OCTOBER 2016

California Governor Signs Carbon Legislation.

The Governor of California signed legislation to reduce carbon emissions and establish restrictions on "super pollutants," such as black carbon. The Governor of California will *direct $900 million in cap-and-trade funds to greenhouse gas (GHG) reduction programs* that benefit disadvantaged communities (AB 2722). In addition, the Governor of California signed *SB 1383*, establishing restrictions on "super pollutants" with the aim of reducing the projected rate of potential climate change by 2050. For more information, view a video of the *SB 1383 bill signing*, or read the Governor's signing messages for *AB 2722* and *SB 1383*. From *Governor Edmund G. Brown, Jr., Press Releases* on September 14 and September 19, 2016.

State of Washington Adopts Climate Change Rule.

The State of Washington's Department of Ecology adopted a clean air rule that caps and reduces carbon emissions. Under the rule, businesses responsible for emitting 100,000 metric tons of carbon dioxide (CO_2) per year will be required to cap and gradually reduce their emissions. Businesses unable to reduce their emissions have the option of developing projects, such as an energy efficiency program, or buying carbon credits from approved carbon markets. The new plan relies on businesses trading independently among themselves and with other markets. More information on the Clean Air Rule is available on the *Washington Department of Ecology's website*. From *Washington Department of Ecology News Release* on September 15, 2016.

Oslo Sets Out Climate Budget to Halve Carbon Emissions in Four Years.

Oslo, Norway, issued a new climate budget that aims to reduce its carbon emissions within the next four years. In addition, the city is researching clean energy technologies such as CCS; in early 2016, Aker Solutions conducted a CO_2-capture experiment at Oslo's main waste incineration plant. Oslo's target is to reduce CO_2 emissions from 1.2 million metric tons in 1990 to 600,000 metric tons annually by 2020. From *Business Green* on September 29, 2016.

NOVEMBER 2016

Legislation Introduced to Encourage Carbon Storage.

A bill, titled "CO_2 Regulatory Certainty Act of 2016," was introduced to encourage carbon storage. The bill aligns tax guidelines with existing federal regulations to ensure taxpayers are better able to utilize the Section 45Q carbon storage tax credit. From *U.S. Senator For Montana Steve Daines Press Release* on October 5, 2016.

Vietnam Commits to [Reductions] in Greenhouse Gas Emissions by 2030.

According to officials, Vietnam has reaffirmed its commitment to an eight percent reduction in greenhouse gas (GHG) emissions by 2030, with the potential to achieve a 25 percent reduction with additional support. The country will apply various methods to reach its GHG reduction goals and encourage green industry development, and will also conduct research to form a national carbon trading market. Vietnam announced its emission goal in 2015 when it submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change. From *VnExpress International* on October 19, 2016.

UNFC Specifications for CO_2 Storage Have Been Approved.

Specifications have been developed for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC) to geologic storage projects. The specifications, developed by the United Nations Economic Commission for Europe (UNECE), are now operational following approval by UNECE's Committee on Sustainable Energy. The Oil and Gas Climate Initiative and the Society of Petroleum Engineers are working on a Storage Resource Management System that will align with the UNFC specifications. *More information on the application of UNFC-2009 to geologic storage projects is available on the UNECE website*. From *Carbon Capture Journal* on November 3, 2016.

DECEMBER 2016

EU Aims to Reduce CO_2 Emissions by 2030.

The European Union (EU) announced its commitment to reduce carbon dioxide (CO_2) emissions by at least 40 percent by 2020, and presented a package of legislative proposals to accelerate clean energy innovation and provide measures to encourage public and private investment. The proposals, titled "Clean Energy for All Europeans," cover energy efficiency, renewable energy, electricity market design, electricity supply security, and governance rules for the EU. From *Global Times* on December 1, 2016.

Saskatchewan, Ottawa Strike Accord on Coal-Fired Power Generation.

The government of Saskatchewan reached a deal on reducing greenhouse gas (GHG) emissions in Saskatchewan's coal-fired power sector. According to the Saskatchewan Environment Minister, Saskatchewan could keep coal-fired power plants operating past 2030 if the province makes GHG reductions elsewhere in the electricity sector. The agreement follows a federal plan released in November 2016 that called for the phase-out of coal-fired electricity as part of Canada's commitment to reduce GHG emissions by 30 percent from 2005 levels by 2030. From *The Globe and Mail* on November 28, 2016.

Legislator Proposes Carbon Tax Bill for 2017 General Session.

A Utah State Representative will propose a carbon tax during the 2017 legislative session. The bill would be revenue neutral and funding from the proposed tax could be used for education or infrastructure initiatives, according to the press release. From *UtahPolicy.com* on December 1, 2016.

Japan's CO_2 Emissions Drop to Five-Year Low in FY 2015.

According to data released by the Japanese Ministry of Environment, Japan's GHG emissions were reduced three percent to 1.321 billion metric tons of CO_2 equivalent in FY 2015, a five-year low. Japan set a goal to reduce its GHG emissions by 26 percent from 2013 levels by 2030. From *Japan Today* on December 7, 2016.

JANUARY 2017

Canada Agrees on National Carbon Price.

The Canadian government reached a deal with 8 of the 10 Canadian provinces to introduce a national carbon price. Part of a framework to help Canada reach its goal of reducing CO_2 emissions by 30 percent from 2005 levels by 2030, the carbon price is accompanied by measures that also include increasing the use of renewable energy and investing in clean technologies. Under the plan, CO_2 emissions would cost $7.60 per metric ton in 2018, increasing by $7.60 a year until it reaches approximately $30 per metric ton in 2022. The provinces can either implement a carbon tax or a cap-and-trade market. From *Reuters* on December 9, 2016.

FEBRUARY 2017

South Korean Government Added to Carbon Emissions Rights.

The South Korean government increased its carbon emissions quota to a total of 539 million tons and added 51 million tons to emission rights prior to the implementation of emissions trading. In addition, the government voted for its second three-year emission-trading plan, which will take place in 2018 to 2020. Under the plan, greenhouse gas (GHG) emission rights will be allocated in return for a payment equivalent to three percent of allowance. From *Business Korea* on January 25, 2017.

Hawaii Approves Carbon Credits Initiative.

The Hawaii State Board of Land and Natural Resources (BLNR) approved a carbon offset project in the state's forests. Hawaii's Department of Land and Natural Resources (DLNR) and its Division of Forestry and Wildfire (DOFAW) will issue a request for proposal (RFP) for private entities to create a carbon forestry project in the Pu'u Mali Restoration Area in the Mauna Kea Forest Reserve on Hawaii island. In addition, DLNR is in the process of creating a carbon offset pilot project in southern Maui. From *Hawaii Department of Land and Natural Resources News Release* on January 30, 2017.

Malaysia Carbon Credit Firm to Offset CO_2 Emissions.

As part of a United Nations' (UN) collaborative program, a Malaysian carbon credit rating company received 25 percent of the land mass in Kelantan, Malaysia, for use in reducing carbon dioxide (CO_2) emissions. A renewable and sustainable energy company received the project under UN's Reducing Environment from Deforestation and Degradation (REDD) initiative for a 30-year concession period with the Kelantan government. According to officials, the program will look to reduce forest emissions and enhance CO_2 stocks in the forest while contributing to national sustainable development. From *Free Malaysia Today* on February 1, 2017.

MARCH 2017

St. Paul Launches Climate Action Plan Effort to Become Carbon Neutral.

Government officials in St. Paul, Minnesota, USA, are launching an effort to draft a Climate Action Plan with a goal of becoming carbon neutral by 2050. Officials aim to have a finalized Climate Action Plan by the end of 2017. In the coming months, a series of meetings will be held to gather input and suggestions from the public. From *Star Tribune* on February 25, 2017.

Australia State Passes Bill to Reduce Emissions.

A bill was passed by legislature in Victoria, Australia, that commits the state to reduce its emissions by 2050. *The Victoria Bill* presents options for the state to reduce emissions, such as participating in an emissions trading scheme or adopting carbon capture measures. Once they receive feedback from experts, the Victoria government will provide opportunities to work toward the 2050 goal. From *Ammonia21* on February 24, 2017.

APRIL 2017

Bill Would Create Commission in Alaska.

A bill (*House Bill 173*) was introduced in Alaska legislature that would establish a 15-member commission to apply for grants, monitor climate, promote green technologies, and look for ways to reduce greenhouse gas (GHG) emissions. From *Alaska Dispatch News* on March 12, 2017.

Bill Introduced to Help Finance CCS Projects.

U.S. Senators introduced a bill to help power plants and industrial facilities finance the purchase and installation of carbon capture and storage (CCS) equipment. The bill, "The Carbon Capture Improvement Act of 2017," would allow businesses to use government-issued private activity bonds (PABs) to finance their projects. More specifically, the legislation would look to improve the economic feasibility of CCS projects and increase oil production through enhanced oil recovery (EOR). From *U.S. Senator Michael Bennet Press Release* on April 5, 2017.

Initiative Launched to Reduce Emissions.

Comeos, the Belgian trade federation, teamed up with ENGIE, a multinational electric utility company, on an initiative to reduce CO_2 emissions in the Belgian retail sector. The initiative will look to reduce CO_2 emissions through the promotion of solar energy and energy-efficient solutions. The collaboration follows an undertaking by businesses in the region to reduce carbon dioxide (CO_2) emissions by 30 percent by 2025, and to double current renewable energy production by 2020. From *European Supermarket Magazine* on March 20, 2017.

Oregon Lawmakers Introduce Carbon Pricing Legislation.

Lawmakers in the Oregon Senate and House introduced legislation to create a statewide cap-and-trade program. The "*Healthy Climate Act of 2017*" will aim to repeal 2007 emissions goals, establishing new goals in which emissions would be reduced 20 percent below 1990 levels by 2025. In addition, the new proposal would impose a statewide limit of 45 percent below 1990 levels by 2035 and 75 percent below 1990 levels by 2050. From *Lexology* on March 29, 2017.

MAY 2017

Carbon Removal Studies to Inform Policy.

The University of Edinburgh School of GeoSciences will conduct carbon-removal studies that will be used to inform policy. The first project, Metrics for Emissions Removal Limits for Nature (MERLiN), will use models to investigate the impacts of reducing emissions now or in the future. In the second project, researchers will assess the global potential for using soil to store carbon dioxide (CO_2) removed from the atmosphere. From *The University of Edinburgh* on April 21, 2017.

Tax to Reduce GHG Emissions.

The House Committee on Appropriations in the Philippines authored a bill to help reduce greenhouse gas (GHG) emissions by passing a law imposing a tax on CO_2. House Bill (HB) 4939 follows Singapore's lead, which will begin taxing the emissions of CO_2 and other GHGs starting in 2019. HB 4939 seeks to impose a tax on the electricity bills of residential or household consumers. From *Business Mirror* on April 16, 2017.

JUNE 2017

Executive Action Signed to Reduce Carbon Emissions in Virginia.

The Governor of Virginia signed an executive directive instructing the Department of Environmental Quality to begin the process of establishing regulations that will reduce carbon emissions from power plants. *Executive Directive 11* follows Executive Order 57, which required the Secretary of Natural Resources to convene a work group to study and recommend methods to reduce carbon emissions and build the state's clean energy economy. In addition, Executive Directive 11 includes a structure that enforces carbon-reduction mechanisms. From *Governor Terry McAuliffe News Release* on May 16, 2017.

Commonwealth Legislation to Support CCS Financing.

The Australian government's Commonwealth Minister for the Environment and Energy *announced* that the Clean Energy Finance Corporation (CEFC) will now be allowed to support investment in CCS technologies. The CEFC Act had previously considered carbon capture and storage (CCS) ineligible for investment. The CEFC is a fund established to facilitate increased flows of finance into Australia-based renewable energy, energy efficiency, and low-emissions technologies. From CO2CRC *Media Release* on May 30, 2017.

JULY 2017

Bill to Expand Federal Tax Credits for Storage.

A forthcoming bill will look to extend tax credits for carbon capture, as well as expand the federal reward for storage and re-utilization of captured carbon. Carbon stored underground is currently rewarded with a $20/ton credit, while captured carbon used for enhanced oil recovery (EOR) receives $10/ton. The new measure would look to increase the credits to $45 and $35 per ton, respectively. In addition, the current statute places a 75-million-ton cap on the amount of captured carbon that qualifies for a tax credit; the new legislation would remove the cap and provide incentive for companies to invest in capture technologies. From *Morning Consult* on June 6, 2017.

Sweden Aims to Reduce Emissions by 2045.

The Swedish government passed new policy framework to become a net-zero emitter of greenhouse gases (GHGs) by 2045. Based on the agreement in the Cross-Party Committee on Environmental Objectives last year, this follows a bill on the policy framework setting new goals alongside a policy council and an act introduced in March 2017. The new act is expected to come into effect in 2018, with the first action plan to be submitted in 2019. From *CTBR* on June 19, 2017.

Carbon Storage MOU Signed.

Officials from Iran's Forests, Range, and Watershed Management Organization and the United Nations Industrial Development Organization (UNIDO) signed a Memorandum of Understanding (MOU) for the third phase of an international carbon storage program in four Iranian provinces. The MOU is expected to cover five regions in Yazd, North Khorasan, South Khorasan, and Golestan Provinces. The carbon storage project started in Iran in North Khorasan Province and is currently being implemented in approximately 300 other villages. From *Middle East North Africa Financial Network* on June 17, 2017.

AUGUST 2017

U.S. and Mexico Strengthen North American Energy Cooperation.

Representatives from the United States and Mexico have identified common goals for a trilateral agenda with Canada to accelerate the development of untapped resources, increase energy trade, and enhance the security of their energy systems. A potential point of emphasis could be furthering the three countries' mutual interest in carbon capture and storage (CCS) technology. From *Platts* on July 13, 2017.

Carbon Capture and Utilization Bill Introduced.

A bill supporting the CCS industry was introduced, in which tax credits would be extended and increased for power generators and industrial facilities that capture and store their own carbon dioxide (CO_2), as well as for carbon utilization. The *Carbon Capture and Utilization Act* would provide a $40 tax credit for every metric ton of CO_2 stored underground, and a $35 per ton credit for CO_2 utilized for purposes such as enhanced oil recovery (EOR). Credits of $20 and $10 per ton are currently offered for capture and utilization, respectively. From *Utility Dive* on July 13, 2017.

California Lawmakers Approve Policy Extension.

The California legislature passed a package of bills that extends the state's plan to address greenhouse gas (GHG) emissions by a decade. The legislation extends California's cap-and-trade program through 2030 and includes requirements for large industrial facilities to upgrade old equipment by 2023. In addition, the new package seeks to reform California's existing cap-and-trade market by reducing the number of free carbon allowances by 40 percent by 2030 and requiring offsets be sourced from within the state. From *Reuters* on July 17, 2017.

Renewable Energy Bill Introduced.

Legislation that would transition the United States to 100 percent clean and renewable energy by 2050 was introduced in the U.S. House of Representatives. The "*100 by '50 Act*" has seven core components, one of which includes investment in carbon storage. A *one-page summary of the bill* is available. From *U.S. Representative Jared Polis Press Release* on July 19, 2017.

SEPTEMBER 2017

New Regulations to Reduce GHG Emissions.

Massachusetts introduced new regulations that will bring the state into full compliance with the state law calling for a 25 percent reduction in greenhouse gas (GHG) emissions by 2020. Among the new set of rules are clean energy requirements for utilities and reductions in carbon dioxide (CO_2) emissions from electricity-generating plants. In addition to the 2020 target of a 25 percent reduction in emissions relative to 1990 levels, the state law also sets an 80 percent reduction goal by 2050. From *Sentinel and Enterprise* on August 11, 2017.

CO_2 Storage Legislation Reintroduced.

The *CO_2 Regulatory Certainty Act*, which encourages CO_2 storage, has been reintroduced. The legislation looks to ensure taxpayers are better able to utilize the Section 45Q carbon storage tax credit by aligning tax guidelines with existing federal regulations. While project developers can currently claim credit for CO_2 storage, the Internal Revenue Service (IRS) does not provide guidance that reflects differences between permanent or geologic storage and enhanced oil and gas recovery. This legislation will look to clarify and align IRS guidelines with current U.S. Environment Protection Agency (EPA) regulations, which reflect the differences between oil and gas recovery and geologic storage. From *U.S. Senator John Hoeven News Release* on August 2, 2017.

EMISSIONS TRADING

OCTOBER 2016

Canada to Impose Carbon Taxes Nationwide.

Canada's Environmental Minister announced that the federal government is planning to impose taxes on carbon dioxide (CO_2) emissions across provinces that do not enact them. Provinces will have the first opportunity to determine how to reduce their greenhouse gas (GHG) emissions and establish their own prices on carbon through taxes or cap-and-trade programs. Four provinces (British Columbia, Alberta, Ontario, and Québec) currently have either carbon taxes or cap-and-trade systems, leaving six provinces that would either implement a regulation or be subject to the federal system. From *The Hill* on September 19, 2016.

RGGI Report: Investments Generate Savings, Reduce [Emissions].

The nine Regional Greenhouse Gas Initiative (RGGI)-participating states released a report tracking the cumulative investment of proceeds generated by RGGI's regional CO_2 allowance auctions through 2014. According to the report, titled "*The Investment of RGGI Proceeds through 2014*," $1.37 billion in RGGI proceeds have been invested in programs such as energy efficiency, clean and renewable energy, and GHG abatement. The report also estimates the investments are projected to save approximately 76.1 million MMBtu of fossil fuels and 20.6 MWh of electricity, avoiding the release of 15.4 million tons of carbon emissions. From *RGGI News Release* on September 26, 2016.

NOVEMBER 2016

Sweden Proposes Measures to Strengthen Carbon Prices.

Sweden has proposed measures to strengthen carbon prices from 2020 and to address the excess credits in the European Union's (EU) Emissions Trading System (ETS), the country's climate minister announced. The proposals were presented to 13 EU environment ministers with the aim of capping carbon emissions. The proposals include removing some of the surplus of allowances via the EU ETS Market Stability Reserve (MSR), eliminating permits above a set ceiling, and possibly introducing an expiration date to cancel surplus permits after five years. From *Daily Mail Online* on October 17, 2016.

EPA Finalizes Voluntary CO_2 Trading Model for Clean Power Plan.

A voluntary carbon-trading model for Clean Power Plan compliance was finalized by the U.S. Environmental Protection Agency (EPA) and sent to the Office of Management and Budget (OMB) for review. Under the program, states could comply with the federal carbon regulations by entering an optional cap-and-trade program for emissions, earning additional credit for early investments in alternative energy through a finalized *Clean Energy Incentive Program*. From *Utility Dive* on November 7, 2016.

DECEMBER 2016

Results of 34th RGGI Auction Released.

The Regional Greenhouse Gas Initiative (RGGI)-participating states announced the results of their 34th auction, the fourth and final of 2016, in which 14,791,315 carbon dioxide (CO_2) allowances were sold at the auction clearing price of $3.55. Bids for the CO_2 allowances ranged from $2.10 to $13.75 per allowance, and the auction generated $52.5 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and greenhouse gas (GHG) abatement. To date, total proceeds from all RGGI CO_2 allowance auctions exceed $2.6 billion. In addition, 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 levels ($8.00 in 2016; $10.00 in 2017). Additional details are available in the "*Market Monitor Report for Auction 34*." From *RGGI Press Release* on December 9, 2016.

Meadow Restoration Studied for Potential to Build Carbon Credits in California.

Scientists from the Soil Science Laboratory at the University of Nevada, Reno, are studying the Sierra Nevada mountain meadows with a goal of developing a model that can predict the amount of CO_2 stored in a meadow. The data gathered has the potential to be used by the California Air Resources Board (CARB) to sell carbon credits through California's cap-and-trade program, which sets to reduce the state's GHG emissions to 1990 levels by 2020. If the research shows meadow restoration has the potential to store CO_2, the cap-and-trade program could permit landowners who restore a meadow area to sell carbon credits, thus offsetting the costs of restoration. From *University of Nevada, Reno*, on December 8, 2016.

JANUARY 2017

EU Lawmakers Adopt Draft Reform of Carbon Market.

European Parliament Environment Committee lawmakers adopted a draft proposal to reform the carbon market after 2020. The draft includes a higher rate at which permits should be removed from the market; an additional draft proposal was endorsed, which will double the rate the Market Stability Reserve (MSR) absorbs excess allowances. From *Euro News* on December 15, 2016.

FEBRUARY 2017

California Offers Plan to Extend Cap-and-Trade Program.

A group of California lawmakers introduced legislation to extend the state's cap-and-trade program. *AB 151* focuses on the future of California's program for requiring companies to purchase emission credits in order to emit greenhouse gases (GHGs) into the atmosphere. From *The Los Angeles Times* on January 12, 2017.

MARCH 2017

European Parliament Adopts Carbon Market Draft Reform.

The European Parliament supported draft reforms of the carbon market post-2020, aligning with the European Commission's proposal for the emissions cap to decrease by 2.2 percent per year. The assembly's environmental committee's lawmakers will begin discussions with the European Union (EU) member states to finalize the legislation. From *Reuters* on February 15, 2017.

China to Launch Carbon Market.

China is expected to launch its emissions trading system (ETS) later this year. The country has launched seven pilot regional carbon trading markets since 2013 (in Beijing, Tianjin, Shanghai, Guangdong, Shenzhen, Hubei, and Chongqing), covering a range of industrial sectors. According to a report by the China Beijing Environment Exchange and the Beijing Emission Trading Association, the cumulative trading volume of the seven pilot markets (as of December 31, 2016) was 160 million tons. From *China Daily* on February 16, 2017.

Singapore to Implement Carbon Tax.

Singapore's government announced plans to implement a carbon tax from 2019 as part of efforts to reduce greenhouse gases (GHGs). The tax is expected to be in the range of $10 to $20 per metric ton of GHG emissions, and revenue generated will be used to fund measures by industries to reduce emissions, as well as potential opportunities in industries such as clean energy. From *The Straits Times* on February 20, 2017.

APRIL 2017

Results of RGGI's CO_2 Auction.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of their 35th auction of CO_2 allowances, in which 14,371,300 carbon dioxide (CO_2) allowances were sold at a clearing price of $3.00. None of the 10 million cost containment reserve (CCR) allowances made available were sold; the CCR is a fixed additional supply of allowances only made available if the CO_2 allowance prices exceed certain price levels. The first auction of 2017, the auction generated $43.1 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and greenhouse gas (GHG) abatement programs. To date, cumulative proceeds from all RGGI CO_2 allowance auctions exceed $2.68 billion. From *RGGI News Release* on March 10, 2017.

Ontario Announces Results of First Cap-and-Trade Auction.

The Ontario Ministry of the Environment and Climate Change announced the results of the province's first auction of GHG allowances, in which 25,296,367 current allowances and 812,000 future allowances were sold. The proceeds generated from the cap-and-trade program auction will be invested in programs that will help reduce GHG emissions. The auction was administered using services contracted by the Western Climate Initiative (WCI); to ensure market integrity, an independent market monitor was also utilized. A *summary report of the results* of the auction has been made available. From *Ontario Ministry of the Environment and Climate Change News Release* on April 3, 2017.

MAY 2017

Report Estimates Tax May Aid in Emission Reduction.

According to a report published by Lux Research, Canada's carbon tax plans have the potential to generate $120 billion in tax revenues by 2030. Beginning in 2022, a Canada-wide carbon tax of $50 per metric ton will implemented. The government is currently planning to directly invest $1.8 billion from its federal budget in clean technology companies. From *Financial Post* on April 20, 2017.

JUNE 2017

Results of RGGI's CO_2 Auction.

The Regional Greenhouse Gas Initiative (RGGI)-participating states announced the results of their 36th auction of carbon dioxide (CO_2) allowances, in which 14,597,470 CO_2 allowances were sold at a clearing price of $2.53. None of the 10 million cost containment reserve (CCR) allowances made available were sold; the CCR is a fixed additional supply of allowances only made available if the CO_2 allowance prices exceed certain price levels. The second of 2017, the auction generated $36.9 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and greenhouse gas (GHG) abatement programs. To date, cumulative proceeds from all RGGI CO_2 allowance auctions exceed $2.7 billion. From *RGGI News Release* on June 9, 2017.

JULY 2017

China May Limit Carbon Market Launch.

According to China's National Center for Climate Change Strategy and International Cooperation, China may limit its first stage of the launch of its nationwide carbon trading scheme to four sectors – power generation, cement, aluminum, and aviation. The nationwide launch of the national emissions trading platform was originally scheduled to also include the iron and steel, petrochemicals, chemicals, and papermaking sectors. China, which has already launched seven pilot regional trading schemes, is expected to launch the nationwide platform later this year. From *Nasdaq via Reuters* on June 30, 2017.

Nordics Consider Alternative to EU Emissions Trading System.

A Nordic carbon price floor may be introduced to secure future green investments in the region, according to a strategic review by the Nordic Council, a geo-political inter-parliamentary forum for cooperation between Nordic countries. Talks of the potential plan came after representatives from the European Union (EU) member states, the European Parliament, and the European Commission met to discuss how the EU Emissions Trading Scheme (ETS) should look in the 2021 through 2030 timeframe. From *euobserver* on June 28, 2017.

AUGUST 2017

Emissions Trading on South Korea's Climate Agenda.

According to the South Korean government, the country will rely on its cap-and-trade program to meet its goals for reducing greenhouse gases (GHGs). Established in 2015, South Korea's emissions trading system (ETS) covers approximately two-thirds of the country's national GHG emissions. The second phase of the system's implementation, which will take place from 2018 through 2020, will introduce foreign credits. The third phase launches in 2021. From *Bloomberg BNA* on July 20, 2017.

New Zealand Government to Reopen ETS.

The New Zealand government will reopen their ETS to international carbon credits, officials announced. In a range of ETS-related decisions, officials also announced the intention to control the number of New Zealand Units (NZUs) of carbon by putting up predetermined quantities for auction, removing the $25 per metric ton upper limit on the price of a metric ton of New Zealand carbon. New Zealand's ETS had been closed to international markets since 2015. From *The National Business Review* on July 26, 2017.

SEPTEMBER 2017

RGGI States Announce Proposed Program Changes.

The states participating in Regional Greenhouse Gas Initiative (RGGI) announced a set of draft program elements to guide them on the final economic analysis and to help establish a post-2020 path forward for the program. The RGGI states propose a regional cap trajectory that will provide an additional 30 percent cap reduction by 2030, relative to 2020 levels. In addition, the proposal also includes: additional adjustments to the RGGI cap to account for the full bank of excess allowances at the end of 2020; modifications to the Cost Containment Reserve (CCR); and the implementation of an Emissions Containment Reserve (ECR) in 2021, which would allow states to withhold allowances from circulation to secure additional emission reductions if prices fall below established trigger prices. From *RGGI News Release* on August 23, 2017.

China to Launch Carbon Emissions Market.

According to a report by *Scientific American*, China's National Development and Reform Commission (NDRC) plans to establish a national carbon-trading system and launch a carbon emissions market. NDRC stated in a report that a carbon emissions quota control system will be applied to manage the cap-and-trade program, and that a state and local two-level management system will be set up for the emissions market. From *China Daily* on August 16, 2017.

Governments Look to Increase Carbon Trading.

Officials from 26 governments have agreed to "renewed cooperation" on carbon trading markets as part of efforts to reduce greenhouse gas (GHG) emissions. The governments, which include Mexico, European Union (EU) member states, California, and the United Kingdom, released the *joint statement* following a meeting of policymakers in Lisbon, Portugal. Organized by the International Carbon Action Partnership (ICAP), the event brought policymakers from around the world together to discuss best practices on carbon markets. From *BusinessGreen* on September 4, 2017.

CLIMATE and SCIENCE NEWS

OCTOBER 2016

Asphalt-Based Carbon-Capture Material Advances.

Researchers from Rice University have developed a method to turn asphalt into a porous material that can store 154 percent of its weight in carbon dioxide (CO_2) at high pressures that are common at gas wellheads. Initial field tests conducted in 2015 found that pressure at the wellhead made it possible for a Rice-developed asphalt material, capable of being used in place of amines to remove CO_2 from natural gas, made it possible to adsorb 114 percent of its weight in CO_2 at ambient pressures. The new form of the material, detailed in a study titled "*Ultra-High Surface Area Activated Porous Asphalt for CO_2 Capture through Competitive Adsorption at High Pressures*" and published in the online journal Advanced Energy Materials, is less expensive and therefore more practical for industry. From *Rice University News Release* on September 12, 2016.

Scientists Uncover Surprising Source of Carbon Storage.

A team of researchers from Asia, Africa, and Europe conducted a study that quantifies the role trees on agricultural land play in storing CO_2. Published in the online journal Scientific Reports, the study used estimates of global farmland tree cover derived from remote sensing observations and calculated the amount of CO_2 captured and stored by trees growing on farmland. The researchers found that when CO_2 stored by the trees was included, the total carbon storage for agricultural land measured more than four times higher than current Intergovernmental Panel on Climate Change (IPCC) default values. The study, titled "*Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets,*" found that as the world's forest resources decline, tree cover on agricultural land is expanding. From *Ensia.com* on September 19, 2016.

Soil will absorb less atmospheric carbon than expected this century, study finds.

Scientists from the University of California, Irvine, found that the ground might absorb less atmospheric CO_2 this century than previously thought. By adding highly accurate radiocarbon dating of soil to standard Earth system models, using carbon-14 data from 157 sample sites, researchers determined that current soil carbon is approximately 3,100 years old (previous models hypothesized soil carbon to be 450 years old). Through photosynthesis, plants absorb CO_2 from the air; when they die and decay, they become part of the soil and "lock in" carbon on or beneath the surface. Since this process takes place over millennia as opposed to decades or centuries, the researchers expect less of this type of geologic carbon storage in the 21st century than previous Earth system models had suggested. From *ScienceDaily* on September 22, 2016.

NOVEMBER 2016

Nano-Spike Catalysts Convert Carbon Dioxide Directly into Ethanol.

Scientists at the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) developed an electrochemical process capable of turning carbon dioxide (CO_2) into ethanol. Using a catalyst made up of carbon, copper, and nitrogen, the research team triggered a complicated chemical reaction by applying voltage, essentially reversing the combustion process. The CO_2 solution dissolved into water and turned into ethanol with a yield of 63 percent. Initial analysis claims the surface of the catalyst provides reactive sites to facilitate the CO_2-to-ethanol conversion and, given the technique's reliance on low-cost materials and the ability to operate at room temperature, that the process could be scaled up for industrially relevant applications. From *Oak Ridge National Laboratory News Release* on October 12, 2016.

Forest Carbon Storage Pilot Project Launched.

A 1.2-million-acre Ghanaian forest carbon storage pilot project was launched for new tradable forest carbon products. The planetary-scale project for the diverse forests of Ghana features direct continuous monitoring of greenhouse gases (GHGs) for new trading products benefiting ecosystems, indigenous people, and stakeholders. From *PR Web* on November 7, 2016.

Record Growth in Atmospheric CO_2 Despite Stable Anthropogenic Emissions.

According to model simulations, atmospheric CO_2 levels exceeded 400 parts per million (ppm) in 2015, which is 44 percent above pre-industrial levels and the highest level in at least the last 800,000 years. Despite no growth in CO_2 emissions for the third straight year, researchers believe the growth in atmospheric CO_2 concentration was caused by a smaller uptake of carbon in the terrestrial biosphere in response to warm and dry conditions over tropical land (caused by the El Niño event from May 2015 to June 2016). Reported emissions cannot be verified with independent data due to an inability to account for carbon fluxes in the natural environment; researchers believe it to take 5 to 10 years before global emissions can be confirmed with independent data. From *Phys.Org* on November 15, 2016.

DECEMBER 2016

Research Published on Soil's Potential Impact on Atmospheric CO_2.

According to a study conducted by researchers from Kansas State University and the Konza Prairie Biological Station, soils may have the potential to release large amounts of carbon dioxide (CO_2) in response to potential higher temperatures. Using data from 49 sites in different ecosystems around the world, the researchers claim that Arctic soils containing large amounts of soil carbon are the most sensitive to potential higher temperatures and will release the most CO_2 into the atmosphere. Published in the online journal Nature, the study, titled "*Quantifying global soil carbon losses in response to warming,*" also found that CO_2 stored in temperate grassland soils, such as Konza Prairie, is less sensitive to comparable temperatures. From *EurekAlert!* on December 7, 2016.

NASA Announces First Geostationary Vegetation, Atmospheric Carbon Mission.

The National Aeronautics and Space Administration (NASA) will measure greenhouse gases (GHGs) from space to advance understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean. Among the primary goals of the Geostationary Carbon Cycle Observatory (GeoCARB) is to probe the natural sources, sinks, and exchange processes that control GHGs, such as CO_2, in the atmosphere. GeoCARB will measure the daily total concentration of CO_2, among other GHGs, in the atmosphere over the Americas from an orbit of approximately 22,000 miles above the equator. From *NASA Press Release* on December 6, 2016.

Study Shows Grassland Environmental Contributions.

Researchers at the University of Alberta and Alberta Environment and Parks studied the effects of land use and grazing on soil carbon levels, finding that grasslands have the capability of storing large amounts of CO_2. The study, conducted at the Rangeland Research Institute at the University of Alberta, Canada, involved 144 grassland enclosures (both grazed and ungrazed sites) and ran from 2013 through 2016. The effects of livestock grazing on the carbon nutrient cycling in the grasslands of central and southern Alberta were measured, and the study found that grazing could provide the opportunity to enhance and maintain soil carbon pools. From *Manitoba Co-operator* on December 7, 2016.

JANUARY 2017

Scientists Measure Pulse of CO_2 Emissions During Spring Thaw in the Arctic.

In collaboration with a team of researchers, scientists from *the U.S. Department of Energy's (DOE) Lawrence Berkeley National Laboratory (LBNL)* have quantified the scale of carbon dioxide (CO_2) release from soil in the frozen arctic tundra once it begins to melt. The study, which used measurements from both the field and the lab, was based on a 2014 spring pulse in northern Alaska, USA, that included CO_2 emissions equivalent to 46 percent of the net CO_2 absorbed in the summer months. The study was a project of *DOE's Next-Generation Ecosystem Experiment (NGEE-Arctic)*, which seeks to gain a predictive understanding of the Arctic terrestrial ecosystem's feedback to climate. Findings of the study were published in a paper, titled "*Large CO_2 and CH_4 emissions from polygonal tundra during spring thaw in northern Alaska,*" in the online journal Geophysics Research Letters. From *Lawrence Berkeley National Laboratory* on December 14, 2016.

NASA Reveals 3-D Visualization of Earth's CO_2 Levels.

The National Aeronautics and Space Administration (NASA) *released a video* representing a 3-D view of Earth's CO_2 levels. The data was gathered by the Orbiting Carbon Observatory satellite (OCO-2), which collected worldwide CO_2 levels from September 1, 2014, through August 31, 2015. The data was used along with a high-resolution weather model to reveal the movements of CO_2 across the world. Scientists then developed a model of the atmospheric CO_2 behavior from the timeframe the data was collected. From *International Business Times* on December 14, 2016.

China Launches CO_2 Monitoring Satellite.

China launched a CO_2 monitoring satellite to contribute to global research on potential climate change. Launched from the Jiuquan Satellite Launch Center in Northwest China' Gansu Province, the TanSat satellite was sent into orbit approximately 430 miles above Earth and will monitor the concentration, distribution, and flow of atmospheric CO_2. TanSat will observe global CO_2 levels every 16 days during its 3-year mission. From *Global Times* on December 22, 2016.

FEBRUARY 2017

Company Designs Carbon-Neutral Concrete.

A company led by McGill University developed technology that has the potential to store carbon dioxide (CO_2) emissions while also eliminating them from the cement manufacturing process. The company, Carbicrete, formulated a method to produce concrete that utilizes a process called "carbonation activation." During the process, the CO_2 is injected into the concrete while it is malleable. When placed inside a pressurized chamber, the permanent storage of CO_2 within the material results in carbon-negative concrete that is more durable than conventional concrete. From *McGill Tribune* on January 24, 2017.

Research Shows Coastal Wetlands Excel at Storing Carbon.

According to research conducted by University of Maryland scientists, intact coastal wetland ecosystems (e.g., mangrove forests, tidal marshes, seagrass meadows) are effective long-term carbon storage systems. In a research paper published in the journal *Frontiers in Ecology and the Environment*, the researchers noted that coastal wetlands have the potential to protect coastal communities from storm surges and erosion. The study was conducted by integrating previous data on a variety of coastal and marine ecosystems. By evaluating how each ecosystem captured CO_2 and how long it was stored, researchers found that coastal wetlands outperformed other marine systems. From *University of Maryland College of Computer, Mathematical, and Natural Sciences* on February 1, 2017.

MARCH 2017

Researcher Receives DOE Grant to Produce Alcohols from CO_2 Flue Gas.

A researcher from the University of Delaware received a grant from the U.S. Department of Energy (DOE) through the National Energy Technology Laboratory (NETL) to investigate the use of carbon dioxide (CO_2) as a cheap feedstock to produce fuels and chemicals. The proposed technology is an integrated electrolyzer system that takes flue gas from the power plant and produces multi-carbon alcohols through a two-stage electrolysis process. The grant, titled "Electrochemical Conversion of Carbon Dioxide to Alcohols," will help fund the effort, which involves electrocatalyst development, system design and evaluation, and investigation of compatibility with simulated flue gas from coal-fired power plants. From *The University of Delaware News Release* on February 23, 2017.

Warming Ponds Could Accelerate Potential Climate Change.

According to a study conducted by the University of Exeter and Queen Mary University of London, rising temperatures may reduce the amount of CO_2 stored in ponds. The study was conducted by warming an array of ponds by 4°C to 5°C for seven years. In studying the impacts on greenhouse gas (GHG) emission rates, scientists observed that after the first year, changes became "amplified" over a longer period. After seven years, the pond's ability to absorb CO_2 was reduced by almost half. The results of the study were published in a paper, titled "*Long-term warming amplifies shifts in the carbon cycle of experimental ponds,*" in the journal *Nature Climate Change*. From *phys.org* on February 20, 2017.

Alberta Invests in CarbonCure.

CarbonCure will receive up to $3 million from Emissions Reduction Alberta (ERA) to further optimize and accelerate the adoption of its CO_2 utilization technology in Alberta, Canada. CarbonCure's technology, which reduces GHGs while providing economic benefit to concrete producers, is installed in more than 40 concrete plants across North America. The retrofit technology will source CO_2 emissions from local industrial emitters and convert it to nano-sized minerals, making concrete stronger and greener. CarbonCure will be competing with three other recipients of the ERA Grand Challenge for the final $10 million grant in 2019. From *Carbon Capture Journal* on March 2, 2017.

APRIL 2017

Chemists Create Usable Material from CO_2.

An international team of scientists achieved a milestone in the search to recycle carbon dioxide (CO_2) in the Earth's atmosphere into carbon-neutral fuels and other materials. Led by Indiana University, the scientists engineered a molecule that uses light or electricity to convert CO_2 into carbon monoxide (a carbon-neutral fuel source). The study, titled "*Well-Defined Nanographene-Rhenium Complex as an Efficient Electrocatalyst and Photocatalyst for Selective CO_2 Reduction,*" appears in the Journal of the American Chemical Society. From *Indiana University Bloomington Newsroom* on March 8, 2017.

Scientists Refine Filters for CO_2 Capture.

Scientists from Rice University created a material that may help improve the ability to draw methane from a well while storing CO_2. Natural gas producers use filters that optimize either carbon capture or methane flow. While no single filter will do both, adjustments in the manufacturing of a polymer-based carbon sorbent make it a candidate material for either capturing the CO_2 or balancing carbon capture with methane selectivity. The material created by Rice University scientists can be tuned to balance CO_2 storage and methane selectivity. For more information, refer to the study, which was published in the Royal Society of Chemistry journal *Sustainable Energy and Fuels*. From *Carbon Capture Journal* on April 2, 2017.

Antarctic Ice Reveals Earth's Accelerating Plant Growth.

According to a recent study conducted by scientists from the University of California, Merced, plants have been growing at a rate faster in the past century than any time in the past 54,000 years and are converting 31 percent more CO_2 into organic matter than before the Industrial Revolution. The results of the study, which were published in the online journal Nature, where gathered by analyzing the icy wastes of Antarctica. Scientists found that the increase in atmospheric CO_2 fertilizes the plants; the CO_2 in the extra plant growth amounts to 28 billion tons per year. From *The New York Times* on April 5, 2017.

MAY 2017

Company Pilots Plan to Store CO_2 in Diamond-Bearing Rock.

De Beers is piloting a project to capture and store carbon dioxide (CO_2) in the rock from which diamonds are extracted. According to the company, the project, which is due to start in 2019, is aiming to remove as much CO_2 as it emits within 5 to 10 years. The CO_2 will be stored in the kimberlite rock once all the diamonds have been removed; when mixed with CO_2, the kimberlite rock turns into a solid compound. From *Reuters* on May 4, 2017.

Agencies Sign Agreement to Monitor Carbon.

The UK Space Agency and CNES, the French government space agency, signed an agreement to monitor carbon via satellite. According to officials, the MicroCarb cooperation agreement intends to characterize greenhouse gas (GHG) fluxes on the Earth's surface and monitor how much carbon is being absorbed by oceans and forests. The UK Space Agency and CNES believe the mission, scheduled to launch in 2020, will lead to a longer-term operational system. From *UK Space Agency Press Release* on April 19, 2017.

Researchers Studying Earth's Natural Carbon Storage Process.

A Columbia University-led team of scientists are digging into the exposed sections of the Earth's mantle in Oman's al-Hajjar mountains to observe how CO_2 naturally petrified into limestone and marble millions of years ago. Half of the landscape in Oman's hills contain peridotite, a rock that removes CO_2 from the atmosphere and converts it into rock. Researchers believe the effort may help develop a drilling operation with a mechanism capable of processing the carbon-rich water and pump it into newly formed seabed. The seabed would then chemically absorb carbon from the water and cycle back the water to the surface to capture more atmospheric CO_2. From Canada Journal on April 15, 2017.

JUNE 2017

Emerging Technologies Addressing Cost and Performance of CCS.

In a recent study, researchers from Kyoto University's Institute for Integrated Cell-Material Sciences, London's Imperial College, and City University of Hong Kong used a method to develop new materials for capturing and storing carbon dioxide (CO_2). The research focused on developing highly engineered thin polymer super filters called Mixed Matrix Membranes (MMMs). The study, titled "*Enhanced selectivity in mixed matrix membranes for CO_2 capture through efficient dispersion of amine-functionalized MOF nanoparticles,*" was published in the online journal Nature. From *ScienceDaily* on June 5, 2017.

Arctic Ocean Research Expedition Studies Ocean Absorption of CO_2.

According to a study conducted by the *U.S. Geological Survey (USGS) Gas Hydrates Project*, the ocean waters near the surface of the Arctic Ocean absorbed 2,000 times more atmospheric CO_2 than the amount of methane that was released into the atmosphere from the same waters. During the study, U.S., Norwegian, and German scientists measured the concentrations of methane and CO_2 in near-surface waters and in the air just above the ocean surface near Norway's Svalbard Islands, above several seafloor methane seeps. The results showed that significant amounts of CO_2 were being absorbed by the waters near the ocean surface, and that the resulting cooling effect was up to 230 times greater than the potential warming effect expected from the methane emitted. From *USGS News Release* on May 8, 2017.

JULY 2017

New Technique Used to Measure CO_2 in Geologic Storage.

A study led by the University of Edinburg's School of Geosciences used a new technique to measure CO_2 released from CCS sites. Developed by researchers from Scottish Carbon Capture & Storage (SCCS), the technique measures tiny traces of inactive natural gases, known as noble gases, found in CO_2, to depict whether the CO_2 is from just below ground or deep below. The technique enables scientists to fingerprint a sample and pinpoint its source. The study found that high levels of CO_2 recorded at a farm in Saskatchewan, Canada, arose from nearby wetlands and not from a carbon capture and storage (CCS) site at the nearby Weyburn Oil Field. From *Scottish Carbon Capture & Storage News* on June 22, 2017.

British Forest to Test CO_2 Absorption.

Scientists at the University of Birmingham's Institute of Forest Research (BIFoR) will expose a fenced-off section of mature woodland to elevated levels of CO_2 to measure the forest's capacity to capture and absorb CO_2. The Free Air Carbon Dioxide Enrichment (FACE) experiment will feed concentrated CO_2 through pipes at the top of a series of masts built into the woodland where it will be pumped into the foliage. To learn more about the decade-long experiment, located in Norbury Park in Staffordshire, West Midlands, visit the *University of Birmingham's website*. From *Reuters* on June 21, 2017.

AUGUST 2017

Carbon Storage Chemical Reaction Identified by Researchers.

Scientists from the California Institute of Technology (Caltech) and the University of Southern California (USC) discovered a way to speed up the slow part of a chemical reaction that allows carbon dioxide (CO_2) to be stored in the ocean, allowing the rate-limiting part of the process to go 500 times faster. The team of researchers collaborated by using isotopic labeling and two methods for measuring isotope ratios in solutions and solids to study calcite, a form of calcium carbonate. The group's findings were published in the online journal *Proceedings of the National Academy of Sciences*. From *ScienceDaily* on July 17, 2017.

Scientists Research 100-Year-Old Fluid Flow Law.

A 100-year-old scientific law used to describe how fluid flows through rocks has been challenged by Imperial College London engineers, which has the potential to lead to advances in carbon capture and storage (CCS). Using 3-D videos to show how fluid moves through rock, the scientists discovered that the fluid flow is unstable, as opposed to the previously held premise in which gases move through rock via their own separate, stable pathways. The process, termed dynamic connectivity, shows that the pathways that fluids flow through last for a short period of time, wherein it then rearranges and forms into different ones. The discovery has the potential to allow engineers to more accurately model how fluids flow through rock. From *ScienceDaily* on July 17, 2017.

Researchers Discover New CO_2 Conversion Process.

Researchers discovered a new process that has the potential to create useful products from carbon emissions. Chemists from Yale and Oregon State University have found the framework for a new method of electrochemical CO_2 reduction (using electricity to change CO_2 into value-added products) by using a zinc-porphyrin electrocatalyst. The researchers discovered the zinc-porphyrin complex acts as a catalyst in that the zinc ion binds the reactant but does not change its oxidation state, while the porphyrin ion (or ligand) is reduced and delivers electrons to complete the reaction. The new finding was *published in the journal ACS Central Science*. From *Yale News* on July 27, 2017.

Mountain Forests Store Carbon Better than Flatland Forests.

Researchers from CyVerse, a project funded by the National Science Foundation and led by the *University of Arizona*, have found that mountain forests may be better at storing CO_2 than flatland forests. Researchers came to their hypothesis by collecting data from reflected light pulses off the surface of the Earth to map the height of trees and elevation. Looking through the cross sections of a 3-D map, the study showed the trees on the valley floors had more biomass than those on the mountaintops; the more biomass a tree has, the more CO_2 it has removed from the air. From *Tuscon.com* on July 29, 2017.

SEPTEMBER 2017

Elevated CO_2 Levels May Strip Food Crops of Nutrients.

According to a study conducted at Harvard's School of Public Health, higher levels of atmospheric carbon dioxide (CO_2) have the potential to lower the level of key nutrients in some food crops. To quantify the effect it could have on the world's population, scientists built a database detailing the foods people eat, and its nutrient content, for 152 countries. Accounting for differences in diets, age, and gender, the researchers calculated the number of people not getting enough of certain nutrients, projecting potential changes in the protein and iron content through 2050. The results, published in two separate reports, showed that an additional 150 million people may be at risk for protein deficiency due to elevated levels of CO_2 in the atmosphere. From *domain-b.com* on August 3, 2017.

JOURNAL ARTICLES

OCTOBER 2016

Translating risk assessment to contingency planning for CO_2 geologic storage: A methodological framework.

The following is the Abstract of this article: "In order to ensure safe and effective long-term geologic storage of CO_2, existing regulations require both assessing [release] risks and responding to [release] incidents through corrective measures. However, until now, these two pieces of risk management have been usually addressed separately. This study proposes a methodological framework that bridges risk assessment to corrective measures through clear and collaborative contingency planning. [The authors] achieve this goal in three consecutive steps. First, a probabilistic risk assessment (PRA) approach is adopted to characterize potential [release] features, events and processes (FEP) in a Bayesian events tree (BET), resulting in a risk assessment matrix (RAM). The RAM depicts a mutually exclusive and collectively exhaustive set of [release] scenarios with quantified likelihood, impact, and tolerance levels. Second, the risk assessment matrix is translated to a contingency planning matrix (CPM) that incorporates a tiered-contingency system for risk-preparedness and incident-response. The [release] likelihood and impact dimensions of RAM are translated to resource proximity and variety dimensions in CPM, respectively. To ensure both rapid and thorough contingency planning, more likely or frequent risks require more proximate resources while more impactful risks require more various resources. In addition, the minimum and maximum risk tolerance levels are translated to contingency thresholds, and all tolerable risk scenarios are categorized under three contingency tiers: Tier 1, Tier 2, and Tier 3. [The authors] highlight how the upper, lower, and inter-tier contingency boundaries should be collaboratively pre-negotiated between the operating party and multiple relevant stakeholders to ensure effective preparedness and response. Finally, [the authors] present a model contingency plan to demonstrate how all newly introduced concepts integrate together. Specifically, [the authors] focus on explaining how the designed contingency tiers facilitate important aspects of contingency planning, primarily: evaluating [release] and initiating response; designing a corrective measures matrix (CMM) that assigns specific control and remediation measures to each [release] scenario; mobilizing, deploying, and sustaining necessary human and equipment resources; and formulating a decision-making hierarchy, a notification protocol, and a communication scheme to effectively administer the CO_2 storage site." **Karim Farhat and Sally M. Benson**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Efficiency of magnesium hydroxide as engineering seal in the geological [storage] of CO_2.

The following is the Abstract of this article: "Injection of CO_2 at depth will cause the acidification of groundwater. As a preliminary study for the potential use of MgO as an alternative to Portland cement in injection wells, MgO carbonation has been studied by means of stirred batch experiments under subcritic (pCO_2 of 10 and 50 bar and T of 25, 70 and 90°C) and supercritic (pCO_2 of 74 bar and T of 70 and 90°C) CO_2 conditions. Magnesium oxide reacts with CO_2-containing and Ca-rich water nearly equilibrated with respect to calcite. MgO quickly hydrates to brucite ($Mg(O\ H)_2$) which dissolves causing the precipitation of magnesium carbonate phases. Precipitation of these secondary phases (magnesite and/or metastable phases such as nesquehonite ($MgCO_3 \bullet 3H_2O$) or hydromagnesite ($Mg_5(CO_3)_4(O\ H)_2 \bullet 4(H_2O)$) depends on pCO_2, temperature and solid/water content. In a constant solid/water ratio, the precipitation of the non-hydrated Mg carbonate is favored by increasing temperature and pCO_2. The experimental variation of Mg and Ca concentrations and pH over time at the different temperatures and pCO_2 has been simulated using the CrunchFlow reactive transport code. Simulations reproduce the experimental evolution of the aqueous concentrations and indicate a decrease in porosity when increasing temperature and pCO_2. This decrease in porosity would be beneficial for the sealing properties of the cement. These results have been used in the simulation of an application case with a deep borehole surrounded by MgO cement at 90°C." **Gabriela Dávila, Jordi Cama, Salvador Galí, Linda Luquot, and Josep M. Soler**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

The Lower Jurassic Johansen Formation, northern North Sea – Depositional model and reservoir characterization for CO_2 storage.

The following is the Abstract of this article: "The Lower Jurassic, Johansen Formation sandstone, located in the Northern North Sea, has been proposed as a reservoir candidate for CO_2 storage by Norwegian authorities. The objective of this study is to evaluate the reservoir quality of the Johansen Formation, as function of depositional history and architecture. [The authors] propose a depositional model comprising an early phase delta progradation, with clinothems building into deep waters, associated with delta front and pro-delta turbidites sourced from river mouths or/and upper delta front collapse. During a subsequent, aggradational stage, thick spit bar deposits developed in the southern, down-current part, sheltering a brackish lagoon, before rapid transgression caused back-stepping and preservation of sandy deposits encased in mud. Considering the depositional model presented, the inferred high porosity spit bar deposits would provide a suitable injection site and reservoir for CO_2. Climatic controlling factors, rather than structural, are interpreted to have exerted the major force on the asymmetric sand distributions observed in the Johansen Formation, an architectural style which is repeated in later Jurassic successions on the Horda Platform. On a local scale, accommodation was created by differential compaction above rotated, Permian fault blocks, in addition to regional, post-thermal subsidence and rising sea-level." **Anja Sundal, Johan Petter Nystuen, Kari-Lise Rørvik, Henning Dypvik, and Per Aagaard**, *Marine and Petroleum Geology.* (Subscription may be required.)

In-situ CO_2 generation huff-n-puff for enhanced oil recovery: Laboratory experiments and numerical simulations.

The following is the Abstract of this article: "The major objective of this paper was to evaluate the validity of in-situ CO_2 generation technique as an enhanced oil recovery method in sandstone reservoirs. In this study, the endothermic decomposition of ammonium bicarbonate solution was used to generate CO_2. The theoretical prediction model of generated CO_2 volume under reservoir conditions was deduced from the reaction kinetics. It was verified by the experimental data from gas-forming reaction test. The results indicated that the prediction based on the established theoretical model was well matched to experimental results at the tested NH_4HCO_3 concentrations of 10, 15, 20 wt%. The oil displacement efficiency of in-situ CO_2 generation huff-n-puff (ISCGHP) were further examined through both sandpack test and reservoir simulation. The gas-forming agent was composed of ammonium bicarbonate, surfactants and polymers. The displacement performance of ISCGHP was examined through the sandpack huff-n-puff test. Effects of the main injection parameters were analyzed, including concentration, slug size, injection mode and chasing water. The sandpack huff-n-puff test indicated that a higher concentration of NH_4HCO_3 and a larger slug size of reagent contributed to an improved oil displacement efficiency. Gradually increasing the slug size reached the remaining oil left in the previous cycle, and simultaneously enlarged swept volume in the following cycle. In the numerical study, the reservoir model of ISCGHP was established using data from interfacial tension test, PVT test and reaction kinetics. It was then calibrated based on sandpack test results and past production observations of the candidate-well. Results showed ISCGHP effectively improved single-well productivity with a growth rate of 56 [percent] in oil production, the effective sweep radius reached about 50 m away from the wellbore along with a slight fall of formation temperature and a maximal 22.8 [percent] of oil viscosity reduction." **Yong Wang, Jirui Hou, and Yong Tang,** *Journal of Petroleum Science and Engineering.* (Subscription may be required.)

The impact of emission trading scheme and the ration of free quota: A dynamic recursive CGE model in China.

The following is the Abstract of this article: "To cope with global warming, China has promulgated *Enhanced actions on climate change: China's intended nationally determined contributions* and will start the national carbon emissions trading market in 2017. Carbon emissions are distributed by the form of free quota and paid quota. However, few literatures have focused on how the economy and the environment would be changed by the change of free quota ratio. This paper establishes the 10 scenarios of different free quota ratio of carbon emissions rights and uses a dynamic, recursive computable general equilibrium (CGE) model to simulate the carbon emissions trading market, to explore the relationship between free quota ratio and carbon trading price, and the impact of carbon trading scheme (ETS) on China's economy and environment. The results show that free quota ratio will not have a direct impact on gross domestic product (GDP) and other economic and environment indicators but carbon trading prices. The prices and the rate of free payment in the current pilot cities in China are still relatively conservative. It is possible to reach emission peak, 8.21 billion ton, in 2025 and accumulative CO_2 reduction from 2017 to 2030 is 20.02 billion tons, or 59.60 [percent] of 2010 world's total CO_2 emission. Cement, minerals, electricity and nonferrous metals under ETS will suffer great losses, so subsidy should be considered. Finally, [the authors] suggested that China should reduce the total carbon rights to increase the carbon price in 2017, and gradually reducing the proportion of free quota, from 90 [percent] in 2017 to 50 [percent] or less in 2030, by which the peak year of CO_2 emission can meet in 2025. [The authors] also suggest that ETS is an effective strategy for CO_2 reduction and the ratio should be gradually reduced in ETS to prevent violent fluctuation of carbon price in China." **Wei Li and Zhijie Jia**, *Applied Energy*. (Subscription may be required.)

Geomechanical effects of CO_2 storage in depleted gas reservoirs in the Netherlands: inferences from feasibility studies and comparison with [formation] storage.

The following is the Abstract of this article: "In this paper, the geomechanical impact of large-scale CO_2 storage in depleted Dutch gas fields is compared with the impact of CO_2 storage in saline [formations]. The geomechanical [behavior] of four potential CO_2 storage sites is examined using flow and geomechanical simulations. Many gas reservoirs in the Netherlands are found in fault blocks, one to a few [kilometers] wide, laterally bounded by sealing faults. [Formation] depletion or re-pressurization in the lateral direction is seldom an issue because of a lack of active [formations]. Reservoir pressure changes are therefore limited to a gas-bearing fault block, while the induced stress changes affect the gas reservoir and extend 1-3 km away into the surrounding rock. Arguments in [favor] of CO_2 storage in depleted gas fields are: proven seal quality, availability of field data, no record of seal integrity failure by fault reactivation from the seismically active producing Dutch gas fields, and the potential benefits of restoring the virgin formation pressure and stress state to geomechanical stability. On the other hand, CO_2 injection in saline [formations] causes pressure build-up that exceeds the virgin hydrostatic pressure. Stress perturbations resulting from pressure build-up affect large areas, extending tens of [kilometers] away from the injection wells. Induced stresses in top seals are, however, small and do not exceed a few tenths of megapascal for a pressure build-up of a few megapascals in the storage formation. Geomechanical effects on top seals are weak, but could be enhanced close to the injection zone by the thermal effects of injection. Uncertainties related to [characterization] of large areas affected by pressure build-up are significant, and seal quality and continuity are more difficult to be demonstrated for [formations] than for depleted gas reservoirs that have held hydrocarbons for millions of years." **Bogdan Orlic**, *Journal of Rock Mechanics and Geotechnical Engineering*. (Subscription may be required.)

NOVEMBER 2016

Data integration, reservoir response, and application.

The following is the Abstract of this article: "The microseismic activity observed in and around a geologic formation undergoing CO_2 injection is a combination of natural, or 'background,' microseismicity plus that activity which is induced by injection operations. Since injection pressure within storage target formations are maintained safely below fracture pressure this induced activity typically originates at natural pre-existing zones of mechanical weakness presented by structural or stratigraphic features. The combination of mechanical properties and in situ stresses dictate the focal mechanism for microseismic emissions, an understanding of which facilitates the use of observed microseismicity for regulatory compliance and project management. Under favorable conditions microseismic activity may be unambiguously correlated with structural and/or stratigraphic features directly observed in seismic data, thus providing strong constraints to interpretation of observed microseismicity for focal mechanisms. However, in many cases, such as at the Illinois Basin–Decatur Project (IBDP), this direct correlation is elusive and other indirect support is required. Analysis of microseismicity at IBDP has been performed within the context of the integrated reservoir and mechanical earth models developed as part of the site characterization and monitoring program. The IBDP integrated modeling workflow involved continuous and geotechnically consistent data integration for geologic modeling, calibrated flow simulation, three-dimensional (3D) mechanical earth model, and coupled hydro-mechanical simulation. Using the coupled model, scenario-based forward modeling of microseismicity was performed for hypothetical focal mechanisms inferred from observed data. The experience gained at IBDP illustrates the importance of integrated modeling in the interpretation of microseismic activity for focal mechanisms and provides valuable insights into critical data gaps which could be the target of future basic research efforts." **Robert Will, Valerie Smith, Don Lee, and Ozgur Senel**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries.

The following is the Abstract of this article: "This study aims to analyze the relationship between CO_2 emissions, trade openness, real income and energy consumption in the top ten CO_2 emitters among the developing countries; namely China, India, South Korea, Brazil, Mexico, Indonesia, South Africa, Turkey, Thailand and Malaysia over the period of 1971–2011. In addition, the possible presence of the EKC hypothesis is investigated for the analyzed countries. The Zivot–Andrews unit root test with structural break, the bounds testing for cointegration in the presence of structural break and the VECM Granger causality method are employed. The empirical results indicate that (i) the analyzed variables are co-integrated for Thailand, Turkey, India, Brazil, China, Indonesia and Korea, (ii) real income, energy consumption and trade openness are the main determinants of carbon emissions in the long run, (iii) there exists a number of causal relations between the analyzed variables, (iv) the EKC hypothesis is validated for Turkey, India, China and Korea. Robust policy implications can be derived from this study since the estimated models pass several diagnostic and stability tests." **Hasan Murat Ertugrul, Murat Cetin, Fahri Seker, and Eyup Dogan**, *Ecological Indicators*. (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.)

Case studies on the CO_2 storage and EOR in heterogeneous, highly water-saturated, and extra-low permeability Chinese reservoirs.

The following is the Abstract of this article: "The CO_2 storage and CO_2 EOR in reservoirs often face challenges due to a high heterogeneity, high levels of water saturation, or low permeability. Based on the evaluation method of the CO_2 storage capacity and EOR, three typical reservoirs representing these challenges are introduced to study their effect on the CO_2 EOR potentials and CO_2 storage capacities. The properties of these reservoirs were analyzed in detail, and geological models were built. The reservoir simulation method is adopted to analyze and validate the CO_2 injection process and the storage effect for different types of reservoirs. From the examples in this paper, the low permeability reservoirs appear to have a higher EOR potential and CO_2 storage capacity than highly heterogeneous reservoirs. These results support the premise of injecting CO_2 into reservoirs to decrease atmospheric [GHG] emissions while enhancing oil recovery." **Xiaoliang Zhao, Zhenhua Rui, and Xinwei Liao**, *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

Evaluation of criteria for CO_2 capture and storage in the iron and steel industry using the 2-tuple DEMATEL technique.

The following is the Abstract of this article: "Nowadays, the development and deployment of alternative iron-making breakthrough technologies along with CO_2 capture technology are receiving high priority to mitigate environmental concerns by reducing pollutants and GHG emissions. During the joint selection and successful implementation of CO_2 CCS technology with iron-making emerging technology in order to allow the continuous use of fossil fuel as a reliable source of energy on demand, decision-makers (DMs) face different uncertainties and barriers as trade-off conditions in a real world environment. This study aims to quantitatively prioritize and analyze the interactions between the complex factors and dimensions in respect of CCS implementation in the iron and steel industry. In addition, research evaluates the CCS systems with twenty-five influential success factors in terms of four prominent aspects of sustainability, namely, engineering, economic, environmental and social. To carry out the research, this study utilizes the modified 2-tuple DEMATEL technique, a Multi-criteria Decision Making (MCDM) tool and the Delphi method by proposing a favorable framework to determine the cause-and-effect relationships among these criteria. The results show that the criteria of energy for capture and storage, and CO_2 removal efficiency are the top two significant influencing factors in selecting CO_2 capture technology with breakthrough iron-making technologies. In addition, an intelligent network relationship map among the dimensions and the overall DEMATEL prominence-effect relationship diagram between the cause group and effect group of criteria have been illustrated clearly. A case study was conducted in an iron and steel manufacturing industry in Malaysia to illustrate the proposed framework and to demonstrate its usefulness and validity." **M. Abdul Quader, Shamsuddin Ahmed, Raja Ariffin Raja Ghazilla, Shameem Ahmed, and Mahidzal Dahari**, *Journal of Cleaner Production*. (Subscription may be required.)

Thermodynamic analysis of a novel energy storage system with carbon dioxide as working fluid.

The following is the Abstract of this article: "Recently, energy storage system (ESS) with CO_2 as working fluid has been proposed as a new method to deal with the application restrictions of Compressed Air Energy Storage (CAES) technology, such as dependence on geological formations and low energy storage density. A novel ESS named as Compressed CO_2 Energy Storage (CCES) based on transcritical CO_2 Brayton cycle is presented in this paper. The working principle of CCES system is introduced and thermodynamic model is established to assess the system performance. Parametric analysis is carried out to study the effect of some key parameters on system performance. Results show that the increase of turbine efficiency is more favorable for system optimization and the effect of minimum pressures on system performance is more significant compared with maximum pressures. A simple comparison of CCES system, liquid CO_2 system and Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) system is conducted. It is shown that the system efficiency of CCES is lower than that of AA-CAES system but 4.05 [percent] higher than that of liquid CO_2 system, while the energy density of CCES system is 2.8 times the value of AA-CAES system, which makes CCES a novel ESS with potential application." **Yuan Zhang, Ke Yang, Hui Hong, Xiaohui Zhong, and Jianzhong Xu**, *Renewable Energy*. (Subscription may be required.)

DECEMBER 2016

Optimization of a recompression supercritical carbon dioxide cycle for an innovative central receiver solar power plant.

The following is the Abstract of this article: "Peculiar thermodynamic properties of CO_2 when it is held at or above its critical condition (stated as supercritical CO_2 or sCO_2) have attracted the attention of many researchers. Its excellent thermophysical properties at medium-to-moderate temperature range have made it to be considered as the alternative working fluid for next power plant generation. Among those applications, future nuclear reactors, solar concentrated thermal energy or waste energy recovery have been shown as the most promising ones. In this paper, a recompression sCO_2 cycle for a solar central particles receiver application has been optimized, observing net cycle efficiency close to 50 [percent]. However, small changes on cycle parameters such as working temperatures, recuperators efficiencies or mass flow distribution between low and high temperature recuperators were found to drastically modify system overall efficiency. In order to mitigate these uncertainties, an optimization analysis based on recuperators effectiveness definition was performed observing that cycle efficiency could lie among 40 [percent]–50 [percent] for medium-to-moderate temperature range of the studied application (630°C–680°C). Due to the lack of maturity of current sCO_2 technologies and no power production scale demonstrators, cycle boundary conditions based on the solar application and a detailed literature review were chosen." **M.A. Reyes-Belmonte, A. Sebastián, M. Romero, and J. González-Aguilar**, *Energy*. (Subscription may be required.)

The Evolution and Control of Fluid Phase During Liquid CO_2 Fracturing.

The following is the Abstract of this article: "Liquid CO_2 fracturing is a novel stimulation technology, which helps realize multiple objectives such as conservation of water, [storage] of [GHGs] and enhancement of single-well productivity and ultimate recovery. During operations, CO_2 flows through storage tank, booster pump, blender, fracturing pump, and eventually into wellbore and production zone, generating a changing temperature and pressure distribution. CO_2's phase state, density and viscosity properties change consequently, which influence significantly the reliability and stimulation effect. In a liquid CO_2 fracturing field test for tight oil, temperature and pressure sensors are positioned at 12 critical nodes (including booster pump, blender, fracturing pump, wellhead and bottom hole) to monitor CO_2 fluid. To ensure the reliability, CO_2 is required to maintain in liquid state both on the surface and subsurface. Inlet, inside and outlet pressure of the blender should be concerned, because the blender utilizes non-mechanical pump, which requires sufficient motive flow to draw proppants into the main pipe, while the pressure difference directly impacts the flow rate of motive flow. The field test is successfully implemented with satisfactory result, 21 m^3 proppants are added into the formation. The main conclusions are as follow. (1) In low-pressure fluid feeding stage, partial CO_2 is gasified, which influences the stability of fluid feeding; In future a buffer vessel will be placed between storage tanks and booster pumps, which will provide adjustment for phase control; And a heat exchanger may help by further reduce the temperature of CO_2.(2) Pressure difference among inlet, inside and outlet pressure of blender fluctuates during the whole process, with the probable reason of two additional static mixers, which create system pressure drop. (3) The temperature of CO_2 is very low in low-pressure stage, and the pipes are frosted; When pumping pressure reaches 38MPa, the temperature gradually exceeds 0°C, and the pipes are defrosted. Phase evolution during liquid CO_2 fracturing has been identified, and phase control method has been determined. This helps improve the stability of fluid feeding and sand adding, and enhances the success ratio and stimulation result of fracturing." **Siwei Meng, He Liu, Jianguo Xu, Yongwei Duan, Qinghai Yang, and Zixiu Yao**, *Society of Petroleum Engineers*. (Subscription may be required.)

Features of CO_2 fracturing deduced from acoustic emission and microscopy in laboratory experiments.

The following is the Abstract of this article: "[The authors] conducted hydraulic fracturing (HF) experiments on 170 mm cubic granite specimens with a 20 mm diameter central hole to investigate how fluid viscosity affects HF process and crack properties. In experiments using supercritical carbon dioxide [($scCO_2$)], liquid carbon dioxide (L-CO_2), water, and viscous oil with viscosity of 0.051–336.6 mPa • s, [the authors] compared the results for breakdown pressure, the distribution and fracturing mechanism of acoustic emission, and the microstructure of induced cracks revealed by using an acrylic resin containing a fluorescent compound. Fracturing with low-viscosity fluid induced three-dimensionally sinuous cracks with many secondary branches, which seem to be desirable pathways for enhanced geothermal system, shale gas recovery, and other processes." **Tsuyoshi Ishida, Youqing Chen, Ziad Bennour, Hiroto Yamashita, Shuhei Inui, Yuya Nagaya, Makoto Naoi, Qu Chen, Yoshiki Nakayama, and Yu Nagano**, *Journal of Geophysical Research*. (Subscription may be required.)

The syringe sampler: An inexpensive alternative borehole sampling technique for CO_2-rich fluids during mineral carbon storage.

The following is the Abstract of this article: "Mineral carbon storage involves the dissolution of injected gaseous or supercritical CO_2 followed by interaction of the carbonated solution with the host rock at depth resulting in the precipitation of carbonate minerals. Monitoring of elemental chemistry and tracers is required to evaluate the evolution of the fluid geochemistry and the degree of CO_2 mineralization during its injection into the subsurface. To avoid degassing during sampling, which is a common feature of commercial groundwater samplers, especially vacuum samplers, a syringe-like sampler was designed, constructed, and tested in the lab and field. This system was successfully deployed during the injection of 175 tons of pure gaseous CO_2 at the CarbFix injection site in Hellisheidi, SW Iceland. This study presents in detail this sampling tool and its application to the monitoring of the CO_2-rich fluid evolution during subsurface carbonation. The syringe sampler was developed as a flexible and mobile unit of low investment and operating costs making it an attractive option for deployment at small scale carbon storage demonstration sites that do not command the budgets to deploy commercial alternatives, e.g. from the oil and gas industry." **Helgi A. Alfredsson, Kiflom G. Mesfin, and Domenik Wolff-Boenisch**, *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

Analysis of state and federal regulatory regimes potentially governing the extraction of water from carbon storage reservoirs in the United States.

The following is the Abstract of this article: "Extracted water—water brought to the surface of the ground during CCS projects to create additional room for [CO_2] injection—exists in a murky legal environment. As part of a broader attempt to identify the complex interactions between water resource policies and CCS, an analysis was undertaken at both the state and the federal level to scope the policy environments surrounding extracted water policies and laws. Six states (California, Illinois, Mississippi, Montana, North Dakota, and Texas) were chosen for this analysis because either active CCS work is currently underway, or the potential exists for future work. Although regulation of extracted waters could potentially occur at many points along the CCS life cycle, this paper focuses on regulation that may apply when the water is withdrawn—that is, accessed and removed from the saline [formation]—and when it is re-injected in a close but unconnected [formation]. It was found that no regulations exist for this source specifically. In addition, greater input is needed from regulators and policy makers in terms of defining this resource. In particular, regulation of extracted waters (and CCS activities broadly) often overlaps with the management of fluids produced during oil and gas development. Many regulations would apply to extracted waters if they were classified as such. Therefore, correct categorization is key as the industry in this space continues to grow." **Jenna N. Schroeder, Christopher B. Harto, and Corrie E. Clark**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Quantifying the potential impacts of China's power-sector policies on coal input and CO_2 emissions through 2050: A bottom-up perspective.

The following is the Abstract of this article: "This study evaluates four recent policies for China's power sector—mandatory renewable targets, green dispatch, [CCS] development, and coal-fired generation efficiency improvements—and quantifies their energy and CO_2 emissions reduction potential through 2050 using bottom-up energy modeling and scenario analysis. [The authors] find renewable targets and green dispatch have crucial interlinked impacts on energy and CO_2 emissions that could change the shape and peak year of China's power-sector emissions outlook. Without either renewable targets or green dispatch, coal will likely continue dominating China's power mix and could delay the power-sector CO_2 emissions peak to the late 2030s." **Nina Zheng Khanna, Nan Zhou, David Fridley, and Jing Ke**, *Utilities Policy*. (Subscription may be required.)

JANUARY 2017

Effectiveness of greenhouse-gas Emissions Trading Schemes implementation: a review on legislations.

The following is the Abstract of this article: "Due to the severe problems caused by global warming, 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 [ETS] needs to be further analysed 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 in this paper. 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% per year since [ETS] implementation. Around 23.43% of CO_2 reduction can be reached after 10 years of [ETS] implementation, compared to the trend when [ETS] was not implemented. Despite [ETS] 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 tonne. However, as the implementation period of [ETS] 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 Rio Merino, Carmen Viñas Arrebola, and Xiangyu Wang**, *Journal of Cleaner Production*. (Subscription may be required.)

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 leakage. 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.)

Time-lapse downhole electrical resistivity monitoring of subsurface CO_2 storage at the Maguelone shallow experimental site (Languedoc, France).

The following is the Abstract of this article: "A shallow field experimental site for CO_2 injection was established at Maguelone (Languedoc, France), in order to test in an integrated manner a suite of surface and downhole hydrogeophysical monitoring methods. The objective is to improve monitoring of gas transport in the shallow subsurface and to determine the sensitivity of CO_2 monitoring systems for leakage detection. The site offers a natural laboratory to study the processes associated with CO_2 injection in a clastic and clay-rich context saturated with saline fluids. Prior to CO_2 injection, three nitrogen (N_2) injections were undertaken in 2012 to measure the site response to neutral gas injection. In 2013, a volume of 111 m^3 (mass of 220 kg) of CO_2 was injected during 3.5 h at 15 m depth. During each experiment, the gas plumes were successfully detected from pressure monitoring, time-lapse induction logging and downhole resistivity monitoring with dipole–dipole array. Increases in resistivity are attributed to free gas propagation (either N_2 or CO_2) whereas decreases in resistivity correlate with CO_2 dissolution in the pore fluid. Chemical analyses confirm this hypothesis with a decrease in pH and an increase in the concentration of dissolved species in the latter case." **Philippe A. Pezard, Nataliya Denchik, Johanna Lofi, Hervé Perroud, Gilles Henry, Denis Neyens, Linda Luquot, and Arnaud Levannier**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Lessons learned from using expert elicitation to identify, assess and rank the potential leakage scenarios at the Heletz pilot CO_2 injection site.

The following is the Abstract of this article: "Expert elicitation is a useful approach to synthesis expert knowledge, experience and insight when the input data and analysis is limited. During the early stages of the EU FP7 MUSTANG pilot CO_2 injection experiment at Heletz, Israel there was very little input data available, yet decisions had to be made regarding data collection, drilling, operation and monitoring strategies. An expert elicitation study was undertaken to identify, assess and rank potential CO_2 leakage scenarios at Heletz to provide guidance to support the decision making processes. This paper presents a critique of the expert elicitation process undertaken, presenting the methodology and a discussion of the results. [The authors] present the lessons learned during the expert elicitation process, highlighting its advantages and limitations and provide suggestions on ways to overcome these limitations. [The authors'] findings show that prudent expert elicitation can make a valuable contribution to decision making, however if done improperly it can equally lead to invalid or misleading results and wrong decisions." **K. Edlmann, J. Bensabat, A. Niemi, R.S. Haszeldine, and C.I. McDermott**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Flow visualization of CO_2 in tight shale formations at reservoir conditions.

The following is the Abstract of this article: "The flow of CO_2 in porous media is fundamental to many engineering applications and geophysical processes. Yet detailed CO_2 flow visualization remains challenging. [The authors] address this problem via positron emission tomography using ^{11}C nuclides and apply it to tight formations—a difficult but relevant rock type to investigate. The results represent an important technical advancement for visualization and quantification of flow properties in ultratight rocks and allowed [the authors] to observe that local rock structure in a layered, reservoir shale ($K = 0.74\ \mu darcy$) sample dictated the CO_2 flow path by the presence of high-density layers. Diffusive transport of CO_2 in a fractured sample (high-permeable sandstone) was also visualized, and an effective diffusion coefficient ($D_i = 2.2 \bullet 10^{-8}\ m^2/s$) was derived directly from the dynamic distribution of CO_2. During CO_2 injection tests for oil recovery from a reservoir shale sample [the authors] observed a recovery factor of RF = 55% of oil in place without fracturing the sample." **M.A. Fernø, L.P. Hauge, A. Uno Rognmo, J. Gauteplass, and A. Graue**, *Geophysical Research Letters*. (Subscription may be required.)

Experimental study of gas–oil relative permeability curves at immiscible/near miscible gas injection in highly naturally fractured reservoir.

The following is the Abstract of this article: "The main aim of this work is to investigate gas–oil relative permeability curves as the main flow function in different gas injection scenarios, immiscible and near miscible in case of highly fractured reservoirs. In this research, some experiments have been done on the reservoir core sample selected from sandstone formation in one of the Iranian naturally fractured oil reservoirs. The core is saturated with oil sample and CO_2 is injected into oil saturated core sample. Experiments have been performed on both of the sandstone and artificial fractured sandstone, represented as no fractured and highly fractured reservoirs, based on incremental pressure algorithm approaching into near miscible condition. Inverse modeling method has been used to calculate relative permeability curves. By comparing the relative permeability curves in immiscible and near-miscible conditions, the results show that in sandstone core type this change is considerable, but in highly artificial fractured sandstone with a high ratio of artificial fractured to sandstone absolute permeability (K_{ef} /K_s) is not substantial. Moreover the results show that in the described case of artificial fractured core type so simple

conventional relative permeability methods have the same results compared to a sophisticated inverse modeling method. The other main result is the lack of miscibility activation in near miscible injection through the highly fractured reservoirs leading to viscose dominant flow rather than capillary. Finally by considering this changing behavior, a better knowledge of gas front movement through highly fractured reservoirs in low [interfacial tension (IFT)] regions can be obtained." **Mohammad Parvazdavani, Saeed Abbasi, and Mohammad-Reza Zare-Reisabadi**, *Egyptian Journal of Petroleum*. (Subscription may be required.)

Investigation of uncertainty in CO_2 reservoir models: A sensitivity analysis of relative permeability parameter values.

The following is the Abstract of this article: "Numerical reservoir models of CO_2 injection in saline formations rely on parameterization of laboratory-measured pore-scale processes. [The authors] performed a parameter sensitivity study and Monte Carlo simulations to determine the normalized change in total CO_2 injected using the finite element heat and mass-transfer code (FEHM) numerical reservoir simulator. Experimentally measured relative permeability parameter values were used to generate distribution functions for parameter sampling. The parameter sensitivity study analyzed five different levels for each of the relative permeability model parameters. All but one of the parameters changed the CO_2 injectivity by <10%, less than the geostatistical uncertainty that applies to all large subsurface systems due to natural geophysical variability and inherently small sample sizes. The exception was the end-point CO_2 relative permeability, k^0_r,CO_2, the maximum attainable effective CO_2 permeability during CO_2 invasion, which changed CO_2 injectivity by as much as 80%. Similarly, Monte Carlo simulation using 1000 realizations of relative permeability parameters showed no relationship between CO_2 injectivity and any of the parameters but k^0_r,CO_2, which had a very strong ($R^2 = 0.9685$) power law relationship with total CO_2 injected. Model sensitivity to k^0_r,CO_2 source points to the importance of accurate core flood and wettability measurements." **Nozomu Yoshida, Jonathon S. Levine, and Philip H. Stauffer**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Rapid method to estimate the minimum miscibility pressure (MMP) in live reservoir oil systems during CO_2 flooding.

The following is the Abstract of this article: "Flooding fuel-generated CO_2 into oil reservoirs will lead to two advantages in both EOR and reduction in atmospheric emission of [CO_2]. The main factor for determination of the possibilities to EOR by e.g. CO_2 injection, in particular miscible case, into a specific oil reservoir is the CO_2–oil minimum miscibility pressure (MMP). In this communication, [the authors] present the utilization of a soft-computing technique – gene expression programming (GEP) – for developing a new symbolic equation to pursue [the authors'] objective. In other words, this work presents a new approach to predict both pure and impure CO_2–oil MMP in live reservoir oil systems. The parameters of the new model involve the molecular weight of C_{5+} fraction in crude oil, reservoir temperature, the mole percentage ratio of volatile to intermediate components of oil and critical temperature. A comprehensive error investigation is done to discuss accuracy of the recently proposed MMP model. Additionally, the results obtained by the new GEP-based model are compared with most widely-used empirically derived correlations available in the literature to show the superiority of the model. The results obtained in this study are encouraging and can propose accurate and efficient solutions for the case of CO_2–oil MMP of pure and impure components in live oil systems." **Arash Kamari, Milad Arabloo, Amin Shokrollahi, Farhad Gharagheizi, and Amir H. Mohammadi**, *Fuel*. (Subscription may be required.)

FEBRUARY 2017

The salt-based catalytic enhancement of CO_2 absorption by a tertiary amine medium.

The following is a summary of the Abstract of this article: "Efficient methods are needed to limit the elevation of CO_2 levels in the atmosphere. Here, [the authors] propose an improved CO_2 [storage] method that uses new catalysts, specifically a series of tertiary amine nitrate salts, in an aqueous tertiary amine medium. [The authors] synthesized the new catalysts and characterized them by using ^1H and ^{13}C NMR, single crystal X-ray analysis, and FT-IR spectroscopy. The effects of the catalysts on CO_2 absorption were assessed by using a stopped-flow spectrophotometer, and their heats of absorption and CO_2 absorption capacities were measured with a differential reaction calorimeter (DRC) at high concentrations of the tertiary amine medium. The CO_2 hydration rate constants were determined under basic conditions and the catalysts were found to exhibit higher absorption of CO_2 (a highest value of 430 M^{-1} s^{-1}) than the tertiary amine medium (133 M^{-1} s^{-1}). The increased absorption of CO_2 and the low heat absorption energies of the new catalysts suggest that they could be used in post-combustion processes." **Dharmalingam Sivanesan, Young Eun Kim, Min Hye Youn, Ki Tae Park, Hak-Joo Kim, Andrew Nirmala Grace, and Soon Kwan Jeong**, *RSC Advances*. (Subscription may be required.)

Inorganic carbon dynamics and CO_2 flux associated with coal-mine drainage sites in Blythedale PA and Lambert WV, USA.

The following is the Abstract of this article: "Drainage from coal mines, where carbonate dissolution is driven by sulfuric acid, can result in a net transfer of geologically-bound carbon to the atmosphere. The flux and downstream evolution of dissolved inorganic carbon (DIC) is presented for two coal mine sites that discharge high concentrations of DIC (3.7–4.5 mM C) producing a total flux of DIC from the mine from 13 to 249 kg-C/year (18–364 metric tons of CO_2/year). More than 65% of the total DIC is lost via CO_2 evasion with the remaining DIC is exported downstream as dissolved species. The fate of the DIC depends upon the pH of the water which is controlled by evasion of CO_2, the concentration of pre-existing alkalinity, carbonate precipitation and dissolution, and metal hydrolysis reactions. The CO_2 concentrations and fluxes from the study sites are comparable to those estimated from literature data for other coal mine sites in the Appalachian region. The total flux estimated from a dataset of 140 coal mines was comparable in magnitude to the CO_2 emissions from a small coal-fired power plant. The extent of CO_2 degassing from mine waters is poorly constrained because (1) flux estimates can be biased low when acid waters are excluded in alkalinity-based estimates; (2) flux estimates can be biased high if non-carbonate alkalinity is present in the mine waters; and (3) mine waters react rapidly following discharge hampering the measurement process. The study sites presented illustrate the impact of coal mining as an anthropogenic influence on carbon cycling; however, more data are necessary to fully estimate the importance of this impact on regional scales." **Dorothy J. Vesper, Johnathan E. Moore, and James P. Adams**, *Environmental Earth Sciences*. (Subscription may be required.)

Potential gains from carbon emissions trading in China: A DEA based estimation on abatement cost savings.

The following is the Abstract of this article: "China has recently launched its pilot carbon emissions trading markets. Theoretically, heterogeneity in abatement cost determines the efficiency advantage of market based programs over command and control policies on carbon emissions. This study tries to answer the question that what will be the abatement cost savings or GDP loss recoveries from carbon emissions trading in China from the perspective of estimating the potential gains from carbon emissions trading. A [data envelopment analysis (DEA)] based optimization model is employed in this study to estimate the potential gains from implementing two carbon emissions trading schemes compared to carbon emissions command and control scheme in China. These two schemes are spatial tradable carbon emissions permit scheme and spatial–temporal tradable carbon emissions permit scheme. The associated three types of potential gains, which are defined as the potential increases on GDP outputs through eliminating technical inefficiency, eliminating suboptimal spatial allocation of carbon emissions permit, and eliminating both suboptimal spatial and temporal allocation of carbon emissions permit, are estimated by an ex post analysis for China and its 30 provinces over 2006-2010. Substantial abatement cost savings and considerable carbon emissions reduction potentials are identified in this study which provide one argument for implementing a market based policy instrument instead of a command and control policy instrument on carbon emissions control in China." **Ke Wang, Yi-Ming Wei, and Zhimin Huang**, *Omega*. (Subscription may be required.)

Carbon capture and storage across fuels and sectors in energy system transformation pathways.

The following is the Abstract of this article: "CCS is broadly understood to be a key mitigation technology, yet modeling analyses provide different results regarding the applications in which it might be used most effectively. Here [the authors] use the Global Change Assessment Model (GCAM) to explore the sensitivity of CCS deployment across sectors and fuels to future technology cost assumptions. [The authors] find that CCS is deployed preferentially in electricity generation or in liquid fuels production, depending on CCS and biofuels production cost assumptions. [The authors] consistently find significant deployment across both sectors in all of the scenarios considered here, with bioenergy with CCS (BECCS) often the dominant application. As such, this study challenges the view that CCS will primarily be coupled with power plants and used mainly in conjunction with fossil fuels, and suggests greater focus on practical implications of significant CCS and BECCS deployment to inform energy system transformation scenarios over the 21st century." **Matteo Muratori, Haroon Kheshgi, Bryan Mignone, Leon Clarke, Haewon McJeon, and Jae Edmonds**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Comparing policy routes for low-carbon power technology deployment in EU – and energy system analysis.

The following is the Abstract of this article: "The optimization energy system model JRC-EU-TIMES is used to support energy technology R&D design by analyzing power technologies deployment till 2050 and their sensitivity to different decarbonization exogenous policy routes. The policy routes are based on the decarbonized scenarios of the EU Energy Roadmap 2050 combining energy efficiency, renewables, nuclear or CCS. A 'reference' and seven decarbonized scenarios are modelled for EU28. [The authors] conclude on the importance of policy decisions for the configuration of the low carbon power sector, especially on nuclear acceptance and available sites for new RES plants. Differently from typical analysis focusing on technology portfolio for each route, [the authors] analyze the deployment of each technology across policy routes, for optimizing technology R&D. R&D priority should be given to those less-policy-sensitive technologies that are in any case deployed rapidly across the modelled time horizon (e.g. PV), but also to those deployed up to their technical potentials and typically less sensitive to exogenous policy routes. For these 'no regret' technologies (e.g. geothermal), R&D efforts should focus on increasing their technical potential. For possibly cost-effective technologies very sensitive to the policy routes (e.g. CSP and marine), R&D efforts should be directed to improving their techno-economic performance." **Sofia Simoes, Wouter Nijs, Pablo Ruiz, Alessandra Sgobbi, and Christian Thiel**, *Energy Policy*. (Subscription may be required.)

The allowance mechanism of China's carbon trading pilots: A comparative analysis with schemes in EU and California.

The following is the Abstract of this article: "The allowance mechanism is one of the core and sensitive aspects in the design of a carbon emissions trading scheme and affects the compliance cost for each entity covered under the scheme. By examining China's allowance mechanism from two aspects-allowance allocation and allowance distribution, this paper compares China's carbon trading pilots with the EU Emissions Trading Scheme and California Cap-and-Trade Program. The comparison identifies the unique features in allowance mechanism and particular issues that affect the efficiency of the pilots. The paper also recommends courses of action to strengthen China's existing pilots and to build valuable experiences for the establishment of the national cap-and-trade system in China." **Ling Xiong, Bo Shen, Shaozhou Qi, Lynn Price, and Bin Ye**, *Applied Energy*. (Subscription may be required.)

Design under uncertainty of carbon capture and storage infrastructure considering cost, environmental impact, and preference on risk.

The following is the Abstract of this article: "[The authors] present a stochastic decision-making algorithm for the design and operation of a CCS network; the algorithm incorporates the decision-maker's tolerance of risk caused by uncertainties. Given a set of available resources to capture, store, and transport CO_2, the algorithm provides an optimal plan of the CCS infrastructure and a CCS assessment method, while minimizing annual cost, environmental impact, and risk under uncertainties. The model uses the concept of downside risk to explicitly incorporate the trade-off between risk and either economic or environmental objectives at the decision-making level. A two-phase-two-stage stochastic multi-objective optimization problem (2P2SSMOOP) solving approach is implemented to consider uncertainty, and the ε-constraint method is used to evaluate the interaction between total annual cost with financial risk and an Eco-indicator 99 score with environmental risk. The environmental impact is measured by Life Cycle Assessment (LCA) considering all contributions made by operation and installation of a CCS infrastructure. A case study of power-plant CO_2 emission in Korea is presented to illustrate the application of the proposed modeling and solution method." **Suh-Young Lee, Jae-Uk Lee, In-Beum Lee, and Jeehoon Han**, *Applied Energy*. (Subscription may be required.)

Tracking the interaction between injected CO_2 and reservoir fluids using noble gas isotopes in an analogue of large-scale carbon capture and storage.

The following is the Abstract of this article: "Industrial scale [CCS] technology relies on the secure long term storage of CO_2 in the subsurface. The engineering and safety of a geological storage site is critically dependent on how and where CO_2 will be stored over the lifetime of the site. Hence, there is a need to determine how injected CO_2 is stored and identify how injected CO_2 interacts with sub-surface fluids. Since July 2008 ~1 Mt of CO_2 has been injected into the Cranfield EOR field (MS, USA), sourced from a portion of the natural CO_2 produced from the nearby Jackson Dome CO_2 reservoir. Monitoring and tracking of the amount of recycled CO_2 shows that a portion of the injected CO_2 has been retained in the reservoir. Here, [the authors] show that the noble gases (^{20}Ne, ^{36}Ar, ^{84}Kr, ^{132}Xe) that are intrinsic to the injected CO_2 can be combined with $CO_2/^3He$ and $\delta^{13}CCO_2$ measurements to trace both the dissolution of the CO_2 into the formation water, and the interaction of CO_2 with the residual oil. Samples collected 18 months after CO_2 injection commenced show that the CO_2 has stripped the noble gases from the formation water. The isotopic composition of He suggests that ~0.2%, some 7 kt, of the injected CO_2 has dissolved into formation water. The $CO_2/^3He$ and $\delta^{13}CCO_2$ values imply that dissolution is occurring at pH = 5.8, consistent with the previous determinations. $\delta^{13}CCO_2$ measurements and geochemical modelling rule out significant carbonate precipitation and [the authors] determine that the undissolved CO_2 after 18 months of injection (1.5 Mt) is stored by stratigraphic or residual trapping. After 45 months of CO_2 injection, the noble gas concentrations appear to be affected by CO_2-oil interaction, overprinting the signature of the formation water." **Domokos Györe, Stuart M.V. Gilfillan, and Finlay M. Stuart**, *Applied Geochemistry*. (Subscription may be required.)

Carbon Sequestration in Olivine and Basalt Powder Packed Beds.

The following is the Abstract of this article: "Fractures and pores in basalt could provide substantial pore volume and surface area of reactive minerals for carbonate mineral formation in geologic carbon sequestration. In many fractures solute transport will be limited to diffusion, and opposing chemical gradients that form as a result of concentration differences can lead to spatial distribution of silicate mineral dissolution and carbonate mineral precipitation. Glass tubes packed with grains of olivine or basalt with different grain sizes and compositions were used to explore the identity and spatial distribution of carbonate minerals that form in dead-end one-dimensional diffusion-limited zones that are connected to a larger reservoir of water in equilibrium with 100 bar CO_2 at 100°C. Magnesite formed in experiments with olivine, and Mg- and Ca-bearing siderite formed in experiments with flood basalt. The spatial distribution of carbonates varied between powder packed beds with different powder sizes. Packed beds of basalt powder with large specific surface areas sequestered more carbon per unit basalt mass than powder with low surface area. The spatial location and extent of carbonate mineral formation can influence the overall ability of fractured basalt to sequester carbon." **Wei Xiong, Rachel K. Wells, and Daniel E. Giammar**, *Environmental Science and Technology*. (Subscription may be required.)

MARCH 2017

Modeling changes in pressure due to migration of fluids into the Above Zone Monitoring Interval of a geologic carbon storage site.

The following is the Abstract of this article: "An increasing emphasis on the industrial-scale implementation of CO_2 storage in geological formations has led to the development of whole-system models to evaluate performance of candidate geologic storage sites and the environmental risk associated with them. Components of that engineered geologic system include the storage reservoir, overlying aquitards (primary caprock and secondary seals) and aquifers (including the above zone monitoring interval, or AZMI, directly overlying the primary seal), and potential leakage pathways including wells, fractures, and faults. Leakage of CO_2 and brine through the primary seal to the overlying porous and permeable formations (AZMI) may occur due to the seal's intrinsic permeability and/or the presence of natural fractures or induced perforations or fractures in the caprock. AZMI monitoring may provide a potentially useful source of information about seal performance and subsurface pressure response to potential CO_2 and/or brine leakage from the reservoir. Unfortunately, full complexity simulations of the geologic storage system are not computationally affordable, especially given the need to develop many realizations to evaluate uncertainties in system performance. Thus, the goal of the current work is to present a novel reduced order model (ROM) for AZMI that simulates fluid (i.e., CO_2 and brine) flow above the seal, and verify performance of the ROM. The AZMI model predicts spatial changes in pressure over time in the zone above the primary seal due to migration of fluids from the reservoir. A case is examined wherein CO_2 is injected into a storage reservoir for 30 years and a heterogeneous primary seal exists above the reservoir with some permeable zones. The model results are verified against those of a numerical simulator. The new AZMI model provides an improvement in computation time by a factor of approximately 2000 times to that of the numerical simulator and provides predictions that approximate those of the comparable numerical simulation." **Argha Namhata, Liwei Zhang, Robert M. Dilmore, Sergey Oladyshkin, and David V. Nakles**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Production and transportation outsourcing decisions in the supply chain under single and multiple carbon prices.

The following is the Abstract of this article: "Cap-and-trade and carbon tax are the two main policies to reduce carbon emissions. Different from the previous literature and practice, this paper examines the production and transportation outsourcing problems of a two-echelon supply chain under the cap-and-trade policy and joint cap-and-trade and carbon tax policy. Enterprise operations are divided into the order stage and transportation outsourcing decision stage. In the order stage, the retailer sets his order schedule for the manufacturing plant for fulfillment, and in the transportation outsourcing decision stage, the manufacturer decides the optimal freight volume based on energy consumption. Furthermore, [the authors] construct a basic model without a carbon policy and two extended models with carbon policies and the optimal solutions of the models are solved. Numerical examples are provided, and the three models are compared. The results indicate that the extended model with carbon policies is more beneficial for emissions reduction, and the effect of emissions reduction gradually becomes smooth as the carbon price increases; the joint cap-and-trade and carbon tax policy is more effective for emissions reduction, especially when the carbon price is lower. These findings will be helpful to policy makers and managers." **Jian Li, Qin Su, and Li Ma**, *Journal of Cleaner Production*. (Subscription may be required.)

Response comment: Carbon sequestration on Mars.

The following is the Abstract of this article: "Martian atmospheric pressure has important implications for the past and present habitability of the planet, including the timing and causes of environmental change. The ancient Martian surface is strewn with evidence for early water bound in minerals and recorded in surface features such as large catastrophically created outflow channels, valley networks, and crater lakes. Using orbital spectral data sets coupled with geologic maps and a set of numerical spectral analysis models, [the authors] constrained the amount of atmospheric sequestration in early Martian rocks and found that the majority of this sequestration occurred prior to the formation of the early Hesperian/late Noachian valley networks, thus implying the atmosphere was already thin by the time these surface-water-related features were formed." **Christopher Edwards and Bethany L. Ehlmann**, *Geological Society of America*. (Subscription may be required.)

Enhancing residual trapping of supercritical CO_2 via cyclic injections.

The following is the Abstract of this article: "[The authors] utilize synchrotron X-ray tomographic imaging to investigate the pore-scale characteristics and residual trapping of supercritical CO_2 ($scCO_2$) over the course of multiple drainage-imbibition (D-I) cycles in Bentheimer sandstone cores. Capillary pressure measurements are paired with X-ray image-derived saturation and connectivity metrics which describe the extent of drainage and subsequent residual (end of imbibition) $scCO_2$ trapping. For the first D-I cycle, residual $scCO_2$ trapping is suppressed due to high imbibition capillary number ($Ca \approx 10–6$); however, residual $scCO_2$ trapping dramatically increases for subsequent D-I cycles carried out at the same Ca value. This behavior is not predicted by conventional multiphase trapping theory. The magnitude of $scCO_2$ trapping increase is hysteretic and depends on the relative extent of the sequential drainage processes. The hysteretic pore-scale behavior of the $scCO_2$-brine-sandstone system observed in this study suggests that cyclic multiphase flow could potentially be used to increase $scCO_2$ trapping for sequestration applications." **Anna L. Herring, Linnea Anderson, and Dorthe Wildenschild**, *Geophysical Research Letters*. (Subscription may be required.)

Assessing the design of three carbon trading pilot programs in China.

The following is the Abstract of this article: "To help overcome the challenge of growing CO_2 emissions, China is experimenting with market-based instruments, including pilot CO_2 emissions trading systems (ETSs) in seven regions that serve as precursors of a national CO_2 ETS. Implementing an ETS in a rapidly growing economy in which government authorities exercise significant control over markets poses many challenges. This study assesses how well three of the most developed pilot ETSs, in Guangdong, Shanghai, and Shenzhen, have adapted carbon emissions trading to China's economic and political context. [The authors] base [their] study on new information gathered through interviews with local pilot ETS regulators and experts, analysis of recent trading data, and extensive legal and literature reviews. [The authors] point out instances in which pilot regulators have deftly tailored carbon emissions trading to China's unique context and instances in which designs are insufficient to ensure smooth operation. [The authors] also indicate areas in which broader institutional reforms of China's political economy may be required for carbon emissions trading to operate successfully. [The authors] make nine recommendations to improve the design and operation of the pilot programs and to inform the construction of a national CO_2 ETS." **Clayton Munnings, Richard D. Morgenstern, Zhongmin Wang, and Xu Liu**, *Energy Policy*. (Subscription may be required.)

Convective mixing fingers and chemistry interaction in carbon storage.

The following is the Abstract of this article: "Dissolution of [CO_2] into formation fluids during CCS can generate an instability with a denser CO_2-rich fluid located above the less dense native aquifer fluid. This instability promotes convective mixing, enhancing CO_2 dissolution and favoring the storage safety. Convective mixing has been extensively analyzed in the context of CCS over the last decade, however the interaction between convective mixing and geochemistry has been insufficiently addressed. This relation is explored using a fully coupled model taking into account the porosity and permeability variations due to dissolution-precipitation reactions in a realistic geochemical system based on the Hontomín (Spain) potential CCS site project. This system, located in a calcite, dolomite, and gypsum bearing host rock, has been analyzed for a variety of Rayleigh and Damköhler values. Results show that chemical reactions tend to enhance CO_2 dissolution. The model illustrates the first stages of porosity channel development, demonstrating the significance of fluid mixing in the development of porosity patterns. The influence of non-carbon species on CO_2 dissolution shown in this study demonstrates the needs for realistic chemical and kinetic models to ensure the precision of physical models to accurately represent the [CO_2] injection process." **Alvaro Sainz-Garcia, Elena Abarca, Albert Nardi, Fidel Grandia, and Eric H. Oelkers**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

APRIL 2017

How to enhance the future use of energy policy simulation models through ex post validation.

The following is the Abstract of this article: "Although simulation and modeling in general and system dynamics models in particular has long served the energy policy domain, ex post validation of these energy policy models is rarely addressed. In fact, ex post validation is a valuable area of research because it offers modelers a chance to enhance the future use of their simulation models by validating them against the field data. This paper contributes by presenting (i) a system dynamics simulation model, which was developed and used to do a three dimensional, socio-economical and environmental long-term assessment of Pakistan's energy policy in 1999, (ii) a systematic analysis of the 15-years old predictive scenarios produced by a system dynamics simulation model through ex post validation. How did the model predictions compare with the actual data? [The authors] report that the ongoing crisis of the electricity sector of Pakistan is unfolding, as the model-based scenarios had projected." **Hassan Qudrat-Ullah,** *Energy.* (Subscription may be required.)

Impact of electrical intertie capacity on carbon policy effectiveness.

The following is the Abstract of this article: "This study investigates the potential cost and emissions reductions that result from an increase in electricity transmission capacity between Canada's two westernmost provinces: Alberta, a fossil fuel dominated jurisdiction, and British Columbia, a predominantly hydroelectric jurisdiction. A bottom-up model is used to find the least cost electricity generation mix in Alberta and British Columbia under different carbon policies. The long-term evolution of the electricity system is determined by minimizing net present cost of electricity generation for the time span of 2010–2060. Different levels of intertie capacity expansion are considered together with a variety of carbon tax and carbon cap scenarios. Results indicate that increased intertie capacity reduces the cost of electricity and emissions under carbon pricing policies. However, the expandable intertie does not encourage greater adoption of variable renewable generation. Instead, it is used to move low-cost energy from the United States to Alberta. The optimal intertie capacity and cost reduction of increased interconnectivity increases with more restrictive carbon policies." **J. English, T. Niet, B. Lyseng, K. Palmer-Wilson, V. Keller, I. Moazzen, L. Pitt, P. Wild, and A. Rowe**, *Energy Policy.* (Subscription may be required.)

Study on the ratio of pore-pressure/stress changes during fluid injection and its implications for CO_2 geologic storage.

The following is the Abstract of this article: "The success of fluid injection into geological formations, which is the main operation during both CO_2 geologic storage and wastewater injection, is contingent on the geomechanical integrity of the site. A key task that allows us to evaluate the risk of geomechanical failure is the precise prediction of pore-pressure buildup and subsequent change in the state of stresses during and after the fluid injection. Contrary to traditional approaches, where total stresses are assumed to remain constant, recent studies have ascertained that total stresses in fact change in every direction as fluid extraction/injection disturbs the pore-pressure field and causes deformations. In this study, [the authors] conduct an in-depth investigation of the ratio of change in total stress to that in pore-pressure, $\Delta\sigma/\Delta P$, which has been denoted in the literature as the pore-pressure/stress coupling. [The authors] employ a numerical simulation method that couples single-phase fluid flow in porous media with poroelasticity to explore the spatiotemporal evolution of the $\Delta\sigma/\Delta P$ ratio for various conditions. These numerical experiments allow [the authors] to examine how different material properties and structural geometries would influence the evolution of $\Delta\sigma/\Delta P$ in both vertical and horizontal directions. These ratios of pore-pressure/stress changes exhibit different spatiotemporal evolutions depending on key factors that include the hydraulic boundary condition, Biot's coefficient, Poisson's ratio, and the hydraulic diffusivity of both the injection zone and caprock. On the basis of observations, [the authors] suggest firsthand guidelines for analytically determining the ratio of pore-pressure/stress changes, $\Delta\sigma/\Delta P$. Finally, [the authors] use examples and case studies to illustrate how the $\Delta\sigma/\Delta P$ ratio can be incorporated into an analytic calculation for determining a maximum sustainable pressure limit." **Seunghee Kim and Seyyed Abolfazl Hosseini**, *Journal of Petroleum Science and Engineering.* (Subscription may be required.)

Thermal effects on geologic carbon storage.

The following is the Abstract of this article: "One of the most promising ways to significantly reduce [GHG] emissions, while carbon-free energy sources are developed, is CCS. Non-isothermal effects play a major role in all stages of CCS. In this paper, [the authors] review the literature on thermal effects related to CCS, which is receiving an increasing interest as a result of the awareness that the comprehension of non-isothermal processes is crucial for a successful deployment of CCS projects. [The authors] start by reviewing CO_2 transport, which connects the regions where CO_2 is captured with suitable geostorage sites. The optimal conditions for CO_2 transport, both onshore (through pipelines) and offshore (through pipelines or ships), are such that CO_2 stays in liquid state. To minimize costs, CO_2 should ideally be injected at the wellhead in similar pressure and temperature conditions as it is delivered by transport. To optimize the injection conditions, coupled wellbore and reservoir simulators that solve the strongly non-linear problem of CO_2 pressure, temperature and density within the wellbore and non-isothermal two-phase flow within the storage formation have been developed. [Carbon dioxide] in its way down the injection well heats up due to compression and friction at a lower rate than the geothermal gradient, and thus, reaches the storage formation at a lower temperature than that of the rock. Inside the storage formation, CO_2 injection induces temperature changes due to the advection of the cool injected CO_2, the Joule-Thomson cooling effect, endothermic water vaporization and exothermic CO_2 dissolution. These thermal effects lead to thermo-hydro-mechanical-chemical coupled processes with non-trivial interpretations. These coupled processes also play a relevant role in 'Utilization' options that may provide an added value to the injected CO_2, such as EOR, Enhanced Coal Bed Methane (ECBM) and geothermal energy extraction combined with CO_2 storage. If the injected CO_2 leaks through faults, the caprock or wellbores, strong cooling will occur due to the expansion of CO_2 as pressure decreases with depth. Finally, [the authors] conclude by identifying research gaps and challenges of thermal effects related to CCS." **Victor Vilarrasa and Jonny Rutqvist**, *Earth-Science Reviews.* (Subscription may be required.)

Effect of Char Preparation Conditions on Gasification in a Carbon Dioxide Atmosphere.

The following is the Abstract of this article: "Pyrolysis conditions have a substantial impact on the properties of the resulting char and, consequently, on the kinetics of the gasification process. The aim of this study was to determine the impact of coal pyrolysis on the gasification stage. By applying the thermogravimetric method, kinetic analyses of CO_2 gasification of chars derived from Polish 'Janina' coal were conducted. Gasification examinations were performed for chars prepared earlier in an argon atmosphere at various heating rates, which, after cooling, were subjected to CO_2 gasification (indirect char gasification). Examinations were also carried out in the case of chars formed during heating of coal samples in a CO_2 atmosphere (direct char gasification). Samples of chars were gasified in non-isothermal conditions of up to 1100°C under 0.1 MPa pressure at various heating rates. The char gasification reaction order with CO_2 was determined with the use of the Coats–Redfern method, and it can be assumed that it is a first-order reaction. The activation energy and pre-exponential factor were calculated using two first-order models: Coats–Redfern method and Senum–Yang method. The results were subsequently compared to kinetic parameters calculated on the basis of the model-free isoconversional method combined with the model-dependent Coats–Redfern method. Despite the differences in values of kinetic parameters obtained from the use of a given model, all results confirmed that the method of char preparation has an influence on the gasification stage and direct char gasification is more favorable. Activation energy obtained from the use of models based on the first-order reaction ranged between 275 and 296 kJ/mol for direct gasification of chars, while the chars gasified indirectly between 307 and 342 kJ/mol, depending upon the heating rate that was used. The model-free isoconversional method confirmed these results. The values for chars gasified directly amounted to Ea = 257–277 kJ/mol, and the values for indirect char gasification obtained by the pyrolysis process at heating rates of 3, 10, and 20 K/min amounted to Ea = 280–291, 287–309, and 289–305 kJ/mol, respectively." **Grzegorz Czerski, Katarzyna Zubek Przemyslaw Grzywacz, and Stanislaw Porada**, *Energy Fuels.* (Subscription may be required.)

Influence of wettability and permeability heterogeneity on miscible CO_2 flooding efficiency.

The following is the Abstract of this article: "[Carbon dioxide] flooding is a proven EOR technique and is also considered as a potential method for CO_2 sequestration. Despite having successful field trials on CO_2 EOR, the effects of reservoir wettability and permeability heterogeneity on the efficiency of miscible CO_2 flooding are not well understood. In this work, laboratory investigations have been carried out to evaluate the influence of these properties on the miscible CO_2 EOR performance. The wettability of hydrophilic Berea core samples was altered to be oil-wet by vacuum saturation of the clean and dry core samples with n-hexadecane. The permeability heterogeneity was obtained by combining two half pieces of axially split water-wet core samples of different permeabilities. Core flooding experiments were conducted for n-hexadecane – synthetic brine – CO_2 systems at 1400 psig backpressure to achieve minimum miscibility pressure (MMP) of CO_2 in n-hexadecane at the test temperature (24 ± 1 °C). It was found that wettability strongly influences CO_2 EOR. For the alternate cases of previously brine flooded (to remaining oil saturation) oil-wet and water-wet core samples, five pore volumes (PVs) of CO_2 recovered 100% and only 43% of remaining oil in place (ROIP) respectively. Three PVs of CO_2 could recover only about 0–5% ROIP from the split core samples. The mechanisms underlying these results are discussed. This study sheds light on the significant influence of reservoir wettability and permeability heterogeneity on the performance of miscible CO_2 EOR." **Prem Bikkina, Jiamin Wan, Yongman Kim, Timothy J. Kneafsey, and Tetsu K. Tokunaga**, *Fuel*. (Subscription may be required.)

CO_2 Emission Trading Effect on Baltic Electricity Market.

The following is the Abstract of this article: "This paper investigates the CO_2 cost pass-through to electricity prices of the Baltic market, as well as CO_2 prices effect on merit order of generation sources and consequently marginal changes of CO_2 emissions in response to changes in electricity demand. Authors use multiple regression analysis to demonstrate that a 1 EUR change in the price of CO_2 emissions would increase the price of the Nordic power market by 0.55 EUR and in the Baltic countries by 0.67 EUR. Additionally, it has been shown that CO_2 prices significantly impact merit order of electricity generators and consequently marginal emissions of CO_2 due to reduction of electricity consumption in case of energy efficiency measures. Based on analysis, it can be concluded that, in the low price scenario (7.5 EUR per ton of CO_2), combined heat and power plants are marginal generators emitting 0.25 tons of CO_2 per 1MWh in cogeneration mode. If CO_2 prices are above 20 EUR, the marginal emitter will become oil shale power plants that emit around 1 ton of CO_2 per 1 MWh of electricity." **Uldis Bariss, Elvijs Avenitis, Gatis Junghans, and Dagnija Blumberga**, *Energy Procedia*. (Subscription may be required.)

Chinese companies' awareness and perceptions of the Emissions Trading Scheme (ETS): Evidence from a national survey in China.

The following is the Abstract of this article: "China announced the launch of a national Emissions Trading Scheme (ETS) in 2017; however, companies appear show little enthusiasm for participation in the ETS in China. This paper identifies the factors affecting companies' awareness and perceptions of ETS by conducting a national survey based on an online questionnaire from May to November 2015 in seven carbon trading pilots. The results indicate that companies' attitudes towards the ETS are positively influenced by government regulations and policy, public relations management and estimated economic benefit. Of these, public relations management is the decisive factor and estimated economic benefit is confirmed to be a relatively weak predictor. A company's environmental and energy strategy exerts insignificant effects on its preference for the ETS, although the sampled companies are very willing to save energy and reduce emissions. There exists an inverted U-shape relationship between a company's level of mitigation technologies and its attitudes towards the ETS. The carbon price fails to stimulate companies to upgrade mitigation technologies. The majority of companies treat participation in the ETS only as a means of improving ties with governments, as well as of earning a good social reputation, rather than as a cost-effective mechanism to mitigate [GHG] emissions." **Lin Yang, Fengyu Li, and Xian Zhang**, *Energy Policy*. (Subscription may be required.)

Coupled effect of CO_2 attack and tensile stress on well cement under CO_2 storage conditions.

The following is the Abstract of this article: "In CCS wells, the well cement is attacked by CO_2-rich fluids, coupled with tensile stress. In this study, well cement samples were designed to be exposed to humid CO_2 gas and CO_2 saturated brine and simultaneously subjected to external tensile stresses with load levels of 25%, 50%, and 75% of the initial tensile strength. The experimental results showed that a higher external tensile stress (50% and 75%) facilitated the generation and propagation of micro-cracks in the tension zone of loaded samples. Hence, the aggressive CO_2-rich medium found direct paths to penetrate further into the core, significantly accelerating the rate of carbonation and failure of the well cement. As a result of the faster ion exchange and transfer, the carbonation rate was faster and the onset of failure in samples immersed in CO_2-saturated brine occurred earlier than in the supercritical CO_2 scenario. Findings from this study provide new, important information for understanding the integrity of well cement sheath under actual CCS well conditions, thereby promoting superior cement system design and safer operation." **Tao Gu, Xiaoyang Guo, Zaoyuan Li, Xiaowei Cheng, Xiaoxia Fan, Asghar Korayem, Wen Hui Duan**, *Construction and Building Materials*. (Subscription may be required.)

MAY 2017

Energy policy for low carbon development in Nigeria: A LEAP model application.

The following is the Abstract of this article: "This paper applied a scenario-based analysis to explore Nigeria's future energy demand, supply and associated GHG emissions from 2010 to 2040 using the Long-range Energy Alternative Planning (LEAP) model. The impact of different energy policies are analyzed for the Nigerian energy system by considering four scenarios: the reference scenario (REF), the low-carbon moderate scenario (LCM), the low-carbon advanced scenario (LCA), and the green optimistic scenario (GO). By considering aggressive energy policies and strategies from LCM to LCA, and even more aggressive options in the GO scenario, [the authors] find that under the REF scenario energy demand is expected to reach 3,075 PJ and a corresponding increase in GHG emissions of 201.2 Mt Co2e by 2040. More aggressive policy intervention by the Nigerian government, as in the GO scenario, would lead to a decrease in energy demand (2,249 PJ) and GHG emissions (124.4 Mt Co2e) in 2040. A cost-benefit and energy system analysis were also carried out in the study." **Nnaemeka Vincent Emodi, Chinenye Comfort Emodi, Girish Panchakshara Murthy, and Adaeze Saratu Augusta Emodi**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

Saturation time dependency of liquid and supercritical CO_2 permeability of bituminous coals: Implications for carbon storage.

The following is the abstract of this article: "Various types of lithospheric geological reservoirs are available for the safe and long-term storage of CO_2. The phase of CO_2 transitions between liquid and supercritical (mostly supercritical for depths greater than 800 m) when injected into the subsurface. This high-density super-critical phase prevents CO_2 molecules from upward diffusion toward the surface. Many questions arise in the context of coal seam sequestration with respect to its capacity, injectivity, plume movement, and leakage assessment. This work examines the effect of various saturation periods on the permeability evolution of porous coal. In this triaxial study, liquid and supercritical CO_2, along with N_2 were injected into a coal sample from the Jharia coal field (Jharkhand state, India). It was observed that the permeability reduction for liquid CO_2 was 25%, 13.5% and 1% for 0–20 h phase, 20–40 h phase and 40–60 h phase, respectively. For supercritical CO_2, the reduction was observed to be 42.5%, 38.4% and 11%, respectively, for the three saturation cycles. The findings highlight that while high CO_2 sorption in supercritical phase stores more of the adsorbate, the reduction in permeability slows down injection operation and the saturation induced coal expansion threatens the overall stability of the system." **Vikram Vishal**, *Fuel*. (Subscription may be required.)

Using Prokaryotes for Carbon Capture Storage.

The following is the Abstract of this article: "Geological storage of CO_2 is a fast-developing technology that can mitigate rising carbon emissions. However, there are environmental concerns with the long-term storage and implications of a leak from a CCS site. Traditional monitoring lacks clear protocols and relies heavily on physical methods. Here, [the authors] discuss the potential of biotechnology, focusing on microbes with a natural ability to utilize and assimilate CO_2 through different metabolic pathways. [The authors] propose the use of natural microbial communities for CCS monitoring and CO_2 utilization, and, with examples, demonstrate how synthetic biology may maximize CO_2 uptake within and above storage sites. An integrated physical and biological approach, combined with metagenomics data and biotechnological advances, will enhance CO_2 sequestration and prevent large-scale leakages." **Natalie Hicks, Unni Vik, Peter Taylor, Efthymios Ladoukakis, Joonsang Park, Frangiskos Kolisis, and Kjetill S. Jakobsen**, *Trends in Biotechnology*. (Subscription may be required.)

Fair design of CCS infrastructure for power plants in Qatar under carbon trading scheme.

The following is the Abstract of this article: "Qatar is currently the highest emitter per capita and targets emission reduction by exercising tight controls on gas flaring. In order to limit the emission under allowances, the power plants have two options: investing in CCS systems or buying carbon credits for the excess emissions above their allowances. However, CCS systems are expensive for installation and operation. In this paper, a mixed integer linear programming (MILP) model is developed for the design of integrated carbon capture, transport and storage infrastructure in Qatar under carbon trading scheme. [The authors] first investigate the critical carbon credit prices to decide under which price it is more beneficial to invest on CCS systems or to buy carbon credits via carbon trading. Then the fair design of the CCS infrastructure is obtained under two fairness scenarios: the same saving ratio and the game theory Nash approach. Fair cost distribution among power plants in Qatar is obtained by selecting the CO_2 resources (power plants) to be captured with available capture technologies and materials, designing the transportation pipeline network to connect the resources with the sequestration and/or utilization sites and determining the carbon trading price and amount among power plants. Under different fairness scenarios, the total costs are slightly higher than that from minimizing the total cost to obtain the fair cost distribution. Power plants with higher CO_2 emissions determine to install CCS system, while other power plants buy the carbon credits from domestic or international market to fulfil their carbon allowance requirements. The future work includes extending the current model by considering power generation distribution and designing the pipeline network with the selection of pump locations and pipe diameters." **Di Zhang, Yousef Alhorr, Esam Elsarrag, Abdul Hamid Marafia, Paola Lettieri, and Lazaros G. Papageorgiou**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Screening and techno-economic assessment of biomass-based power generation with CCS technologies to meet 2050 CO_2 targets.

The following is the Abstract of this article: "Biomass-based power generation combined with CO_2 capture and storage (Biopower CCS) currently represents one of the few practical and economic means of removing large quantities of CO_2 from the atmosphere, and the only approach that involves the generation of electricity at the same time. [The authors] present the results of the Techno-Economic Study of Biomass to Power with CO_2capture (TESBiC) project, that entailed desk-based review and analysis, process engineering, optimization as well as primary data collection from some of the leading pilot demonstration plants. From the perspective of being able to deploy Biopower CCS by 2050, twenty-eight Biopower CCS technology combinations involving combustion or gasification of biomass (either dedicated or co-fired with coal) together with pre-, oxy- or post-combustion CO_2 capture were identified and assessed. In addition to the capital and operating costs, techno-economic characteristics such as electrical efficiencies (LHV% basis), Levelized Cost of Electricity (LCOE), costs of CO_2 captured and CO_2 avoided were modelled over time assuming technology improvements from today to 2050. Many of the Biopower CCS technologies gave relatively similar techno-economic results when analyzed at the same scale, with the plant scale (MW_e) observed to be the principal driver of CAPEX (£/MW_e) and the cofiring % (i.e. the weighted feedstock cost) a key driver of LCOE. The data collected during the TESBiC project also highlighted the lack of financial incentives for generation of electricity with negative CO_2 emissions." **Amit Bhave, Richard H.S. Taylor, Paul Fennell, William R. Livingston, Nilay Shah, Niall Mac Dowell, John Dennis, Markus Kraft, Mohammed Pourkashanian, Mathieu Insa, and Jenny Jones**, *Applied Energy*. (Subscription may be required.)

Characterization and modeling of the alteration of fractured class-G Portland cement during flow of CO_2-rich brine.

The following is the Abstract of this article: "[The authors] investigate experimentally the alteration of fractured class-G cement flowed by CO_2-rich brine. The experiment mimics a mechanically damaged rough-walled fractured cement annulus at temperature 60 °C and pressure 10 MPa. The experiment consists of flowing a reservoir-equilibrated brine mixed with CO_2 (partial pressure of 2.3 MPa) through the fracture of average aperture 14 μm at constant flow rate (100 μL min−1). This flow rate corresponds to pressure gradient representative of an average in situ hydrodynamic condition. Results indicate an intense alteration of the cement with a large removal of mass at the scale of the sample. However, the fracture alteration patterns are triggered by the initial heterogeneity of the fracture aperture; the aperture of the low aperture zones tends to decrease due to calcite precipitation whereas preferential paths develop in the zones of higher aperture associated. Nevertheless, the expected large permeability increase triggered by the mass removal is mitigated by the precipitation of a low density Si-rich amorphous material. The alteration rate will decrease with time because of the increasing distance of diffusion between the fracture where the reactants are actively renewed by advection and the portlandite and C-S-H dissolution fronts. The different zones of reaction can be adequately modeled by a simple 1D diffusion-reaction model using published kinetics coefficients and extrapolation to larger times than the experiment time can be drawn. Altogether, and in addition to the previous studies of the alteration of fractured well cement annulus, this study shows that the leakage potential is strongly controlled by the initial distribution of the aperture along the fracture: low aperture zones will tend to self-heal while localized flow in connected high aperture paths will be perennial." **H. Abdoulghafour, P. Gouze, L. Luquot, and R. Leprovost**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

CO_2 Accounting and Risk Analysis for CO_2 Sequestration at Enhanced Oil Recovery Sites.

The following is the Abstract of this article: "Using CO_2-EOR is a promising technology for emissions management because CO_2-EOR can dramatically reduce sequestration costs in the absence of emissions policies that include incentives for [CCS]. This study develops a multiscale statistical framework to perform CO_2 accounting and risk analysis in an EOR environment at the Farnsworth Unit (FWU), Texas. A set of geostatistical-based Monte Carlo simulations of CO_2–oil/gas–water flow and transport in the Morrow formation are conducted for global sensitivity and statistical analysis of the major risk metrics: CO_2/water injection/production rates, cumulative net CO_2 storage, cumulative oil/gas productions, and CO_2 breakthrough time. The median and confidence intervals are estimated for quantifying uncertainty ranges of the risk metrics. A response-surface-based economic model has been derived to calculate the CO_2-EOR profitability for the FWU site with a current oil price, which suggests that approximately 31% of the 1000 realizations can be profitable. If government carbon-tax credits are available, or the oil price goes up or CO_2 capture and operating expenses reduce, more realizations would be profitable. The results from this study provide valuable insights for understanding CO_2 storage potential and the corresponding environmental and economic risks of commercial-scale CO_2-sequestration in depleted reservoirs." **Zhenxue Dai, Hari Viswanathan, Richard Middleton, Feng Pan, William Ampomah, Changbing Yang, Wei Jia, Ting Xiao, Si-Yong Lee, Brian McPherson, Robert Balch, Reid Grigg, and Mark White**, *Environmental Science and Technology*. (Subscription may be required.)

A big data study on emitting companies' performance in the first two phases of the European Union Emission Trading Scheme.

The following is the Abstract of this article: "As CO_2 emissions are quantified by allowances and traded in markets, wise trading strategies will bring emitting companies higher profits or lower costs. Based on the big data of Community Independent Transaction Log (CITL), this article hereby presents a micro study on the emitting companies' efforts in increasing profits and saving costs during the allowances trading in the first two phases of the European Union Emission Trading Scheme (EU ETS). The efforts are measured by an after-action factor of trading performance, which is built on a series of behavior and monetary variables. By comparison, demanders of the emitting companies are more inclined to reach a higher trading performance, while that inclination is heterogeneous among the suppliers. In addition, emitting companies with lower emission levels had a better trading performance. With a higher proportion of low-emitting companies, the manufacturing sector had a better trading performance than the energy sector. The effect of the trading requirement on trading performance are investigated via a quantile regression mode. Results suggest that: (1) the selling requirement of suppliers has a positive effect on their trading performance, while the effect becomes weaker when the selling requirement increases; (2) the buying requirement has a positive effect on the demanders' trading performance only when the requirement is high, and the effect becomes stronger as the requirement increases; and (3) when the buying requirement is at a lower level, demanders' trading performance becomes worse as the requirement grows. The conclusion is that the emission level, industrial sector and trading requirement do have influences on the trading performance of emitting companies in emission trading." **Yin-Peng Liu, Jian-Feng Guo, and Ying Fan**, *Journal of Cleaner Production*. (Subscription may be required.)

JUNE 2017

Carbon policy in a high-growth economy: The Case of China.

The following is the Abstract of this article: "There is widespread concern that a stringent international agreement will not be reached because it would imply too high costs for fast growing economies. To test this hypothesis [the authors] develop a general equilibrium model with fully endogenous growth and estimate the policy cost for China. The framework includes disaggregated industrial and energy sectors, endogenous innovation, and sector-specific investments. [The authors] find that the governmental target of a 65 percent carbon intensity reduction until 2030 causes a welfare reduction of 0.5 percent for China, compared to the business-as-usual scenario. Costs of carbon policy for China under an internationally coordinated emission reduction amount to 4 percent of total welfare. [The authors] highlight that lower economic growth, faster energy technology development, and stronger induced innovation reduce welfare losses significantly. Increased urbanization raises the policy costs because urban households consume more energy and energy intensive goods." **Lucas Bretschger and Lin Zhang**, *Resource and Energy Economics.* (Subscription may be required.)

Experimental assessment of well integrity for CO_2 geological storage: A numerical study of the geochemical interactions between a CO_2-brine mixture and a sandstone-cement-steel sample.

The following is the Abstract of this article: "Geologic storage of CO_2 is one option for avoiding CO_2 emissions from a large-scale point source such as a thermal power plant and a gas refinery. The alteration of well materials by CO_2 under reservoir conditions requires characterization because the wells are the main possible leakage pathways for CO_2 from a geological reservoir. This paper presents a numerical modeling of interaction experiments involving a composite well sample formed from steel casing surrounded by Portland cement, itself surrounded by sandstone and CO_2-saturated brine at 10 MPa and 50°C during a period of up to 8 weeks, as reported by Mito et al. (2015). A reactive-transport model was developed to simulate diffusion of the CO_2-saturated brine in the well sample and the resulting successive dissolution/precipitation reactions in the sandstone, cement and steel. The observed changes in mineralogy (which primarily consist of dissolution of portlandite and Ca-rich CSH phases and precipitation of calcite, amorphous silica and zeolite) and the associated evolution in brine composition were reproduced by the model. A buffering role of sandstone on the cement degradation was evidenced, thus avoiding the re-dissolution of calcite usually observed in experiments with direct interaction between cement and CO_2-saturated brine. Interestingly, the model results also noted a possible perturbation in the measured pH and Ca content due to CO_2 outgassing during solution sampling. The Si behavior control linked with the uncertainty in zeolite stability is also discussed." **Joachim Tremosa, Saeko Mito, Pascal Audigane, and Ziqiu Xue**, *Applied Geochemistry*. (Subscription may be required.)

Geomechanical effects of CO_2 storage in depleted gas reservoirs in the Netherlands: Inferences from feasibility studies and comparison with aquifer storage.

The following is the Abstract of this article: "In this paper, the geomechanical impact of large-scale CO_2 storage in depleted Dutch gas fields is compared with the impact of CO_2 storage in saline aquifers. The geomechanical behavior of four potential CO_2 storage sites is examined using flow and geomechanical simulations. Many gas reservoirs in the Netherlands are found in fault blocks, one to a few kilometers wide, laterally bounded by sealing faults. Aquifer depletion or re-pressurization in the lateral direction is seldom an issue because of a lack of active aquifers. Reservoir pressure changes are therefore limited to a gas-bearing fault block, while the induced stress changes affect the gas reservoir and extend 1–3 km away into the surrounding rock. Arguments in favor of CO_2 storage in depleted gas fields are: proven seal quality, availability of field data, no record of seal integrity failure by fault reactivation from the seismically active producing Dutch gas fields, and the potential benefits of restoring the virgin formation pressure and stress state to geomechanical stability. On the other hand, CO_2 injection in saline aquifers causes pressure build-up that exceeds the virgin hydrostatic pressure. Stress perturbations resulting from pressure build-up affect large areas, extending tens of kilometers away from the injection wells. Induced stresses in top seals are, however, small and do not exceed a few tenths of megapascal for a pressure build-up of a few megapascals in the storage formation. Geomechanical effects on top seals are weak, but could be enhanced close to the injection zone by the thermal effects of injection. Uncertainties related to characterization of large areas affected by pressure build-up are significant, and seal quality and continuity are more difficult to be demonstrated for aquifers than for depleted gas reservoirs that have held hydrocarbons for millions of years." **Bogdan Orlic**, *Journal of Rock Mechanics and Geotechnical Engineering*. (Subscription may be required.)

Quantifying the value of CCS for the future electricity system.

The following is the Abstract of this article: "Many studies have quantified the cost of CCS power plants, but relatively few discuss or appreciate the unique value this technology provides to the electricity system. CCS is routinely identified as a key factor in least-cost transitions to a low-carbon electricity system in 2050, one with significant value by providing dispatchable and low-carbon electricity. This paper investigates production, demand and stability characteristics of the current and future electricity system. [The authors] analyze the Carbon Intensity (CI) of electricity systems composed of unabated thermal (coal and gas), abated (CCS), and wind power plants for different levels of wind availability with a view to quantifying the value to the system of different generation mixes. As a thought experiment [the authors] consider the supply side of a UK-sized electricity system and compare the effect of combining wind and CCS capacity with unabated thermal power plants. The resulting capacity mix, system cost and CI are used to highlight the importance of differentiating between intermittent and firm low-carbon power generators. [The authors] observe that, in the absence of energy storage or demand side management, the deployment of intermittent renewable capacity cannot significantly displace unabated thermal power, and consequently can achieve only moderate reductions in overall CI. A system deploying sufficient wind capacity to meet peak demand can reduce CI from 0.78 tCO_2/MWh, a level according to unabated fossil power generation, to 0.38 tCO_2/MWh. The deployment of CCS power plants displaces unabated thermal plants, and whilst it is more costly than unabated thermal plus wind, this system can achieve an overall CI of 0.1 tCO_2/MWh. The need to evaluate CCS using a systemic perspective in order to appreciate its unique value is a core conclusion of this study." **Clara F. Heuberger, Iain Staffell, Nilay Shah, and Niall Mac Dowell,** *Energy & Environmental Science*. (Subscription may be required.)

Carbon capture and storage: Lessons from a storage potential and localization analysis.

The following is from the Abstract of this article: "[The challenges involve totally rethinking the world's energy system. In particular, CCS technologies are still presented as a solution to reach ambitious targets.] However, avoiding the required Gt of CO_2 emissions by investing in CCS technologies supposes the development of carbon storage capacities. This analysis, conducted with TIAM-FR and based on a wide review of geological storage potential and various data, aims to discuss the impact of this potential on the development of the CCS option. [The authors] also specify a scenario allowing the exclusion of onshore storage due to a hypothetic policy considering public resistance to onshore storage, and carbon transport costs variation effects. The implementation of CCS is less impacted by the level of carbon storage potential - except in the lowest case of availability - than by the type of sequestration site. However, the development of CCS is lower at the end of the period in the case of a decrease in carbon storage potential. Indeed, the question of type of storage site appears to have a greater impact, with an arbitrage between deep saline aquifers and depleted basins and enhanced recovery. Doubling the cost of carbon transport does not limit the penetration of carbon capture technologies, but it does impact the choice of site. Finally, a limitation of onshore storage could have a significant impact on the penetration of the CCS option. The explanation for this limited deployment of CCS is thus the higher cost of offshore storage more than the level of storage potential." **Sandrine Selosse and Olivia Ricci**, *Applied Energy*. (Subscription may be required.)

Review of CO_2 price in Europe using feed-in tariff rates.

The following is the Abstract of this article: "The price of carbon emitted by thermal plants has always been a favorite topic of researchers and policy makers. A substitute price for CO_2 is calculated in this study based on real-time payments through government tariffs. These payments aim to mitigate CO_2 emission caused by unregulated electricity generation. The total CO_2 produced by the thermal plants of 10 European countries is shown in this study. The government's payment for each technology is utilized to clear the final CO_2 abatement cost. The substitute price of avoiding CO_2 emission (SPAC) for each technology and country is estimated. SPAC is basically the price that each country pays to avoid producing CO_2. The conducted survey shows that the SPAC of the 10 European countries ranges from 63 to 2951 Euros depending on the type of technology used and the country's policy. Results confirm a competitive payment by governments only for German and UK hydro and UK wind technologies. Comparison of the countries' payments for renewable energies and CO_2 market price shows that governments incurred an inefficient payment of liquidity as a carbon mitigation policy." **B. Bakhtyar, A. Fudholi, Kabir Hassan, M. Azam, C.H. Lim, N.W. Chan, and K. Sopian**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

Trade-off between carbon reduction benefits and ecological costs of biomass-based power plants with carbon capture and storage (CCS) in China.

The following is the Abstract of this article: "Integrating [CCS] into biomass power plants (BioCCS) can reduce carbon emissions, but its ecological performance associated with natural resources consumption remains unexamined. Taking a typical BioCCS project – the Maowusu biomass direct-fired power plant with the CCS of Spirulina cultivation in Inner Mongolia of China – as a case, this study observed the trade-offs between the carbon reduction benefits and ecological performance of adding CCS to the power plant. Life cycle assessment (LCA) revealed that the combination of CCS avoids 1228 metric tons of CO_2 emissions annually, while emergy analysis revealed that it deteriorated the ecological performance of the BioCCS system because considerable nonrenewable resources were required by Spirulina cultivation. The BioCCS system is unsustainable in the long run from the ecological point of view. The sensitivity analyses show that there would be no carbon reduction benefits by adding CCS when 60% of designed CO_2 capacity is fixed by Spirulina, and insufficient biomass for electricity generation also affects system performance significantly, which are two main barriers to the BioCCS project. These results indicate that decision-makers should take into account both the carbon reduction benefits and the ecological costs in the development of BioCCS systems." **Mingyue Pang, Lixiao Zhang, Sai Liang, Gengyuan Liu, Changbo Wang, Yan Hao, Yafei Wang, and Ming Xu,** *Journal of Cleaner Production*. (Subscription may be required.)

Impacts of the coming emission trading scheme on China's coal-to-materials industry in 2020.

The following is the Abstract of this article: "China will establish a national emission trading scheme (ETS) in 2017, and the excessive development of coal-to-materials may hinder China's emission reduction goals, specifically to reduce carbon emissions intensity by 40–45% from 2005 to 2020. In this study, the status of China's coal-to-materials projects is presented, based on which [the authors] forecasted the high, middle and low CO_2 emission scenarios for the coal-to-materials industry in 2020, which were determined to be approximately 580, 290, and 180 Mt CO_2, respectively. The high scenario is approximately equivalent to the total emission from Canada, the world's 11th-largest emitter in 2014. The main purpose of this study is to research the impacts of ETS on the coal-to-materials industry in 2020. Oil-to-materials is an ineluctable and powerful competitor to the coal-to-materials industry, complicating this matter. Therefore, the Cournot model was applied to quantitatively analyze the competition between these two monopolistic entities and determine the influence of oil, coal and carbon prices on CO_2 emissions from coal-to-materials. The visual simulation of the results shows that ETS can improve the competitiveness of oil-to-materials, resulting in a decline in production of coal-to-materials. However, the effect of the carbon cost with historical price range of Chinese ETS pilots on mitigating CO_2 emissions from the coal-to-materials industry is limited. High oil prices and low coal prices can increase the emissions from coal-to-materials significantly. [The authors'] study also provides a tool to analyze the feasibility of ETSs for a set emission reduction goal. Additionally, the necessary sensitivity analysis was also provided." **Guangyoa Li, Jin Yang, Dingjiang Chen, and Shanying Hu**, *Applied Energy*. (Subscription may be required.)

JULY 2017

Carbon dioxide utilization in a microalga-based biorefinery: Efficiency of carbon removal and economic performance under carbon taxation.

The following is the Abstract of this article: "Coal-fired power plants are major stationary sources of [CO_2] and environmental constraints demand technologies for abatement. Although [CCS] is the most mature route, it poses severe economic penalty to power generation. Alternatively, this penalty is potentially reduced by Carbon Capture and Utilization, which converts [CO_2] to valuable products, monetizing it. This work evaluates a route consisting of [CO_2] bio-capture by Chlorella pyrenoidosa and use of the resulting biomass as feedstock to a microalgae-based biorefinery; [CCS] route is evaluated as a reference technology. The integrated arrangement comprises: (a) [CO_2] biocapture in a photobioreactor, (b) oil extraction from part of the produced biomass, (b) gasification of remaining biomass to obtain bio-syngas, and (c) conversion of bio-syngas to methanol. Calculation of capital and operational expenditures are estimated based on mass and energy balances obtained by process simulation for both routes ([CCS] and the biorefinery). Capital expenditure for the biorefinery is higher by a factor of 6.7, while operational expenditure is lower by a factor of 0.45 and revenues occur only for this route, with a ratio revenue/operational expenditure of 1.6. The photobioreactor is responsible for one fifth of the biorefinery capital expenditure, with footprint of about 1000 ha, posing the most significant barrier for technical and economic feasibility of the proposed biorefinery. The Biorefinery and [CCS] routes show [CO_2] capture efficiency of 73% and 48%, respectively, with capture cost of 139$/t and 304$/t. Additionally, the biorefinery has superior performance in all evaluated metrics of environmental impacts." **Igor Lapenda Wiesberg, George Victor Brigagão, José Luiz de Medeiros, and Ofélia de Queiroz Fernandes Araújo**, *Journal of Environmental Management*. (Subscription may be required.)

Flue gas injection into gas hydrate reservoirs for methane recovery and carbon dioxide sequestration.

The following is the Abstract of this document: "Flue gas injection into methane hydrate-bearing sediments was experimentally investigated to explore the potential both for methane recovery from gas hydrate reservoirs and for direct capture and sequestration of [CO_2] from flue gas as [CO_2] hydrate. A simulated flue gas from coal-fired power plants composed of 14.6 mol% [CO_2] and 85.4 mol% nitrogen was injected into a silica sand pack containing different saturations of methane hydrate. The experiments were conducted at typical gas hydrate reservoir conditions from 273.3 to 284.2 K and from 4.2 to 13.8 MPa. Results of the experiments show that injection of the flue gas leads to significant dissociation of the methane hydrate by shifting the methane hydrate stability zone, resulting in around 50 mol% methane in the vapor phase at the experimental conditions. Further depressurization of the system to pressures well above the methane hydrate dissociation pressure generated methane-rich gas mixtures with up to 80 mol% methane. Meanwhile, [CO_2] hydrate and [CO_2]-mixed hydrates were formed while the methane hydrate was dissociating. Up to 70% of the [CO_2] in the flue gas was converted into hydrates and retained in the silica sand pack." **Jinhai Yang, Anthony Okwananke, Bahman Tohidi, Evgeny Chuvilin, Kirill Maerle, Vladimir Istomin, Boris Bukhanov, and Alexey Cheremisin**, *Energy Conversion and Management*. (Subscription may be required.)

Carbon dioxide storage schemes: Technology, assessment and deployment.

The following is the Abstract of this article: "[CCS] is the only technology available to mitigate large-scale [GHG] emissions from fossil fuel based power and industrial sectors in the near future. When technology to capture CO_2 is relatively mature and commercially available for power and industrial sectors, safe, reliable and long-term storage of captured CO_2 remains a key uncertainty affecting wide-spread deployment of [CCS] technology yet. In this paper, the authors assessed techno-economic aspects of geological CO_2 storage options, from CO_2 transportations, various geological storage approaches, to CO_2 leakage monitoring. Compared with depleted oil/gas reservoirs and coal seams, deep saline aquifers possess much larger storage capacities and may be possibly near many CO_2 emission sites due to widespread distributions. If CO_2 storage is combined with enhanced industrial production (e.g. oil, natural gas), it has a greater potential to reducing the overall cost of CO_2 storage. Potential CO_2 leakage may be the main barriers to the development of CO_2 geological storage. It is recommended to make full use of big data mining approach in selection and approval of CO_2 geological sites, estimation of storage capacities, assessment of potential leakage risks, awarding of carbon credits, as well as analysis of public acceptations. At the same time, as a leakage-free CO_2 storage option, CO_2 mineralization & industrial utilization is to trap CO_2 permanently in stable minerals by reactions with metal oxides and forming stable carbonates. These CO_2 mineralization & industrial utilization schemes need to guarantee sustainable or environmentally friendly processes and satisfy basic principles of industrial ecology if implemented on a large industrial scale. Currently, most of CO_2 storage schemes are still in the early stage of technological development and are still far from large-scale commercialization. The high cost, high energy penalty, safety and reliability, and policy uncertainties are main barriers for the implement of carbon storage schemes." **Zhihua Zhang and Donald Huisingh**, *Journal of Cleaner Production*. (Subscription may be required.)

Combined positron emission tomography and computed tomography to visualize and quantify fluid flow in sedimentary rocks.

The following is the Abstract of this article: "Here [the authors] show for the first time the combined positron emission tomography (PET) and computed tomography (CT) imaging of flow processes within porous rocks to quantify the development in local fluid saturations. The coupling between local rock structure and displacement fronts is demonstrated in exploratory experiments using this novel approach. [The authors] also compare quantification of 3-D temporal and spatial water saturations in two similar CO_2 storage tests in sandstone imaged separately with PET and CT. The applicability of each visualization technique is evaluated for a range of displacement processes, and the favorable implementation of combining PET/CT for laboratory core analysis is discussed. [The authors] learn that the signal-to-noise ratio (SNR) is over an order of magnitude higher for PET compared with CT for the studied processes." **M. A. Fernø, J. Gauteplass, L. P. Hauge, G. E. Abell, T. C. H. Adamsen, and A. Graue**, *Water Resources Research.* (Subscription may be required.)

Carbon capture and storage across fuels and sectors in energy system transformation pathways.

The following is the Abstract of this article: "CCS is broadly understood to be a key mitigation technology, yet modeling analyses provide different results regarding the applications in which it might be used most effectively. Here [the authors] use the Global Change Assessment Model (GCAM) to explore the sensitivity of CCS deployment across sectors and fuels to future technology cost assumptions. [The authors] find that CCS is deployed preferentially in electricity generation or in liquid fuels production, depending on CCS and biofuels production cost assumptions. [The authors] consistently find significant deployment across both sectors in all of the scenarios considered here, with bioenergy with CCS (BECCS) often the dominant application. As such, this study challenges the view that CCS will primarily be coupled with power plants and used mainly in conjunction with fossil fuels, and suggests greater focus on practical implications of significant CCS and BECCS deployment to inform energy system transformation scenarios over the 21st century." **Matteo Muratori, Haroon Kheshgi, Bryan Mignone, Leon Clarke, Haewon McJeon, and Jae Edmonds**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Management and dewatering of brines extracted from geologic carbon storage sites.

The following is the Abstract of this article: "Subsurface pressure management is a significant challenge in geologic CO_2 storage. Elevated pressure generated from the injection of supercritical CO_2 can be managed by the withdrawal of brine from saline formations before or during CO_2 injection; however, management of the extracted brines is non-trivial because they may have high concentrations of dissolved solids and other contaminants. Dewatering a brine can reduce the volume needing disposal; in addition, water separated from the brine can be a source of usable low salinity water. This review will summarize the composition of brines extracted from select domestic geologic CO_2 storage sites, will calculate the minimum of work of dewatering, and will provide a critical review of developed and developing desalination/dewatering technologies that could be applied to brines extracted from saline formations before or during geologic CO_2 storage operations. Herein are also highlighted, when appropriate, the similarities and the differences between dewatering brines produced from oil/gas operations and brines extracted from geologic CO_2 storage. Since a source of steam or natural gas is likely unavailable/unsuitable for dewatering brines extracted during CO_2 storage, the ideal treatment processes should have a high electrical efficiency and, if possible, should be able to take advantage of the inherent elevated temperature of these brines." **Jason T. Arena, Jinesh C. Jain, Christina L. Lopano, J. Alexandra Hakala, Timothy V. Bartholomew, Meagan S. Mauter, and Nicholas S. Siefert**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Research on the efficiency of carbon trading market in China.

The following is the Abstract of this article: "In 2014, China proposed medium and long-term low carbon development goals in China-U.S. Joint Statement on Climate Change that the emission of [CO_2] would reach its peak and the proportion of non-fossil energy accounted for the primary energy consumption would increase to 20% in 2030. In order to achieve these goals, the unified carbon emission trading system should be put into effect by 2017, the implementation of the unified carbon emission trading system depends on the effectiveness of the current carbon trading market in China. On the basis of the effective market theory and fair game model, the unit root test and the run test are developed to analyze the carbon emission market of four representative cities in China. The results show that (1) the carbon trading market in China has only achieved weak efficiency, while the semi strong efficiency and the strong efficiency have not been reached; (2) with the expansion of the market scale, the increase of trading volume, the carbon trading market would

converge from the state of inefficiency to weak form efficiency gradually, and the carbon trading market in China shows signs of restoring market efficiency." **Xin-gang Zhao, Lei Wu, and Ang Li**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

AUGUST 2017

Assessing the Risk of Carbon Dioxide Emissions from Blue Carbon Ecosystems.

The following is the Abstract of this article: "'Blue carbon' ecosystems, which include tidal marshes, mangrove forests, and seagrass meadows, have large stocks of organic carbon (Corg) in their soils. These carbon stocks are vulnerable to decomposition and – if degraded – can be released to the atmosphere in the form of CO_2. [The authors] present a framework to help assess the relative risk of CO_2 emissions from degraded soils, thereby supporting inclusion of soil Corg into blue carbon projects and establishing a means to prioritize management for their carbon values. Assessing the risk of CO_2 emissions after various kinds of disturbances can be accomplished through knowledge of both the size of the soil Corg stock at a site and the likelihood that the soil Corg will decompose to CO_2." **Lovelock, Catherine E.; Atwood, Trisha; Baldock, Jeff; Duarte, Carlos M.; Hickey, Sharyn; Lavery, Paul S.; Masqué, Pere; Macreadie, Peter I.; Ricart, Aurora M.; Serrano, Oscar; and Steven, Andy D. L.**, *Frontiers in Ecology and the Environment*. (Subscription may be required.)

CO_2 Trapping in the Context of Geological Carbon Sequestration.

The following is the Abstract of this article: "Geological sequestration of CO_2 has been identified as a mitigation option to the problem of climate change which the world is facing today. This review gives a comprehensive overview of carbon storage technology and focuses on the different methods that have been used for the sequestration of CO_2 in geological formation. [CCS] involves the capturing of [CO_2] from large commercial plant such as power plant, and transports them to geological storage site for long-term storage in geological formations such as basalt, depleted oil and gas field, coal seams, and saline aquifers. The principles of CO_2 sequestration and trapping mechanisms are presented in this work. CO_2 hydrate formation, which is a good trapping mechanism if it is thermodynamically stable, is also explained along with the important geological site selection characteristics. Finally, the monitoring techniques for detection of CO_2 plumes in the reservoir using geophysical and geochemical methods are explored." **Kazeem O. Rabiu, Lidong Han, and Diganta Bhusan Das**, *Reference Module in Earth Systems and Environmental Sciences.* (Subscription may be required.)

The Application of Supercritical Carbon Dioxide for the Recovery of Residual Hydrocarbon Reserves at the Late Stage of Reservoir Engineering.

The following is the Abstract of this article: "The unique experimental base which allows to investigation and model the processes of extraction, wipe hard-to-recover hydrocarbon resources from a variety of solid porous media in a wide range of state parameters including critical area, using a variety of solvents, including [CO_2], is created. The experiments on the displacement of various hydrocarbons from the reservoir model [CO_2] in the temperature range 20-200°C and pressures of 5 to 45 MPa, as well as qualitative experiments on the extraction of hydrocarbons from core samples are conducted. The experimental results obtained prove high efficiency of the supercritical [CO_2] for the displacement and extraction of hard to recovery hydrocarbon deposits." **Filenko DG, Dadashev MN, Grigoryev EB, and Vinokurov VA**, *Recent Advances in Petrochemical Science*. (Subscription may be required.)

Screening Test of Amino Acid Salts for CO_2 Absorption at Flue Gas Temperature in a Membrane Contactor.

The following is the Abstract of this article: "[Carbon dioxide] absorption at the temperature of flue gas inlet could reduce the costs related to flue gas cooling systems and improve the economic feasibility of the [post-combustion] carbon capture processes. Amino acid salts are considered as promising absorbents to absorb CO_2 in a membrane contactor at elevated temperatures because of their advantages of lower volatility, less degradation, and higher surface tension. In this study, 24 common amino acids have been screened for their potential to absorb CO_2 at the temperature of flue gas inlet in a membrane contactor. These screening processes involved examination of the water solubility of amino acids, measurement of surface tension and viscosity of their potassium salts, CO_2 capacity, and CO_2 membrane absorption test. Taurine, sarcosine, and glycine were identified as performing well in all the screening tests and were further investigated for CO_2 membrane absorption at high temperatures up to 80°C and various CO_2 loadings in a polypropylene hollow fiber membrane module. The results show that those amino acid salts are feasible to absorb CO_2 at high temperatures in a membrane contactor. Potassium sarcosinate is identified as the most promising absorbent for high-temperature CO_2 absorption with a better absorption performance than monoethanolamine and other amino acid salts." **Feijie He, Tao Wang, Mengxiang Fang, Zhen Wang, Hai Yu, and Qinhui Ma**, *Energy Fuels*. (Subscription may be required.)

Study on the ratio of pore-pressure/stress changes during fluid injection and its implications for CO_2 geologic storage.

The following is the Abstract of this article: "The success of fluid injection into geological formations, which is the main operation during both CO_2 geologic storage and wastewater injection, is contingent on the geomechanical integrity of the site. A key task that allows us to evaluate the risk of geomechanical failure is the precise prediction of pore-pressure buildup and subsequent change in the state of stresses during and after the fluid injection. Contrary to traditional approaches, where total stresses are assumed to remain constant, recent studies have ascertained that total stresses in fact change in every direction as fluid extraction/injection disturbs the pore-pressure field and causes deformations. In this study, [the authors] conduct an in-depth investigation of the ratio of change in total stress to that in pore-pressure, $\Delta\sigma/\Delta P$, which has been denoted in the literature as the pore-pressure/stress coupling. [The authors] employ a numerical simulation method that couples single-phase fluid flow in porous media with poroelasticity to explore the spatiotemporal evolution of the $\Delta\sigma/\Delta P$ ratio for various conditions. These numerical experiments allow us to examine how different material properties and structural geometries would influence the evolution of $\Delta\sigma/\Delta P$ in both vertical and horizontal directions. These ratios of pore-pressure/stress changes exhibit different spatiotemporal evolutions depending on key factors that include the hydraulic boundary condition, Biot's coefficient, Poisson's ratio, and the hydraulic diffusivity of both the injection zone and caprock. On the basis of observations, [the authors] suggest firsthand guidelines for analytically determining the ratio of pore-pressure/stress changes, $\Delta\sigma/\Delta P$. Finally, [the authors] use examples and case studies to illustrate how the $\Delta\sigma/\Delta P$ ratio can be incorporated into an analytic calculation for determining a maximum sustainable pressure limit." **Seunghee Kim and Seyyed Abolfazl Hosseini**, *Journal of Petroleum Science and Engineering.* (Subscription may be required.)

Liquidity, information, strategic trading in an electronic order book: New insights from the European carbon markets.

The following is the Abstract of this article: "The electronic limit order book (LOB hereafter) has rapidly become the primary way of trading European carbon assets over the 4 years of the EU ETS programme (2008–2012). In this first attempt of examining the informational content of an electronic order book, [the authors] evidence that order flow imbalances have a moderate capacity to predict short term price changes. However, [the authors] find that both LOB slope and immediacy costs help to forecast quote improvements and volatility in the next 30 min. Further, [the authors] explain why informed trading is highly influential and show that it consists in mixing order splitting strategies and posting fleeting orders once the asymmetric information is reduced. Overall, the consolidated status of the order book mirrors a high level of market uncertainty and a low degree of informational efficiency. In this way, strategic trading can in itself explain some of order book properties, independently of the degree of traders' sophistication and market competition." **Yves Rannou**, *Research in International Business and Finance*. (Subscription may be required.)

Mapping research on carbon emissions trading: a co-citation analysis.

The following is the Abstract of this article: "Carbon emissions trading (CET) is a market mechanism, aims to promote the control of globe [GHG] emissions. It is an important part of international environmental cooperation and it is also the important application research filed of environmental economics and institutional economics. There is a very obvious phenomenon that the publications about CET increasing year by year. This paper adopts the scientometric analysis method to assess the current state and explore the development trends of carbon emission trading domain based on the literature data retrieved from Web of Science. The research results of this paper could answer the following questions clearly. 1) Which subject category is the most popular in CET research area? Which journal published the most number of articles in this area? Which institution and country is the most productive in CET domain? 2) What are the major research areas and what documents are the most cited? Which journal are the most representative in CET research domain? 3) What are the new emerging trends and development in CET research area? On the whole, the research method in this paper provided a fresh research approach to assess the performance of CET research. The findings may help for the new researchers to pick out the most relevant articles, journals, institutions and seize the research frontier in CET field." **Dejian Yu and Chao Xu**, *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

SEPTEMBER 2017

A techno-economic analysis of EU renewable electricity policy pathways in 2030.

The following is the Abstract of this article: "The aim of this paper is to assess several pathways of a [harmonized] European policy framework for supporting renewable electricity (RES-E) in a 2030 horizon according to different criteria. The pathways combine two main dimensions: degrees of [harmonization] and instruments and design elements. A quantitative model-based analysis with the Green-X model is provided. The results of the simulations show that there are small differences between the evaluated cases regarding effectiveness. All the policy pathways score similarly with respect to RES-E deployment, i.e., with different degrees of [harmonization] and whether using a feed-in tariff, a feed-in premium, a quota system with banding or a quota without banding scheme. In contrast, the policy costs clearly differ across the pathways, but the differences can mostly be attributed to the instruments rather than to the degrees of [harmonization]. This is also the case with other criteria (static and dynamic efficiency and the socioeconomic and environmental benefits in terms of CO_2 emissions and fossil fuels avoided). Both the degree of [harmonization] and the choice of instrument influence the distribution of support costs across countries. Finally, [the authors'] findings suggest that keeping strengthened national support leads to similar results to other policy pathways." **Pablo del Rio, Gustav Resch, Andre Ortner, Lukas Liebmann, Sebastian Busch, and Christian Panzer,** *Energy Policy*. (Subscription may be required.)

An analysis of CO_2 emissions in Italy through the Macro Multiplier (MM) approach.

The following is the Abstract of this article: "The issue of policy design into the environmental economic literature is becoming a crucial point especially for the relevance of its implication on international agreements for climate change and for the definition of climate actions against GHGs emissions. The identification of economic drivers accountable for the CO_2 emissions, which represent the major part of GHGs emissions, represents a central topic on literature using Input-Output analysis. The paper proposes a methodological innovation on the study of suitable policy instrument against the raise of CO_2 emissions, which is based on the approach of the Macro Multipliers (MM) that leads with the recognition of the impact of all those industries responsible for CO_2 emissions. From the policy perspective, the relevance of industries responsible for CO_2 emissions is also [analyzed] in this approach in which [the authors] introduce the target efficiency index and the control effectiveness index across industries. As part of final demand vector, each commodity has its own relevance, or effectiveness, in pursuing the attainment of the target vector. On the other hand as part of the target vectors, each industry emission has its own efficiency in being conveniently modified by changing the policy control vector. The results deriving from the MM approach demonstrate the possibility to overcome the limits of the linkages analysis. In particular, the set of information deriving from the target efficiency and the control effectiveness indices for industries allows designing environmental policies in a framework where economic aggregates are defined in value and physical units. Using the input-output table, this study investigates the impacts of industries activities on CO_2 emission using the MM approach for the Italian economy." **Yousaf Ali, Maurizio Ciaschini, Claudio Socci, Rosita Pretaroli, and Francesca Severini,** *Journal of Cleaner Production*. (Subscription may be required.)

The role of carbon dioxide in the transport and fractionation of metals by geological fluids.

The following is from the Abstract of this article: "Although [CO_2] is one of the major components of crustal fluids responsible for ore deposit formation, its effect on transport and precipitation of metals remains unknown, due to a lack of direct experimental data and physical–chemical models for CO_2-rich fluids. To fill this gap, [the authors] combined laboratory experiments and thermodynamic modeling to systematically quantify the role played by CO_2 for the solubility of economically important metals such as Fe, Cu, Zn, Au, Mo, Pt, Sn under hydrothermal conditions. Solubility measurements of common ore minerals of these metals (FeS_2, $CuFeS_2$, ZnS, Au, MoS_2, PtS, SnO_2) were performed, using a flexible-cell reactor equipped with a rapid sampling device, in a single-phase fluid (CO_2–H_2O–KCl) at 350–450°C and 600–750 bar, buffered with iron sulfide and oxide and alkali-aluminosilicate mineral assemblages. In addition, another type of experiments was conducted to measure gold solubility in more sulfur-rich supercritical CO_2–H_2O–S–NaOH fluids at 450°C and 700 bar using a batch reactor that allows fluid quenching. [The authors'] results show that the solubilities of Si, Au, Mo, Pt and Cu either decrease (within <1 log unit) or remain constant upon CO_2 increase, whereas those of Fe, Zn and Sn increase significantly (>1 log unit) with CO_2 contents in the fluid increasing from 0 to 50 wt%. These data were interpreted using a simple model that does not require any new adjustable parameters, and is based on the dielectric constant of the H_2O–CO_2 solvent and on the Born solvation parameter for the dominant metal-bearing species in an aqueous fluid. [The authors'] predictions using this model suggest that in a supercritical CO_2–H_2O–S-salt fluid typical of metamorphic Au deposits, in equilibrium with pyrite and chalcopyrite, the Cu/Fe ratio decreases by up to 2 orders of magnitude with an increase of CO_2 content from 0 to 70 wt%. This effect is due to the decrease of the fluid dielectric constant in the presence of CO_2, which favors the stability of neutral species ($FeCl_2^0$) compared to charged ones ($CuCl_2^-$)..." **Maria A. Kokh, Nikolay N. Akinfiev, Gleb S. Pokrovski, Stefano Salvi, and Damien Guillaume,** *Geochimica et Cosmochimica Acta*. (Subscription may be required.)

Phase equilibrium of CCS mixtures: Equation of state modeling and Monte Carlo simulation.

The following is the Abstract of this article: "To understand the role played by the impurities (such as N_2, Ar, H_2, CO, SO_2, O_2 and NO) during the processes of CCS, it is essential to know the thermodynamic properties of the CO_2-impurities mixtures under the conditions of CO_2 capture, transport and storage. Considering the variety of composition of these gas mixtures, it is necessary to have at one's disposal suitable models to predict their thermodynamic properties. In this work, two thermodynamic models: the E-PPR78 (Enhanced Predictive Peng-Robinson, 1978) and the PC-SAFT (Perturbed-Chain Statistical Associating Fluid Theory) models, are applied for describing the phase equilibria properties of 77 binary CCS mixtures containing CO_2, gas impurities (SO_2, O_2 and NO), water and hydrocarbons. [The authors'] research results indicate that both models are able to accurately predict the phase behavior of binary CCS mixtures. It was however necessary to adjust the binary interaction parameters ($k_{ij,PC\text{-}SAFT}$) within the PC-SAFT model to improve the prediction accuracy. Compared to the PC-SAFT model with one temperature-independent binary interaction parameter, the E-PPR78 model normally shows better prediction accuracy for the investigated systems. In addition, to extend the experimental database which was built for the evaluations of Equation-of-State (EoS) modeling, the Monte Carlo (MC) simulation method is employed in this work to generate phase-equilibrium data of a few CCS mixtures deemed as insufficiently described by experimental measurements reported in the open literature." **Xia-oChun Xu, Romain Privat, Jean-Noel Jaubert, Veronique Lachet, and Benoit Creton**, *The Journal of Supercritical Fluids*. (Subscription may be required.)

Using noble gas fingerprints at the Kerr Farm to assess CO_2 leakage allegations linked to the Weyburn-Midale CO_2 monitoring and storage project.

The following is the Abstract of this article: "For [CCS] technology to successfully contribute to climate mitigation efforts, the stored CO_2 must be securely isolated from the atmosphere and oceans. Hence, there is a need to establish and verify monitoring techniques that can detect unplanned migration of injected CO_2 from a storage site to the near surface. Noble gases are sensitive tracers of crustal fluid input in the subsurface due to their low concentrations and unreactive nature. Several studies have identified their potential to act as tracers of deep fluid migration to the shallow subsurface, but they have yet to be used in a contested situation. In January 2011 it was reported extensively in global media that high CO_2 concentrations in soils and related groundwater pollution had been identified on a farm property belonging to the Kerr family, located near to the town of Weyburn in Saskatchewan, Canada. The origin of this CO_2 pollution was cited to be the nearby Weyburn-Midale CO_2 Monitoring and Storage Project. Here, as part of an investigation funded independently of the Weyburn-Midale field operators, [the authors] present $\delta^{13}C_{DIC}$, $^{3}He/^{4}He$, $^{4}He/^{20}Ne$, ^{20}Ne, ^{36}Ar, ^{40}Ar and Kr measured in waters obtained from four groundwater wells located on and surrounding the Kerr property. [The authors] aim to establish if stable carbon and noble gas natural tracers are effective at determining if migration of CO_2 from the storage project was responsible for the alleged high CO_2 concentrations and water pollution measured on the Kerr farm. [The authors] compare the stable carbon isotope and noble gas 'fingerprints' of the Kerr groundwaters to those expected in a water equilibrated with the atmosphere under local recharge conditions, the produced CO_2 obtained from production wells, and the CO_2 injected into the Weyburn and Midale oil fields. [The authors] find that the stable carbon isotope data do not constrain the origin of the dissolved CO_2 in the Kerr groundwaters. Due to low noble gas concentrations in the captured CO_2 [the authors] are unable to completely rule out the presence of 20–34% contribution from injected CO_2 to the groundwaters surrounding the Kerr property. However, [the authors] find that all of the Kerr groundwater samples exhibit noble gas fingerprints that would be expected in a shallow groundwater in contact with the atmosphere and hence there is no evidence for the addition of a deep radiogenic component or dilution from the addition of a gas phase low in atmospheric derived noble gases. [The authors'] findings corroborate previous studies that indicate that elevated CO_2 concentrations found on the Kerr property are almost certainly of biological origin, and not migrated from the deep subsurface. The comprehensive follow up to these CO_2 leakage allegations outlined in this study provides a robust framework for responses to any future leakage allegations at CO_2 storage sites and further highlights that no single technique can categorically identify the origin of CO_2 in the shallow subsurface. Hence, it is essential that the full range of geochemical tracers (stable carbon and ^{14}C isotopes, noble gases, water chemistry, process based gas ratios) are integrated with a good understanding of geological and engineering data in response to CO_2 leakage allegations in the future." **Stuart M.V. Gilfillan, George William Sherk, Robert J. Poreda, and R. Stuart Haszeldine**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

The New Zealand forestry sector's experience in providing carbon sequestration services under the New Zealand Emissions Trading Scheme, 2008 to 2012.

The following is the Abstract of this article: "The New Zealand government established the New Zealand Emissions Trading scheme (NZ ETS) as the primary mechanism for achieving New Zealand's Kyoto obligations between 2008 and 2012. The legislation made planted forests the first sector to participate in the NZ ETS, starting in 2008. At the same time, other schemes to encourage carbon sequestration through forestry were also implemented. The implementation of the NZ ETS has [focused] on meeting New Zealand's international obligations between 2008 and 2012 at minimum cost, and there is little evidence it has led to any reduction in [GHG] emissions or investment in new planted forests in New Zealand. The NZ ETS has been most effective at facilitating the transfer of international (Kyoto compliant) carbon credits from emitters to the New Zealand government. These credits have been used to partially meet New Zealand's obligations for the first Kyoto commitment period, allowing other units to be carried over to meet obligations from 2013 to 2020. The paper shows that participation in the NZ ETS is unlikely to contribute a long-term positive impact on profitability of commercial forestry, and that the liabilities created through participation in the NZ ETS do not assist the development of the forestry sector in New Zealand. The paper suggests that the NZ ETS is not the correct policy instrument to encourage carbon sequestration by planted forests." **David Evison**, *Forest Policy and Economics.* (Subscription may be required.)

An improved correlation to estimate the minimum miscibility pressure of CO_2 in crude oils for carbon capture, utilization, and storage projects.

The following is the Abstract of this article: "The utilization of anthropogenic CO_2 for [EOR] while sequestering CO_2 in depleted oil and gas fields is increasingly being viewed as an attractive economic proposition for reducing [GHG] emissions. Typically, CO_2 assisted [EOR] projects are operated at the minimum miscibility pressure (MMP), beyond which the CO_2 and oil phases are completely miscible and the incremental oil recovery from CO_2 displacement does not increase dramatically anymore. Thus, the MMP is a critical parameter in screening-level performance assessments of potential CO_2 floods. The MMP can be measured from displacement experiments in a laboratory using a slim tube apparatus. Alternatively, it can be estimated from statistical correlations developed using reservoir temperature and detailed crude oil composition and analytical methods such as equation of state based simulations. In this paper, [the authors] describe the development and validation of an improved correlation to estimate the MMP of CO_2 in crude oil based only on: (a) reservoir temperature, and (b) molecular weight of the C_{5+} fraction, which can also be estimated from the oil's specific gravity. A power law based predictive model for MMP has been developed through statistical analysis of data from published literature pertaining to crude oil with a wide range of temperatures and molecular weights. The resulting predictions were compared with those obtained from previously established and widely used correlations and found to have a higher degree of accuracy." **Manoj Kumar Valluri, Srikanta Mishra, and Jared Schuetter**, *Journal of Petroleum Science and Engineering.* (Subscription may be required.)

REPORTS and PUBLICATIONS

OCTOBER 2016

A Clean Energy Action Plan for the United States.

The following is from the Introduction and Summary of this Center for American Progress document: "This report proposes policy recommendations that promote the three elements of decarbonization—energy efficiency, low-carbon electricity generation, and the electrification of end uses—and that address their integration, financing, and implementation at the federal level. It examines specific policy actions that a new administration and Congress can take in the short term to expedite deployment of renewable energy and energy efficiency technologies. This is just one part of an overall climate mitigation strategy U.S. leaders will need to employ to meet the nation's long-term carbon pollution reduction targets."

3D Mapping and correlation of Intraformational seals within the Latrobe Group in the nearshore Gippsland Basin.

The following is from the Introduction of this Global CCS Institute document: "In this study [the authors] approach the issue of intraformational seals in the Gippsland Basin from a variety of perspectives: these include the observations of actual trapped hydrocarbons with some gas columns in excess of 100m, measurements of seal capacity (MICP) from core samples, observations of pressure and salinity differences across key intraformational aquitards (seal units), and full 3D seismic geobody mapping and attribute extraction of seal-related lithologies. [The authors] use these observations to interpret the geometry of active seal units and their depositional context within the basin. [The authors] will show that a series of backstepping coal sequences are associated with intraformational petroleum traps and aquitards across at least 50 km of basin dip extent, and 20 million years of geologic time. The basal shales and seat earths underlying the freshwater facies of these coals will be shown to have distinctive properties that lead to effective sealing characteristics. This study is based on depositional geometries and facies interpreted from the extensive open-file 3D seismic data that has been collected in the basin by the Esso-BHP Joint Venture and other operators. Individual and composite coal beds are mapped and fluvial cut-outs are identified. As a result, a detailed 3D basin model is developed which maps fluvial and swamp facies to predict reservoirs and seals at Intra-Latrobe levels, and the lateral connections of these facies to coeval paralic barrier bar systems further to the east at top Latrobe Group. A revised well and seismic correlation of the Traralgon T2 Member in the nearshore Gippsland Basin is presented, and the implications of this correlation discussed."

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."

Global Carbon Capture & [Storage] Market Insights, Opportunity Analysis, Market Shares and Forecast, 2016 – 2022.

The following is a description of this document: "The [CCS] market globally is estimated to be $4.25 Billion in year 2016, and is likely to grow with a [compound annual growth rate (CAGR)] of 13.9 [percent] from year 2016 to 2022, to grow $8.15 Billion by the end of year 2022. [These capturing] technologies separates CO_2 from other gases produced via industrial processes and electricity generation mainly by three different ways, pre-combustion, post-combustion and last oxy-fuel combustion. Millions of tons of CO_2 are being transported for commercial uses every year this can be fulfilled by this capturing process. Transportation stages includes transfer by ship, pipelines and road tanker for commercial purpose majorly for oil recovery projects. The CO_2 which is stored in cautiously targeted geological rocks that are located several [kilometers] below the earth surface. Growth in exploration activities, research, and investment is expected to drive the growth. The [CCS] market is likely to witness significant growth in the coming years owing to growing investment in emission reduction technologies. The carbon capturing and packing technology is still in its stages of development and globally, and later with the increasing awareness, growth in the market is expected."

NOVEMBER 2016

Well Integrity in CO_2 Storage Operations: Current Understanding and Open Questions.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "Among the various risks associated with CO_2 storage in deep geologic formations, [wells] are an important pathway for fluid [releases] and potential groundwater contamination. Injection of CO_2 will typically create a pressure perturbation in the storage reservoir that covers a larger area than the CO_2 plume itself, and any wells that penetrate that pressure footprint are potential pathways for [release] of CO_2 and/or reservoir brine. Historically, the mechanisms and fate of [release] through and around wells have not been extensively studied, especially from the standpoint of quantitative risk assessment. However, since the publication of the review paper by Zhang and Bachu (2011), there have been important advances, with significant contributions from researchers associated with NRAP. The goal of this report is to summarize recent key advances in the state of knowledge, and to detail the efforts to develop tools that can estimate [release] over the long time scales that are relevant to carbon storage (10s to 100s of years). [Wells] are ubiquitous in regions with a long history of oil and gas exploration, yet until recently the construction, completion, plugging, and abandonment of these wells did not anticipate the potential use of geologic reservoirs for storage of supercritical CO_2. This report explores in detail the ability of abandoned wells to retain their integrity against [release] as well as the circumstances when that integrity may be compromised, with careful examination of the coupled physical and chemical processes involved. Understanding time-dependent [release] is complicated by the coupling of fluid flow, solute transport, chemical reactions, and geomechanical stresses, which will interact over decades or longer of site operations and post-injection monitoring. The design of a typical well incorporates several components to restrict unintended fluid migration that include cement, casing, tubing, and packers. Wells are typically constructed so that a loss of well integrity requires the breach of multiple barriers as well as [release] of fluids outside of the well. Barrier failures can originate from problems with the primary construction of the well (e.g., failure to place cement adequately or [connections] in the casing joints) or as a result of subsequent stresses to the well system that damage these barriers."

A Critical Review of the Impacts of [Releasing] CO_2 Gas and Brine on Groundwater Quality.

The following is the Abstract of this NRAP document: "This report is a summary of modeling efforts, in combination with laboratory batch and column experiments and a review of current literature, undertaken to determine the effect of CO_2 and brine [release] from deep storage reservoirs on the quality of overlying groundwater [formations]. For two [formation] types (i.e., carbonate and unconsolidated sand and gravel [formations]), "no-impact" thresholds were determined to evaluate the results of the laboratory and modeling. Modeling and laboratory results emphasized the importance of site-specific data and analysis for determining potential impacts of CO_2 and brine intrusion into overlying groundwater [formations]. "No-impact" thresholds were variable between the two studied sites, and were mostly more conservative than the U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs). The [formation] calcite and clay content, as well as the storage reservoir sa-

linity and organic and trace metals contents are all crucial site-specific data that must be collected for successful evaluation by the developed models. Using these inputs, the site-specific reduced-order models (ROMS) were able to predict [formation] response and the degree of impact due to leaking CO_2. Results have indicated that the risk to [formations] is site-specific, and directly proportional to the mass of CO_2 or brine [released]. Several questions remain unanswered, in particular, related to [formation] recovery time, partitioning of organic matter between phases, and the limitations of existing ROMs to infinite buffering capacity, requiring further investigation to enhance understanding of the impact of [releasing] CO_2 and brine on groundwater [formations]."

Reduced-Order Model for Estimating Impacts from CO_2 Storage [Release] to Alluvium [Formations]: Third-Generation, Combined Physical and Chemical Processes.

The following is from the Executive Summary of this NRAP document: "NRAP is developing a science-based toolset for the quantitative analysis of the potential risks associated with changes in groundwater chemistry from CO_2 injection. In order to address uncertainty probabilistically, NRAP is developing efficient, ROMs as part of its approach. These ROMs are built from detailed, physics-based process models to provide confidence in the predictions over a range of conditions. The ROMs are designed to reproduce accurately the predictions from the computationally intensive process models at a fraction of the computational time, thereby allowing the utilization of Monte Carlo methods to probe variability in key parameters. This research developed ROMs that describe changes in diluted groundwater chemistry if CO_2 and brine were to [release] into an overlying alluvium [formation] similar to the High Plains [formation], Haskel County, Kansas, USA. The protocol allows uncertainty and variability in [formation] heterogeneity, fluid transport and geochemical reactions to be collectively evaluated to assess potential changes in groundwater pH, total dissolved solids (TDS), As, Ba, Cd, Pb, benzene, naphthalene, and phenol concentrations by developing a scaling function that can be applied to correct the output from the hydrology ROM for geochemical reactions. The hydrology ROM takes into account the uncertainties in brine and CO_2 [release, formation] heterogeneity and fluid transport, whereas the geochemical scaling function considers the uncertainties in chemical reactions. Inclusion of chemical correction increases trace metal plumes by 10 to 100 times, suggesting that CO_2 [release] leaches trace metals from the [formation] sediments and should be considered. Corrections are needed for other trace metals, such as chromium, iron, manganese, and zinc. In contrast to the observed increases in trace metal plume volumes, inclusion of bio-degradation greatly reduces plume volumes for organics."

DECEMBER 2016

The Evidence for Deploying Bioenergy with CCS (BECCS) in the [United Kingdom (UK)].

The following is from the Executive Summary of this Energy Technologies Institute (ETI) document: "Bioenergy with CCS (BECCS) is a credible, scalable and efficient technology, and is critical to deploy in order for the UK to meet its 2050 GHG emission reduction targets cost-effectively. Major advances in the fundamental science and technology development have been made by the ETI and others over the last ten years – significantly de-risking this value chain, and evidencing that there are no 'showstopping' technical barriers to BECCS. Specifically, advances have been made in understanding: [1] The costs, efficiencies and challenges of biomass-fed combustion systems with carbon capture. [2] The evidence that numerous bioenergy value chains can deliver significant carbon savings, and sizeable negative emissions when including BECCS, based on certain feedstocks. [3] The potential availability and sustainability of feedstocks relevant to the UK. [4] The identification and assessment of high capacity, low cost, low-risk stores for CO_2 around the UK and the infrastructure required to connect to them."

Putting the Puzzle Together: State & Federal Policy Drivers for Growing America's Carbon Capture & CO_2-EOR Industry.

The following is a summary of this document: "This report offers readers both an in-depth look at [CO_2-EOR], while explaining the current policy landscape and recommendations for future action. The report first provides background information on the formation of the Work Group and the process utilized to develop this report. The next section of the report provides the rationale for the capture of [CO_2] from power plants and industrial facilities and its use and storage through [EOR] as a key component of a U.S. and global energy strategy with the potential to provide economic, environmental, and national security benefits. The subsequent sections take a detailed look at the current policy landscape and several core state and federal policy options. The report concludes with a glossary and detailed appendices that provide state-level information on existing laws and policies related to CO_2-EOR."

JANUARY 2017

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 from 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 [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% 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."

Combining CO_2 Enhanced Oil Recovery with Permanent Storage in Mexico.

The following is from the Executive Summary of this Battelle Memorial Institute document: "The goal of the current project is to review state-of-the-art practices related to combining CO_2 EOR with geologic storage for CCUS in Mexico. This was accomplished by an assessment of the requirements a CO_2-EOR project must satisfy in order to qualify as a permanent storage project to earn carbon credits. The material presented is based on review of latest literature, discussions with relevant experts, as well as Battelle's direct experiences from multiple in-house geologic CO_2 storage projects. The report focuses on the key technical and practical considerations and provides an overview of related technologies for economic and efficient CO_2-EOR storage. The technology and operational practices for CCUS have been developed over decades of CO_2-EOR experience established in the oil and gas industry. Hence, the key barriers and uncertainties in accounting for associated CO_2 storage during CO_2-EOR operations are not technical but economic and policy-related. While economic favorability can be improved by investing in improvements to the current CO_2 infrastructure, strong constructive policy measures for geologic CO_2 storage are also important. CO_2-EOR projects demonstrating storage of anthropogenic CO_2 in Mexico may be eligible to provide carbon credits. The minimum requirements to gain storage credits according to protocols stated in the United Nations Framework Convention on Climate Change Clean Development Mechanism (CDM), California Cap-and-Trade Regulation Instructional Guidance, American Carbon Registry, and U.S. Environmental Protection Agency regulatory guidance were compared and contrasted. The protocols typically outline requirements as performance measures without prescribing technologies to meet these requirements. Accordingly, there is significant flexibility for the project proponent to fashion the project details and submit for approval plans that describe how requirements will be met."

Scotland's Energy Strategy: The role of carbon dioxide capture and permanent storage.

The following is from this Scottish Carbon Capture & Storage document: "This briefing from Scottish Carbon Capture & Storage (SCCS) sets out reasons for Scottish Government continuing to provide positive support for technologies and infrastructure that capture CO_2 from emissions and permanently store it in geological formations. Such technologies, collectively known as CCS, are complementary to several options being pursued for decarbonisation of the energy system. Including CCS in Scotland's whole energy-system strategy can make other options more effective and will be needed to extend the 2032 targets to an ambition of a net zero carbon Scotland in 2050."

FEBRUARY 2017

National Risk Assessment Partnership (NRAP) Phase I Accomplishments: 2011-2016.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "NRAP brings together scientists and engineers from five DOE national laboratories (NL), to develop insights into the environmental risk behavior of long-term CO_2 storage in geologic formations. Through stakeholder involvement, the NRAP program also benefits from the perspective of industry, government, non-government organizations, and academia regarding research needs on this topic. Phase I of the NRAP effort has recently concluded and this report summarizes the results of this 6-year effort. Phase I was focused on quantification of risk and related uncertainties, using the approach detailed in this report… Improving the science base to build confidence for long-term CO_2 storage decisions was another key aspect that was studied by the project personnel. The main results for this part of the effort are: [development of physics based models of geologic carbon storage (GCS), systems and system components; demonstration of the validity and limitations of reduced complexity models, and integrated assessments models; computational and experimental analysis to address key system uncertainties; and simulation of long term carbon storage system performance, in the context of those uncertainties]. An important set of products from NRAP's Phase I effort is the set of tools that can be used to explore environmental risk behavior at CO_2 storage sites. The NRAP toolset is comprised of ten simulation tools representing important components of the engineered geologic system related to understanding the risk for and associated with potential fluid migration and induced seismicity."

Ready for CCS retrofit: The potential for equipping China's existing coal fleet with carbon capture and storage.

The following is from the Executive Summary of this International Energy Agency (IEA) document: "Retrofitting CCS on existing coal-fired power stations in People's Republic of China (hereafter referred to as 'China') represents a major opportunity, with significant benefits for emission reductions. In total, some 310 gigawatts (GW) of existing coal-fired power capacity meet a number of basic criteria for being suitable for a retrofit. This number is likely to increase, as new efficient plants are being commissioned during the next several years. Regardless of how much retrofitting will finally be required in a low-emissions pathway, this analysis indicates that there is ample potential available. Simultaneously the world's leader in renewable electricity capacity and the world's largest emitter of energy-related CO_2, China emitted some 8.6 billion [metric tons] in 2014. Around half of these emissions were from coal-fired power stations. China currently has around 900 GW of installed coal-fired power capacity, representing almost 50% of global coal-fired capacity, and has nearly 200 GW under construction. The existing power plants considered in this study represent potential emissions of 85 billion [metric tons] of CO_2 ($GtCO_2$), if they continue to operate at current load factors for the remainder of their lives, even if smaller units are retired early. Despite such massive emissions, the Chinese coal-fired power fleet is on average one of the world's most efficient, as over two thirds of the capacity was built since 2005. As a result, the average operational efficiency of the Chinese coal fleet increased six percentage points in the last ten years, bringing it to the same level as that in OECD countries. Through its 'Intended Nationally Determined Contribution' (INDC) under the UNFCCC framework, China has committed to peaking CO_2 emissions by 2030. The enduring emissions from China's coal-fired power plants present a challenge to efforts to reduce [GHG] emissions beyond any peak. Coal use is also being shaped by policies to control local pollutants, which make low carbon electricity and power plant upgrades more attractive. A part-solution can be found in retrofitting existing coal-fired power stations with CCS, which can reduce their emissions rate by around 85%. The emissions of a CCS-retrofitted coal plant are equivalent to less than a quarter of that of a combined cycle gas plant. In the best conditions, equipping a power plant with CCS only requires investment in the equipment for CO_2 capture, transport and storage and not in the power plant itself. In other situations, the power plant can be upgraded at the same time as CCS retrofit, delivering several additional decades of lifetime to the plant. In both cases, a CCS retrofit can avoid the need to write-off otherwise productive generating capacity, or otherwise limit its use, and be a cheaper option than a new low-carbon generation capacity."

Carbon Capture And Storage (CCS) Market Analysis By Application (EOR, Industrial & Agriculture), By Capture Technology (Pre-Combustion, Industrial, Oxy-Firing & Post-Combustion), Competitive Strategies, And Segment Forecasts, 2014 – 2025.

The following is from a summary of this report: "The rising energy demand globally has led to the increasing uses of fossil fuels, the major source of carbon emission. Though many alternate technologies such as wind, solar and nuclear are now in practical use or under development, CCS is the most viable technology currently available to mitigate [GHG] emissions from large scale fossil fuel usage. Currently, over 22 CCS projects are in operation globally and another 14 planned projects are expected to be functional in the next few years. However, the global CCS industry is still at its nascent stage in comparison to the amount of [CO_2] emitted yearly. Some of the factors such as inconsistent government regulations and economic slowdown in the past few years are the main factors responsible for the slow growth of the market. The current regulatory [framework] is not designed prominently to address some of the special issues that arise in the CCS industry such as cautious monitoring [and] long-term stewardship and the need for thorough site characterization."

Global Carbon Capture and Storage Market 2017-2021.

The following is from a description of this document: "The use of CCS technology is one of the novel ideas that help reduce the amount of CO_2 released into the atmosphere by fossil fuel-dependent industries such as power generation and oil and gas processing. The basic functioning of the CCS technology includes capturing the CO_2 before its release into the atmosphere and then transporting and storing it in an environmentally safe location. Technavio's analysts forecast the global [CCS] market to grow at a [compound annual growth rate (CAGR)] of 9.18% during the period 2017-2021. The report covers the present scenario and the growth prospects of the global [CCS] market for 2017-2021. To calculate the market size, the report analyzes business dimensions with an eye on individual growth trends and contribution of upcoming market segments. The market is divided into the following segments based on geography: Americas, APAC, EMEA. Technavio's report, Global Carbon Capture and Storage Market 2017-2021, has been prepared based on an in-depth market analysis with inputs from industry experts. The report covers the market landscape and its growth prospects over the coming years. The report also includes a discussion of the key vendors operating in this market."

MARCH 2017

Siting and Regulating Carbon Capture, Utilization and Storage Infrastructure.

The following is the Background of this DOE Workshop Report: "[DOE's] first Quadrennial Energy Review (QER) identified CO_2 pipelines as 'an important enabling infrastructure for GHG emissions in the future.' Carbon dioxide capture, utilization, and storage (CCUS) may involve moving CO_2 significant distances from power plants and other industrial sources to storage sites, including saline geologic formations and oil fields (where CO_2 is stored during and potentially after EOR operations), as well as to entities that employ other technologies to utilize captured CO_2, such as photosynthesis, chemosynthesis, or mineralization. The regulation of CO_2 pipelines and other CCUS infra-

structure is a joint responsibility of Federal and State governments. However, states typically play a primary role in establishing the requirements for siting, construction, and operations of CO_2 pipelines. The first QER found that the development of a national CO_2 pipeline infrastructure should 'build on state experiences, including lessons learned from the effectiveness of different regulatory structures, incentives, and processes that foster interagency coordination and regular stakeholder engagement.' DOE sponsored a technical workshop in April 2016 in Washington, D.C., to identify and promote best practices for siting and regulating CO_2 infrastructure (pipelines, EOR, and other geologic CO_2 storage sites). The purpose of the workshop was to foster communication, coordination, and sharing of lessons learned and best practices among states and entities that are involved in siting and regulating CO_2 infrastructure, or that may have CO_2 infrastructure projects within their borders in the future. The scope of the technical workshop also encompassed issues being addressed in the second installment of the QER, including discussions around regulation and management of CO_2 storage sites, which serve as critical infrastructure for entities capturing CO_2."

Probabilistic approach to CO_2 plume mapping for prospective storage sites: The CarbonNet experience.

The following is from the Executive Summary of this Global CCS Institute document: "In CO_2 storage, there is a requirement to predict the range of possible plume extents and travel paths and associate a probability with this range. This requirement is in the context that subsurface uncertainty is a given, and that no single plume prediction can be 100% precise. The probabilistic expectation of the plume at future times is used for project purposes and for regulatory assurance that the plume will remain within the defined storage boundaries (both geographical and stratigraphic) for the required period of time with an appropriate high level of confidence. In particular, Australian GHG storage regulations call for a prediction of all plume paths with more than 10% probability of occurrence (i.e. plume paths at P90 confidence level). Here [the authors] outline a probabilistic approach based on reservoir modelling sensitivity and uncertainty analysis, adapted from the petroleum industry and suitable for high-mobility CO_2 plumes in thick and well-defined reservoirs. The method can also be extended to other basins and geological circumstances. In the petroleum industry, it is commonplace to evaluate resources in probabilistic terms with some objective parameter such as oil in place, recoverable reserves, or nett present value. This methodology can be adapted easily to objective measures such as vertical ascent of a plume relative to a caprock or lateral approach of the plume to a boundary or other geographic feature to be avoided (e.g. a mapped fault). What is novel in [the authors'] approach is to analyze plume paths (extents) in a statistical manner to generate probabilistic maps and cross-sections of plume extents to inform on containment risks and areas with key monitoring requirements. In [the authors'] approach, the reservoir layering must first be analyzed and the principal hydrodynamic flow units (HFU's) and the intervening seals identified. In the Gippsland Basin, multiple reservoir layers of 100-150m of multi-darcy, clean quartz-dominated sands form the main reservoir units and are proven by over 1,500 hydrocarbon exploration and development wells and are mappable on extensive 3D marine seismic data. The reservoirs are supported by an ideal, almost infinite aquifer which buffers pressure effectively and dissipates it regionally over short timescales (100 km in decades). In these reservoirs, CO_2 plumes are highly mobile and must be controlled by either structural trapping, or by careful mapping and use of non-structural (saline aquifer) storage. The CarbonNet Project aims to store a nominal 125 million tonnes of CO_2 over 25 years in the same basin still in use for hydrocarbon extraction, and adjacent to an important onshore aquifer. Plume management and containment is therefore vital and high confidence must be placed on plume path modelling, including the analysis of rare statistical outliers."

A Business Case for a UK Industrial CCS Support Mechanism.

The following is the Introduction of this Teesside Collective document: "Large manufacturing industry is a major contributor to the British economy: in 2015, for example, nationally it accounted for 2.6 million jobs, [$195] billion Gross Value Added and contributed around half of UK exports. However, it also has around 70 million tonnes (mt) annual direct CO_2 emissions. As the UK Government formulates its industrial strategy, it is inevitable that the impact of legally binding carbon budgets form part of that consideration – including the provision of necessary infrastructure to reduce industrial emissions. Beyond further energy efficiency, deep emissions reduction for many industries is only possible through CCS technology. During the most recent UK competition for CCS on power, modest funding was provided by Government to scope CCS for industry, as represented by Teesside Collective. Following the cancellation of the CCS Commercialization Program in 2015, and an evident need to gain industry confidence after a number of failed competitions, there is a need to revitalize this effort in a more structured approach. This report proposes a business model that could make cost-effective, near-term investment in CCS attractive to the Government and to Energy Intensive Industries (EIIs) and so form a basis to enable the Government and industry to jointly to take forward delivery of Industrial CCS."

APRIL 2017

Feasibility study for full-scale CCS in Norway.

The following is the Introduction of this Norwegian Ministry of Petroleum and Energy document: "In the Sundvolden Political platform, the Government states that it will 'invest on a broad front to develop cost-effective technology for CCS and seek to build at least one full-scale carbon capture demonstration plant by 2020.' The Government's CCS strategy was presented in Proposition 1 S to the Storting (2014-2015). The strategy covers a wide range of activities, including the assessment of potential full-scale CCS projects in Norway. Gassnova's pre-feasibility 'Study report on potential full-scale CCS projects in Norway' from May 2015 identified several emission sources and storage sites that may be technically feasible for a CCS project. It also identified industrial players that could be interested in participating in further studies. In the autumn of 2015, the Government decided to continue this work and initiated a feasibility study. The Ministry of Petroleum and Energy (MPE) has had overall responsibility for the feasibility study. Gassnova SF has been project coordinator and responsible for the CO_2 capture and storage components of the study, while Gassco AS has been responsible for the CO_2 transport component. Three companies have studied the feasibility of CO_2 capture at their industrial facilities. Norcem AS has assessed the feasibility of capturing CO_2 from the flue gas at its cement factory in Brevik; Yara Norge AS has assessed CO_2 capture from three different emission points at its ammonia plant at Herøya in Porsgrunn; the Waste-to-Energy Agency in Oslo municipality (EGE) has assessed CO_2 capture from the energy recovery plant at Klemetsrud (Klemetsrudanlegget AS). Gassco has carried out a ship transport study with assistance from Larvik Shipping AS and Knutsen OAS Shipping AS. Statoil ASA has assessed the feasibility CO_2 geological storage at three different sites on the Norwegian Continental Shelf. The aim of this feasibility study was to identify at least one technically feasible CCS chain (capture, transport and storage) with corresponding cost estimates and this has been achieved. The results of this study demonstrate that a flexible CCS chain is feasible that makes use of CO_2 transport by ship from multiple sources to a single storage hub. That would mean the initial investment in CO_2 infrastructure can benefit several CO_2 capture projects."

Energy Security and Prosperity in Australia: A ROADMAP FOR CARBON CAPTURE & STORAGE.

The following is from this document: "As the world makes the necessary and urgent transition to a low carbon future, resource and system diversity will be key to maintaining a resilient, competitive energy economy. Australia's abundant, cost competitive and high quality coal and gas resources have long underpinned the economic strength and high standard of living achieved in Australia. The challenge that Australia and the world face is to continue to realize the benefits and value of fossil energy resources without the associated emissions. It is therefore imperative that commercial-scale CCS is developed and available. This assures that Australia and its trading partners can maintain energy security and meet future emissions reduction targets at the lowest economic cost. Australia has the capability to provide leadership in CCS, especially CO_2 storage with the Otway and Gorgon projects. These are considered leading examples of CO_2 storage research, development and demonstration (RD&D) and commercial-scale deployment. Urgent investment in CO_2 storage site characterization, CCS projects, techno-economic assessments, and public engagement is required to ensure that CCS can be deployed to achieve the deep reduction in greenhouse gas emissions required to meet national and global targets."

MAY 2017

Review of UK Energy Policy.

The following is from the Executive Summary of this UK Energy Research Center (UKERC) document: "This review takes stock of UK energy policy ahead of the Autumn Statement, the Industrial Strategy and the Emissions Reduction Plan that is expected in 2017. It is an evidence-based commentary covering the major components of the energy system and the links between them. The focus of the review is not only on progress with emissions reductions to tackle climate change, but also on synergies and trade-offs with other policy goals: security, affordability and (due to the recent creation of [the Department of Business, Energy, and Industrial Strategy (BEIS)]) industrial development. The UK has a world leading policy framework for emissions reduction in the Climate Change Act, including legislated carbon budgets to 2032. This does not have to be affected by Brexit. In October, ten years on from his landmark report, Lord Nicholas Stern reiterated that clean, green development is the only route to global economic growth. As the Committee on Climate Change have noted, there has been good progress with emissions reductions so far. This has been driven by changes in the electricity system and reductions in energy demand, some of which have been policy driven. But this progress will not last into the 2020s unless policies are significantly strengthened in this Parliament. As [the authors] discuss in this review, priority areas for action include energy efficiency, low carbon heat, the investment framework for low carbon power and citizen engagement."

Pathways to a low carbon future.

The following is from the Introduction of this Energy UK document: "A low carbon society is a long term project requiring a vision to take us through the transition and transformation necessary, with buy-in from government, all political parties, the public, business and industry. A whole system approach that considers the interactions between heat, power and transport must be adopted to deliver an infrastructure that is fit for purpose to achieve high energy efficiency, low carbon heat, power and transport and a highly flexible and secure energy system. Long term predictable policy and planning will lay the foundations for the investment needed to create a modern, efficient and sustainable low carbon society. The Climate Change Act (2008) set an ambitious commitment to reduce [GHG] emissions in the UK by at least 80 percent of 1990 levels by 2050. The UK has so far delivered on its interim targets through the Carbon Budget process, mainly through reducing emissions in the power sector. The period 2028 – 2032 (known as the fifth carbon budget) is set to be more challenging as it requires action from both the heat and transport sector, and further decarbonization of power. This paper presents Energy UK's recommendations that government should consider as a minimum necessary to set the country on track to deliver its fifth carbon budget. Some recommendations highlight the increasing interdependencies between sectors, industries, customers and providers, and demonstrate the need to use a whole system approach to ensure a holistic vision and capture the role of each and all stakeholders..."

China-Australia CCUS Integrated International Cooperation Demonstration Project.

The following is from the Introduction of this document: "Yanchang Petroleum has been engaging in CO_2 capture, utilization and sequestration (CCUS) for a coal conversion project in northern Shaanxi Province since 2010. The pilot experiment for CO_2 flooding and sequestration (known as CO_2-EOR) was initially completed in the Jingbian and Wuqi counties, Shaanxi Province. By July 2015, Yanchang Petroleum had built the skid-mounted injection stations for CO_2-EOR to serve five well groups in Chang-6 Oil Reservoir of Qiaojiawa Block, Jingbian County, with the cumulative injection volume of 48,000 tonnes (t) liquefied CO_2. Yanchang also built the skid-mounted injection stations for CO_2-EOR to serve five well groups in Chang-4+5 Oil Reservoir of Yougou Block in Wuqi County, with a cumulative injection volume of 2,767.8t liquefied CO_2. Both injection projects are ongoing. Safe and secure storage of CO_2 is the cornerstone of CO_2 geological sequestration (herein sequestration). After injection of CO_2 into the reservoir, the location and state of CO_2 migration in the reservoir needs to be determined. Additionally, the permanency and effectiveness of sequestration must be evaluated..."

JUNE 2017

Development of a General Form CO_2 and Brine Flux Input Model.

The following is the Abstract of this National Risk Assessment Partnership (NRAP) document: "The NRAP project is developing a science-based toolset for the quantitative analysis of the potential risks associated with changes in groundwater chemistry from CO_2 injection. In order to address uncertainty probabilistically, NRAP is developing efficient, reduced-order models (ROMs) as part of its approach. These ROMs are built from detailed, physics-based process models to provide confidence in the predictions over a range of conditions. The ROMs are designed to reproduce accurately the predictions from the computationally intensive process models at a fraction of the computational time, thereby allowing the utilization of Monte Carlo methods to probe variability in key parameters. This report presents the procedures used to develop a generalized model for CO_2 and brine leakage fluxes based on the output of a numerical wellbore simulation. The resulting generalized parameters and ranges reported here will be used for the development of third-generation groundwater ROMs."

Characterizing Construction of Existing Wells to a CO_2 Storage Target: The Kimberlina Site, California.

The following is from the Executive Summary of this NRAP document: "Early versions of the NRAP integrated risk model treated plugged wells as a continuous cemented interval of homogeneous porous media from the storage formation to an underground source of drinking water (USDW) and the atmosphere. This assumption of homogeneity is simplistic, but was necessary for the purpose of calculating CO_2 and brine movement via these features without a better statistical understanding of well characteristics. Future generations of the integrated risk model will move toward incorporating more detail, such as heterogeneity of the geological formation along the well path, and construction heterogeneity of the wells themselves. This study identified approximately 100 wells penetrating the Vedder Formation storage reservoir within the simulated 6 bar (0.6 MPa) or greater pressure increase associated with a hypothetical Kimberlina industrial-scale CO_2 injection and storage operation. This study collected cemented interval information for these wells from scanned well records maintained by the State of California, and developed a statistical representation of cement seal and plug extents and depths from those data."

Commercial Scale Feasibility of Clean Hydrogen.

The following is from the Executive Summary of this European Zero Emission Technology and Innovation Platform document: "It is widely recognized that hydrogen has the potential to decarbonize a number of different industries and play a key role in the energy transition. Decarbonized hydrogen can be produced through the application of CCS on established natural gas to hydrogen production units ('clean'/'low GHG emissions' hydrogen), or electrolysis using renewable energy sources. This report addresses the role of clean hydrogen and provides recommendations for its promotion. Clean hydrogen currently has lower production costs than that of electrolysis-derived hydrogen from renewable energy (3-4 €/kg ex-works at 30-40 bar) and could be a key accelerator of the hydrogen economy. This report shows that, depending on location specifics, clean hydrogen production is currently achievable at the same cost as that projected for the renewables route for around 10 to 25 years. Furthermore, hydrogen production equipped with CCS in industrial clusters - where several large users for hydrogen can co-exist - could also trigger the initiation of a CO_2 transport and storage network. There are multiple country roadmaps and studies that discuss the ability of hydrogen to decarbonize different industries...The technologies required to produce clean hydrogen from natural gas are available, with multiple projects already capturing CO_2 from the hydrogen production process. Today the limiting factors are the availability of CO_2 transport and storage infrastructure, demand for hydrogen as a clean fuel, and the requirement for substantial hydrogen infrastructure and adaptations at points of use."

Enabling Efficient Networks for Low Carbon Futures: Options for Governance & Regulation.

The following is from Chapter 1 of this report: "This report summarizes key themes emerging from the Energy Technologies Institute's (ETI) project 'Enabling efficient networks for low carbon futures'. The project aimed to explore the options for reforming the governance and regulatory arrangements to enable major changes to, and investment in, the UK's energy network infrastructures. ETI commissioned four expert perspectives on the challenges and options facing the UK. The ETI decided to initiate this new thinking because its scenarios for a low carbon UK energy transition highlight major challenges for energy network infrastructures and how investment decisions are governed, incentivized and regulated. The ETI scenarios were developed from a 'whole system' perspective, and point to the high value of enabling a broader mix of energy vectors (heat, power and gaseous fuels), within a more integrated 'system' of energy transmission, storage and distribution."

JULY 2017

Empirical Analysis of Seismicity Induced by Brine Injection in the U.S. Bureau of Reclamation Paradox Valley PVU#1 Well and Development of an Induced Earthquake Simulation Model.

The following is from the Abstract of this NRAP document: "The U.S. Bureau of Reclamation (USBR) has been injecting brine in the deep PVU#1 well located in the Paradox Valley in Colorado continuously for the last 25 years. Injection-induced seismicity in the shallow crust surrounding the well has been monitored by the Paradox Valley seismic network operated by USBR since 1985. The long duration, high fluid volumes and flow rates, the depth of injection, and the large number of recorded earthquakes make this project an ideal case to investigate several aspects of fluid-induced seismicity important to the development by NRAP of a toolset to assess hazard and risk from earthquakes that may be induced by subsurface injection of CO_2. The toolset currently under development includes both short-term seismic hazard forecasting based on empirical analysis of earthquakes recorded during and after injection, and a physics-based simulation approach to assess hazard and risk before injection begins. Empirical analyses of time- and space-dependent frequency-magnitude distributions of earthquakes that occurred in the vicinity of the PVU#1 well between July 1996 and March 2012 show that the overall level of activity progressively decreased over the four phases of continuous injection during this period; but the Gutenberg-Richter b-value, which characterizes the relative numbers of large to small events, remained approximately constant. The b-value during continuous injection was significantly lower than that during initial injection trials carried out between 1991 and 1995, corresponding to a relatively larger number of small events during this period. Spatial analysis indicates that seismicity associated with interpreted faults that are favorably aligned for shear failure within the prevailing tectonic stress field is characterized by relatively low b-values. The results of these analyses inform the development of time-dependent empirical short-term induced seismicity hazard forecasting methods, and will be used to calibrate and validate the simulation-based hazard assessment method."

CCS for industry – Modelling the lowest-cost route to decarbonizing Europe.

The following is a summary of this Zero Emissions Platform (ZEP) document: "ZEP modelled the lowest-cost route to decarbonizing Europe by looking at CCS for industries as refining, steel and cement. After modelling the lowest-cost route for decarbonising European power, ZEP turned its attention to industry. With direct industry-related emissions accounting for a quarter of total EU CO_2 emissions, it is clear that Europe must look beyond the power sector to include core industries such as refining, steel and cement. Not only is CCS the only option for substantially reducing CO_2 emissions in these industries, but the costs of CO_2 transport and storage – 10-30% of the total CCS costs – can be significantly reduced by clustering power and industrial emitters."

Global Carbon Capture and Storage Market 2017-2021.

The following is from a summary of this document: "The use of CCS technology is one of the novel ideas that help reduce the amount of CO_2 released into the atmosphere by fossil fuel-dependent industries such as power generation and oil and gas processing. The basic functioning of the CCS technology includes capturing the CO_2 before its release into the atmosphere and then transporting and storing it in an environmentally safe location. Technavio's analysts forecast the global [CCS] market to grow at a CAGR of 9.18% during the period 2017-2021. The report covers the present scenario and the growth prospects of the global [CCS] market for 2017-2021. To calculate the market size, the report analyzes business dimensions with an eye on individual growth trends and contribution of upcoming market segments…Technavio's report, Global Carbon Capture and Storage Market 2017-2021, has been prepared based on an in-depth market analysis with inputs from industry experts. The report covers the market landscape and its growth prospects over the coming years. The report also includes a discussion of the key vendors operating in this market."

Challenges related to carbon transportation and storage – showstoppers for CCS?

The following is from the Introduction of this Global CCS Institute document: "As two of the authors have described in previous work, CCS technologies can become an important tool in a wider carbon mitigation portfolio in the coming decades. That earlier study concentrated mostly on challenges related to capturing carbon, with a special focus on the United States (U.S.). However, transportation and storage infrastructure is required to remove CO_2 captured from power plants and industrial installations, and to inject the CO_2 into deep saline geological formations or depleted oil and gas fields for permanent sequestration. Transportation can be undertaken using pipelines or (if in an offshore environment) ships, and storage facilities are analogous to those used for temporary or seasonal natural gas storage. The U.S. has a substantial network of CO_2 pipelines and injection facilities that has been developed over four decades for use in oil production in a process known as EOR. Unlike the U.S., the European Economic Area (EEA) has not developed such an infrastructure and consequently Europe needs to start from scratch if CCS is to be deployed at scale as a decarbonization tool. Existing European oil and gas transport and production infrastructure does, however, offer some potential for re-use in some limited circumstances..."

AUGUST 2017

A Reduced-Order Model for Wellbore Permeability Induced by Geomechanical Damage.

The following is the Executive Summary of this NRAP document: "This work is part of a broader effort to develop risk assessment models of potential leakage of CO_2 from existing and new wells at a CO_2 sequestration site. This report focuses on potential geomechanical damage to wells following injection of CO_2 into the storage reservoir and the resulting changes in reservoir and caprock stress. This report includes a description of the development of a geomechanical model of the wellbore, two different stress-permeability relations, the creation of a reduced-order model (ROM) providing a simple algebraic representation of the results of geomechanical stress on the wellbore, and the results of the application of the model to an example reservoir at 1,000 m depth. The model is preliminary in nature, and future work will include the development of a more complete representation of the stress relationships in the wellbore system. The preliminary work shows that relatively high injection pressures would be required to damage the wellbore."

Compressive and Tensile Strength of Class H Cement Exposed to High Pressure and Temperature Storage Conditions.

The following is the Abstract of this NRAP document: "In the United States, the implementation of [co]-storage (CO_2-O_2-SO_2 mixtures) from oxy-fueled combustion, coal gasification and sour gas is currently being considered in saline geologic formations. DOE NETL, as part of NRAP, was tasked to determine the risk related to geologic carbon storage. This report addresses the potential impacts on wellbore cement integrity following exposure to storage conditions. When plumes of injected CO_2 (or co-stored) gas come in contact with existing wells, the cement lining in the well is vulnerable to geochemical alteration, and impact the well's effectiveness as a barrier for unwanted fluid migration. In this study, cured Class H cement paste, used in well construction, was exposed to co-storage conditions, and the tensile and compressive strength were measured to understand the effects of co-stored gas on the geomechanical properties of cement. In addition, co-storage settings at higher formation temperatures may result in loss of cement strength under acidic conditions, though cement integrity has not been tested under fully in situ conditions. These observed effects have implications for the long-term effectiveness of wells using Class H cement paste in co-storage scenarios."

UK decarbonisation and carbon capture and storage.

The following is the Summary of this document: "CCS is a way of 'decarbonising' fossil fuel power generation, through capturing and storing the CO_2 produced. CCS involves three steps; [1] Capturing CO_2 from power plants or industry, band compressing it to a liquid state [2] Transporting the CO_2 (usually via pipelines) to deep geological storage points such as depleted oil and gas fields or deep saline aquifers; and [3] Storing the CO_2 in these sites. [Carbon dioxide] can be captured pre- or post-combustion; [1] Post-combustion removes CO_2 from flue gases. This can be retro-fitted. [2] Pre-combustion reacts the fuel with oxygen, air, or steam, and after a further catalytic process removes the CO_2 and uses the hydrogen left over as fuel in a combined cycle gas turbine generating station. Only new fossil fuel power plants can be equipped with this. [3] Oxyfuel technology burns fossil fuels with nearly pure oxygen producing a flue gas of CO_2 and steam; the water condenses leaving flue gas of almost pure CO_2. This can be applied to new and existing fossil fuel stations. The ideal site for CCS generation is therefore close to a storage reservoir like depleted oil and gas fields and saline aquifers. A network of onshore and offshore pipelines to transport the captured CO_2 is also required. This could perhaps even be on a scale equivalent to the North Sea oil and gas industry. CCS is regulated through a licensing regime laid out in the Energy Act 2008. The Secretary of State for Business, Energy and Industrial Strategy (BEIS) is the licensing authority for offshore storage except within the territorial sea adjacent to Scotland."

SEPTEMBER 2017

Compressive and Tensile Strength of Class H Cement Exposed to High Pressure and Temperature Storage Conditions.

The following is the Abstract of this National Risk Assessment Partnership (NRAP) document: "In the United States, the implementation of [co]-storage (CO_2-O_2-SO_2 mixtures) from oxy-fueled combustion, coal gasification and sour gas is currently being considered in saline geologic formations. [DOE's] NETL, as part of NRAP, was tasked to determine the risk related to geologic carbon storage. This report addresses the potential impacts on wellbore cement integrity following exposure to storage conditions. When plumes of injected CO_2 (or co-stored) gas come in contact with existing wells, the cement lining in the well is vulnerable to geochemical alteration, and impact the well's effectiveness as a barrier for unwanted fluid migration. In this study, cured Class H cement paste, used in well construction, was exposed to co-storage conditions, and the tensile and compressive strength were measured to understand the effects of co-stored gas on the geomechanical properties of cement. In addition, co-storage settings at higher formation temperatures may result in loss of cement strength under acidic conditions, though cement integrity has not been tested under fully in situ conditions. These observed effects have implications for the long-term effectiveness of wells using Class H cement paste in co-storage scenarios."

Chemical – Mechanical – Transport Model for Wellbore Permeability for CO_2 Storage.

The following is the Introduction of this NRAP document: "Wellbores are considered to be a primary pathway of concern for potential CO_2 and brine leakage from storage reservoirs to drinking water aquifers and the atmosphere. This study investigated how chemical alteration of wellbore cement affects the mechanical and hydraulic properties of wellbore fractures and interfaces to better assess the risk for CO_2 leakage from storage reservoirs. The observed trends are explained in hydraulic aperture in these experiments by proposing that chemical alteration weakens the asperities that hold open pathways at cement-caprock interfaces, thereby causing the fracture to close in response to pressure placed on the sample."

Public outreach approaches for carbon capture and storage projects.

The following is a description of this International Energy Agency Clean Coal Center (IEA CCC) document: "Following a few early failures of large-scale CCS demonstration projects due to public opposition to the technology, a considered public communication strategy is now regarded as an essential factor in the success of any prospective CCS project. Most active opposition to CCS has occurred in parts of Europe, where public fears over CO_2 leaks, water contamination, or '[industrialization]' of rural areas have combined with opposition by environmental groups and others to fossil fuels playing any role in a future energy mix. However, many other projects have since won acceptance or even widespread support, thanks either to improved public engagement or more [favorable] local context. Several key features of a successful communications strategy have been identified, including the need for engagement early in the process, encouraging and responding to community feedback, building and maintaining trust in the project developers, and use of a dedicated communications team with clear messages which are tailored to their intended audience. This report provides a comprehensive review of the public outreach strategy and results at most notable CCS demonstrations to date, and looks to future challenges for CCS communication. With the barrier of local acceptance appearing surmountable in most regions, the problem of making the wider case for CCS as a viable option for climate change mitigation largely remains. This could potentially be addressed through education initiatives and more effective use of mass media."

ANNOUNCEMENTS

OCTOBER 2016

NRAP Featured in Journal.

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. 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 carbon dioxide (CO_2) storage.

NOVEMBER 2016

Team Formed to Study CCUS Technologies.

Japanese companies are collaborating with the International CCS Knowledge Center to assess the potential application of Japanese technologies in future carbon capture, utilization, and storage (CCUS) projects in Saskatchewan, Canada. In addition to identifying potential global applications of the technologies, the consortium intends to show how the technologies could improve carbon capture system and air-quality control system applications for CCUS projects in Saskatchewan.

CCS Study Aims to Boost Industry.

A new study will explore carbon capture and storage (CCS) and the refinement and development of a financing option for the industrial CCS network in Teesside, England, known as the Teesside Collective. The study will also recommend a regulatory regime to manage the system, known as the Hybrid Incentive Model. The work will take account of existing documented work on industrial CCS financing, storage, and regulation.

DECEMBER 2016

CO_2 Capture Project Releases CO_2 Storage Report.

The CO_2 Capture Project (CCP) published a report looking at international best practices for transitioning from carbon dioxide-enhanced oil recovery (CO_2-EOR) to CO_2 storage sites. The report studied the legal frameworks for carbon capture and storage (CCS) and CO_2-EOR sites within the United States, Canada, Europe, Australia, and Brazil.

RGGI Releases Report.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "Report on the Secondary Market for RGGI CO_2 Allowances: Third Quarter 2016." The report, prepared by independent market monitor Potomac Economics, provides a summary of activity in the secondary market in the third quarter of 2016 and discusses the results.

Research Report Explores Global CO_2 Market.

This report examines the sales of CO_2 in the global market, providing a basic overview of the current state of the CO_2 industry. The report, titled "*2016 Market Research Report on Global Carbon Dioxide Market*," also discusses development policies and plans, manufacturing processes, and cost structures.

JANUARY 2017

Final Report on the Task Force on CO_2 Utilization.

The U.S. Secretary of Energy Advisory Board (SEAB) Task Force on CO_2 Utilization released a report representing their findings and recommendations. The Task Force set out to describe a framework for a U.S. Department of Energy (DOE) research, development, and demonstration (RD&D) program on carbon dioxide (CO_2) utilization technologies that have the potential to reduce CO_2 emissions.

MOU Signed for CCS Collaboration.

Pale Blue Dot Energy, an energy sector management consultant company based in Aberdeenshire, United Kingdom (UK), signed a Memorandum of Understanding (MOU) with the Guangdong Carbon Capture, Utilization, and Storage (CCUS) Centre in China for collaboration on carbon capture and storage (CCS) projects. In addition, the MOU provides for the exchange of capability and learning between UK and Chinese project design and development.

EU Adds to Emissions Trading Scheme.

The European Parliament's Environment Committee voted to include maritime transport in the European Union (EU) Emissions Trading Scheme (ETS) by 2023.

FEBRUARY 2017

NETL Signs MOU to Advance Fossil Energy Technologies.

Representatives from the National Energy Technology Laboratory (NETL) and the Office of Fossil Energy (FE) signed a memorandum of understanding (MOU) with Dubai Electricity and Water Authority (DEWA) to collaborate on the advancement of fossil energy technologies and to foster assessments of technology options and economics.

Energy Collaboration Extended.

The Massachusetts Institute of Technology (MIT) and Italian energy company Eni renewed their collaboration on low-carbon research. The agreement also extends research support for three of the MIT Energy Initiative's (MITEI) Low-Carbon Energy Centers in the areas of solar energy; energy storage; and carbon capture, utilization, and storage (CCUS).

U.S.-China Energy Center Receives Funds.

The *Berkeley-Tsinghua Joint Research Center on Energy and Climate Change* received a donation that will be used to further its scientific research and analysis on clean energy solutions in areas such as low-carbon cities, carbon markets, and clean energy system planning and integration. The U.S.-China Energy Center was announced in 2015 as a partnership between Beijing's Tsinghua University and Lawrence Berkeley National Laboratory (LBNL). LBNL is managed by the University of California for *DOE's Office of Science*.

MARCH 2017

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 2016*." Prepared by the independent market monitor Potomac Economics, the report addresses the period from October through December 2016 and contains information on the secondary market for RGGI carbon dioxide (CO_2) allowances, such as future prices, market activity, and allowance holdings. In addition, RGGI released the "*2016 Interim Compliance Summary Report*," which contains data regarding CO_2 allowances provided by CO_2 budget sources to meet their 2016 interim control period compliance.

New Report Backs CCS in Australia.

An independent report on carbon capture and storage (CCS) in Australia, commissioned by government, industry, and research organizations, has been released. Titled "A Roadmap for Carbon Capture and Storage," the report states, among other findings, that CCS could play a vital role in decarbonizing energy-intensive industries in Australia.

APRIL 2017

Carbon Storage Webinar.

The Global CCS Institute, with Australian National Low Emissions Coal Research and Development (ANLEC R&D), conducted a webinar focused on managing carbon storage and natural resources in sedimentary basins. The webinar, the eighth of a series being held by Global CCS Institute and ANLEC R&D, presented a framework for the management of basin resources.

MAY 2017

IEAGHG Information Papers Available.

The International Energy Agency Greenhouse Gas Research and Development Program (IEAGHG) produces Information Papers (IPs) on a variety of topics to provide timely reporting within the carbon capture and storage (CCS) arena. Most IEAGHG IPs are free to access and will be uploaded as they are published. Recent uploads include IPs on the *implications of the 2016 global carbon budget* and a *European Union (EU) project to advance environmental monitoring for offshore carbon dioxide (CO_2) storage projects*.

10 Years of CCS Research Available.

The Energy Technologies Institute (ETI) has released 10 years of CCS research, including videos, news, and other resources. According to ETI, the mission is to invest in innovation to reduce the cost of capture and reduce the risks of storage; build knowledge to understand the infrastructure requirements for CCS application in the UK; and build knowledge to create confidence amongst investors, policy makers, and industry towards CCS opportunities.

JUNE 2017

RGGI Releases Reports.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "*Annual Report on the Market for RGGI CO_2 Allowances*." Prepared by independent market monitor Potomac Economics, the report evaluates 2016 activity in the RGGI carbon dioxide (CO_2) allowance market. In addition, RGGI also released the "*Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2017*," which addresses the period from January through March 2017 and contains information on the secondary market for RGGI CO_2 allowances, such as future prices, market activity, and allowance holdings.

New Carbon Economy Effort Launched.

The Center for Carbon Removal launched an industrial innovation initiative to develop solutions that transform waste atmospheric CO_2 into products and services. The launch is in partnership with Arizona State University, as well as Iowa State University and Purdue University; Lawrence Livermore National Laboratory (LLNL) also participated in the launch event.

New CCS Campaign Implemented.

The Global CCS Institute is implementing a new campaign to raise awareness of the role carbon capture and storage (CCS) technology has in meeting international targets. The campaign involves releasing a suite of "memes" – virally transmitted cultural symbols or social ideas – that communicate facts about CCS, such as its chemical process, safety, and low cost.

CCS Webinar Series.

The Carbon Sequestration Leadership Forum (CSLF), with support from the Global CCS Institute, is conducting a series of webinars showcasing academics and researchers working in the CCS field. The first webinar, held in April 2017, focused on carbon capture, utilization, and storage (CCUS) in the United Arab Emirates (UAE).

JULY 2017

ETI Report on CO_2 Storage Capacity in the UK.

The Energy Technologies Institute (ETI) published a report, titled "*Taking Stock of CO_2 Storage*," which analyzes aspects of carbon capture and storage (CCS) that have changed since their previous report was published in 2013. Specifically, their research found that the United Kingdom (UK) has enough potential carbon dioxide (CO_2) storage sites to meet its needs out to 2050.

New Carbon Economy Consortium.

The Center for Carbon Removal launched a "New Carbon Economy" consortium in partnership with several research institutions. The initiative will look to remove CO_2 from the atmosphere and convert it into valuable products and services. The partners of the consortium agreed to produce a roadmap that will outline the steps needed for translating relevant research into business and policy actions.

Report on Global Carbon Storage Market.

A recently released report studies the global market for carbon storage in North America, Europe, China, Japan, Southeast Asia, and India. Specifically, the report focuses on top manufacturers in the global market, with capacity, production, price, revenue, and market share for each manufacturer.

AUGUST 2017

CSLF 2017 Mid-Year Meeting Proceedings Available.

The proceedings from Carbon Sequestration Leadership Forum's (CSLF) 2017 Mid-Year Meeting, held April 30 through May 4, 2017, in Abu Dhabi, United Arab Emirates, are now available online. The documents and presentations cover the Projects Interaction and Review Team Meeting, Technical Group Meeting, and Policy Group Meeting.

Collaboration to Test CO_2 Reduction in Residential Houses.

Iida Group Holdings Co Ltd (Iida GHD) and Osaka City University will collaborate to test residential houses that store carbon dioxide (CO_2) by using artificial photosynthesis. The houses supplied for the test will not only reduce CO_2 emissions, but also "consume" it by using an artificial photosynthesis technology that uses solar energy to convert CO_2 into hydrogen.

SEPTEMBER 2017

CCS Research Grant Extended.

Gassnova, a Norwegian state-owned carbon capture technology firm, extended a grant for research at the CO_2 Technology Centre Mongstad (TCM). TCM conducts carbon capture and storage (CCS) emissions testing using carbon dioxide (CO_2) from a combined heat and power plant and an oil refinery cracker.

RGGI Releases Reports on Secondary Market and Results for Auction 37.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "*Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2017*," addressing the period from April 2017 through June 2017. Prepared by independent market monitor Potomac Economics, the report includes information on the secondary market for RGGI CO_2 allowances, including futures prices, market activity, and allowance holdings. In addition, RGGI also *announced the results of their 37th auction of CO_2 allowances, in which 14,371,585 CO_2 allowances* were sold at the auction at a clearing price of $4.35. More details are available in the Market Monitor Report for Auction 37.

Report Details Growth of CCS Market.

A study by Global Market Insights details how the growing demand for CCS technologies, along with government regulations to reduce greenhouse gas (GHG) emissions, will drive the CCS market size. The report states that the product's ability to reduce carbon emission by 85 to 90 percent makes its adoption preferable over other available alternates.

India Plans to Establish Voluntary Carbon Market.

According to India's union minister for environment, forest, and climate change, India plans to establish a voluntary carbon market. The announcement was made at the Business and Climate Summit (BCS) 2017 in Delhi.

ABOUT DOE'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** advances the development and validation of technologies that enable safe, cost-effective, permanent geologic storage of CO_2. The Carbon Storage Program also supports the development of best practices for CCS that will benefit projects implementing CCS at a commercial scale, such as those being performed under NETL's Clean Coal Power Initiative and Industrial Carbon Capture and Storage Programs. The technologies being developed and the small- and large-scale injection projects conducted through this program will be used to benefit the existing and future fleet of fossil fuel power-generating facilities by developing tools to increase our understanding of the behavior of CO_2 in the subsurface and identifying the geologic reservoirs appropriate for CO_2 storage.

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

CARBON STORAGE PROGRAM RESOURCES

The *National Energy Technology Laboratory's CCS Database* includes active, proposed, and terminated CCS projects worldwide. The information is taken from publically available sources to provide convenient access to information regarding efforts by various industries, public groups, and governments towards development and eventual deployment of CCS technology. NETL's CCS Database is available as a Microsoft Excel spreadsheet and also as a customizable layer in Google Earth.

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more are available via the *Carbon Storage Program Publications webpage*.

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

ABOUT NETL'S CARBON STORAGE NEWSLETTER

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

NATIONAL ENERGY TECHNOLOGY LABORATORY

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GET SOCIAL WITH US

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

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