NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON STORAGE NEWSLETTER

ANNUAL INDEX

FISCAL YEAR (FY) 2018

October 2017 – September 2018

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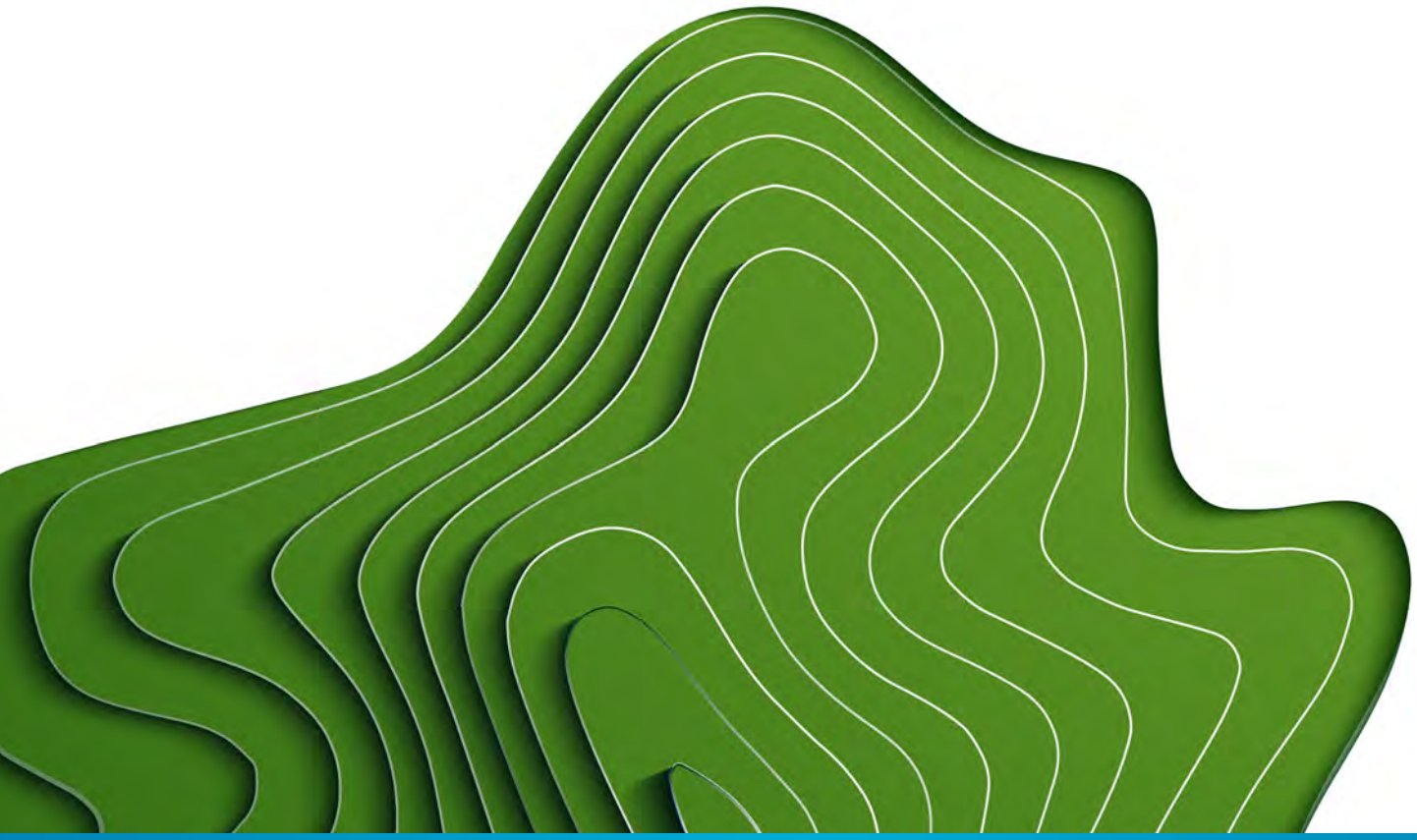
ANNUAL INDEX – FY 2018

This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters (CSN) published from October 2017 to September 2018. 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 Outdated information (e.g., conference dates, paper submittals, etc.)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.

CONTENTS



DOE/NETL HIGHLIGHTS

OCTOBER 2017

NRAP Commences Phase II Research Program.

The U.S. Department of Energy's (DOE) *National Risk Assessment Partnership (NRAP)* has entered Phase II of its research, in which researchers will consider how potential geologic carbon storage risks can be mitigated and how uncertainties in site performance can be reduced using strategic monitoring. Initiated in 2011, the National Energy Technology Laboratory (NETL)-led NRAP quantifies environmental risks at geologic carbon storage sites. *Phase I resulted in accomplishments* such as the first quantitative risk profiles for a full geologic carbon storage system, identification of key geologic storage reservoir risk relationships, and development of the NRAP Toolset. Phase II objectives include the development of advanced predictive models of geologic carbon storage system containment effectiveness/leakage response; development of a second-generation, open-source integrated assessment framework to quantify containment effectiveness/leakage response; development of improved tools and protocols to support advanced seismic hazard analysis and forecasting; development of tools to model monitoring and optimize design of monitoring networks for leak detection; and testing and validation of NRAP tools and methods using field data sets. From *energy.gov* on September 25, 2017.

NETL-Developed Software Toolset Recognized.

NETL's NRAP Toolset has been selected as a finalist for *R&D Magazine's annual R&D 100 Awards*, which recognize the top 100 technologies and services of the year. The Toolset software package includes 10 science-based computational tools that predict environmental risk performance of geologic carbon dioxide (CO_2) storage sites. The Toolset supports industry and regulatory stakeholders in the design and implementation of safe and effective large-volume geologic CO_2 storage sites, providing users with credible, science-based resources for evaluating, developing, and managing the geologic storage of CO_2. In addition, the Toolset expedites selection and characterization of candidate storage sites, builds public and industry stakeholder confidence in predictive data regarding storage site performance, aids in the preparation and evaluation of permits, and helps decision makers address large-scale implementation of geologic carbon storage projects. From *energy.gov* on October 6, 2017.

NOVEMBER 2017

DOE/FE Selects Projects for Offshore Carbon Storage Resources and Technology Development.

Two projects have been selected by the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) to receive Federal funding to assess offshore geologic storage of carbon dioxide (CO_2) and technology development in the Gulf of Mexico. Selected as part of FE's Carbon Storage Program, the National Energy Technology Laboratory (NETL)-managed projects will focus on assembling the knowledge base required for secure, long-term, large-scale CO_2 storage and assessing technology-development needs, such as infrastructure, operational, and monitoring (the technology-development needs of offshore storage differ from those of onshore storage). From *energy.gov* on November 7, 2017.

DOE Selects Two Projects to Ensure Safe Storage of CO_2 in Geologic Formations.

DOE/FE selected two projects to receive Federal funding for cost-shared research and development (R&D) for the safe storage of CO_2 in geologic formations. The two projects are supported through Funding Opportunity Announcement (FOA) DE-FOA-0001725, "*Technology Development to Ensure Environmentally Sustainable CO_2 Injection Operations*," which focuses on developing modeling and monitoring methods, technologies, and tools that help assess the position of CO_2 plume over time within various geologic formations and sedimentary environments. The NETL-managed projects will support the *Carbon Storage Program*. More information on the selected projects is available on the *FE website*. From *energy.gov* on October 26, 2017.

DOE-Supported CCS Project Reaches Milestone.

An FE/NETL-supported large-scale CO_2 capture and storage (CCS) system reached a milestone by capturing and transporting 4 million metric tons of CO_2. Air Products and Chemicals designed, built, and is currently operating the CCS system at their hydrogen-production facility located at the Valero Port Arthur Refinery in Port Arthur, Texas, USA. Utilizing a gas-separation technology called *vacuum swing adsorption*, the project captures more than 90 percent of the CO_2 from the product streams of two commercial-scale steam methane reformers. In addition, the project is also helping to verify the effectiveness of enhanced oil recovery (EOR) for permanently storing CO_2 by injecting it at the West Hastings Unit oil field in southwest Texas, USA. From *energy.gov* on October 11, 2017.

DECEMBER 2017

ASFE Leads Policy Group During CSLF Meeting.

The U.S. Department of Energy's (DOE) Assistant Secretary for Fossil Energy (ASFE) led the Policy Group meeting at the 7th Ministerial Meeting of the Carbon Sequestration Leadership Forum (CSLF) in Abu Dhabi, United Arab Emirates (UAE), on December 5, 2017. The CSLF is an international initiative focused on the development of cost-effective carbon capture, utilization, and storage (CCUS) technologies. The CSLF, which holds a ministerial-level conference every two years, fosters international collaboration to address key challenges to CCUS technology development and deployment. The Policy Group, chaired by the United States, is responsible for addressing the legal, regulatory, and financial issues associated with CCUS technologies. More information on the Ministerial Meeting, as well as Policy Group documents, is available on the *CSLF website*. From *energy.gov* on December 6, 2017.

NETL Software Developers Win Award.

The National Risk Assessment Partnership (NRAP) Toolset, developed by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) and in collaboration with other national laboratories, was recognized by R&D Magazine as one of the 100 most technologically significant products introduced into the marketplace in the past year. The NRAP Toolset software package includes 10 science-based computational tools that predict environmental risk performance of geologic carbon dioxide (CO_2) storage sites. Led by NETL, NRAP also includes expertise from Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and the Pacific Northwest National Laboratory (PNNL). The computational tools in the NRAP Toolset support industry and provide technical insight to regulatory projects to store large volumes of CO_2. A full list of the 2017 award winners is available on the *R&D 100 Conference website*. From *energy.gov* on November 20, 2017.

JANUARY 2018

DOE Swears in New Assistant Secretary for Fossil Energy.

The new Assistant Secretary for the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) was officially sworn in by the Energy Secretary. The Assistant Secretary for Fossil Energy (ASFE) will oversee FE's research and development (R&D) program; serve as a primary policy advisor for the Energy Secretary and DOE on issues involving U.S. fossil fuels; and supervise the more than 1,000 scientists, engineers, technicians, and administrative members of the FE staff across the Nation. From *NETL News Release* on December 14, 2017.

APRIL 2018

NETL-Managed Project Stores One Million Tons of CO_2.

The NETL-managed Midwest Regional Carbon Sequestration Partnership (MRCSP) has safely and permanently stored one million metric tons of carbon dioxide (CO_2). MRCSP stored the CO_2 into a series of depleted oil fields in northern Michigan, USA, for enhanced oil recovery (EOR) operations. The project developed novel approaches for monitoring CO_2 in fields that were in different stages of their production life cycles. Techniques were then tested to track the CO_2 and quantify the amount that is retained after the oil is removed. The data can be used to further optimize CO_2 storage and energy production in other areas, and the work furthers the understanding of the subsurface by assessing potential storage capacity and validating computer models of the subsurface geology. From *energy.gov* on March 12, 2018.

JUNE 2018

DOE Launches CCUS Initiative.

The U.S. Department of Energy (DOE) launched the *Carbon Capture, Utilization, and Storage (CCUS) Initiative*, which will focus on strengthening the framework for building collaborative partnerships on CCUS between the public and private sectors. The initiative will complement existing CCUS efforts led by the Carbon Sequestration Leadership Forum (CSLF), the International Energy Agency (IEA), the IEA's Greenhouse Gas Research and Development (R&D) Programme (IEAGHG), Mission Innovation, and the Global CCS Institute. The announcement was made at the 9th Clean Energy Ministerial (CEM9) in Copenhagen, Denmark. From *energy.gov* on May 24, 2018.

DOE Releases CCUS Experts' Workshop Report.

DOE's FE and Oak Ridge National Laboratory (ORNL) released a report of the Mission Innovation CCUS Experts' Workshop, which discussed basic R&D needs in CO_2 capture, CO_2 utilization, geologic storage, and crosscutting CCUS topics. Hosted by the United States in conjunction with Saudi Arabia, the workshop brought together worldwide CCUS experts from academia and industry. The report, titled "*Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage*," was released at the Mission Innovation CCUS Roundtable in Malmo, Sweden, where DOE officials took part in discussing the role of CCUS technologies in global decarbonization efforts. From *energy.gov* on May 23, 2018.

JULY 2018

DOE Selects Carbon Storage Projects to Receive Federal Funding.

Three projects have been selected by the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) to receive funding for cost-shared research and development (R&D) under Phase II of Funding Opportunity Announcement (FOA) *DE-FOA-0001450, Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Storage Complex Feasibility*. Projects selected under this FOA will determine the feasibility for commercial-scale storage complexes that can hold 50+ million metric tons (MMT) of carbon dioxide (CO_2). The projects, to be managed by the National Energy Technology Laboratory (NETL), were selected as part of the *Carbon Storage Program* and will help inform the characterization and permitting of a commercial-scale complex with at least one storage site, ultimately demonstrating the potential for safe and secure storage in time for the anticipated deployment of transformative carbon capture technologies in the 2025 timeframe. From *energy.gov* on May 24, 2018.

AUGUST 2018

DOE Invests in Technologies that Assess Subsurface Stress for Carbon Storage.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) has selected five projects to receive Federal funding for cost-shared research and development (R&D) through FE's *Carbon Storage Program*. The projects, supported through Funding Opportunity Announcement (FOA) DE-FOA-0001826 "*Developing Technologies to Advance the Understanding of State of Stress and Geomechanical Impacts within the Subsurface*," will provide tools for measuring, estimating, and understanding underground stress impacts that may occur in carbon storage activities. The National Energy Technology Laboratory (NETL)-managed projects were selected under two Areas of Interest (AOI): AOI 1 – Tools and Methods for Determining Maximum Principal Stress in the Deep Subsurface, and AOI 2 – Methods for Understanding Impact of Vertical Pressure Migration Due to Injection on State of Subsurface Stress. From *energy.gov* on July 25, 2018.

SEPTEMBER 2018

DOE Invests to Advance Associated Geologic Storage.

The U.S. Department of Energy's (DOE) *Office of Fossil Energy (FE)* selected two projects to receive Federal funding for cost-shared research and development (R&D). Selected under Funding Opportunity Announcement (FOA) DE-FOA-0001829, "*Developing Technologies for Advancement of Associated Geologic Storage in Basinal Geo-Laboratories*," the projects will address technical research needs and key challenges in advancing associated geologic storage in support of DOE's *Carbon Storage Program*. In addition, the projects will support the development of best practices for commercial implementation of carbon storage technologies. From *energy.gov* on August 28, 2018.

NETL Explores Subsurface Data to Ensure Safe Carbon Storage.

Researchers at DOE's National Energy Technology Laboratory (NETL) are exploring rock pores to better understand the interaction between liquids and gas. The measurements collected are being used to expand scientific knowledge of the subsurface environment to ensure safe and effective carbon storage and enhanced resource recovery. NETL's Reservoir Engineering Team is using SyGlass – imaging technology that enables 3D visualization and analysis of volumetric data at the submillimeter scale – to investigate how carbon dioxide (CO_2) physically reacts with water within rock pores. From *DOE/NETL News Release* on August 15, 2018.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2017

CO_2 Storage Partnership Signed.

A CO_2 storage partnership has been signed to mature the development of carbon storage on the Norwegian continental shelf (NCS). Part of Norwegian efforts to develop full-scale carbon capture and storage (CCS) in Norway, the Statoil-led partnership involves partners Norske Shell and Total E&P Norge. The project will store CO_2 captured from industrial facilities in Eastern Norway, transporting it by ship from the capture facilities to a receiving terminal located onshore on the west coast of Norway, where it will be transferred to storage tanks prior to being sent through pipeline for injection east of the Troll field on the NCS. The project's objective is to stimulate development of CCS so the long-term targets in Norway and the European Union (EU) can be reached. From *equinor.com* on October 2, 2017.

Safe CO_2 Storage Test Aids Top Research Project.

A new method that monitors the safe storage of industrial GHGs will be used at a Carbon Management Canada-operated CCS test site in Alberta, Canada. Developed by researchers from the University of Edinburgh, the method shows that the chemical fingerprint of CO_2 captured from power plants remains recognizable after underground injection, enabling stored industrial CO_2 to be distinguished from other sources of CO_2 (e.g., groundwater, natural emissions from plants, bacteria). The method was verified by studying experimental storage sites in Australia and Canada in which the gas was sampled before and after injection, leading to researchers finding that the fingerprints remained identifiable. From *The University of Edinburgh* on September 20, 2017.

EOR Research Partnership Formed.

The Abu Dhabi National Oil Company (Adnoc) and the Center of Integrated Petroleum Research (CIPR) at Bergen University, Norway, have agreed to a partnership to conduct applied research into enhanced oil recovery (EOR) techniques. Under the agreement, Adnoc and CIPR will collaborate on research into a range of EOR applications while looking to reduce the risk of the different technologies and prepare for future full field expansion of the solutions that demonstrate the best deployment value. From *Trade Arabia* on October 2, 2017.

Canadian Investment in Carbon Capture and Conversion.

The Government of Canada and the Government of British Columbia have invested in a carbon capture and conversion testing facility. The new BC Research (BCRI) Technology Commercialization and Innovation Centre is home to the Carbon Capture and Conversion Institute (CCCI); together, BCRI and CCCI offer experts, pilot plant, and laboratory space for the development of technologies to reduce industrial GHGs. The funding is expected to help CCCI develop and scale-up CO_2 capture and conversion technologies. From *Carbon Capture and Conversion Institute (CCCI)* on September 14, 2017.

NOVEMBER 2017

Battelle Completes CO_2 Storage Project.

A 15-year DOE/NETL-funded research project that tested geologic CO_2 storage at a commercial-scale, coal-fired power plant has concluded. Battelle started the CCS research project at American Electric Power's (AEP) Mountaineer Plant in New Haven, West Virginia, USA, in 2002. AEP decided in 2007 to proceed with a 20-MW pilot-test facility with onsite CO_2 capture, compression, transport, and injection. From 2009 through 2011, CO_2 was injected into two injection zones; this was followed by a post-injection monitoring and site-closeout phase, which ended in 2017. The project helped establish the technical viability of CCS to reduce greenhouse gas (GHG) emissions from coal-fired power plants and to store CO_2 in geologic layers with limited prior data. The collaboration has led to geologic, engineering, field implementation, and regulatory lessons learned, with regional and global impact for CCS technology development and new knowledge for DOE's *Regional Carbon Sequestration Partnerships (RCSPs)*. From *Battelle News Release* on October 26, 2017.

Montana Pipeline Proposed to Transport CO_2 for EOR.

Denbury Resources, Inc. is seeking to build a pipeline in eastern Montana, USA, that would transport CO_2 for use in oil production along the North Dakota border. The proposed pipeline would begin near the Wyoming border and extend 110 miles to the Cedar Creek Anticline, an aging oil field with potential reserves of 260 to 290 million barrels of oil, according to Denbury officials. From *Casper Star Tribune* on October 9, 2017.

Partnership to Combine Carbon Capture, Storage in Pilot Plant.

In partnership with Reykjavik Energy, the Swiss company Climeworks will demonstrate a safe, economically viable, and highly scalable carbon removal technology. Part of the CarbFix2 project, which stores air-captured CO_2 safely and permanently in basalt, the pilot plant centers around a geothermal power plant in Hellisheidi, Iceland, where CO_2 is currently being injected and mineralized at an industrial scale. Climeworks has initiated the testing phase, during which the CO_2 is captured from ambient air, bound to water, and sent underground where it reacts with the basalt to form solid minerals, creating a permanent storage solution. From *Climeworks Press Release* on October 12, 2017.

EOR Project in UK North Sea.

Chevron North Sea (CNSL) will proceed with Phase I of its Captain EOR project located in the UK North Sea. The first stage of the project involves the use of polymer technology to increase the overall recovery rate from the Captain heavy oil field, located on the edge of the outer Moray Firth. From *Energy Business Review* on October 23, 2017.

Underground CO_2 Storage Test Facility Opens.

A new facility that will develop and demonstrate technologies for the safe underground storage of CO_2 was officially opened in Alberta, Canada. Built by CMC Research Institute and operated by its Containment and Monitoring Institute, the Field Research Station (FRS) was developed with an investment by the Canadian government's Western Economic Diversification Program and is supported by the University of Calgary. Monitoring technologies developed at the site will provide results that demonstrate methods for tracking the movement of CO_2 underground and verifying safe and secure storage. From *CMC Research Institutes News Release* on October 24, 2017.

DECEMBER 2017

DOE Issues Grant for CO_2 Storage.

DOE issued a grant to the University of Texas at Austin Bureau of Economic Geology to lead a regional partnership to explore the safe storage of CO_2 in geologic formations under the Gulf of Mexico. The Gulf Coast Carbon Center (GCCC) will lead the partnership, whose mission is to develop a large storage capability and support economic growth. In addition, the program will focus on offshore storage resources geologic characterization; risk assessment, simulation, and modeling; monitoring, verification, and accounting; infrastructure, operations, and permitting assessment; and knowledge dissemination. From *The University of Texas at Austin* on December 4, 2017.

DOE-Funded Study to Determine Feasibility of Underground CO_2 Storage.

Two exploratory wells are being drilled in central North Dakota, USA, to help researchers determine the feasibility of safely storing CO_2 deep underground. The drilling is part of the DOE-funded *CarbonSAFE* project, led by the University of North Dakota's Energy and Environmental Research Center (UNDEERC). Researchers will investigate the geology more than one mile underground to determine its suitability for CO_2 storage captured from coal-based energy facilities. The study will provide researchers with information to use in computer modeling. The DOE study is looking to determine the feasibility of injecting 2 million tons of CO_2 per year for 25 years. From *WDAZ* on December 1, 2017.

Contract for Onshore CO_2 Storage Terminal.

KBR Inc. will perform the front-end engineering and design (FEED) on Statoil's onshore CO_2 storage terminal, called Northern Lights, in Norway. The project is a key component of the CCS demonstration project being undertaken by Gassnova, with Statoil, in partnership with Royal Dutch Shell PLC and Total SA, responsible for transport and storage. In Phase I of the project, as much as 1.5 million metric tons of CO_2 will be captured per year from onshore industrial plants in eastern Norway, eventually transported to the onshore storage terminal. From *Oil and Gas Journal* on November 30, 2017.

States, Canadian Province Sign MOU on CCUS.

The states of Wyoming, Montana, and North Dakota signed a Memorandum of Understanding (MOU) with the Canadian province of Saskatchewan to collaborate on CCUS research. According to a press release, the MOU calls for engagement of other related research groups within the states/province, prioritizes joint cooperative projects, and ensures a formal evaluation process of activities and accomplishments. From *Gillette News Record* on December 3, 2017.

JANUARY 2018

CCS Project Begins Feasibility Study.

The Acorn CCS Project in North East Scotland has begun a feasibility study. The project will transport captured CO_2 offshore, storing it underground in a deep saline formation. While the initial phase will focus on CO_2 captured from the St. Fergus gas-processing unit, later phases will store CO_2 from other sources. The feasibility study will demonstrate the commercial and regulatory aspects of CCS project development in the United Kingdom (UK). Researchers will develop a full-chain business case and economic model, as well as locate a North Sea geologic CO_2 storage site for the project. From *Carbon Capture Journal* on December 7, 2017.

MHI to License Capture Technology Capable of CCS.

Mitsubishi Heavy Industries (MHI) has agreed to license its flue gas carbon capture technology to a Swiss engineering company, Casale SA, which in turn will sublicense the technology license to a methanol producer, Metafrax. Casale SA will undertake the engineering, procurement, and construction management (EPCm) for Metafrax's facility, which has the potential to recover 1,200 metric tons of CO_2 per day. While Metafrax will use the CO_2 to produce ammonia, urea, and melamine, MHI's technology can also be used for CCS generated by thermal power plants and enhanced oil recovery (EOR). From *Power Engineering International* on December 27, 2017.

MOU to Include CCUS Research.

Khalifa University of Science and Technology, located in Abu Dhabi, United Arab Emirates (UAE), signed a Memorandum of Understanding (MOU) with Tsinghua University in Beijing, China, to collaborate on a program to support transformative scientific research. As part of the agreement, the two universities will form a collaborative program that will include research in engineering fields, such as carbon capture, utilization, and storage (CCUS). The collaboration covers the exchange of materials in education, research, publications, and academic information, as well as visitation and exchange of faculty members, researchers, and students. From *Masdar Institute News* on December 18, 2017.

FEBRUARY 2018

UAE Company to Expand CCUS Technology.

The Abu Dhabi National Oil Company (ADNOC) announced plans to expand its use of carbon capture, utilization, and storage (CCUS) technology. The United Arab Emirates (UAE) company said it is expanding its use of the technology in order to meet an increase in CO_2 utilization for enhanced oil recovery (EOR) over the next 10 years. Starting in 2021, ADNOC will increase CO_2 utilization, expecting to reach 250 million standard cubic feet per day (MMscfd) by 2027 by capturing additional CO_2 from its gas processing plants and injecting it into different onshore oil fields. To date, ADNOC has stored approximately 240,000 metric tons of CO_2. From *Thomson Reuters Zawya* on January 17, 2018.

Carbon Capture Testing at Facility for Advancement of CCS Technologies.

Cansolv Technologies will use SaskPower's carbon capture test facility to explore new and existing capture technologies, from which the research gained will be used to inform future projects and the next generation of CCS technologies. Testing on new CCS technologies was completed at SaskPower's carbon capture test facility in 2017; with SaskPower's "plug-and-play" system, the tested technology has been removed and new equipment and chemistry will be added for testing. From *Carbon Capture Journal* on January 22, 2018.

Carbon Fund Invests in Carbon Project.

Climate Trust Capital, a U.S.-based private investment fund, has invested in a carbon project in the biogas sector. Climate Trust Capital will invest more than $1 million in a covered lagoon digester that will, among other effects, produce carbon offsets under California's (USA) cap-and-trade system. The investment comes from Climate Trust Capital's Fund I, which focuses on investing in U.S.-based carbon offset projects. From *The Climate Trust Media Release (via PR-Web)* on January 23, 2018.

MARCH 2018

Climeworks Establishes New Market Mechanism with Carbon Storage.

Climeworks has signed several contracts for its new Carbon Dioxide Removal solution. Using direct air capture (DAC), Climeworks can remove CO_2 emissions from the atmosphere and store them underground via the CarbFix process in Iceland. Climeworks opened a commercial DAC plant in Hinwil, Switzerland, in May 2017, and, in October 2017, began participating in the CarbFix project in Iceland, where its DAC technology is capturing CO_2 to be mineralized and stored underground. From *Gasworld* on February 15, 2018.

Latrobe Valley Plants Looking at CCS.

CO_2CRC is conducting a pre-feasibility study with Latrobe Valley power generators (located in Victoria, Australia) to explore retrofitting CCS technology. According to officials from CO_2CRC, CCS technology has the potential to prolong the life of Latrobe Valley coal-fired generators, create jobs, and reduce the region's CO_2 emissions. Current CO_2CRC research is being used to inform the CarbonNet project at Golden Beach (Victoria, Australia), where seismic seabed testing is being conducted to determine potential commercial-scale storage sites. From *Latrobe Valley Express* on February 12, 2018.

APRIL 2018

DOE Funds Monitoring of Underground Carbon Storage.

DOE is funding a carbon storage monitoring project that will use a novel, real-time monitoring system to track the spread of CO_2 underground. Researchers from Penn State University (PSU), Lawrence Berkeley National Laboratory (LBNL), and the University of Texas at Austin are partnering on the project, which will investigate underground storage in a reservoir, such as a saltwater aquifer or a mineral deposit, using real-time monitoring equipment that is installed during the construction of an injection well. From *Penn State University* on March 14, 2018.

Carbon Capture Utilization Demonstration Plant Opens in UK.

Econic Technologies has opened a carbon capture utilization plant in the United Kingdom (UK) to demonstrate the conversion of CO_2 into plastics. The new demonstration plant, located in the North of England, will be able to produce samples of CO_2-based polyols at lower, industrially relevant temperatures and pressures (previously, the creation of polyols from CO_2 had been performed in plants at high pressures and temperatures). Econic Technologies' catalysts allow manufacturers to reuse waste CO_2 by incorporating it as a feedstock. From *Carbon Capture Journal* on March 1, 2018.

Organizations Collaborate to Advance CCUS.

Two Canadian and Chinese organizations have agreed to collaborate on the development of carbon capture, utilization, and storage (CCUS) technologies to reduce GHG emissions. CMC Research Institutes (CMCRI) and the Guangdong CCUS Centre in China will promote joint R&D, advance the commercialization of CCUS, support training and education through workshops and conferences, and encourage the development of joint projects at the Guangdong CCUS Centre and MCMRI's Carbon Capture and Conversion Institute in Richmond, British Columbia, Canada. The Memorandum of Understanding (MOU) was signed at the 2nd Canada-China CCUS Forum held by Natural Resources Canada. From *JWN Energy* on March 15, 2018.

CCS Study Initiated at Refinery.

Preem, a Swedish fuel company, has initiated a CCS study at their refinery in Lysekil, Sweden. The study is expected to be conducted in spring 2018 and will examine the possibility of building a demonstration plant that will capture CO_2 at Preem's refinery. The west coast geographical location of the refinery exhibits a connection to the Norwegian full-scale CCS project. The overall goal, according to Preem officials, is a full-scale CCS capture plant at the refinery, and then transport of the liquified CO_2 by boat to the planned CCS hub on the Norwegian west coast for permanent storage in a formation below the seabed. From *Carbon Capture Journal* on March 1, 2018.

Australian Government Awards CO_2 Storage Contract.

The Government of Victoria in Australia awarded a contract to AGR Australia to manage its CarbonNet Offshore Appraisal Well Drilling Program. In addition to being responsible for the well engineering, design, supervision, and execution, AGR Australia will also manage the health, safety, and regulatory aspects of the project. The CarbonNet project is investigating the potential for establishing a large-scale CCS network that would unite multiple CO_2 projects in the Australian state's Latrobe Valley, transporting the CO_2, via pipeline, for injection into underground offshore storage sites in Gippsland (Victoria, Australia). From *Offshore Technology* on March 5, 2018.

MAY 2018

CCS Centerpiece for New Hydrogen Supply Chain.

According to the Global CCS Institute, CCS will be at the center of a new Australian-Japanese hydrogen supply chain. The Hydrogen Energy Supply Chain (HESP) Project, a joint venture between Australian and Japanese industries and governments, will build a pilot plant to produce hydrogen from Latrobe Valley brown coal for export to Japan. If successful, the pilot plant is expected to lead to a commercial-size plant that will incorporate CCS. From *Global CCS Institute Media Release* on April 12, 2018.

CO_2-EOR Project Commences.

Elk Petroleum Limited announced that its Grieve CO_2-enhanced oil recovery (EOR) project has commenced oil production within start-up deadlines. According to independent engineers and reserve auditors, initial gross oil production is expected to be in the range of 1,100 to 1,200 barrels of oil per day (BOPD), with a projection to increase to approximately 2,100 BOPD, and the potential to achieve a peak gross production rate of more than 3,400 BOPD. From *Elk Petroleum Limited Media Release* on April 18, 2018.

Japan CCS Site Shows Promise.

According to project developers, a CCS test site in Japan has the potential for reducing CO_2 emissions from industries such as gas processing and cement and chemical production. The Tomakomai CCS test site, which stores the captured CO_2 below the seabed off Hokkaido island, focuses on industrial applications. The site's injection project, with a target of 300,000 metric tons of injected CO_2, is scheduled to run until 2020. According to the site's developers, 150,000 metric tons of CO_2 have been injected to date. From *Reuters* on April 19, 2018.

CCS Plan for Vacated Gas Field.

The Kinsale gas fields located off the Cork coast in Ireland may be used as a site to store carbon, according to officials. In production since 1978, the gas reserves at the Kinsale gas fields are expected to deplete by 2020 or 2021; Kinsale Energy is preparing a decommissioning plan for the fields for the Department of Communications, Climate Action, and Environment. State officials claim the empty gas fields have the potential to store CO_2 released from existing natural gas-fired power stations in East Cork, southwest Ireland. From *The Irish Examiner* on April 19, 2018.

JUNE 2018

Norway Government Supports CO_2 Capture, Transport, and Storage Demonstrations.

The Norwegian government announced funding for demonstration studies on how to capture, transport, and store CO_2 from a cement factory in Brevik, Norway. The announcement was made with the publishing of the government's assessment of plans for a full-scale carbon capture and storage (CCS) demonstration project that would eventually result in CO_2 captured at industrial sites in Norway and transported for storage under the North Sea. In addition to the CO_2 transport and storage studies, the Norwegian government funding will also support engineering and design studies and up to two capture facilities. From *Business Green* on May 15, 2018.

Drax Power Station to Lead BECCS Trial.

The Drax Group will lead a bioenergy with carbon capture and storage (BECCS) trial at its north Yorkshire power station. Drax will store the carbon in a compressed form onsite, where it has the potential to be sold for industrial processes. From *The Guardian* on May 21, 2018.

Power Plant Reaches CCS Milestone.

NET Power, LLC, announced it has achieved a milestone in the large-scale development and deployment of CCS technologies at its supercritical CO_2 (sCO_2) demonstration power plant and test facility located in La Porte, Texas, USA. The milestone validates the fundamental operability and technical foundation of NET Power's power system, and involves the integrated operation of the full NET Power process. In addition, the achievement confirms the operation at commercial-scale of Toshiba's 50-MWth combustor. Following testing, the combustor will be integrated with the turbine and power will be generated. NET Power produces pipeline-ready CO_2. From Global *CCS Institute* on May 31, 2018.

JULY 2018

Demonstration of Geologic Carbon Storage Verified.

A DOE-funded project successfully verified geologic CO_2 storage, according to a joint announcement by WellDog, Virginia Tech, and Carbon GeoCycle. The test involves injecting more than 13,000 tons of CO_2 into stacked unmineable coal seems for enhanced oil recovery (EOR) in Buchanan County, Virginia, USA. The verification revealed that CO_2, injected over the last two years, successfully flowed into all of the targeted coal seams. From *Oil & Gas 360* on June 27, 2018.

CO_2-EOR Project Approved.

Denbury Resources announced the approval of a CO_2-EOR project at Cedar Creek Anticline (CCA), a geologic feature that covers parts of Montana, North Dakota, and South Dakota (USA). The 125-mile-long CAA is estimated to hold up to 5 billion barrels of original oil in place. The project has the potential to recover more than 400 million barrels, with initial tertiary production expected by late 2021 or early 2022. Phase I of the project targets 30 million barrels of estimated recoverable oil in the Red River formation at East Lookout Butte and Cedar Hills South fields, and Phase II will target approximately 100 million barrels of recoverable oil in the Interlake, Stony Mountain, and Red River formations at Cabin Creek field. Future phases will be developed based on CO_2 availability and other factors. From *Denbury Press Release* on June 18, 2018.

Feasibility of CCUS Project to Be Studied.

Occidental Petroleum Corporation and White Energy have agreed to evaluate the economic feasibility of a CCUS project that would capture CO_2 at White Energy's ethanol facilities in Hereford and Plainview, Texas, USA. The CO_2 captured would then be transported to the Permian Basin, where Occidental Petroleum would use it for EOR operations. The engineering study is expected to last six months and will examine the costs of building a carbon capture facility. If deemed economically feasible, operations could begin as soon as 2021. The project would be designed to be eligible for 45Q tax credits and California's (USA) Low-Carbon Fuel Standard CCS protocol. From *Occidental Petroleum News Release* on June 19, 2018.

Chevron's CCS Project to Begin in 2018.

Chevron is expected to start a CCS project at the Gorgon liquified natural gas (LNG) facility in Australia in 2018. Australia approved the project on the condition that Chevron committed to storing 80 percent of the CO_2 emitted from Gorgon over a five-year period. The LNG facility is located off the coast of Western Australia. From *The Chemical Engineer* on July 2, 2018.

AUGUST 2018

DOE and NPPD to Study Carbon Storage.

The Nebraska Public Power District (NPPD) has agreed to be part of a DOE Carbon Storage Assurance Facility Enterprise (CarbonSAFE) study that will look to safely, permanently, and economically store commercial-scale quantities of CO_2. NPPD is currently working to complete a final report on a pre-feasibility study for a commercial-scale CO_2 geologic storage complex, and on the integrated CO_2 capture facility design for Gentleman Station Unit 2 (the design work is expected to be completed in 2019). *DOE's CarbonSAFE Initiative* projects focus on the development of geologic storage sites for the storage of CO_2 from industrial sources. From *The News Tribune* on July 20, 2018.

MOU to Develop Bio-Energy Combined with CCS.

Researchers, scientists, and experts from Indonesia and Austria signed a Memorandum of Understanding (MOU) for a joint research project that will focus on bio-energy with carbon capture and storage (BECCS). Under the MOU, the Bandung Institute of Technology (ITB) and the International Institute for Applied Systems Analysis (IIASA) will also develop scientific publications and provide academic staff for research participation in seminars and conferences. In addition, the MOU allows for the possibility of graduate student exchanges and sharing access to relevant databases. From *OpenGovAsia* on July 30, 2018.

New Oil and Gas Program to Seek Safe CO_2 Storage Technologies.

The Oil & Gas Technology Centre announced the launch of the TechX Ventures Program, which combines science with engineering to create start-up companies with technologies that lead to a sustainable future in a low-carbon economy. A partnership with Deep Science Ventures, the program will seek to create new technologies that will allow the safe storage and conversion of CO_2 to useful products. From *The Oil & Gas Technology Centre* on July 30, 2018.

SEPTEMBER 2018

DOE, India Partner on CCS.

DOE has partnered with an Indian firm to advance the adoption, use, and research of commercial-scale coal gasification and to develop carbon capture, utilization, and storage (CCUS) technologies in India. As part of the agreement, DOE's National Carbon Capture Center (NCCC) will provide knowledge-sharing relevant to private and state enterprises in India. From *India Post* on September 1, 2018.

DOE-Funded Project to Use Microbes to Convert CO_2 to Natural Gas.

A DOE-funded, power-to-gas project is using microbes to convert CO_2 directly into renewable natural gas. The research, which is being conducted by Lawrence Livermore National Laboratory (LLNL) in collaboration with Southern California Gas Co. and Stanford University, will leverage previous research conducted by Stanford's Spormann Laboratory, as well as advances in 3D printer carbon aerogel electrode materials made by LLNL. From *Lawrence Livermore National Laboratory* on August 6, 2018.

Agreement Reached on Alberta Carbon Trunk Line.

Enhance Energy and Wolf Carbon Solutions, Inc., announced a project development and coordination agreement related to the construction and operation of the Alberta Carbon Trunk Line (ACTL). The ACTL pipeline will collect CO_2 from industry and transport it to aging reservoirs throughout central and southern Alberta, Canada, for secure storage and enhanced oil recovery (EOR) projects. Under the agreement, Wolf Carbon Solutions will construct, own, and operate the CO_2 capture and pipeline transportation assets, while Enhance will be the owner and operator of the CO_2 utilization and storage portion of the ACTL project through its EOR operations. Initial CO_2 flow rates are expected to start at 800 metric tons per day in the fourth quarter of 2019 and increase to 4,400 metric tons of CO_2 per day by the end of 2019. From *Wolf Midstream News* on August 2, 2018.

China Establishes Large-Scale CCS Facility.

China's carbon capture and storage (CCS) facility in Jilin has been established as the 18th large-scale CCS facility in the world, reaching a storage capacity of 0.6 million metric tons of CO_2 per year. Located in northeastern China, Jilin CCUS is capturing CO_2 from a natural gas processing plant at the Changling gas field and transporting it by pipeline to onshore injection sites. From *Gas World* on August 13, 2018.

LEGISLATION and POLICY

OCTOBER 2017

EU Roadmap to Be Updated.

The European Commission is preparing an update of its low-carbon economy roadmap for 2050. According to officials, the European Commission will launch a public consultation with a view to updating its low-carbon economy roadmap in 2018. The *2050 low-carbon economy roadmap* was originally published in 2011 and laid the foundation for the EU's energy policy, with the goal of at least 80 percent reduction in the bloc's emissions by mid-century. From *EURACTIV.com* on September 21, 2017.

Research on Benefits of CCS in UK.

According to new research conducted by the Global CCS Institute, the deployment of CCS technology could have potential benefits to the East Coast of the United Kingdom. In addition to creating sustainable jobs, the study, titled "Clean Air – Clean Industry – Clean Growth: How carbon capture will boost the UK economy," also finds that CCS technology deployed in the region could lead to the capture and storage of 1,500 million metric tons of CO_2. From *Global CCS Institute* on October 5, 2017.

NOVEMBER 2017

New Standards for the Transport and Storage of CO_2 Announced.

In cooperation with Standards Norway and Gassnova, the Norwegian Petroleum Directorate announced the launch of two international standards for the transport and storage of CO_2. The transport standard stipulates the requirements related to the design, construction, and operation of pipelines; the storage standard contains requirements related to storage site selection, operation, and shutdown. The two CCS standards were researched and developed in the International Organization for Standardization (ISO). From *World Oil* on November 1, 2017.

Singapore Government Seeks Public Consultation on Carbon Bill.

The Singapore government is conducting a second round of public consultation on a carbon tax as it releases a draft carbon pricing bill that sets out the overall carbon tax framework and obligations for GHG emitters. The tax would be a credits-based mechanism in which facilities buy carbon credits that correspond to their GHG emissions, surrendering the credits to the National Environment Agency (NEA). The consultation for the draft bill, which was launched online on October 31, 2017, will last until December 8, 2017. The proposed tax would be applied to companies that emit more than 25,000 metric tons of CO_2-equivalent GHGs a year. From *The Strait Times* on October 31, 2017.

Canadian Province Announces Low-Carbon Tax Policy.

The Canadian province of Manitoba will introduce a carbon tax in 2018, government officials announced. The carbon tax of $19 per metric ton is half the amount mandated by the Canadian government, which agreed to the Pan-Canadian Framework on Clean Growth and Climate Change in 2016. Under the framework, Canadian federal carbon levy rates will initially be set for the period of 2018 through 2022; the Manitoban rate of $19 per metric ton will rise after 2018, and a full review of the carbon pricing plan will take place in 2022. From *Tax-News* on November 1, 2017.

DECEMBER 2017

U.S., Saudi Arabia Sign Carbon Management MOU.

Officials from DOE and Saudi Arabia signed an MOU to establish a framework for mutually beneficial cooperation in the area of clean fossil fuels and carbon management. Under the MOU, the United States and Saudi Arabia will exchange experts, engineers, and scientists; facilitate the transfer of technology; and encourage the organization of joint seminars and workshops, as well as visits by experts to facilities (e.g., research labs, institutes, industrial sites). Technical fields covered under the MOU include supercritical carbon dioxide (sCO_2) and CCUS. From *energy.gov* on December 4, 2017.

Brazilian Low-Carbon Emissions Program Bill Passed.

The lower house of Brazil's National Congress passed a bill to create a nationwide carbon credits program to drive the use of renewable fuels. Referred to as RenovaBio, the bill will create a carbon credit scheme to increase the value of biofuels. The bill, which is estimated to become law in 2018 according to the Brazilian Sugarcane Industry Association (UNICA), establishes goals for lowering carbon emissions by distributors and the use of carbon credits. From *Platts* on November 29, 2017.

JANUARY 2018

Virginia Carbon Emission Legislation Considered.

As part of a proposed legislative agenda, Virginia may place a cap on carbon emissions by joining the Regional Greenhouse Gas Initiative (RGGI). The Virginia State Air Pollution Control Board had *previously approved* draft regulations in November 2017 to reduce carbon emissions from power plants and link the state to RGGI. The new legislation would enable the state to auction the allowances and invest the revenues in public-benefiting programs. From *Utility Dive* on January 10, 2018.

Washington State Proposes Carbon Tax.

In a "*State of the State*" address, Washington's Governor detailed a proposal to reduce the state's carbon footprint by implementing a carbon tax plan. Under the proposed plan, a tax starting at $20/ton of CO_2 emissions (with adjustments for inflation) would be put in place in July 2019, generating approximately $1.5 billion every two years. The revenue generated would be reinvested in a series of initiatives aimed at reducing carbon emissions and providing exemptions and credits for some businesses, agricultural operations, and low-income residents. From *The Spokesman-Review* on January 9, 2018.

European Parliament, Council Agree on Forestry GHG Reduction Law.

The European Parliament and Council informally agreed on plans to reduce greenhouse gas (GHG) emissions and increase carbon absorption from forests as a way to offset potential climate change. Under the proposed law, European Union (EU) countries would have to ensure their CO_2 emissions are offset by the CO_2 absorption of forests, croplands, and grasslands. If the countries absorb more CO_2 than they emit in the first five-year period (2021 to 2025), the credit can be used to help achieve goals for the second five-year period (2026 to 2030). From *European Parliament Press Release* on December 14, 2017.

New Zealand Forms Zero Carbon Climate Act.

The government of New Zealand will start public consultation in May 2018 to lay groundwork for a "Zero Carbon Act" and to establish an independent commission. In addition, an Interim Committee will be established while the commission is set up. New Zealand government officials anticipate the framework for a net-zero emissions economy by 2050 to be in place by the end of the New Zealand parliamentary term. From *New Zealand Herald* on December 18, 2017.

FEBRUARY 2018

Oregon Unveils Carbon Legislation.

Oregon lawmakers are offering public review of a *pair of bills* designed to reduce GHG emissions. Currently labeled as *Legislative Concept 44* (Senate version) and *Legislative Concept 176* (House version), the "cap and invest" bills would establish limits on GHG emissions in Oregon, USA, requiring the purchase of allowances to cover output above the limit. The cap and available allowances would gradually be reduced in order to meet Oregon's GHG emissions goals of 45 percent below 1990 levels by 2035, and 80 percent below 1990 levels by 2050. From *Oregon Live* on January 9, 2017.

DNV GL Launches Certification Framework and Recommended Practice for CCS.

DNV GL has launched a framework for certifying geologic storage of CO_2, as well as a recommended practice for the design and operation of CO_2 pipelines. The *certification framework*, which enables verification and conformity with the new International Organization for Standardization (ISO) standard "ISO 27914:2017 Carbon dioxide capture, transportation and geological storage – Geological storage," represents international consensus on the requirements for the safe and effective storage of CO_2 in geologic formations. The *recommended practice* provides guidance on safe and reliable design, construction, and operation of pipelines intended for large-scale transportation of CO_2, and enables compliance with the requirements of the new ISO standard "ISO 27913:2017 Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems." From *DNV GL Press Release* on January 17, 2018.

Washington State House Committee Approves Low-Carbon Standards Bill.

A Washington state House committee approved a bill requiring fuel producers and importers to reduce GHG emissions. *House Bill 2338*, which will look to reduce CO_2 emissions from the transportation sector, will now head to a fiscal committee. If passed, the bill would direct the state's Department of Ecology to adopt a clean fuels program requiring fuel producers to reduce their carbon emissions 10 percent below 2017 levels by 2028. The program would begin in 2020. From *AP News* on January 24, 2018.

State Lawmakers Form Alliance on Carbon Pricing.

State legislators from nine U.S. states announced the formation of a coalition focused on, among other areas, reducing CO_2 emissions, ensuring policy proposals, and developing market-based solutions. The Carbon Costs Coalition, in which lawmakers from Connecticut, Maryland, Massachusetts, New Hampshire, New York, Oregon, Rhode Island, Vermont, and Washington have been meeting informally for two years, has been working with business leaders on implementing a carbon price. From *National Caucus of Environmental Legislators (NCEL) Press Release* on January 31, 2018.

CCS Bill Revived.

Legislation to boost CCS projects through the tax code has been introduced into the U.S. House of Representatives. According to the bill's sponsors, *H.R. 4857* ("The CO_2 Regulatory Certainty Act") aligns with tax guidelines and U.S. regulations related to CCS. From *E&E News* on January 23, 2018.

MARCH 2018

Carbon Capture Bill Signed in to Law.

A bill to encourage technological innovation in carbon capture, utilization, and storage (CCUS), while also reducing CO_2 emissions, has passed U.S. Congress and was signed in to law. The *FUTURE Act, first introduced in July 2017*, supports maintaining a place for existing resources, such as coal, in the Nation's energy mix by encouraging the development and use of CCUS technologies and processes, while simultaneously spurring the adoption of low-carbon technologies to transform carbon emissions into useable products. In addition, the FUTURE Act extends and expands the 45Q tax credit to provide certainty to utilities and other industrial sources, and incentivizes the build-out of industrial carbon capture products that use CO_2 and carbon monoxide (CO) for enhanced oil recovery (EOR) and carbon utilization. The bill also supports carbon capture technologies by increasing the "commence construction" window for carbon capture projects from five to seven years and the number of years to claim the credits from 10 to 12 years. From *U.S. Senator Heidi Heitkamp Press Release* on February 9, 2018.

APRIL 2018

Bill Supporting CCUS Introduced.

Legislation to promote carbon utilization and direct air capture R&D has been introduced in Congress. The "Utilizing Significant Emissions with Innovative Technologies Act" (USE IT Act) supports Federal, state, and non-governmental collaboration in the development and construction of CCUS facilities and CO_2 pipelines. The legislation would support carbon utilization and direct air capture research, clarify that CCUS projects and CO_2 pipelines are eligible for the permitting review process, direct the Council on Environmental Quality (CEQ) to establish guidance at CCUS facilities and CO_2 pipelines, and establish task forces to update and improve guidance over time. From *Daily Energy Insider* on March 26, 2018.

North Dakota Approved as Carbon Storage State.

The U.S. Environmental Protection Agency (EPA) granted North Dakota (USA) primacy over Class VI injection of CO_2 for long-term storage, making it the first state in the Nation to receive final EPA approval to regulate the geologic storage of CO_2. North Dakota initiated preparations for primacy after the North Dakota legislature gave the Industrial Commission's Oil and Gas Division regulatory authority over geologic carbon storage in 2009. Geologic storage of CO_2 is regulated under the Safe Drinking Water Act's Underground Injection Control Program and is classified as Class VI injection (also known as CCS). From *Bakken.com* on April 10, 2018.

MAY 2018

New Jersey Legislature Approves Zero-Emissions Credit Program.

New Jersey (USA) lawmakers approved two sets of companion bills, one of which creates a zero-emissions credit program. S2313 and A3724 would provide plants with financial credit for producing carbon-free electricity. Both the zero-emissions credit program bills and the clean energy set of bills (A3723 and S2314) will advance to the New Jersey governor. From *Daily Energy Insider* on April 16, 2018.

California to Extend Low-Carbon Fuel Standard.

The California Air Resources Board (CARB) is looking to extend the Low-Carbon Fuel Standard (LCFS) Program through 2030 and to reduce the carbon intensity of fuels sold within California (USA) by 20 percent. In addition, CARB is planning to add new methodology to encourage companies to deploy CCS technologies. From *Scientific American* on April 30, 2018.

Carbon Pricing Proposal Released.

The New York (USA) Independent Systems Operator (NYISO) released a Carbon Pricing Straw Proposal focused on aligning wholesale energy markets to reflect New York's carbon-reduction goals. New York is looking to reduce CO_2 emissions by 80 percent by 2050. The NYISO is the organization responsible for managing New York's electric grid and its competitive wholesale electric marketplace. From *Utility Dive* on May 1, 2018.

JUNE 2018

CCUS Legislation Advanced by Senate Committee.

Legislation that will promote coordination among Federal, state, and private entities on CCUS facilities and CO_2 pipelines was approved by the U.S. Senate Environment and Public Works (EPW) Committee. Under the Utilizing Signification Emissions with Innovative Technologies (USE IT) Act, the Clean Air Act would be amended to allow the U.S. Environmental Protection Agency (EPA) to support carbon utilization. In addition, the measure would clarify that CCUS facilities and CO_2 pipelines are eligible for expedited permitting review. From *Daily Energy Insider* on May 25, 2018.

UK Commits Funding for CCS.

The United Kingdom (UK) government pledged funding for innovative CCUS technologies as part of an international challenge to invest in new ways of reducing the cost to make the technology commercially viable at scale. As part of the funding, a call for CCUS innovation will offer funding for projects up to 28 months, and further funding will be provided under an R&D program made up of 10 European nations. From *Energy Live News* on May 23, 2018.

Committee to Examine CCUS.

A UK parliamentary committee will examine the government's plans to reduce CO_2 emissions and meet goals with CCUS technologies. The Business, Energy, and Industrial Strategy (BEIS) Committee in the House of Commons will observe the UK government's support for CCUS, inviting industry and other stakeholders to submit written opinions. CCUS was identified in the UK government's "*Clean Growth Strategy*," published in October 2017. From *Out-Law* on May 31, 2018.

JULY 2018

Massachusetts Senate Authorizes Carbon Pricing.

The Massachusetts State Senate (USA) passed a bill authorizing a carbon pricing program that approves revenue-neutral fees as a carbon pricing option. The bill will next be debated in the Massachusetts House and, if signed into law, would have a deadline for carbon pricing in the transportation sector by 2020, commercial and industrial building and processes by the end of 2021, and residential buildings by the end of 2022. From *U.S. State Senator Mike Barrett Press Release* on June 14, 2018.

Netherlands Proposes Emissions Cut.

A draft law proposed in the Netherlands would set a 49 percent greenhouse gas (GHG) emission reduction target by 2030, compared to 1990 levels, and a 95 percent reduction by 2050. Other features of the proposal include a carbon neutral electricity system, as well as the establishment of an annual day in which the Dutch Ministry of Energy and Climate will give a progress update on achieving targets. In addition, beginning in 2019, future Dutch governments would be required to present updated plans every five years. From *Climate Change News* on June 27, 2018.

Zimbabwe Releases Climate Policies.

Zimbabwe released three policies designed to help meet its pledges to reduce CO_2 emissions. The "Child Friendly Climate Policy" will educate the youth, and the "Climate Smart Agriculture Policy" will promote farming practices. In addition, the country's first "National Climate Policy" will create legal structures to help businesses meet Zimbabwe's emission-reduction targets. From *Economic Times* on June 26, 2018.

AUGUST 2018

Carbon Tax Bill Introduced.

A *bill introduced by a member of the U.S. House of Representatives* would create a tax on CO_2 emissions while also limiting the U.S. Environmental Protection Agency's (EPA) authority to regulate GHG emissions from stationary sources under the Clean Air Act. The legislation, referred to as the "*MARKET CHOICE Act*," would establish a $24/metric ton tax on CO_2-equivalent emissions beginning in 2020. The tax would rise at an annual rate of two percent above inflation or more if specific emissions reduction targets are not achieved. From *S&P Global Platts* on July 23, 2018.

UK to Require Companies to Report CO_2 Emissions.

The British government announced plans to require companies to report energy use, CO_2 emissions, and energy efficiency measures in their annual reports. The new framework will streamline reporting requirements while looking to improve energy efficiency by at least 20 percent by 2030. From *Reuters* on July 18, 2018.

Liverpool Bids to Become "Climate-Positive City."

Liverpool Council (England, UK) announced a partnership with a blockchain non-profit to make Liverpool a "climate-positive city" by the end of 2020. As part of the deal, Poseidon Foundation will integrate its blockchain-powered platform into Liverpool city council's day-to-day operations in an effort to help further reduce emissions impacts through offsetting. Liverpool city council is currently committed to cut its overall CO_2 emissions by 40 percent by 2030 against 1990 levels. From *Business Green* on July 20, 2018.

SEPTEMBER 2018

Bill Promotes CCUS Technology.

A bill that promotes biogas and CCUS technologies to increase biogas production has been introduced into Congress. The *Carbon Utilization Act of 2018* incentivizes the use of CCUS technologies for farmers, ranchers, biotech, and small businesses by broadening U.S. Department of Agriculture (USDA) loan guarantees, rural development loans, and research programs to include CCUS technologies. In addition, the bill promotes collaboration between government agencies and creates education programs that highlight carbon capture technology. From *Biomass Magazine* on August 6, 2018.

Scottish Government Sets 2050 Carbon Target.

The Scottish government unveiled a new proposal to reduce emissions by at least 90 percent by 2050. The Zero Greenhouse Gas Plan is a 10 percent increase over current legislation; while it matches the Government's first interim target of a 56 percent reduction by 2020, the interim goal of 77 percent by 2030 differs from the government's 66 percent reduction target. From *The Daily Record* on August 13, 2018.

EMISSIONS TRADING

OCTOBER 2017

California and Québec Joint Cap-and-Trade Auction Notice.

The California and Québec governments released the Auction Notice for their 13th joint auction of GHG allowances, to be held in November 2017. The November 2017 Joint Auction #13 will make 79,548,286 CO_2 allowances available for sale in the Current Auction, which is the auction of allowances from the current and previous budget years. In addition, 9,723,500 CO_2 allowances will be made available for sale in the Advance Auction, which is the auction of future vintage allowances. From *The Ministry of Sustainable Development, the Environment, and the Fight Against Climate Change Auction Notice* on September 15, 2017.

France and Germany Seek Agreement on EU Carbon Market Reform.

The French and German governments will work together to reinforce carbon pricing in the European electricity sector, France's ecology ministry announced. In addition, the governments will seek an agreement on the EU's Emissions Trading System (ETS) carbon market by November 2017. From *Reuters* on September 4, 2017.

RGGI Report: Investments Generating Consumer Benefits.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released a report that tracks the investment of proceeds generated in 2015 by RGGI's regional CO_2 allowance auctions. According to the report, which provides state-specific highlights, in 2015 more than $410 million in RGGI proceeds were invested in programs such as energy efficiency, clean and renewable energy, GHG abatement, and direct bill assistance. For more information on both 2015 and cumulative investments and benefits, refer to the report, titled "*The Investment of RGGI Proceeds in 2015*." From *RGGI News Release* on October 3, 2017.

NOVEMBER 2017

RGGI to Hold 38th Quarterly CO_2 Allowance Auction.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their 38th quarterly CO_2 allowance auction, to be held on December 6, 2017. As indicated in the Auction Notice, the states will offer 14,687,989 CO_2 allowances for sale with a minimum reserve price of $2.15. In addition, there is also a 10 million CO_2 allowance cost containment reserve (CCR) available, which will be accessed if the interim clearing price exceeds the CCR trigger price of $10.00. Auction 38 will be the final quarterly auction in which states will offer CO_2 allowances for purchase to meet CO_2 compliance obligations for the third control period, which began on January 1, 2015. From *RGGI News Release* on October 10, 2017.

DECEMBER 2017

Virginia Approves Carbon Cap-and-Trade Program.

Virginia state regulators granted preliminary approval to regulate carbon emissions from power plants through a state-wide carbon cap-and-trade program. Approved by the Virginia Air Pollution Control Board, the proposal would cap emissions from most power plants beginning in 2020, then require a 30 percent reduction over a decade. In addition, eligible carbon emitters would have to participate in the RGGI cap-and-trade program. From *AP News* on November 17, 2017.

California and Québec Release Results of Cap-and-Trade Auction.

Officials from California, USA, and Québec, Canada, released the results of their 13th joint cap-and-trade auction of carbon allowances. According to the California Air Resources Board (CARB), all of the 79,548,286 allowances for current vintages (2016 and 2017) were sold at a settlement price of $15.06, and all of the 9,723,500 allowances for 2020 vintages were sold at a settlement price of $14.76. More detailed results of the auction, as well as maximum and minimum bids placed, are available on the *CARB website*. From *California Air Resources Board* on November 21, 2017.

JANUARY 2018

RGGI Releases Updated Model Rule.

The states participating in RGGI released an updated model rule, concluding the regional process of the RGGI Program review; these changes will next be brought into effect with state-specific processes. The RGGI states will propose statutory and/or regulatory revisions to their CO_2 Budget Trading Programs consistent with the updated *2017 Model Rule*, which also includes an additional 30 percent regional cap reduction between 2020 and 2030 (summarized in the *Summary of Model Rule Updates*). In addition, the RGGI states agreed to *Principles to Accompany Model Rule Amendments* that will guide the proposing of these revisions. From *RGGI News Release* on December 19, 2017.

China Outlines Details of Emissions Trading Scheme.

The Chinese government announced the details of its nationwide carbon emissions trading scheme (ETS). According to the Chinese State Council and the National Development and Reform Commission (NDRC), trading will be based in Shanghai, China, and involve 1,700 power companies and more than 3 billion metric tons of CO_2 annually. Nine regions and cities (pilot schemes have taken place in seven of them) will coordinate to establish the market-oriented ETS system, which will help companies reduce emissions and carbon-intensified assets through the controlled allocation and trading of carbon emission allowances. From *Reuters* on December 19, 2017.

FEBRUARY 2018

New Jersey Re-Joins RGGI..

The New Jersey Governor initiated the process of rejoining RGGI after the state had previously withdrawn from the cap-and-trade program in 2011. The next step is for the state's legislature to pass legislation to implement the Governor's order and devise a spending plan for the funds generated in RGGI's trading auctions, which, to date, have generated $2.8 billion in proceeds to finance clean energy and energy efficiency projects. From *Reuters* on January 29, 2018.

Mexico Launches Updated Carbon Market.

Mexico will launch a national carbon emissions trading system (ETS) in 2018 in order to fund projects that help reduce emissions. According to Mexico's Ministry of Environment and Natural Resources, approximately 100 Mexican companies are currently participating in the California ETS to determine how carbon market prices would be set in Mexico. Once it becomes operational, the Mexican government will plan to link it with the markets in California, USA, and Québec, Canada. From *Diálogo Chino* on January 8, 2017.

UAE Proposes Emissions Trading.

The UAE's Security and Commodities Authority (SCA) announced an initiative to launch CO_2-focused emissions trading within the region. The initiative is part of an SCA-deliberated roadmap to ensure sustainable financial markets and comply with world standards. From *Al Bawaba* on January 29, 2018.

MARCH 2018

Three-Way Joint Cap-and-Trade Auction Results Released.

California (USA), Québec, and Ontario (Canada) released the results of the first joint cap-and-trade auction of carbon allowances involving three jurisdictions. All of the 98,215,920 current (2016 and 2018) vintage CO_2 allowances sold at a settlement price of $14.61, while 8,576,000 of the 12,427,950 advance (2021) vintage allowances sold at a settlement price of $14.53. More information on the auction is *available online*. From *California Air Resources Board* on February 28, 2018.

New Timeline Proposed for Oregon's Cap-and-Trade Bill.

Oregon (USA) government officials proposed an *amendment* to a cap-and-trade bill. The *Clean Energy Jobs* Bill would cap Oregon's greenhouse gas (GHG) emissions in 2021 and launch a trading system for emissions permits. The amendment would allow lawmakers to vote on the "cap" for GHG emissions this session, while moving a vote on the "trade" portion of the bill to 2019. According to the amendment, if lawmakers do not approve a cap-and-trade program by the end of next year's legislative session, the Oregon Environmental Quality Commission will adopt one instead. From *OPB News* on February 20, 2018.

European Council Approves Carbon Market Reform.

Reforms to the cap-and-trade system with the European Union's (EU) carbon market received final approval from the EU Council. The changes to the EU's Emissions Trading System (ETS), which involve reducing the number of permits in circulation, seek to encourage industries to emit less carbon. The reform will strengthen prices by doubling the rate at which the scheme's Market Stability Reserve (MSR) soaks up excess allowances in the short-term; a new mechanism to limit the validity of allowances in the MSR will be put in place in 2023. In addition, the overall cap on the total volume of emissions will be reduced 2.2 percent each year. From *Reuters* on February 27, 2018.

APRIL 2018

RGGI States Announce Results of 39th Auction.

The RGGI-participating states released the results of their 39th auction of CO_2 allowances, in which 13,553,767 CO_2 allowances were sold at a clearing price of $3.79. Bids ranged from $2.20 to $5.80 per allowance at the auction. None of the 10 million cost containment reserve (CCR) allowances were sold (CCR is a fixed additional supply of allowances only available for sale if CO_2 allowance prices exceed certain price levels [$10.25 in 2018]). Auction 39, the first auction of the fourth control period, generated $51.4 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement programs. To date, proceeds from all RGGI CO_2 allowance auctions have generated $2.89 billion. From *RGGI News Release* on March 16, 2018.

Britain Announces ETS Plans.

According to Britain's Energy Minister, the country intends to remain in Europe's emission trading system (ETS) until at least the end of Phase III, which runs from 2013 through 2020. Britain has a legally binding target to reduce GHG emissions by 80 percent from 1990 levels by 2050. From *Reuters* on March 21, 2018.

China's Carbon Trading Pilot Boosts Emissions Control.

China's carbon trading system has helped the country reach its 2020 carbon emissions target in 2017, according to officials. China committed to reducing its CO_2 emissions by 40 to 45 percent from 2005 levels by 2020; however, this target was reached early, as China reduced CO_2 emissions by 46 percent from 2005 levels by the end of 2017. China's carbon emissions trading system was initiated in 2011, and transactions totaling 200 million metric tons of carbon emissions quotas were completed via the platform by 2017. According to its next commitment, China will have to reduce CO_2 emissions by 60 to 65 percent from 2005 levels by 2030. From *Xinhua* on March 27, 2018.

MAY 2018

RGGI States Release Auction Notice and Electricity Monitoring Report.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their 40th quarterly CO_2 allowance auction, to be held June 30, 2018. As indicated in the Auction Notice, the states will offer 13,771,025 CO_2 allowances for sale with a minimum reserve price of $2.20. In addition, there is also a 10 million CO_2 allowance cost containment reserve (CCR) available, which will be accessed if the interim clearing price exceeds the CCR trigger price of $10.25. The RGGI states also released the "CO_2 Emissions from Electricity Generation and Imports in the Regional Greenhouse Gas Initiative: 2015 Monitoring Report." The seventh in a series of annual monitoring reports, this report summarized data for electricity generation, electricity imports, and related CO_2 emissions for the RGGI states. From *RGGI News Releases* on April 17, 2018, and April 27, 2018.

Carbon Credit Program Approved.

The West Springfield Town Council (Massachusetts, USA) approved joining an intermunicipal carbon storage program known as the Tri-City Carbon Project. The approved deal authorizes the town to execute a contract with Bluesource, a global vendor of carbon credits, as well as an interim municipal agreement with Holyoke and Westfield (Massachusetts, USA). From *MassLive* on April 24, 2018.

JUNE 2018

Joint Cap-and-Trade Auction Results Released.

California (USA), Québec, and Ontario (Canada) released the results of the second joint cap-and-trade auction of carbon allowances involving three jurisdictions. All of the 90,587,738 current (2016 and 2018) vintage CO_2 allowances sold at a settlement price of $14.65, while 6,057,000 of the 12,427,950 advance (2021) vintage allowances sold at a settlement price of $14.53. More information on the auction is *available online*. From *California Air Resources Board* on May 23, 2018.

RGGI Releases Two Reports.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released two reports. Prepared by independent market monitor Potomac Economics, the "*Annual Report on the Market for RGGI CO_2 Allowances: 2017*" evaluates 2017 activity in the RGGI CO_2 allowance market, focusing on allowance prices, trading and acquisition of allowances in the auctions and the secondary market, participation in the market by individual firms, and market monitoring. The RGGI states also released the "*Compliance Summary Report*" for its third three-year control period, finding that, at the time of the report being published, 161 of the 163 power plants subjected to RGGI requirements met their compliance obligations. From *RGGI News Release* on May 24 and June 4, 2018.

Lawmakers Begin Cap-and-Trade Talk.

An Oregon (USA) joint legislative committee began to develop policy for a statewide cap-and-trade program. The Joint Committee on Carbon Pricing initiated its work by holding discussions with experts on state and national environmental policies. Oregon state legislative leaders have committed to recommending a carbon-pricing policy during next year's legislative session. The Oregon legislature set a goal of reducing carbon emissions to 10 percent less than 1990 levels by 2020. From *The Dalles Chronicle* on May 23, 2018.

UN Issues Carbon Credits.

The United Nations (UN) issued carbon credits to SABIC, a Saudi Arabian petrochemicals manufacturer, for a Clean Development Mechanism (CDM) project. Under the CDM, emission-reduction projects in developing countries can earn certified emission-reduction credits, which can be used to meet targets. From *SABIC News Release* on May 23, 2018.

JULY 2018

RGGI States Announce Results of 40th Auction.

The RGGI-participating states released the results of their 40th auction of CO_2 allowances, in which 13,771,025 CO_2 allowances were sold at a clearing price of $4.02. Bids ranged from $2.20 to $6.00 per allowance. None of the 10 million cost containment reserve (CCR) allowances were sold (CCR is a fixed additional supply of allowances only available for sale if CO_2 allowance prices exceed certain price levels [$10.25 in 2018]). Auction 40, the second auction of the fourth control period, generated $55.4 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement programs. To date, proceeds from all RGGI CO_2 allowance auctions have generated $2.94 billion. From *RGGI News Release* on June 15, 2018.

AUGUST 2018

RGGI Initiates Auction Process.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their 41st quarterly auction of CO_2 allowances, to be held September 5, 2018. The "*Auction Notice for CO_2 Allowance Auction 41*" provides the information needed for potential participants to indicate their intent to bid on the 13,590,107 CO_2 allowances offered for sale at a minimum reserve price of $2.20. In addition, the RGGI states will also make available a 10 million CO_2 allowance cost containment reserve (CCR), which will be accessed if the interim clearing price exceeds the CCR trigger price of $10.25. From *RGGI News Release* on July 10, 2018.

Partnership to Launch Transparent Carbon Credit Trading Market.

Xarbon Sustainability Limited and the United Nations Office for Project Service (UNOPS) have entered into a strategic partnership to support low-carbon economy development. Xarbon, a Hong Kong-based sustainability technology company, uses blockchain technology to improve carbon credit trading market transparency. UNOPS focuses on supporting low-carbon economy development by establishing digitalized carbon, aiming to improve education, awareness-raising, and social impact. From *Asia One* on July 18, 2018.

Carbon Tax Plan Unveiled.

The Canadian province of Manitoba unveiled details of its "Made-in-Manitoba" plan, which includes a cap-and-trade style carbon tax for certain industries. Most companies in the province will pay a $25/metric ton tax, but larger industrial emitters will be exempt up to a certain benchmark, which will be individually established by Manitoba's Climate and Energy Branch. When a company exceeds their benchmark, they can either pay the $25/metric ton tax or purchase carbon credits from other companies; those who do not reach their benchmark can accumulate carbon credits, which can be sold on an open market or used to offset future taxes. Only companies that release more than 50,000 metric tons of CO_2 annually will qualify for the output-based pricing system framework. From *CBC News* on July 30, 2018.

SEPTEMBER 2018

Québec-California Carbon Market Joint Auction Held.

The California Air Resources Board (CARB) and Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change (MDDELCC) held a joint auction of greenhouse gas (GHG) allowances on August 14, 2018. The auction included a Current Auction of 2016 and 2018 vintage allowances and an Advanced Auction of 2021 vintage allowances. From *Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change* on August 14, 2018.

Singapore To Use Study on Carbon Pricing for Future Tax.

Singapore's National Climate Change Secretariat (NCCS) commissioned a study on carbon pricing in other countries that will be used to help shape any potential carbon taxes in Singapore. The study will quantify the effectiveness of various measures in reducing carbon emissions across different jurisdictions and will also look at direct costs from carbon taxes or emissions trading schemes and indirect costs from compliance. Beginning in 2019, Singapore will begin pricing carbon at $5/metric ton of emissions through 2023, at which point the rate will be reviewed with the intention of raising it to $10 to $15/metric ton by 2030. From *The Straits Times* on August 13, 2018.

Countries Plan Carbon Trading.

Six countries are preparing the first carbon trades under the 2015 United Nations (UN) pact. According to the World Bank Group, the nations are assessing projects to reduce GHGs in exchange for emission credits that can be used to comply with set goals. From *Financial Post* on August 16, 2018.

RGGI States Announce Results of 41st Auction.

The RGGI-participating states released the results of their 41st auction of CO_2 allowances, in which 13,590,107 CO_2 allowances were sold at a clearing price of $4.50. Bids ranged from $2.20 to $6.20 per allowance. None of the 10 million cost containment reserve (CCR) allowances were sold (CCR is a fixed additional supply of allowances only available for sale if CO_2 allowance prices exceed certain price levels [$10.25 in 2018]). Auction 41 generated $61.2 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement programs. To date, proceeds from all RGGI CO_2 allowance auctions have generated $3 billion. From *RGGI News Release* on September 7, 2018.

CLIMATE and SCIENCE NEWS

OCTOBER 2017

Collaboration Studies Carbon Storage in Organic Soils.

A collaboration between the National Soil Project at Northeastern University and The Organic Center led to a study that found soils from organic farms store more CO_2, and for longer periods of time, than soil from conventional farms. Conducted by Northeastern University researchers, the study compared more than 1,000 soils from organic and conventional farms across the United States to understand how different agriculture management practices influence components of soil organic carbon (SOC). The findings showed that soils from organic farms have 13 percent more SOC and store 25 percent more CO_2. From *The Organic Center* on September 11, 2017.

U.S. Naval Research Laboratory Patent Contributes to CO_2 Removal.

A *recently awarded patent* to the U.S. Naval Research Laboratory (NRL) has the potential to aid in the removal of approximately five tons of CO_2 per year. NRL's electrolytic-cation exchange module (E-CEM) design provides the capability to produce the raw materials necessary to develop synthetic fuel stock. E-CEM is capable of producing hydrogen (H_2) while simultaneously removing CO_2 from seawater. From *U.S. Naval Research Laboratory News Release* on October 3, 2017.

NOVEMBER 2017

Project to Study Economic Models for CCS.

Three universities are receiving funding as part of a National Science Foundation project to determine if changes in commodity production and capturing CO_2 are sustainable in the Upper Missouri River Basin. The University of Wyoming will develop the economic models; Montana State University will study agriculture and biofertilizers, food security, clean energy, and water supply and quality; and the University of South Dakota will focus on land use, biodiversity, and ecosystem services assessment. Together, the project will look to decrease atmospheric CO_2 through alternative agricultural and energy approaches, such as biofuels and carbon storage. More information on the project is *available online*. From *Carbon Capture Journal* on October 10, 2017.

Potential Climate Change Could Alter Microbial Interactions.

According to a study conducted by scientists at Lamont-Doherty Earth Observatory, rising levels of oceanic CO_2 may influence the activity of two marine organisms essential to ocean health. By potentially altering the relationship between the two ocean-dwelling microbes, Prochlorococcus and Alteromonas, the overall structure and function of an ecosystem can be impacted, the study claims. The new study builds on previous research conducted in 2015, which concluded that "vast swaths of the ocean where Prochlorococcus now dominates" may change due to potentially high CO_2 levels and ocean acidification. From *phys.org* on November 1, 2017.

DECEMBER 2017

Modified Plant Capable of Storing CO_2.

A team of biologists from the Salk Institute for Biological Studies at the Howard Hughes Medical Institute (HHMI) created a plant capable of storing CO_2. The research team created new plant varieties that can capture and store atmospheric CO_2 with the infusion of suberin, a naturally produced material that can last a few thousand years when infused with CO_2. According to the study, the plant has the potential to reduce CO_2 emissions by 50 percent by using 5 percent of Earth's cultivatable ground. From *International Business Times* on December 5, 2017.

Researchers Study Geologic Storage of CO_2.

Researchers from Stanford University are using computed tomography (CT) scanners to help understand the behavior of CO_2 in geologic subsurface storage projects. The experiments are intended to recreate, at small-scale, the movement of various substances through vast rock formations and to provide real-world validation of computer simulations of the same processes. From *Carbon Capture Journal* on November 10, 2017.

Monitoring Offshore CO_2 Storage Using Chemical Tracers.

Scientists from the Scottish Carbon Capture and Storage (SCCS) partnership conducted a study focusing on the use of chemical tracers in CO_2 leakage monitoring for offshore CCS projects. Following consultation from the CCS community, the scientists identified the measuring of CO_2 leakage to the seabed as an area requiring further research. The research team then identified key challenges to using tracers for offshore monitoring. The work was published by the *International Journal of Greenhouse Gas Control* in a paper, titled "*Geochemical tracers for monitoring offshore CO_2 stores*." From *SCCS News* on November 16, 2017.

JANUARY 2018

Report Highlights Whales' Carbon Storage Potential.

A new report documents the role of whales in the storage of atmospheric CO_2. The report, titled "*The Role of Cetaceans in Ecosystem Functioning: Defining Conservation Policies in the 21st Century*," is a product of a workshop conducted at the July 2017 International Congress for Conservation Biology. The report found that whales can trigger phytoplankton blooms that increase the productivity of the entire marine food web and store thousands of tons of atmospheric CO_2. From *Animal Welfare Institute Press Release* on December 19, 2017.

Wetland Erosion from Rising Lake Levels Could Create New Source of Carbon Emissions.

Fast-growing wetland plants use photosynthesis to absorb CO_2, storing it underground in their soil. The Illinois State Geological Survey launched a study to determine if wetlands are now releasing more CO_2 than they are storing as increased erosion releases CO_2. By studying Illinois Beach (USA), which has eroded approximately 21 feet within the past six months, researchers will be able to study how rising lake levels may affect the 500,000 acres of coastal wetlands across the Great Lakes basin. The research is expected to show how much carbon is at risk of being released once the wetland soil erodes. From *Chicago Tribune* on January 1, 2018.

Study Shows Bacteria's CO_2 Storage Potential.

According to scientists from the University of Dundee's School of Life Sciences, E. coli bacteria may lead to a method of capturing and storing CO_2. By developing a process that enables the E. coli bacterium to act as an efficient carbon capture device, scientists also claim that the E. coli solution could convert the CO_2 into a liquid that is "stable and comparatively easily stored." The results of the research have been published in the journal *Current Biology*, in a study titled "*Efficient Hydrogen-Dependent Carbon Dioxide Reduction by Escherichia coli*." From *Carbon Capture Journal* on January 8, 2018.

FEBRUARY 2018

Researchers Discover Catalyst for Converting CO_2.

Scientists from the University of Toronto; the University of California, Berkeley; and the Canadian Light Source (CLS) have developed a method for the efficient conversion of CO_2 into plastic. The researchers were able to do so by designing a catalyst and identifying the conditions that maximize ethylene production during reaction, while also minimizing methane and carbon monoxide production. The research paper, titled "*Catalyst electro-redeposition controls morphology and oxidation state for selective carbon dioxide reduction*," was published in the online journal *Nature Catalysis*. From *The Independent* on January 16, 2018.

Coastal Water Absorbing More CO_2.

According to researchers, the water over the continental shelf is storing more atmospheric CO_2, which increases the acidity of seawater and has the potential to affect the health of marine organisms and the ocean ecosystem. By using recently available and historical data from the previous 35 years to calculate global trends of CO_2 concentration increases in the coastal ocean, scientists found that while the amount of CO_2 in the open ocean is increasing at the same rate as in the atmosphere, these same CO_2 concentrations are increasing slower in the coastal ocean. According to the research team, the study's findings suggest that the continental shelves are becoming a crucial element in the global carbon cycle. From *Chemeurope* on February 2, 2018.

MARCH 2018

Study Observes CO_2 Exposure in Marine Ecosystem.

A study conducted by a team of marine scientists showed that CO_2 from industry and land run-off may affect the marine ecosystem. During an experiment at Loch Sween on Scotland's west coast, researchers from Heriot-Watt University and Edinburgh and Glasgow University discovered that acute levels of CO_2 cause starfish to dissolve. While previous studies focused on the effect high levels of CO_2 had on individual plants or animals, this study, published in the *Marine Progress Ecology Series*, observed how whole marine ecosystems respond to short-term CO_2 exposure. From *BBC News* on February 19, 2018.

Ocean Warming May Lead to "Disappearance" of King Penguin.

Due to potentially warming oceans, up to 70 percent of the king penguin population may be forced to relocate or "disappear" from their breeding grounds in Antarctica, according to research published in *Nature Climate Change*. Scientists have found that future ocean warming could drive the Antarctic Polar Front, where king penguins typically hunt for food, further away from penguin breeding sites, causing the animals to find other suitable breeding locations. By using a set of global models to simulate future sea temperatures, the researchers determined that the maximum distance the penguins could travel to hunt fish was 700 kilometers. Their current typical journey from their breeding ground to the Antarctic Polar Front is in the range of 300 to 500 kilometers. From *Carbon Brief* on February 26, 2018.

Pulverized Volcanic Rock Could Potentially Store CO_2.

According to a study published in the journal Nature Plants, spreading pulverized volcanic rock on farm soils could absorb significant amounts of CO_2 from the atmosphere. Led by the University of Sheffield (UK), an international team of researchers studied the effect of "enhanced rock weathering" – using pulverized silicate rocks to speed the ability of minerals to store carbon in soil – on portions of the world's cropland. The researchers' preliminary estimates found that if farmers add enough pulverized rock per acre on a majority of the world's cropland, up to 4 billion metric tons of CO_2 could be removed from the atmosphere per year by 2100. From *Inside Climate News* on February 20, 2018.

APRIL 2018

Hunting Squid Slowed by Rising CO_2 Levels.

Australian scientists have found that potentially higher levels of oceanic CO_2 may impact the hunting patterns of cephalopods, a group of highly active invertebrates that includes squid, cuttlefish, and octopuses. Led by the James Cook University (JCU) ARC Centre of Excellence for Coral Reef Studies, the investigative group tested the effects of elevated CO_2 on the hunting behaviors of pygmy squid and bigfin reef squid, finding a decrease in the pigmy squids' attacking of prey. When either species of squid did attack, they did so from a further distance and at a slower speed. In addition, both species displayed "more conspicuous body patterns" and increased activity when they were not hunting, which scientists believe could be a result of elevated CO_2 levels altering their "energy budgets." From *Phys.Org* on March 21, 2018.

Study Links Policy, Carbon Emissions from Permafrost.

According to researchers from the U.S. Geological Survey (USGS) and the University of Alaska Fairbanks Institute of Arctic Biology, controlling GHG emissions through policy could reduce potential consequences of carbon releases from thawing permafrost during the next 300 years. Scientists used simulations to study changes in permafrost and carbon storage in the northern permafrost region from 2010 to 2299 using two separate potential scenarios – one with low CO_2 emissions and one with high CO_2 emissions. The results led scientists to believe that GHG controls could lessen the effects on the release of carbon from soils. The study, titled "Dependence of the evolution of carbon dynamics in the northern permafrost region on the trajectory of climate change," was published in the journal *Proceedings of the National Academy of Sciences*. From *Eurasia Review* on March 27, 2018.

New Research Studies Underground CO_2 Abatement.

New research has provided a quantifiable look at carbon trapping rates in basalt, providing a baseline to scale-up. Working in collaboration with Pacific Northwest National Laboratory (PNNL), researchers from Washington University in St. Louis collected samples of the rock from Washington state, where a thousand tons of CO_2 gas was previously injected into an underground basalt flow. The rocks were then placed in small reactors to simulate underground conditions and injected with CO_2 to test the variables involved in the carbonization process. Using 3-D imaging, the scientists watched the CO_2 precipitate into the mineral and studied the voids within the basalt it filled, as well as the spots in the rock where the carbonization process began. Once the data were collected and analyzed, scientists predicted 47 kilograms of CO_2 can be converted into mineral inside one cubic meter of basalt. From *Phys.Org* on April 5, 2018.

MAY 2018

Researchers Study Potential of BECCS to Reduce CO_2 Emissions.

DOE-funded research is using algae, eucalyptus, and bioenergy with carbon capture and storage (BECCS) to power and provide food to large regions of the world while simultaneously removing CO_2 emissions from the atmosphere. Scientists from Cornell, Duke University, and the University of Hawaii at Hilo combined two technologies (BECCS and microalgae production) to form a new, integrated algae bioenergy with carbon capture and storage (ABECCS) system, which can act as a CO_2 "sink" while generating food and electricity. The research appears in a paper, titled "Integrating Algae with Bioenergy Carbon Capture and Storage (ABECCS) Increases Sustainability," which was published by the American Geophysical Union. From *Carbon Capture Journal* on April 13, 2018.

Afforestation Increases Carbon Stock in Soil: Research.

According to research by scientists from the Xinjiang Institute of Ecology and Geography (China), afforestation can increase soil organic carbon (SOC) and nitrogen stocks in arid and semi-arid regions. The research, which was published in the journal *Science of The Total Environment*, evaluated the influences of afforestation on SOC and nitrogen stocks in topsoil in arid and semi-arid regions around the world. The data showed that afforestation increased SOC stock by 131 percent, providing a scientific basis for the restoration and improvement of soil fertility in arid and semi-arid regions as well a reference for carbon storage and emission reduction. From *Xinhua* on April 25, 2018.

Technology Demonstrates Simplified Conversion of CO_2 into Storable Renewable Energy.

Researchers from Southern California Gas Company (SoCalGas) and Opus 12, a clean-energy startup, demonstrated a new process of converting CO_2 in raw biogas to methane, simplifying the process of storing surplus renewable electricity as renewable natural gas. Opus 12 used a new electrolyzer technology to show the CO_2 can be converted to methane using renewable electricity. The research is part of SoCalGas' development of power-to-gas (P2G) technologies, a method of storing excess renewable energy using existing infrastructure. From *SoCalGas News Release* on April 19, 2018.

Study Focuses on Land Use, Agricultural Practices Impact on CO_2 Storage.

According to research conducted by scientists from Iowa State University, changes in land use and agricultural practices may impact the amount of CO_2 stored in midwestern soils. Published in the journal *Global Change Biology*, the study models how changes in midwestern land use since 1850 have impacted CO_2 storage. Specifically, the study focuses on the storage of CO_2 from terrestrial sources (e.g., soil, plants) during crop production. According to the data compiled, land use changes from 1850 to 2015 reduced billions of tons of CO_2 storage capacity in plants and soil. From *Iowa State University News* on May 1, 2018.

JUNE 2018

Science Advisors Examine CCUS.

The European Union (EU) published the fourth scientific opinion of the European Commission's *Group of Chief Scientific Advisors*, examining the potential and possible implementation of CCUS technologies. The published opinions and recommendations draws on the best available scientific and technical evidence across Europe, as well as a comprehensive review of scientific literature. From *Carbon Capture Journal* on May 24, 2018.

Atmospheric CO_2 May Make Food Less Nutritious.

According to a new study co-authored by the U.S. Department of Agriculture (USDA), potentially rising atmospheric CO_2 levels may be making food less nutritious by altering their chemical makeup and diluting vitamins and minerals. Specifically, the study, *published in Scientific Advances*, found that rice exposed to elevated levels of CO_2 contains lower amounts of several important nutrients. The USDA researchers exposed experimental rice fields in China and Japan to anticipated future levels of CO_2, finding that most of the 18 varieties tested contained less protein, iron, and zinc than rice grown today. From *The New York Times* on May 23, 2018.

Volcanic Study Finds Coral Changes in High CO_2.

A large-scale experiment conducted off Papua New Guinea has found that potentially high levels of CO_2 could have an impact on coral reefs. *In a paper published in the journal Plos One*, researchers from the Australian Institute for Marine Science (AIMS) and the University of Otago (New Zealand) studied 90 small coral communities, half of which were positioned close to two shallow-water volcanic CO_2 seeps (the other half – the control sites – were positioned a short distance away), for 13 months. The researchers found that the coral communities near the volcanic vents considerably changed. From *Cosmos Magazine* on May 31, 2018.

JULY 2018

Researchers Study Safety of CO_2 Storage.

A new study shows that captured CO_2 can be safely stored underground through injection into the microscopic pore spaces of common rocks. Researchers from the Universities of Aberdeen and Edinburgh used computer simulations to model the storage of CO_2 for 10,000 years into the future, combining information from natural CO_2 and methane accumulations and hydrocarbon industry experience (e.g., engineered gas storage, decades of borehole injection, and laboratory experiments). The results of the study were *published in the journal Nature Communications*. From *SCCS News* on June 12, 2018.

Victoria's Inland Wetlands CO_2 Storage Potential.

Victoria's inland wetlands have the potential to store approximately 3 million tons of CO_2 a year, according to research conducted by the Deakin School of Life and Environmental Sciences' Blue Carbon Lab. Funded by Victoria, Australia's Department of Environment, Land, Water and Planning, the study analyzed soil samples from more than 100 different wetlands across Victoria. The results, *published in the journal Global Change Biology*, estimated that Victoria's inland wetlands had a soil carbon stock of 68 million tons. From *Blue Carbon Lab* on June 25, 2018.

Catalyst Improves CO_2-to-Methanol Process.

Researchers from Penn State University claim to have made improvements to the process of converting CO_2 to methanol, according to a study *published in the journal ACS Catalysis*. Integrated experimental and computational research showed the benefit of a new catalyst that uses a specific formulation of palladium and copper. Researchers found that combining the metals in the new formulations increased the rate of methanol formation by three times over palladium alone and by four times over copper alone, representing an improvement over previous methods. From *Penn State University* on June 28, 2018.

AUGUST 2018

Acidic Oceans May Cause Fish to Lose Their Sense of Smell.

A new study shows evidence that fish's ability to smell may be affected by potentially elevated levels of CO_2 in the ocean. When CO_2 is absorbed by seawater, the water becomes more acidic, which affects the ability of fish to detect odors. Fish would become vulnerable, as they use their sense of smell to find food, safe habitats, avoid predators, and find suitable spawning grounds. The study, titled "*Near-future CO_2 levels impair the olfactory system of a marine fish*," appeared in the journal *Nature Climate Change* and was led by the University of Exeter (England, UK). From *Phys.Org* on July 23, 2018.

Report Shows Missouri Farms Carbon Storage Potential.

A research report conducted by Climate Central analyzed the extent to which the use of conservation farming practices can reduce carbon emissions in Missouri (USA). The report, titled "*Soil Solutions: Carbon-Smart Farming in the Show Me State*," found that the estimated total annual carbon storage potential for the entire state, with the adoption of conservation practices, is equivalent to twice the annual total GHG emissions of Columbia, Missouri. From *Climate Central* on July 18, 2018.

SEPTEMBER 2018

Lab-Made Mineral Developed to Address CO_2 in the Atmosphere.

Scientists from Trent University in Ontario, Canada, have developed a way to create the mineral magnesite at room temperature, allowing for the possibility to expand the process to industrial scale. If implemented at scale, CO_2 could potentially be stored long-term in the mineral. According to the research, the new method moves the rate of magnesite formation from hundreds to thousands of years in nature to within 72 days in a lab. Based on previous studies, magnesite can remove approximately half its weight in CO_2 from the atmosphere. Thus, by speeding up the process of creating the mineral, magnesite could represent a legitimate resource for removing and storing atmospheric CO_2. From *Forbes* on August 15, 2018.

Underwater Canyon Storing CO_2.

A research expedition to an Irish underwater canyon has revealed a process that removes CO_2 from the atmosphere and stores it under the sea. Led by the University of College Cork (Ireland), the research team built a map of the boundaries and interior of the Porcupine Bank Canyon (where Ireland's continental shelf ends), discovering a process at the edge of the canyon that pulls CO_2 from the atmosphere and stores it under the sea. The rim of the canyon is populated with cold-water corals that thrive on dead plankton, which are built up from carbon extracted from atmospheric CO_2. As the coral consume the dead plankton, they assume the same carbon. Over time, as the coral die, they fall into canyon, essentially storing their CO_2 under the sea. From *Live Science* on August 10, 2018.

CO_2 Levels May Lead to Nutritional Deficiencies.

Potentially rising levels of atmospheric CO_2 may deplete nutrients in crops, according to a new study. Researchers from Harvard's T.H. Chan School of Public Health studied the effects of CO_2 on crops such as rice and wheat, finding that elevated CO_2 levels could lead to zinc, protein, and iron deficiencies, putting people at risk for anemia and other illnesses. The study, titled "*Impact of anthropogenic CO_2 emissions on global human nutrition*," appeared in the journal *Nature Climate Change*. From *Fortune* on August 27, 2018.

Thawing Permafrost Could Release CO_2.

According to the National Geographic, a field experiment in northern Siberia has revealed that some layers of permafrost are no longer freezing, potentially releasing previously stored CO_2 into the atmosphere. Scientists drilled into the soil in Cherskiy (Russia), located 200 miles north of the Arctic Circle, and found "slushy mud" in areas that should have been frozen. Beneath the soil is the permafrost, which in this region has been frozen for hundreds to thousands of years, and stores billion of tons of CO_2. According to the study, the permafrost may continue to thaw at an accelerated rate without its protective layer of frozen ground. From *Earth.com* on August 23, 2018.

JOURNAL ARTICLES

OCTOBER 2017

Advantages from Combining CCS with Geothermal Energy.

The following is the Abstract of this article: "CCS technology is one important option to reduce CO_2 emissions, however social, political and mainly economic barriers limit its implementation. A combination of CCS-geothermal technologies can contribute to achieve faster this reduction and to decrease costs by sharing injection wells, using CO_2 instead of water as heat transfer fluid, thereby lowering water consumption and saving pump costs. It can also change public perception towards CCS. This technology is currently in mature level, allowing to store CO_2 in a safe way. Moreover all knowledge acquired on CO_2 storage and monitoring can be also used for geothermal energy." **Edesio Miranda-Barbosa, Bergur Sigfússon, Johan Carlsson, and Evangelos Tzimas**, *Energy Procedia*. (Subscription may be required.

Developing a Consistent Database for Regional Geologic CO_2 Storage Capacity Worldwide.

The following is the Abstract of this article: "Assessments of the geologic storage capacity of CO_2 in the current literature are incomplete and inconsistent, complicating efforts to assess the worldwide potential for CCS. [The authors] developed a method for generating first-order estimates of storage capacity requiring minimal data to characterize a geologic formation. [The authors] show this simplified method accounts for the majority of the variance in storage capacity found in more detailed studies conducted in the United States. [The authors] apply [their] method to create a worldwide database of storage capacity, disaggregated into 18 regions, and compare this storage capacity to CCS deployment in the MIT Economic Prediction and Policy Analysis (EPPA) model. Globally, [the authors] estimate there are between 8,000 and 55,000 gigatonnes (Gt) of practically accessible geologic storage capacity for CO_2. For most of the regions, [the authors'] results indicate storage capacity is not a limiting factor for CCS deployment through the rest of this century even if stringent emissions reductions are required." **Jordan Kearns, Gary Teletzke, Jeffrey Palmer, Hans Thomann, Haroon Kheshgi, Yen-Heng, Henry Chen, Sergey Paltsev, and Howard Herzog**, *Energy Procedia*. (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 $\delta^{13}C_{CO2}$ 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 $\delta^{13}C_{CO2}$ values imply that dissolution is occurring at pH = 5.8, consistent with the previous determinations. $\delta^{13}C_{CO2}$ 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.)

Readily implementable techniques can cut annual CO_2 emissions from the production of concrete by over 20%.

The following is the Abstract of this article: "Due to its prevalence in modern infrastructure, concrete is experiencing the most rapid increase in consumption among globally common structural materials; however, the production of concrete results in approximately 8.6% of all anthropogenic CO_2 emissions. Many methods have been developed to reduce the [GHG] emissions associated with the production of concrete. These methods range from the replacement of inefficient manufacturing equipment to alternative binders and the use of breakthrough technologies; nevertheless, many of these methods have barriers to implementation. In this research, [the authors] examine the extent to which the increased use of several currently implemented methods can reduce the [GHG] emissions in concrete material production without requiring new technologies, changes in production, or novel material use. This research shows that, through increased use of common supplementary cementitious materials, appropriate selection of proportions for cement replacement, and increased concrete design age, 24% of [GHG] emissions from global concrete production or 650 million [metric tons] CO_2-eq can be eliminated annually." **Sabbie A Miller, Arpad Horvath, and Paulo J M Monteiro**, *Environmental Research Letters*. (Subscription may be required.)

The impacts of emissions accounting methods on an imperfect competitive carbon trading market.

The following is the Abstract of this article: "To achieve a reduction in carbon intensity, the Chinese government has committed to establishing a nationwide carbon market. In this study, an interregional input-output model is proposed to derive cost curves for regional marginal abatement and to estimate interregional embodied emissions. An emissions trading model is presented for exploring the impacts of emissions accounting methods on imperfect competitive trading markets in the context of China achieving its 12th FYP intensity reduction target. The results indicated that emissions permits could be reallocated according to the CBA method. This could reduce both carbon emissions and total cost. Compared to the PBA method, the CBA method could lead to a greater change in permit prices and the amount of carbon trading in an imperfect competitive carbon market. Moreover, more regions with market power could cause declines in permit prices, resulting in changes in abatement costs. In addition, seven pilot markets (excluding Hubei province) are net embodied emissions importers. Pilot trading schemes in China could lead to carbon leakage among the other non-trading regions and sectors." **Yan Xia and Zhipeng Tang**, *Energy.* (Subscription may be required.)

Carbon allowance auction design of China's emissions trading scheme: A multi-agent-based approach.

The following is the Abstract of this article: "In this paper, a multi-agent-based ETS simulation model is proposed for carbon allowance auction design in China. In the proposed model, two main agents, i.e., the government (the ETS implementer) and the firms in different sectors (the ETS targets), are considered. Under the ETS policy, all agents make various decisions individually according to their own goals, and interact with each other through three main markets: the commodity market, the primary carbon auction market and the secondary carbon trading market. Different popular auction designs are introduced into the ETS formulation to offer helpful insights into China's ETS design. (1) Generally, the ETS would lead to positive effects on China's carbon mitigation and energy structure improvement, but a negative impact on economy. (2) As for auction forms, the uniform-price design is relatively moderate, while the discriminative-price design is quite aggressive in both economic damage and emissions reduction. (3) As for carbon price, the uniform-price auction might generate a slightly higher market clearing price than the discriminative-price auction, and the prices under two auction rules fluctuate about RMB 40 per metric ton. (4) As for carbon cap, the total allowances in the carbon auction market should be carefully set to well balance economic growth and mitigation effect." **Ling Tang, Jiaqian Wu, Lean Yu, and Qin Bao**, *Energy Policy*. (Subscription may be required.)

NOVEMBER 2017

Estimation of soil carbon sequestration and profit analysis on mitigation of CO_2-eq. emission in cropland cooperated with compost and biochar.

The following is the Abstract of this article: "Only a few have evaluated the mitigation of greenhouse emissions and profit analysis along with soil carbon sequestration for corn cultivation. This experiment was conducted to evaluate the carbon sequestration and mitigation of [GHG] emissions as well as their profit analysis with different composts mixed with biochar during corn cultivation. This experimental data provided the second year of corn cultivation. The soil type used was clay loam. The application amounts of synthetic fertilizer and biochar were 220–30–155 kg ha^{-1} (N–P–K) as the recommended amount after soil analysis and 2600 kg ha^{-1} based on 1.3% of soil bulk density. For the biannual experimental results, it appeared that carbon sequestration in cow manure cooperated with biochar was highest at 2.3 tons ha^{-1} and recovered from 67.3 to 78.5% with biochar application. Furthermore, mitigation of CO_2-eq. emission as [GHGs] was estimated to be at 7.3–8.4 MT ha^{-1}, and its profit was evaluated from $7.2 to 8.4 as lowest, from $57.2 to 66.6 as medium and from $139.7 to 162.7 as highest per hectare regardless of organic compost types used. For agricultural practice in Korea, it is evaluated that the market price of CO_2 in corn field cooperated with 2600 kg ha^{-1} of biochar application ranged from $57.2 to 162.7 per hectare in Korean Climate Exchange. For corn biomass, the treatment with biochar application did not significantly decrease compared with the only organic compost application. Based on these experimental results, it might be applied for carbon trading with clean development mechanism for agricultural practices." **JoungDu Shin, Seung Gil Hong, SunIl Lee, SungChang Hong, and JongSik Lee**, *Applied Biological Chemistry*. (Subscription may be required.)

Can energy policies affect the cycle of carbon emissions? Case study on the energy consumption of industrial terminals in Shanghai, Jiangsu and Zhejiang.

The following is the Abstract of this article: "This paper proposes an approach to calculate the time series of cumulative CO_2 emissions between 1995 and 2014 based on industrial energy consumption data in three Eastern China jurisdictions in Shanghai, Jiangsu and Zhejiang during these two decades. Using the Hodrick-Prescott filter, the fluctuation components of the cumulative CO_2-emission time-series data in the three provinces are obtained. Subsequently, a grey correlation-based change-point search algorithm is used to determine change-points in these data. Additionally, the CO_2-emission time-series is divided into stages based on the change-points. The cycle characteristics of national energy policies, laws, and regulations are compared with those of the cumulative CO_2-emission cycle of the three provinces to [analyze] the impact of energy policies on CO_2 emissions. This study shows that, although the industrial structure and trends in the CO_2 emission time-series data of the three provinces are different, their cumulative CO_2-emission cycle remains the same from 1995 to 2014. The variation characteristics of the cumulative CO_2 emissions for each cycle during this period are well aligned with the stage characteristics of energy policies, laws, and regulations, indicating that energy policies play a consistent role in regulating such emissions. This study examines low-carbon production and sustainable energy development, and offers suggestions for issuing and perfecting energy policies, laws, and regulations, considering the indicators of energy consumption and CO_2 emissions." **Lihong Wang, Zaiwu Gong, Ge Gao, and Changkai Wang**, *Ecological Indicators*. (Subscription may be required.)

CCS Leakage Detection Technology - Industry Needs, Government Regulations, and Sensor Performance.

The following is the Abstract of this article: "Reliable CCS monitoring is vital in order to confirm that injected CO_2 stays in the reservoir as intended, and that any occurring leakage is promptly detected allowing corrective actions to be initiated. Motivations for implementing monitoring strategies beyond the legal minimum required by government regulations, can be divided into economic, environmental and reputational factors, where the latter is significant; adequate monitoring is important for attaining public acceptance. CCS monitoring methods can be divided into deep focused (reservoir, overburden) and shallow focused (seabed, water column) methods. Shallow monitoring methods include acoustic and chemical sensors placed in the water column. For the CCS application, these sensor technologies are complementary; acoustic sensors are sensitive to CO_2 in gas phase and chemical sensors can detect water-dissolved CO_2 or formation fluids. [The authors] discuss the motivations for CCS monitoring, and offer a structured overview of acoustic and chemical technologies for CCS monitoring at the seabed and in the water column. Each technology is evaluated in terms of its applicability to CCS monitoring, highlighting its strengths and limitations for detection, quantification and characterization of CCS related leakage. [The authors] conclude that while state of the art sensor technology is sufficient to meet government requirements, there is potential for improved integrated monitoring through optimal use and combination of technologies. The concept of integrated monitoring where different sensor types measure different parameters is emerging as a promising monitoring strategy." **Ivar-Kristian Waarum, Ann E.A. Blomberg, Espen Eek, Jock Brown, Amund Ulfsnes, Mike Carpenter, Torleiv S. Grimsrud, Joonsang Park, Gerard Cornelissen, and Per Sparrevik**, *Energy Procedia*. (Subscription may be required.)

Recent increases in terrestrial carbon uptake at little cost to the water cycle.

The following is the Abstract of this article: "Quantifying the responses of the coupled carbon and water cycles to current global warming and rising atmospheric CO_2 concentration is crucial for predicting and adapting to climate changes. Here [the authors] show that terrestrial carbon uptake (i.e. gross primary production) increased significantly from 1982 to 2011 using a combination of ground-based and remotely sensed land and atmospheric observations. Importantly, [the authors] find that the terrestrial carbon uptake increase is not accompanied by a proportional increase in water use (i.e. evapotranspiration) but is largely (about 90%) driven by increased carbon uptake per unit of water use, i.e. water use efficiency. The increased water use efficiency is positively related to rising CO_2 concentration and increased canopy leaf area index, and negatively influenced by increased [vapor] pressure deficits. [The authors'] findings suggest that rising atmospheric CO_2 concentration has caused a shift in terrestrial water economics of carbon uptake." **Lei Cheng, Lu Zhang, Ying-Ping Wang, Josep G. Canadell, Francis H. S. Chiew, Jason Beringer, Longhui Li, Diego G. Miralles, Shilong Piao, and Yongqiang Zhang**, *Nature Communications*. (Subscription may be required.)

Laboratory measurements monitoring supercritical CO_2 sequestration using ghost reflections retrieved by seismic interferometry.

The following is the Abstract of this article: "Monitoring of seismic changes inside the reservoir layer during CO_2 sequestration can be valuable for extraction of reservoir quantities like saturation and pore pressure. The accuracy of the monitoring could be deteriorated due to nonrepeatability errors in the source and receiver geometry. Applying seismic interferometry (SI) to permanent networks of seismic stations to retrieve virtual sources at the positions of the stations eliminates the non-repeatability in the source positioning. SI is traditionally applied using crosscorrelation. [The authors] show results from application of SI to ultrasonic data for layer-specific monitoring of sequestration of supercritical CO_2. The data are recorded on a two-layer sample consisting epoxy (caprock) and Bentheimer sandstone (reservoir). [The authors] apply SI by crosscoherence, which has the potential to retrieve results with higher temporal resolution that SI by crosscorrelation. Using SI, [the authors] retrieve non-physical reflections from the bottom of the sandstone as if source and receiver were placed at the top of the sandstone. The velocities [the authors] estimate from the non-physical reflections during injection of brine aiming to displace supercritical CO_2 and during injection of supercritical CO_2 aiming to displace brine indicate rather similar saturation for both injection cases. [The authors] confirm the latter by transmission measurements, but with lower resolution." **Deyan Draganov, Alex Kirichek, Karel Heller, and Ranajit Ghose**, *Society of Exploration Geophysicists*. (Subscription may be required.)

Carbon dioxide and heat integration of industrial parks.

The following is the Abstract of this article: "The depletion of natural resources and the increase in [GHGs] emissions has led to policies aiming at drastic [CO_2] emissions reductions over current levels. This work addresses the [CO_2] integration of industrial parks, i.e. the integration of [CO_2] sources, sequestration and utilization options to achieve required emissions reductions at minimum cost. The work makes use of the recently proposed [CO_2] integration approach to explore carbon management options across an industrial park together with energy integration approaches to (1) minimize net energy demand of the industrial park and therefore cut fuel and corresponding emissions, and (2) explore synergies available from utilizing excess process heat to provide low-cost, emissions free heat and power sources for energy intensive carbon capture and compression costs. The proposed approach integrates methods for [CO_2] and heat integration. The approach is demonstrated through a case study for which substantial savings are identified with the new approach." **Raid J. Hassiba, Dhabia M. Al-Mohannadi, and Patrick Linke**, *Journal of Cleaner Production*. (Subscription may be required.)

Accounting and structure decomposition analysis of embodied carbon trade: A global perspective.

The following is the Abstract of this article: "In this paper, a multi-regional input-output model is built to estimate the global embodied carbon trade from 1995 to 2009 based on the World Input-Output Database (WIOD). The method of structure decomposition analysis (SDA) is applied to quantify the changes in the scale and structure of embodied carbon trade in China, India, Japan, and the United States. According to the results, the top three countries with the most embodied carbon trade were: the United States, China and Japan in 1995, and the United States, China and India in 2009. In 1995 and 2009, the sectors which have the highest direct carbon emission coefficients and total carbon emission coefficients in China, India and the United States are electricity, gas and water supply sectors, while each country maintained a different coefficient. A decrease of direct carbon emission coefficient will result in a reduction of the imports and exports, as well as the self-consumption of embodied carbon. Therefore, it is suggested that countries should develop low-carbon industries, and reduce the carbon emissions per unit of output. In addition, those countries with higher carbon emission coefficients should consider of importing products to lower carbon emissions." **Guangyao Deng and Yan XU**, *Energy*. (Subscription may be required.)

DECEMBER 2017

Considerations in the Development of Flexible CCS Networks.

The following is the Abstract of this article: "This paper discusses considerations for the design of flexibly operated CCS pipeline networks and is based on the findings of the Flexible CCS Network Development project (FleCCSnet), funded as part of the UK CCS Research Centre. The project considered the impact of flexibility across the whole CCS chain, as well as studying the interfaces between each element of the system; e.g. at the entry to the pipeline system from the capture plant and at the exit from the pipeline to the storage site. The factors identified are intended to allow CCS network designers to determine the degree of flexibility in the system; allowing them to react effectively to short, medium and long term variations in the flow of CO_2 from capture plants and the constraints imposed on the system by CO_2 injection and storage. The work of the project is reviewed in this paper which explores the flexibility of power plants operating with post combustion capture systems; quantifies the available time to store (line pack) CO_2 in the pipeline as a function of pipeline size, the inlet mass flow rate and operating pressure; and explores the influence that uncertainty in injection and storage parameters have on the design of the pipeline. In addition, parameters influencing short and longer term network designs are discussed in terms of varying flow rates. Two practitioner workshops contributed to the direction of the project. The first workshop identified and confirmed key questions to be considered in order to understand the most likely impacts of variability in both the CO_2 sources and CO_2 sinks on CO_2 transport system design and operation. The second workshop focused on transient issues in the pipeline and storage site. Although the case studies in the work are UK based, this work is applicable to other situations where large and small sources of CO_2 are expected to be feeding into a CCS transportation system. The work is expected to inform a broad range of stakeholders and allow network designers to anticipate potential problems associated with the operation of a CCS network. For an effective design of CCS infrastructure, all of the factors that will have a substantial impact on CO_2 flow will have to be [analyzed] at an early stage to prevent possible bottle necks in the whole chain." **Ben Wetenhall, Julia Race, Hamed Aghajani, Eva Sanchez Fernandez, Mark Naylor, Mathieu Lucquiaud, and Hannah Chalmers**, *Energy Procedia*. (Subscriptions may be required.)

Multiple Pollutants, Co-Benefits, and Suboptimal Environmental Policies.

The following is the Abstract of this article: "In [the authors'] analytical general equilibrium model, polluting inputs can be substitutes or complements. [The authors] study a tax increase on one pollutant where the other faces a tax or permit policy. [The authors'] solutions highlight key parameters and welfare effects with gains from abatement plus positive or negative co-benefits from other pollutants in the covered and uncovered sectors. [The authors] demonstrate several ways taxes and permits differ. First, the change in taxed pollutant depends on whether the other pollutant faces a tax or permit policy. Also, only with a tax on the other pollutant can a co-benefit arise. The sign of co-benefits depends on the sign of cross-price elasticities and on whether the other pollutant's price is above or below marginal damages. Finally, the other pollutant's tax or permit policy also affects emissions in the uncovered sector (leakage). In a numerical illustration of carbon tax in U.S. electricity, [the authors] calculate emissions of CO_2 and [sulfur dioxide (SO_2)] in both sectors. For plausible parameters, co-benefits are larger than direct." **Don Fullerton and Daniel H. Karney**, *Journal of Environmental Economics and Management*. (Subscription may be required.)

High Temperature CO2-in-Water Foams Stabilized with Cationic Quaternary Ammonium Surfactants.

The following is the Abstract of this article: "The design of surfactants for stabilizing CO_2-in-water (brine) (C/W) foams at high temperature is challenging given the low density (solvent strength) of CO_2, limited surfactant solubility in brine, and a lack of knowledge of the interfacial and rheological properties. Herein, the tail length of trimethylammonium cationic surfactants was optimized to provide the desired phase behavior and interfacial properties for formation and stabilization of the C/W foams. The headgroup was properly balanced with a $C_{12–14}$ hydrocarbon tail to achieve aqueous solubility in 22% total dissolved solids (TDS) brine up to 393 K (120°C) along with high surfactant adsorption (area/surfactant molecule of 154 Å^2) at the CO_2–water (C–W) interface which reduced the interfacial tension from ~40 mN/m to ~6 mN/m. For $C_{12–14}N(CH_3)_3Cl$, these properties enabled stabilization of a C/W foam with an apparent viscosity of 14 mPa•s at 393 K in both a crushed calcium carbonate packed bed (75 μm^2 or 76 Darcy) and a capillary tube downstream of the bed. In addition, the partition coefficient of the surfactant between oil and 22% TDS (255 kg/m^3) brine was less than 0.15, which would be beneficial for minimizing the loss of the surfactant to an oil phase in applications including [EOR] and hydraulic fracturing." **Yunshen Chen, Amro S. Elhag, Andrew J. Worthen, Prathima P. Reddy, Anne Marie Ou, George J. Hirasaki, Quoc P. Nguyen, Sibani L. Biswal, and Keith P. Johnston**, *Journal of Chemical and Engineering Data*. (Subscription may be required.)

Emission trading and carbon market performance in Shenzhen, China.

The following is the Abstract of this article: "China has developed its own domestic carbon markets by setting up emission trading schemes. This study addresses concerns about the functioning of these schemes and the financial performance of the Chinese carbon market. It aims to assess an actual outcome of this policy intervention, i.e. trading records, which were used in [the authors'] analysis to examine a key financial property of the allowance-based market in Shenzhen. In a mature market, assets that incur higher risks are likely to yield higher returns, i.e. a positive relationship. To examine this property, [the authors] solicited historical data on the price and trading volume of emission allowances. [The authors] statistically estimated the degree of volatility in the Shenzhen market and its relationship with expected return premium. [The

authors] found that the rate of return was negatively associated with expected risk. This stands at odds with the usual expectation in the financial market and the prediction of asset pricing theory. Also, kurtosis in trading volume was excessively high and its fluctuations were highly concentrated. [The authors] discuss these findings in terms of market liquidity and information uncertainties, and offer some policy recommendations. More regulatory attention and economic fixes are needed to improve market efficiency and eliminate sources of market distortions." **Ren Cong and Alex Y. Lo**, *Applied Energy*. (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.)

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.)

Hydraulic characterization of fractured carbonates for CO_2 geological storage: Experiences and lessons learned in Hontomín Technology Development Plant.

The following is the Abstract of this article: "The Hontomín Technology Development Plant for CO_2 geological storage located in Spain, owned by Fundación Ciudad de la Energía (CIUDEN) is the only current onshore injection site in the European Union. It has been recognized by the European Parliament as a key test facility. The storage reservoir is a deep saline aquifer comprised of carbonates (limestones and dolomites) of the120 m thick Sopeña Fm, and seal rocks belong to the overlying series of Pozazal and Lias formations. In this article experiences and lessons learned during the reservoir hydraulic characterization are discussed, analyzing the methodology of different types of tests performed at laboratory and field scale. [Carbon dioxide] injection in this reservoir shows specific features that are different than injection in porous media. Considering the low porosity/permeability of the rock matrix in the case study, the CO_2 transmissivity is dominated by the fracture network where hydrodynamic and geochemical effects play a key role influencing the reservoir behavior and defining conditions for safe and efficient injection. The challenge at Hontomín was to manage the low injectivity in the reservoir. Recommendations to overcome this difficulty are analyzed. The design of injection strategies must consider characteristic parameters at the well head, tubing and bottom hole according to the interpretation of results from petrophysical laboratory tests, in particular those performed under reservoir conditions, and from field tests conducted on site. The use of an appropriate dynamic model is essential to achieve a realistic assessment of reservoir behavior. The hypothesis, data interpretation and conclusions reached with the modeling are discussed." **J. Carlos de Dios, Miguel A. Delgado, Carlos Martínez, Alberto Ramos, Iñaki Álvarez, Juan A. Marín, and Ignacio Salvador**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Regional carbon emission evolution mechanism and its prediction approach driven by carbon trading – A case study of Beijing.

The following is the Abstract of this article: "Resources and environmental issues have become the main obstacles to the global sustainable development. For example, the global warming and paroxysmal environmental problems induced by fossil energy consumption are highlighted in recent years. As a big energy consumption and carbon emission country, China has tried to establish and implement the carbon emission trading mechanism in order to adjust the economic development patterns, optimize the energy structure and fulfill the emission goals. This mechanism has played a certain role in guiding and supporting the energy saving and carbon emission reduction. With the wide popularization and acceptance of low-carbon and green development, the advantages and the benefits of regional carbon emission trading mechanism will gradually show up with more trading activities and enterprise participation. Therefore, it's imperative to explore the carbon emission trading mechanism and provide relative suggestions for government and enterprises. For analyzing the carbon emission trading mechanism in China, the development situations of economy, energy and policy were reviewed firstly. Then, based on the direct and indirect emissions, the carbon emission measurement method was used to study the emission trends of Beijing and pilot areas. With the system dynamics analysis model, the key factors and evolution circuits influential to the carbon emission mechanism were identified from the aspects of society, energy, economy and environment. The factors were further selected by extended STIRPAT model and ridge regression model in order to construct the BP Neural Network prediction model of carbon emissions. Meanwhile, take Beijing as an example, seven different development scenarios were set to test the rational levels of carbon emissions in the next five years. At last, with the prediction and scenario analysis results, some policy advices were discussed and provided theoretical and practical references for reasonable and efficient carbon emission trading." **Jin-peng Liu, Xu-bei Zhang, and Xiao-hua Song**, *Journal of Cleaner Production*. (Subscription may be required.)

JANUARY 2018

U.S. DOE's Economic Approaches and Resources for Evaluating the Cost of Implementing Carbon Capture, Utilization, and Storage (CCUS).

The following is the Abstract of this article: "[DOE] and [NETL] are world leaders in CCUS research and analysis. They have developed resources and a set of economic tools to evaluate the cost to implement CCUS for each segment of the value chain: capture, transport, and storage. This paper provides a comprehensive review of the economic models and analytical approaches DOE/NETL has developed for assessing the CO_2 capture, storage, and transport cost drivers that impact the entire CCUS value chain. Failure to effectively evaluate the economic opportunity for CCUS technology to reduce CO_2 emissions would deter wide-spread deployment. DOE's economic models and resources enable a variety of possible analytical approaches to evaluate the economics associated with deploying CCUS. The resources are open-source so that interested stakeholder groups can apply them to their specific problems, and to enable feedback to improve these models moving forward." **Derek Vikara, Chung Yan Shih, ShangMin Lin, Allison Guinan, Timothy Grant, David Morgan, and Donald Remson**, *Journal of Sustainable Energy Engineering*. (Subscription may be required.)

The Evolution of European CCS Policy.

The following is the Abstract of this article: "The European CCS industry is still grasping for an effective policy structure which will support deployment of commercial CCS projects. This paper will consider the current context of CCS policy given three significant developments: (a) the agreement in 2014 for a technology neutral 2030 EU emissions reduction target; (b) a binding commitment at COP21 in Paris, Dec 2015, for a global emissions reduction target; (c) the collapse of the UK's CCS [Commercialization] Programme in Nov 2015. The period 2010-2015 saw continued stagnation in the European CCS industry, with a series of projects proposed but then subsequently cancelled. This hints as three problems (1) an industry which is weak in communicating why CCS is important, and failed to engage a wider stakeholder base; (2) incumbent governments which are not willing to fund the initially high costs of the first CCS projects; (3) weak market based structures which force industrial consortia to rely on government subsidy, thus leaving projects vulnerable to political forces. The tension within the UK's [Commercialization] Programme could still offer lessons for other potential CCS projects in Europe; and inform policy developments at the UK and European level. Namely (i) payment flows between the emitter / capture plant to the transport & storage provider, and the risk apportionment between those partners; (ii) the cost-benefit of oversized infrastructure and the challenges of a first project to finance the bulk of these costs..." **Matthew Billson and Mohamed Pourkashanian,** *Energy Procedia*. (Subscription may be required.)

The Politics of Large-scale CCS Deployment.

The following is the Abstract of this article: "Since the early 2000s, there has been growing recognition of the important role that CCS can play as part of a least-cost, global solution to climate change. Modelling by the International Energy Agency (IEA) has consistently highlighted a significant role for CCS in achieving a 2°C target, and recognition of the role of CCS has also increasingly been a feature of reports by the Intergovernmental Panel on Climate Change (IPCC). However, this growing appreciation of the value of CCS has not been accompanied by commensurate growth in political and policy support for the technology. In fact, support for CCS has been inconsistent and at times tumultuous, and has been closely intertwined with progress in global climate negotiations and wider economic conditions. CCS will not advance without significant public investment and the required support policies will not be put in place without political support – hence the politics of CCS play a major role in this respect. This paper looks at the politics of deploying large-scale CCS projects, including the drivers for CCS support, the opposing political forces and the practical challenges of deploying CCS." **Juho Lipponen, Samantha McCulloch, Simon Keeling, Tristan Stanley, Niels Berghout, and Thomas Berly,** *Energy Procedia*. (Subscription may be required.)

Diffusive leakage of brine from aquifers during CO_2 geological storage.

The following is the Abstract of this article: "The area of investigation in this study is designed around an improved understanding of fundamentals of the diffusive leakage of brine from a storage aquifer into overlying and underlying low permeability layers during geosequestration of CO_2 through development of a theoretical model. Here, [the authors] consider a two-dimensional domain in cylindrical coordinates, comprised of an aquifer and an overburden, where the interaction between the two media is handled by imposing the continuities of pressures and fluid fluxes at the aquifer-overburden interface. This coupled problem is solved by successive implementation of the Laplace and finite Hankel transforms. The developed solutions can be used to analyze diffusive leakage of brine from the aquifer into overburden and generate type curves for average pressures in the aquifer and overburden during injection and post injection periods. The results show that the leakage rate at early times is scaled with $t^{1/2}$ while it remains constant at late times. It is also shown that the average pressure in the aquifer is scaled with t for short and long times. Moreover, the average pressure in the overburden is scaled with t at late times while it is scaled with $t^{3/2}$ at early times. In addition, the results reveal that factors affecting diffusive leakage rate through intact overburden during CO_2 storage are, in decreasing order of significance, thickness of overburden, thickness of aquifer, aquifer to overburden permeability ratio, and aquifer to overburden porosity ratio. However, thickness of aquifer has minimal effect on diffusive leakage of brine within post injection period. To evaluate the theoretical model, case studies for two potential sites in United Kingdom, one in Lincolnshire and the other one in the Firth of Forth, are conducted. The field studies show that the diffusive leakage from the aquifer into the overburden diminishes ~40 years after the injection has ceased for Lincolnshire while it stops after ~12 years for Firth of Forth. The average amount of the brine leaked from the aquifers per standard cubic meter (Sm^3) of the injected CO_2 through diffusive leakage was found to be 6.28×10^{-4} m^3 of brine (or 0.330 kg of brine/kg of CO_2) over ~70 years for Lincolnshire and 4.59×10^{-4} m^3 of brine (or 0.242 kg of brine/kg of CO_2) over ~42 years for Firth of Forth." **Morteza Dejam and Hassan Hassanzadeh,** *Advances in Water Resources*. (Subscription may be required.)

Efficiency of Carbon Dioxide Storage and Enhanced Methane Recovery in a High Rank Coal.

The following is the Abstract of this article: "The high affinity and adsorption capacity of coal to [CO_2] provides an alternative approach for the enhanced recovery of methane [CH_4)] from unminable coalfields (CO_2-ECBM) by which a potential solution for long-term CO_2 sequestration in deep geological formations can also be achieved. However, due to chemomechanical effects induced by the interactions between CO_2 and coal, the effective methane production and [CO_2] storage can be degraded which has caused uncertainties about the techno-economic feasibility of the CO_2-ECBM process. This study presents an experimental investigation that aims to address key knowledge gaps related to the efficiency of CO_2 storage and CH_4 recovery in high rank coals for which a comprehensive experimental data set and analysis are largely missing. Competitive displacements of CH_4 with N_2 or CO_2 in an anthracite coal sample from a South Wales coalfield have been studies, based on a series of core flooding experiments. The results show that the N_2 breakthrough time (the time at which 1% of the total gas injected was recovered) was almost spontaneous whereas a considerably delayed breakthrough time was observed for the case of the CO_2-ECBM experiment. In addition it was observed that for the CO_2-ECBM experiment, the ratios of CH_4 recovery with respect to the total amount of gas injected and gas stored were higher by factors of 10 and 2.4, respectively. The results also show that 90% of the total N_2 injected was produced in the outflow gas, whereas for the case of the CO_2 experiment, only 63% of the total injected CO_2 was produced. The presence of a high amount of N_2 in the outflow may lead to additional challenges in order to separate N_2 from CH_4 and thus affect the efficiency of the N_2-ECBM method. Under the conditions of the experiments, the total CH_4 displacement ratio and breakthrough for the case CO_2-ECBM were found to be more favorable compared to those obtained from N_2-ECBM. This study provides new insights into the efficiency of the CO_2-ECBM process and offers a comprehensive experimental data set that can be used for testing the accuracy of predictive models." **Mojgan Hadi Mosleh, Majid Sedighi, Philip J. Vardon, and Matthew Turner,** *Energy Fuels*. (Subscription may be required.)

Geochemical tracers for monitoring offshore CO_2 stores.

The following is the Abstract of this article: "Chemical tracers are proposed as an effective means of detecting, attributing and quantifying any CO_2 leaks to surface from geological CO_2 storage sites, a key component of CCS technology. A significant proportion of global CO_2 storage capacity is located offshore, with some regions of the world having no onshore stores. To assure regulatory bodies and the public of CO_2 storage integrity it is important to demonstrate that robust offshore monitoring systems are in place. A range of chemical tracers for leakage have been tested at onshore pilot CCS projects worldwide, but to date they have not been trialled at injection projects or CO_2 release experiments located offshore. Here, for the first time, [the authors] critically review the current issues surrounding commercial scale use of tracers for offshore CCS projects, and examine the constraints and cost implications posed by the marine environment. These constraints include the logistics of sampling for tracers offshore, the fate of tracers in marine environments, tracer background levels, marine toxicity and legislative barriers – with particular focus on the Europe and the UK. It is clear that chemicals that form a natural component of the CO_2 stream are preferable tracers for ease of permitting and avoiding cost and risks of procuring and artificially adding a tracer. However, added tracers offer more reliability in terms of their unique composition and the ability to control and regulate concentrations. [The authors] identify helium and xenon isotopes (particularly $^{124,129}Xe$), and artificial tracers such as PFCs and deuterated methane as the most suitable added tracers. This is due to their conservative [behavior], low environmental impact and relative inexpense. Importantly, [the authors] also find that SF_6 and C^{14} are not viable tracers for CCS due to environmental concerns, and many other potential tracers can be ruled out on the basis of cost. Further, [the authors] identify key challenges that are unique to using tracers for offshore monitoring, and highlight critical uncertainties that future work should address. These include possible adsorption or dispersion of tracer compounds during ascent through the overburden, longevity of tracers over the timeframes relevant for CCS monitoring, the permissible environmental effects of tracer leakage, and tracer [behavior] in seabed CO_2 bubble streams and in dissolved CO_2. These uncertainties directly affect the selection of appropriate tracers, the injection program and concentrations necessary for their reliable detection, and appropriate sampling approaches. Hence offshore tracer selection and associated expense are currently poorly constrained. Further, there is limited experience of sampling for tracers in the marine environment; current approaches are expensive and must be streamlined to enable affordable monitoring strategies. Further work is necessary to address these unknowns so as to evaluate the performance of potential tracers for CO_2 leak quantitation and provide more accurate costings for effective offshore tracer monitoring programs." **Jennifer J. Roberts, Stuart M.V. Gilfillan, Linda Stalker, and Mark Naylor,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Cleaner coal and greener oil production: An integrated CCUS approach in Yanchang Petroleum Group.

The following is the Abstract of this article: "The Ordos Basin has the richest natural resources in China. It has over one third of the coal resources of China and it is the second largest oil and natural gas sedimentary basin in China. The Yanchang Petroleum Group is the only company that has both coal and petroleum mineral rights in this basin, which provides a unique favorable condition for implementing a CCUS project in China. The CCUS project conducted by the Yanchang Petroleum Group integrates a clean coal chemical plant with low-cost CO_2 capture facilities and CO_2 enhanced oil recovery (EOR) and storage in tight formations. The coal chemical plant produces methanol and acetic acid from coal using the Texaco coal gasification process. High purity CO_2 is separated from the methanol rich solvent. After compression and deep-freezing treatment, liquid CO_2 with a purity of 99% is produced for CO_2 EOR and the storage project. The cost of the CO_2 product is about 117 Renminbi (RMB)/[metric ton] CO_2, which is less than US $18/[metric ton] of CO_2. This cost is about half of the cost of CO_2 in the coal power plant (US $30-40/[metric ton]). The captured CO_2 is transported to a CO_2 EOR and storage project about 30–100 km away, which is a much shorter distance than the required transportation distances of other commercial CO_2 EOR and storage projects. For example, the transportation distance is over 300 km for the Weyburn project. The short distances between the CO_2 capture facility and the oil fields further reduce the transportation costs of the CCUS project in China. The oil fields in the Ordos Basin are mainly tight formations with low reservoir pressures. Water resources are very limited in the basin. Thus, minimizing water usage in the petroleum industry can significantly protect the environment in this area. Carbon dioxide EOR can reduce the water usage and [EOR] at the same time. An extensive experimental study was conducted to maximize the performance of CO_2 EOR in tight formations with low reservoir pressures. The current reservoir pressure in those oil fields is less than 10 MPa, which is far lower than the minimum miscible pressure (MMP) (16–22 MPa). Different approaches, such as CO_2 foam flooding and huff-n-puff, have been proposed to build up the reservoir pressure to enhance the oil recovery performance. A field pilot test, containing about 50 wells, has been conducted for four years, and the oil production rates for those wells have been doubled or tripled. This project is the first integrated CCUS project operated in China. Currently seventy thousand [metric tons] of CO_2 have been injected. In the next five years, this project will be expanded to 1 million [metric tons] of CO_2 injection, which will make it the second largest CCUS project in the world after Canada's Weyburn project." **Xiangzeng Wang, Fanhua Zeng, Ruimin Gao, Xisen Zhao, Shiyan Hao, Quansheng Liang, and Shaojing Jiang**, *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

The impact of carbon emission costs on manufacturers' production and location decision.

The following is the Abstract of this article: "This paper investigates how emerging carbon emission costs may affect the joint production and location decisions for a manufacturer across the world's regions. Specifically, [the authors] develop a new theoretical model which explicitly links product demand, production costs and carbon emission levels to location decisions, and investigate the manufacturer's optimal decisions between two distinct regions. The results show that the influence of carbon emissions on manufacturers' decisions can vary greatly under different circumstances: both off-shoring and near-shoring are possible under rising carbon emission costs; manufacturers with high or low demand have different tolerance levels to the rising carbon emission costs when considering an alternative location; trade costs can change the pattern of relocation. To gain policy insights for those who pursue reducing carbon emissions, different product examples are used to calculate the critical carbon price which triggers different location choices. The results suggest that if production technology is stable, raising carbon cost itself has only limited effects on reducing total carbon emissions, especially for high-value-low-emission industries. The location shift, which is more sensitive to changes in variable carbon emissions, may lead to a significant emission reduction when completed. Additional pricing decision from the manufacturer shows no significant effect on the location decisions; however, if demand is linked directly to carbon emission footprint of the product, then it is more hopeful that a raised carbon price would reduce the carbon emissions significantly through relocation." **Peng Wu, Ying Jin, Yongjiang Chi, and Hawfeng Shyu,** *International Journal of Production Economics.* (Subscription may be required.)

Carbon emissions quotas in the Chinese road transport sector: A carbon trading perspective.

The following is the Abstract of this article: "In response to the growing need to reduce carbon emissions, it is necessary to explore the design of carbon trading mechanisms and discuss allocation options for the transport sector. This paper examines the allocation of carbon quotas with the introduction of an emissions trading scheme (ETS) in the Chinese road transport sector. Aiming to simulate the allocation of carbon emissions quotas, [the authors] forecast vehicle possession using a gray forecast model and trend extrapolation; consider the CO_2 emissions of the transport sector using a top-down approach; and design three policy scenarios. [The authors] provide the following findings. First, vehicle possession in the road transport sector and carbon emissions both display an increasing trend, reaching 180 million units and 6.6 billion tons by 2020, respectively. Second, the road transport sector has the largest carbon quota under the benchmark scenario and the smallest under a low-carbon scenario. The difference between these two scenarios is 2.7 billion tons of carbon emissions. Finally, [the authors] design a carbon emissions trading mechanism for the transport sector based on China's special development period, and provide a sensitivity analysis." **Rong Han, Bi-Ying Yu, Bao-Jun Tang, Hua Liao, and Yi-Ming Wei,** *Energy Policy*. (Subscription may be required.)

Probabilistic modeling and global sensitivity analysis for CO_2 storage in geological formations: a spectral approach.

The following is the Abstract of this article: "This work focuses on the simulation of CO_2 storage in deep underground formations under uncertainty and seeks to understand the impact of uncertainties in reservoir properties on CO_2 leakage. To simulate the process, a non-isothermal two-phase two-component flow system with equilibrium phase exchange is used. Since model evaluations are computationally intensive, instead of traditional Monte Carlo methods, [the authors] rely on polynomial chaos (PC) expansions for representation of the stochastic model response. A non-intrusive approach is used to determine the PC coefficients. [The authors] establish the accuracy of the PC representations within a reasonable error threshold through systematic convergence studies. In addition to characterizing the distributions of model observables, [the authors] compute probabilities of excess CO_2 leakage. Moreover, [the authors] consider the injection rate as a design parameter and compute an optimum injection rate that ensures that the risk of excess pressure buildup at the leaky well remains below acceptable levels. [The authors] also provide a comprehensive analysis of sensitivities of CO_2 leakage, where [the authors] compute the contributions of the random parameters, and their interactions, to the variance by computing first, second, and total order Sobol' indices." **Bilal M. Saad, Alen Alexanderian, Serge Prudhomme, and Omar M. Knio,** *Applied Mathematical Modelling*. (Subscription may be required.)

FEBRUARY 2018

U.S. DOE's Economic Approaches and Resources for Evaluating the Cost of Implementing Carbon Capture, Utilization, and Storage (CCUS).

The following is the Abstract of this article: "[DOE] and [NETL] are world leaders in CCUS research and analysis. They have developed resources and a set of economic tools to evaluate the cost to implement CCUS for each segment of the value chain: capture, transport, and storage. This paper provides a comprehensive review of the economic models and analytical approaches DOE/NETL has developed for assessing the CO_2 capture, storage, and transport cost drivers that impact the entire CCUS value chain. Failure to effectively evaluate the economic opportunity for CCUS technology to reduce CO_2 emissions would deter wide-spread deployment. DOE's economic models and resources enable a variety of possible analytical approaches to evaluate the economics associated with deploying CCUS. The resources are open-source so that interested stakeholder groups can apply them to their specific problems, and to enable feedback to improve these models moving forward." **Derek Vikara, Chung Yan Shih, ShangMin Lin, Allison Guinan, Timothy Grant, David Morgan, and Donald Remson,** *Journal of Sustainable Energy Engineering*. (Subscription may be required.)

The Value of CCS under Current Policy Scenarios: NDCs and Beyond.

The following is the Abstract of this article: "This paper describes preliminary results of analysis using the Global Change Assessment Model (GCAM) to evaluate the potential role of CCS in achieving emissions reduction targets. Scenarios are modelled using the *Paris-Increased Ambitio*n (PIA) case developed by Fawcett et al. (2015), and a more aggressive *Paris Two-Degree Ambition* (P2A) case. Both cases are based upon nationally determined contributions (NDCs) agreed to at the UNFCCC Conference of Parties (COP-21) in December 2015, coupled with additional mitigation effort beyond the 2030 Paris timeframe, through the end of the century. Analysis of CCS deployment and abatement costs under both policy scenarios suggests that, as modelled, having CCS in the technological portfolio could reduce the global cost of addressing emissions reduction targets specified under the policy scenario by trillions of dollars. Through the end of the century, total global abatement costs over the century associated with the PIA case – with five percent annual reduction in emission intensity and reaching 2.2 degrees by 2100 – are reduced by $15 trillion USD in the scenario where CCS is available to deploy by 2025 and remains available through 2100, nearly halving the cost of climate change abatement. Under the more ambitious P2A case, with 8 percent annual reduction in emission intensity and reaching 1.9 degrees by 2100, the availability of CCS reduces global abatement costs by $22 trillion USD through the end of the century, again nearly halving the costs of addressing the policy, relative to achieving the same target using an energy portfolio that does not include CCS. PIA and P2A scenarios with CCS result in 1,250 and 1,580 $GtCO_2$ of global geologic storage through the end of the century, respectively." **Casie L. Davidson, Robert T. Dahowski, Haewon C. McJeon, Leon E. Clarke, Gokul C. Iyer, and Matteo Muratori,** *Energy Procedia*. (Subscription may be required.)

A review of developments in carbon dioxide storage.

The following is the Abstract of this article: "CCS has been identified as an urgent, strategic and essential approach to reduce anthropogenic CO_2 emissions, and mitigate the severe consequences of climate change. [Carbon dioxide] storage is the last step in the CCS chain and can be implemented mainly through oceanic and underground geological sequestration, and mineral carbonation. This review paper aims to provide state-of-the-art developments in CO_2 storage. The review initially discussed the potential options for CO_2 storage by highlighting the present status, current challenges and uncertainties associated with further deployment of established approaches (such as storage in saline aquifers and depleted oil and gas reservoirs) and feasibility demonstration of relatively newer storage concepts (such as hydrate storage and CO_2-based enhanced geothermal systems). The second part of the review outlined the critical criteria that are necessary for storage site selection, including geological, geothermal, geohazards, hydrodynamic, basin maturity, and economic, societal and environmental factors. In the third section, the focus was on identification of CO_2 [behavior] within the reservoir during and after injection, namely injection-induced seismicity, potential leakage pathways, and long-term containment complexities associated with CO_2-brine-rock interaction. In addition, a detailed review on storage capacity estimation methods based on different geological media and trapping mechanisms was provided. Finally, an overview of major CO_2 storage projects, including their overall outcomes, were outlined. This review indicates that although CO_2 storage is a technically proven strategy, the discussed challenges need to be addressed in order to accelerate the deployment of the technology. In addition, beside the necessity of techno-economic aspects, public acceptance of CO_2 storage plays a central role in technology deployment, and the current ethical mechanisms need to be further improved." **Mohammed D. Aminu, Seyed Ali Nabavi, Christopher A. Rochelle, and Vasilije Manovic,** *Applied Energy*. (Subscription may be required.)

An interval robust stochastic programming method for planning carbon sink trading to support regional ecosystem sustainability—A case study of Zhangjiakou, China.

The following is the Abstract of this article: "In this study, an interval two-stage robust optimization method (ITRM) is developed for planning carbon-emission trading between ecosystem and industrial systems under uncertainty. The developed ITRM incorporates interval-parameter programming (IPP) and two-stage stochastic programming (TSP) within a robust optimization (RO) framework to deal with uncertainties presented as both probabilities and intervals and to reflect economic penalties as corrective measures or recourse against any infeasibilities arising due to a particular realization of an uncertain event. Compared with the traditional TSP, ITRM can effectively reflect the risk generated by stochastic programming process and enhance the robustness of the model, such that it is suitable for risk-aversive planners under high-variability conditions. The ITRM is applied to a case of carbon sink trading of Zhangjiakou and CO_2 emission planning under uncertainty. The results obtained reveal that carbon trading mechanism can greatly optimize the allocation of resources and reduce the cost of emission abatement. The results also reveal that the contribution of forest ecosystems to carbon sinks and ecosystem services than others. Moreover, the system benefit would decrease as the robustness level is raised. Results indicate that when the robustness level is relatively low, the decision makers would pay more attention to the economic benefit of the system and neglect the stability of the system." **Z.S. Guo, Y.P. Li, G.H. Huang, S.W. Jin, and Brian W. Baetz,** *Ecological Engineering.* (Subscription may be required.)

Heterogeneity, pore pressure, and injectate chemistry: Control measures for geologic carbon storage.

The following is the Abstract of this article: "Desirable outcomes for geologic carbon storage include maximizing storage efficiency, preserving injectivity, and avoiding unwanted consequences such as caprock or wellbore leakage or induced seismicity during and post injection. To achieve these outcomes, three control measures are evident including pore pressure, injectate chemistry, and knowledge and prudent use of geologic heterogeneity. Field, experimental, and modeling examples are presented that demonstrate controllable GCS via these three measures. Observed changes in reservoir response accompanying CO_2 injection at the Cranfield (Mississippi, USA) site, along with lab testing, show potential for use of injectate chemistry as a means to alter fracture permeability (with concomitant improvements for sweep and storage efficiency). Further control of reservoir sweep attends brine extraction from reservoirs, with benefit for pressure control, mitigation of reservoir and wellbore damage, and water use. State-of-the-art validated models predict the extent of damage and deformation associated with pore pressure hazards in reservoirs, timing and location of networks of fractures, and development of localized leakage pathways. Experimentally validated geomechanics models show where wellbore failure is likely to occur during injection, and efficiency of repair methods. Use of heterogeneity as a control measure includes where best to inject, and where to avoid attempts at storage. An example is use of waste zones or leaky seals to both reduce pore pressure hazards and enhance residual CO_2 trapping." **Thomas Dewers, Peter Eichhubl, Ben Ganis, Steven Gomez, Jason Heath, Mohamad Jammoul, Peter Kobos, Ruijie Liu, Jonathan Major, Ed Matteo, Pania Newell, Alex Rinehart, Steven Sobolik, John Stormont, Mahmoud Reda Taha, Mary Wheeler, and Deandra White,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Carbon tariffs: An analysis of the trade, welfare, and emission effects.

The following is the Abstract of this article: "The potential of carbon tariffs to restore competitiveness, avoid carbon leakage, and reduce global carbon emissions has been prominently discussed. To analyze the effects of carbon tariffs on trade, welfare, and carbon emissions, [the authors] develop a multi-sector, multi-factor structural gravity model that allows an analytical and quantitative decomposition of the emission changes into scale, composition, and technique effects. [The authors'] analysis shows that carbon tariffs are able to reduce world emissions, mainly via altering the production composition within and across countries, hence reducing carbon leakage. This reduction comes at the cost of lower world trade flows and lower welfare, especially for developing countries. Applying [the authors'] framework to investigate the effects of the emission reduction pledges made by the Annex I countries in the Copenhagen Accord, [the authors] find that combining national emission targets with carbon tariffs would increase the Accord's effectiveness by lowering the leakage rate from 13.4% to 4.1% (with bootstrapped 95% confidence intervals of [11.5, 15.8] and [3.3, 4.9], respectively)." **Mario Larch and Joschka Wanner,** *Journal of International Economics.* (Subscription may be required.)

Supercritical CO_2 uptake by nonswelling phyllosilicates.

The following is the Abstract of this article: "Interactions between supercritical (sc) CO_2 and minerals are important when CO_2 is injected into geologic formations for storage and as working fluids for [EOR], hydraulic fracturing, and geothermal energy extraction. It has previously been shown that at the elevated pressures and temperatures of the deep subsurface, $scCO_2$ alters smectites (typical swelling phyllosilicates). However, less is known about the effects of $scCO_2$ on nonswelling phyllosilicates (illite and muscovite), despite the fact that the latter are the dominant clay minerals in deep subsurface shales and mudstones. [The authors'] studies conducted by using single crystals, combining reaction (incubation with $scCO_2$), visualization [atomic force microscopy (AFM)], and quantifications (AFM, X-ray photoelectron spectroscopy, X-ray diffraction, and off-gassing measurements) revealed unexpectedly high CO_2 uptake that far exceeded its macroscopic surface area. Results from different methods collectively suggest that CO_2 partially entered the muscovite interlayers, although the pathways remain to be determined. [The authors] hypothesize that preferential dissolution at weaker surface defects and frayed edges allows CO_2 to enter the interlayers under elevated pressure and temperature, rather than by diffusing solely from edges deeply into interlayers. This unexpected uptake of CO_2, can increase CO_2 storage capacity by up to ~30% relative to the capacity associated with residual trapping in a 0.2-porosity sandstone reservoir containing up to 18 mass % of illite/muscovite. This excess CO_2 uptake constitutes a previously unrecognized potential trapping mechanism." **Jiamin Wan, Tetsu K. Tokunaga, Paul D. Ashby, Yongman Kim, Marco Voltolini, Benjamin Gilbert, and Donald J. DePaolo,** *Proceedings of the National Academy of Sciences of the United States of America.* (Subscription may be required.)

Policy Parity for CCS? – Public Preference on Low Carbon Electricity.

The following is the Abstract of this article: "To examine the rationale for policy parity of three basic low carbon power sources, the consumer preference for those power sources was evaluated by choice experiment through a public survey in December 2015 - January 2016. A sample with decent representativeness was obtained by two stage stratified sampling and door-to-door canvassing. The choice questions were designed with realistic attributes simulating power retail market starting from April 2016. Through the data analysis, using random parameter logit model, [the authors] found that respondents' WTP shows that they considered not only CO_2 emission reductions but also the characteristics of the three methods of low carbon power generation. It is also found that WTP is 11 yen per 1% increase in renewables, 14 yen per 1% decrease in nuclear (this WTP varies from one individual to another), and 4 yen per 1% increase in thermal power generation with CCS. The results of WTPs for the share of renewables and CCS in the power mix of new electricity retail companies in the future market rationalizes the necessity of policy parity to some extent for those technologies implying inclusion of CCS in the FIT but not nuclear." **Kenshi Itaoka, Aya Saito, and Makoto Akai,** *Energy Procedia.* (Subscription may be required.)

MARCH 2018

Highlights and Lessons from the EU CCS Demonstration Project Network.

The following is the Abstract of this article: "The European CCS Demonstration Project Network (the 'Network') is currently composed of projects located in the Netherlands, Norway, Spain, and the UK. The goal of the Network is to accelerate deployment of CCS by sharing project development experiences about technology implementation, including transport and storage of CO_2, as well as regulatory environment and financial structures. This paper aims to provide an overview of some CCS insights gained from developing the Network projects. Besides technology and project development, sharing knowledge and lessons learned on project-level basis, have also given valuable insights on how policies can enable development and implementation of appropriate regulatory frameworks, and funding schemes towards effective deployment of CCS technology in power generation sector." **Zoe Kapetaki, Jens Hetland, Thomas Le Guenan, Tom Mikunda, and John Scowcroft,** *Energy Procedia*. (Subscription may be required.)

How should Information about CCS be Shared with the Japanese Public?

The following is the Abstract of this article: "CCS is regarded as an important mitigation option of climate change. However, the public discussion about CCS has not conducted, and an energy policy concerning the introduction of CCS to thermal power plants has not been decided in Japan. There are little social researches about the public recognition of the current situation about the energy portfolio and the public's informational needs. The objective of this study is to analyze the attitudes and perception of CCS and thermal power generation through internet questionnaire surveys, and to provide appropriate information to promote public understanding and decision-making for introducing CCS technology for thermal power plants. Results showed that respondents did not grasp an accurate perception of the present energy situation such as the current energy portfolio and the role of thermal power generation. On the other hand, their risk perception toward climate change tended to decrease over time. They were not interested in CCS and almost everyone had not formed an impression of CCS yet, but people thought that CCS technology is more useful in Japan than the rest of the world. Thus the current energy situation, the baseline information and major premise, has to be shared in order to understand the impacts of introducing CCS technology. The public needs scientific evidence and explanation of implications and impacts in order to make decisions concerning the introduction of this technology. It is essential to provide appropriate information to the public linked with high public interest topics in order to overcome the lack of interest in CCS and increase public perception of it's role in thermal power." **Hiromi Kubota and Akiro Shimota,** *Energy Procedia*. (Subscription may be required.)

Probabilistic modeling and global sensitivity analysis for CO_2 storage in geological formations: a spectral approach.

The following is the Abstract of this article: "This work focuses on the simulation of CO_2 storage in deep underground formations under uncertainty and seeks to understand the impact of uncertainties in reservoir properties on CO_2 leakage. To simulate the process, a non-isothermal two-phase two-component flow system with equilibrium phase exchange is used. Since model evaluations are computationally intensive, instead of traditional Monte Carlo methods, [the authors] rely on polynomial chaos (PC) expansions for representation of the stochastic model response. A non-intrusive approach is used to determine the PC coefficients. [The authors] establish the accuracy of the PC representations within a reasonable error threshold through systematic convergence studies. In addition to characterizing the distributions of model observables, [the authors] compute probabilities of excess CO_2 leakage. Moreover, [the authors] consider the injection rate as a design parameter and compute an optimum injection rate that ensures that the risk of excess pressure buildup at the leaky well remains below acceptable levels. [The authors] also provide a comprehensive analysis of sensitivities of CO_2 leakage, where [the authors] compute the contributions of the random parameters, and their interactions, to the variance by computing first, second, and total order Sobol' indices." **Bilal M. Saad, Alen Alexanderian, Serge Prudhomme, and Omar M. Knio,** *Applied Mathematical Modelling.* (Subscription may be required.)

Effect of wettability heterogeneity and reservoir temperature on CO_2 storage efficiency in deep saline aquifers.

The following is the Abstract of this article: "Reservoir heterogeneity at various length scales is a well-established fact. This includes reservoir wettability – a key factor influencing CO_2 geo-storage efficiency and containment security – which changes with depth, and is generally non-uniform due to different depositional environments and fluid flow paths over geological times. However, the effect of heterogeneous wettability distribution on CO_2 storage efficiency is not understood. Moreover, there is a knowledge gap in terms of how temperature affects capillary and dissolution trapping, CO_2 mobility and vertical CO_2 migration distance, particularly when coupled with wettability heterogeneity effects. Thus, in this work [the authors] studied the effect of wettability heterogeneity and reservoir temperature on the vertical CO_2 plume migration, and capillary and dissolution trapping capacities. [The authors'] results clearly show that both wettability heterogeneity and reservoir temperature have a significant effect on vertical CO_2 migration, and the associated capillary and dissolution trapping mechanisms: both heterogeneously distributed wettability and higher temperature significantly accelerated the vertical CO_2 migration, CO_2 mobility and solubility trapping, while it reduced residual trapping. [The authors] thus conclude that wettability heterogeneity and reservoir temperature are important factors in the context of CO_2 geo-storage, and that heterogeneous wettability and higher reservoir temperatures reduce storage capacity." **Emad A. Al-Khdheeawi, Stephanie Vialle, Ahmed Barifcani, Mohammad Sarmadivaleh, and Stefan Iglauer,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

The impact of time-varying CO_2 injection rate on large scale storage in the UK Bunter Sandstone.

The following is the Abstract of this article: "CCS is expected to play a key role in meeting targets set by the Paris Agreement and for meeting legally binding [GHG] emissions targets set within the UK. Energy systems models have been essential in identifying the importance of CCS but they neglect to impose constraints on the availability and use of geologic CO_2 storage reservoirs. In this work [the authors analyze] reservoir performance sensitivities to varying CO_2 storage demand for three sets of injection scenarios designed to encompass the UK's future low carbon energy market. [The authors] use the ECLIPSE reservoir simulator and a model of part of the Southern North Sea Bunter Sandstone saline aquifer. From a first set of injection scenarios [the authors] find that varying amplitude and frequency of injection on a multi-year basis has little effect on reservoir pressure response and plume migration. Injectivity varies with site location due to variations in depth and regional permeability. In a second set of injection scenarios, [the authors] show that with envisioned UK storage demand levels for a large coal fired power plant, it makes no difference to reservoir response whether all injection sites are deployed upfront or gradually as demand increases. Meanwhile, there may be an advantage to deploying infrastructure in deep sites first in order to meet higher demand later. However, deep-site deployment will incur higher upfront cost than shallow-site deployment. In a third set of injection scenarios, [the authors] show that starting injection at a high rate with ramping down, a low rate with ramping up or at a constant rate makes little difference to the overall injectivity of the reservoir. Therefore, such variability is not essential to represent CO_2 storage in energy systems models resolving plume and pressure evolution over decadal timescales." **Clea Kolster, Simeon Agada, Niall Mac Dowell, and Samuel Krevor,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Optimal production and carbon emission reduction level under cap-and-trade and low carbon subsidy policies.

The following is the Abstract of this article: "In recent years, massive carbon emissions have caused serious global environmental damage such as a worsening greenhouse effect and thick haze. To curb carbon emissions as well as maintain sustainable economic development, governments promote the development of low carbon economy by issuing multiple policies among which the cap-and-trade policy (CTP) and low carbon subsidy policy (LCSP) are widely adopted. Moreover, manufacturers are increasingly adopting carbon emission reduction technology to produce greener products considering related government policies and rising environmental awareness among consumers. To give policy-making insights to governments as well as production and carbon emission reduction decision-making insights to manufacturers, this paper investigates the impacts of CTP and LCSP on the production and carbon emission reduction level of a manufacturer, and explores which policy is better for society. The results show that the carbon emission reduction level increases as the carbon trading price increases, whereas it is independent of the unit low carbon subsidy. Interestingly, the carbon trading price does not always have a negative effect on the manufacturer's profit, and the cap does not always produce a positive effect on the manufacturer's profit. More importantly, [the authors] find that LCSP is more beneficial to society when the environmental damage coefficient is less than a threshold, but otherwise CTP is more beneficial." **Kaiying Cao, Xiaoping Xu, Qiang Wu, and Quanpeng Zhang,** *Journal of Cleaner Production.* (Subscription may be required.)

The market performance of carbon trading in China: A theoretical framework of structure-conduct-performance.

The following is the Abstract of this article: "In order to provide feasible platform for the establishment of national carbon market in China and other developing countries, it is vital to competitively assess China's seven Pilot [ETSs] by comparing market performances. Hence, this paper employs the structure-conduct-performance (SCP) framework to qualitatively evaluate the external and internal performances of the China's carbon market. Particularly, a structural vector auto-regression (SVAR) approach is adopted to calculate the three invisible indicators of internal performance using time series of three typical Pilot ETS from the launching dates till May 4, 2016 with restrictions on return, trading volume and volatility variables. The results depicted that: (i) absence of legal binding forces (Market environment), market segmentation (Structure), excessive allowance allocation and lack of investment (Conduct) are main reasons for poor performance of China's Pilot ETS; (ii) with respect to internal performance, Hubei ETS has higher speculation and volatility sensitive to pricing returns. Hubei ETS also has the fastest information diffusion speed followed by Guangdong and Shanghai ETS. Guangdong ETS has a conservative investment environment and volatility is receptive to the changes in trading volume whereas Shanghai ETS has a mature investment environment." **Xueping Tan and Xinyu Wang,** *Journal of Cleaner Production.* (Subscription may be required.)

A systematic review of key challenges of CO_2 transport via pipelines.

The following is the Abstract of this article: "Transport of CO_2 via pipeline from the point of capture to a geologically suitable location for either sequestration or enhanced hydrocarbon recovery is a vital aspect of the CCS chain. This means of CO_2 transport has a number of advantages over other means of CO_2 transport, such as truck, rail, and ship. Pipelines ensure continuous transport of CO_2 from the capture point to the storage site, which is essential to transport the amount of CO_2 captured from the source facilities, such as fossil fuel power plants, operating in a continuous manner. Furthermore, using pipelines is regarded as more economical than other means of CO_2 transport. The greatest challenges of CO_2 transport via pipelines are related to integrity, flow assurance, capital and operating costs, and health, safety and environmental factors. Deployment of CCS pipeline projects is based either on point-to-point transport, in which case a specific source matches a specific storage point, or through the development of pipeline networks with a backbone CO_2 pipeline. In the latter case, the CO_2 streams, which are [characterized] by a varying impurity level and handled by the individual operators, are linked to the backbone CO_2 pipeline for further compression and transport. This may pose some additional challenges. This review involves a systematic evaluation of various challenges that delay the deployment of CO_2 pipeline transport and is based on an extensive survey of the literature. It is aimed at confidence-building in the technology and improving economics in the long run. Moreover, the knowledge gaps were identified, including lack of analyses on a holistic assessment of component impurities, corrosion consideration at the conceptual stage, the effect of elevation on CO_2 dense phase characteristics, permissible water levels in liquefied CO_2, and commercial risks associated with project abandonment or cancellation resulting from high project capital and operating costs." **V.E. Onyebuchi, A. Kolios, D.P. Hanak, C. Biliyok, and V. Manovic,** *Renewable and Sustainable Energy Reviews.* (Subscription may be required.)

Global Sequestration Potential of Increased Organic Carbon in Cropland Soils.

The following is the Abstract of this article: "The role of soil organic carbon in global carbon cycles is receiving increasing attention both as a potentially large and uncertain source of CO_2 emissions in response to predicted global temperature rises, and as a natural sink for carbon able to reduce atmospheric CO_2. There is general agreement that the technical potential for sequestration of carbon in soil is significant, and some consensus on the magnitude of that potential. Croplands worldwide could sequester between 0.90 and 1.85 Pg C/yr, i.e. 26–53 [percent] of the target of the '4p1000 Initiative: Soils for Food Security and Climate.' The importance of intensively cultivated regions such as North America, Europe, India and intensively cultivated areas in Africa, such as Ethiopia, is highlighted. Soil carbon sequestration and the conservation of existing soil carbon stocks, given its multiple benefits including improved food production, is an important mitigation pathway to achieve the less than 2°C global target of the Paris Climate Agreement." **Zomer, Robert J.; Bossio, Deborah A.; Sommer, Rolf; Verchot, Louis V.,** *Scientific Reports.* (Subscription may be required.)

APRIL 2018

Comparative analysis of transport and storage options from a CO_2 source perspective.

The following is the Abstract of this article: "This study evaluated integrated CCS costs from the perspective of a CO_2 source. A source will have captured CO_2 requiring suitable storage and affordable transportation between source and storage. Capture, transport, and storage are the links of the CCS value chain. For this study, capture costs were modeled for six hypothetical sources (various industrial and power-generation facilities) with annual CO_2 capture rates ranging from 0.65 to 3.90 million [metric tons (Mt)]. Seven storage reservoirs located in the Appalachian, Illinois and Gulf Coast Basins—and of various quality with respect to CO_2 storage—were modeled: two within the Rose Run Formation, three within the Mount (Mt.) Simon Formation, one in the Lower Tuscaloosa Formation, and one in the Frio Formation. Storage costs were calculated with the FE/NETL CO_2 Saline Storage Cost Model for the seven selected storage reservoirs under dome and regional dip structural settings. For transportation, a dedicated pipeline system and a trunkline pipeline system were modeled. Transportation costs from source to storage reservoirs were evaluated using the FE/NETL CO_2 Transport Cost Model. A source may not always be able to find suitable proximal storage. Low CCS costs reflect a source's mass of captured CO_2 finding suitable storage within an affordable transportation distance. Economies of scale are present in each link of the CCS value chain. These economies of scale are limited with respect to storage or the distance captured CO_2 can be transported to storage." **Timothy Grant, Allison Guinan, Chung Yan Shih, ShangMin Lin, Derek Vikara, David Morgan, and Donald Remson,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Timescapes of CCS Projects: Is Deferring Projects and Policies Just Kicking the Can Down the Road?

The following is the Abstract of this article: "CCS is considered a transition measure to a completely sustainable energy regime. Nonetheless, in recent years, several projects have been cancelled or postponed. This raises some questions about temporal issues. This study defines temporal features (i.e. frame, timing, tempo, and duration) for policy making and deployment of large-scale CCS projects. According to this study, it appears that CCS deployment is lagging behind due to institutional inertia and poor temporal fit. Thus, unless significant progress is made in a very few years, CCS will lose ground to other alternatives. Timing should be taken into consideration in every matter of CCS." **Farid Karimi,** *Energy Procedia*. (Subscription may be required.)

Efficiency of Carbon Dioxide Storage and Enhanced Methane Recovery in a High Rank Coal.

The following is the Abstract of this article: "The high affinity and adsorption capacity of coal to [CO_2] provides an alternative approach for the enhanced recovery of methane from unminable coalfields (CO_2-[enhanced coalbed methane (ECBM)]) by which a potential solution for long-term CO_2 sequestration in deep geological formations can also be achieved. However, due to chemomechanical effects induced by the interactions between CO_2 and coal, the effective methane production and [CO_2] storage can be degraded which has caused uncertainties about the techno-economic feasibility of the CO_2-ECBM process. This study presents an experimental investigation that aims to address key knowledge gaps related to the efficiency of CO_2 storage and [methane (CH_4)] recovery in high rank coals for which a comprehensive experimental data set and analysis are largely missing. Competitive displacements of CH_4 with [nitrogen (N_2)] or CO_2 in an anthracite coal sample from a South Wales coalfield have been studies, based on a series of core flooding experiments. The results show that the N_2 breakthrough time (the time at which 1% of the total gas injected was recovered) was almost spontaneous whereas a considerably delayed breakthrough time was observed for the case of the CO_2-ECBM experiment. In addition it was observed that for the CO_2-ECBM experiment, the ratios of CH_4 recovery with respect to the total amount of gas injected and gas stored were higher by factors of 10 and 2.4, respectively. The results also show that 90% of the total N_2 injected was produced in the outflow gas, whereas for the case of the CO_2 experiment, only 63% of the total injected CO_2 was produced. The presence of a high amount of N_2 in the outflow may lead to additional challenges in order to separate N_2 from CH_4 and thus affect the efficiency of the N_2-ECBM method. Under the conditions of the experiments, the total CH_4 displacement ratio and breakthrough for the case CO_2-ECBM were found to be more favorable compared to those obtained from N_2-ECBM. This study provides new insights into the efficiency of the CO_2-ECBM process and offers a comprehensive experimental data set that can be used for testing the accuracy of predictive models." **Mojgan Hadi Mosleh, Majid Sedighi, Philip J. Vardon, and Matthew Turner,** *Energy Fuels*. (Subscription may be required).

A plant tolerance index to select soil leaking CO_2 bio-indicators for carbon capture and storage.

The following is the Abstract of this article: "Plant response to the leakage of stored CO_2 is a key concern for safe CCS. An understanding of plant tolerance to high soil CO_2 concentrations is urgently required to facilitate bio-indicator selection for both long-term environmental monitoring and prevention of stored CO_2 leakage. In this study, [the authors] propose a new index, the Leaking CO_2 Tolerance Index, LCTI, which assesses plant CO_2 tolerance using the change (downward shift) in index values under leakage treatments. The calculated LCTI reveals that, of the four studied plants, clover was the most tolerant (0.42), followed by alfalfa (0.4), teosinte (0.33), and finally maize (0.29). [The authors'] results suggest that clover, along with other high-LCTI species, should be selected as species that can potentially adapt and respond to CCS leakage. Furthermore, plants such as maize appear suitable as bio-indicators to monitor carbon storage fields, allowing early detection of CO_2 leakage." **Xueyan Zhang, Xin Ma, Yang Wu, Qinzhu Gao, and Yue Li,** *Journal of Cleaner Production*. (Subscription may be required.)

Potential for using municipal solid waste as a resource for bioenergy with carbon capture and storage (BECCS).

The following is the Abstract of this article: "Bioenergy with Carbon Capture and Storage (BECCS) is a carbon removal technology that offers permanent net removal of CO_2 from the atmosphere. One of the significant bioenergy resources is organic waste collected from municipal solid waste (MSW). The goal of this study was to provide an estimate of the global potential for using municipal solid waste as a resource for BECCS and to compare the feasibility of two specific BECCS options: municipal solid waste incineration with carbon capture and storage (MSW-CCS), and landfill gas combusted in a gas turbine with carbon capture and storage (LFG-CCS). To assess the feasibility of MSW-based BECCS options, techno-economic and environmental impact assessments were conducted. In the case of a 'business-as-usual' scenario with no emission policy in effect, the [levelized] cost of electricity production from both BECCS options is higher than a coal power plant with CCS. However, these BECCS systems offer a lower cost of avoided CO_2. Introducing renewable energy certificates or negative emission refund schemes to BECCS has a significant impact on the economic viability of these technologies in coal-dominant power markets. Environmental impact assessment shows that around 0.7 kg CO_2-eq is removed for each kg of wet MSW incinerated, for the MSW-CCS scenario. This translates to approximately negative 2.8 billion tonnes CO_2 if all the available 4 billion tonnes MSW generated per year by 2100 is [utilized] in a MSW-CCS system. The net GHG emission of the LFG-CCS system with an average LFG collection rate of 75% was 0.56 kg CO_2-eq. Challenges include the dispersed nature of MSW resources and the lack of economic support schemes, such as commonly apply to solar and wind. Nonetheless, MSW-based BECCS technologies have significant potential for abating and in some cases removing considerable amounts of the [GHGs] from the atmosphere, thereby contributing significantly to the COP21 emission reduction targets." **Nasim Pour, Paul A. Webley, and Peter J. Cook,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

The cost of conserved water for coal power generation with carbon capture and storage in Alberta, Canada.

The following is the Abstract of this article: "The impact of CCS technology on the coal-fired power generation was evaluated in this paper. The impact was measured through the cost of conserved water (CCW) as an indicator. This indicator was estimated by combining water demand coefficients and levelized cost of electricity (LCOE). CCW was calculated based on a reference case for each of the developed 66 generic pathways of coal-based power generation with CCS. The current existing mix of power generation in the Province of Alberta, Canada was taken as the reference case in this paper. Water consumption coefficients for coal-based power generation with CCS were found in the range 1.01–4.85 m^3/MWh based on the complete life cycle and 0.15–3.65 m^3/MWh for the power generation stage. Based on the complete life cycle boundary, pathways involved ultra-supercritical configuration and oxyfuel combustion CCS technology offer the lowest CCW, with values less than 0.89 USD per m^3 of water saved for consumption and less than 0.66 USD per m^3 of water saved for withdrawals. In the sensitivity analysis, LCOE for the pathways involved dry cooling was increased by 6.00 USD/MWh over the base case value, and the resulted corresponding increase in the CCW was found in the range 9–33% compared to the base case." **Babkir Ali,** *Energy Conversion and Management*. (Subscription may be required.)

Interactions and coordination between carbon emissions trading and other direct carbon mitigation policies in China.

The following is the Abstract of this article: "China has decided to rely on a variety of policy approaches to achieve its ambitious [GHG] mitigation targets, with carbon emissions trading as the latest policy alongside many existing policies, such as GDP CO_2 intensity reduction, energy efficiency and renewable energy policies. This article is intended to elucidate from a qualitative perspective the interactions between emissions trading and other relevant policies in China through the analysis of their elements, policy processes, characteristics, dimensions, performances and impacts. Intensive interviews were conducted with more than 50 major stakeholders involved in the policy formulation and implementation process, including policy makers at different levels, experts, industries and verifiers. The authors themselves were also deeply involved in

the policy formulation and implementation process. The analysis shows that coordination between emissions trading and other policies, which is urgently needed from many aspects, is lacking in most aspects in practice for many reasons, among which institutional vested interests are possibly the most important. It is proposed that coordination should be conducted at both political and technical levels to achieve the full benefits of emissions trading, and starting from technical aspects may be a practical approach." **Maosheng Duan, Zhiyu Tian, Yongqiang Zhao, Mengyu Li,** *Energy Research & Social Science*. (Subscription may be required.)

Remanufacturing with trade-ins under carbon regulations.

The following is the Abstract of this article: "Observing prevalent concerns about the influence of carbon emissions on climate change, [the authors] address the problem of remanufacturing with trade-ins under carbon regulations. [The authors] analyze the optimal pricing and production decisions of the manufacturer under the carbon tax policy and the cap and trade program. The results show that the introduction of carbon regulations can promote sales of remanufactured products while reducing the demands of new products. However, the implementation of carbon regulations has negative impacts on the manufacturer's profits. Nevertheless, the manufacturer's profits can be improved through deliberately designed government subsidy schemes. [The authors] also demonstrate that the government has the incentive to propose such subsidy schemes because the total emissions can be reduced under well-designed regulations, but not at the cost of the manufacturer's profits." **Zhaowei Miao, Huiqiang Mao, Ke Fu, and Yu Wang,** *Computers and Operations Research*. (Subscription may be required.)

MAY 2018

World Bank CCS Program Activities in Botswana – Results and Lessons Learned.

The following is from the Abstract of this article: "The World Bank Carbon Capture and Storage Trust Fund (CCS TF) was established in 2009 to support CCS capacity and knowledge building in developing countries. CCS TF Phase 1 support for CCS in Botswana included an allocation of USD 1.4 million and had the objective of supporting the Government of Botswana in the following areas: [1] Identifying potential geological reservoirs that can be utilized to store CO_2 captured from coal-fired power plants; [2] Evaluating institutional and regulatory arrangements for CCS deployment in the country and recommendations for reinforcing institutional capacity; and [3] Providing training, education and capacity building at all stages throughout implementation, including a Study Tour for key individuals. For all three studies, the WB selected Environmental Resources Management Southern Africa (Pty) Ltd (ERM) as the lead consultant, in association with Wellfield Geosciences (Botswana) and Carbon Counts Company (UK) Ltd. The completed geological assessment found that there may be technical potential for geological storage of CO_2 in Botswana's geological formations within the Kalahari Karoo Basin, including three areas of interest -- the Passarge Basin, the Lephephe Graben and the Mmashoro Low. There is, however, a general lack of CO_2 storage-relevant geological data that needs to be developed, if a more accurate assessment of CO_2 storage potential is to be undertaken. The Passarge Basin was seen to be worthiest of additional investigation, which could be done through the re-examination of existing data or through new geological exploration. The Mashoro Low and Lephephe Graben are in close proximity to the centers of current coal-bed methane (CBM) exploration, suggesting that the integration of CBM exploitation and CO_2 storage processes could be considered." **Brendan Beck and Natalia Kulichenko-Lotz**, *Energy Procedia.* (Subscription may be required.)

Subsurface CO_2 storage estimation in Bakken tight oil and Eagle Ford shale gas condensate reservoirs by retention mechanism.

The following is the Abstract of this article: "This paper describes the CO_2 geological sequestration process in unconventional reservoirs in northern and southern United States such as Bakken tight oil and Eagle Ford shale gas condensate reservoirs. The hysteresis modelling and retention mechanism was performed in this research and this is one of the efficient and proven method to store CO_2 in the subsurface. This can be achieved through CO_2 EOR process while injecting CO_2, the fluid will be trapped in the pore spaces between the impermeable rocks and oil can be recovered simultaneously. A total of four cases was taken for the analysis, such as the Bakken and Eagle Ford reservoirs with CO_2 huff-n-puff process and another two cases with CO_2 Flooding. Injection pressure, injection rate, injection time, number of cycles, [CO_2] soaking time, fracture half-length, fracture conductivity, fracture spacing, porosity, permeability, and initial reservoir pressure as is taken as inputs and cumulative oil production, and oil recovery factor was taken as outputs. The reservoirs were modelled for 30 years of oil production and the factor year was taken as Decision Making Unit (DMU) and the models was calculated at each year. The retention was successfully calculated in all four models and percentage of retention above 90% was observed in all four cases and the injection pressure has the most dominating effect on the CO_2 geological sequestration. It was also revealed that the CO_2 huff-n-puff performance in Bakken reservoir is not that much more effective since the retention rate decreases during soaking period and flooding was found to be a suitable method in this formation. Even in Eagle Ford formation, the average performance of CO_2 flooding process is better than the huff-n-puff, but the latter process was quite effective in this shale gas condensate reservoir." **Venkat Pranesh**, *Fuel*. (Subscription may be required.)

An innovative computationally efficient hydromechanical coupling approach for fault reactivation in geological subsurface utilization.

The following is the Abstract of this article: "Estimating the efficiency and sustainability of geological subsurface utilization, i.e., CCS requires an integrated risk assessment approach, considering the occurring coupled processes, beside others, the potential reactivation of existing faults. In this context, hydraulic and mechanical parameter uncertainties as well as different injection rates have to be considered and quantified to elaborate reliable environmental impact assessments. Consequently, the required sensitivity analyses consume significant computational time due to the high number of realizations that have to be carried out. Due to the high computational costs of two-way coupled simulations in large-scale 3D multiphase fluid flow systems, these are not applicable for the purpose of uncertainty and risk assessments. Hence, an innovative semi-analytical hydromechanical coupling approach for hydraulic fault reactivation will be introduced. This approach determines the void ratio evolution in representative fault elements using one preliminary base simulation, considering one model geometry and one set of hydromechanical parameters. The void ratio development is then approximated and related to one reference pressure at the base of the fault. The parametrization of the resulting functions is then directly implemented into a multiphase fluid flow simulator to carry out the semi-analytical coupling for the simulation of hydromechanical processes. Hereby, the iterative parameter exchange between the multiphase and mechanical simulators is omitted, since the update of porosity and permeability is controlled by one reference pore pressure at the fault base. The suggested procedure is capable to reduce the computational time required by coupled hydromechanical simulations of a multitude of injection rates by a factor of up to 15." **M. Adams, T. Kempka, E. Chabab, and M. Ziegler**, *Computers & Geosciences*. (Subscription may be required.)

Managing Forest Soils for Carbon Sequestration: Insights From Modeling Forests Around the Globe.

The following is the Abstract of this article: "Soil carbon (C), a fundamental component of soil organic matter (SOM), is commonly recognized as one of the key parameters of soil quality. It has been linked to ecosystem productivity because it is a sensitive indicator for monitoring programs. It is a critical pool in the carbon cycle, and through its influence on many fundamental biological and chemical processes, it plays a pivotal role in nutrient release and availability. Through its role in soil aggregation, it influences soil porosity and thus gas exchange reactions and water storage and availability for plants and microorganisms. However, several processes can deplete or alter SOM in different ways (acid rain, atmospheric deposition, fire, intensive harvesting, etc.). Such phenomena can prevent forest soils from reaching their potential for biomass production and C sequestration, therefore reducing their contribution to climate change mitigation and adaptation strategies. However, the long-time scales involved in forest soil ecological processes make it difficult to study the effects of forest management on soil C. An alternative is to use 'virtual experiments' through ecological models. In this chapter an overview is provided of the most

important factors altering soil C in forests soils, showcasing three examples of how ecological modeling can be used to better define forest management plans to maximize soil C sequestration." **Juan A. Blanco**, *Soil Management and Climate Change*. (Subscription may be required.)

Consumption-based accounting and the trade-carbon emissions nexus.

The following is the Abstract of this article: "This paper considers a recently developed consumption-based carbon emissions database from which emissions calculations are made based on the domestic use of fossil fuels plus the embodied emissions from imports minus exports, to test directly for the importance of trade in national emissions. Comparing such consumption-based emissions data to conventionally-measured territory-based emissions data produces several useful conclusions. For example, most countries are net importers of carbon emissions—their consumption-based emissions are higher than their territory-based emissions. Also, while low and high income countries tend to have the largest ratios (of consumption-based emissions to territory-based emissions), the majority of middle-income countries have ratios greater than one as well. Furthermore, China alone is responsible for over half the global outflows of carbon via trade. The econometric estimations—which were robust across income levels—determined that: (i) trade was significant for consumption-based emissions but not for territory-based emissions; (ii) exports and imports offset each other so that exports lower consumption-based emissions, whereas imports increase them; and (iii) the fossil fuel content of a country's energy mix is more important (likely significantly so) for territory-based emissions than for consumption-based emissions; and (iv) domestic fossil fuel prices (oil, gasoline) had a negative impact on territory-based emissions but were insignificant for consumption-based emissions. Hence, there is a wedge between (i) the emissions a country is responsible for—consumption-based emissions—and (ii) the emissions that a country's domestic policies affect—territory-based emissions. So, countries should have both an interest and a responsibility to help lower the carbon intensity of energy in countries that are particularly important for global carbon transfers—China and India." **Brantley Liddle**, *Energy Economics*. (Subscription may be required.)

Dynamics of China's carbon prices in the pilot trading phase.

The following is the Abstract of this article: "This paper is the first to investigate empirically the link between carbon prices and macro risks in China's cap-and-trade pilot scheme. Using data from four pilot markets in Beijing, Guangdong, Hubei, and Shenzhen from 2014 to 2016, [the authors] demonstrate that the carbon price in Hubei is weakly linked to international prices of natural gas. [The authors'] results also indicate that energy, utilities, industrial and materials sector indices are positively related to the allowance prices in Shenzhen and Guangdong, suggesting that higher emitters in the region may have factored the carbon price into their production mix. [The authors] find no statistically significant relationship in the Beijing pilot. Overall, the findings suggest that China's carbon market is currently in an early stage of development, as the carbon price fundamentals are weak and the markets are comparatively less efficient than the European trading scheme in an informational sense. The findings of the paper have policy implications for the upcoming integration of regional markets into the national carbon market." **John Hua Fan and Neda Todorova**, *Applied Energy*. (Subscription may be required.)

Making the Communication of CCS more "Human."

The following is the Abstract of this article: "CCS communication has proven a tough challenge, particularly for the difficulty in raising interest for the technology, which is still unknown to the majority of the population, and for the complexity of conveying information about its potential for reducing emissions. In this paper [the authors] present a research based effort for bringing CCS nearer to people, through visual material developed taking into account emotional needs related to the technology. The production of a short introductory film on CCS is illustrated and its testing with a sample of 700 high school students." **Samuela Vercelli, Salvatore Lombardi, Federica Modesti, Maria Chiara Tartarello, Maria Grazia Finoia, Davide De Angelis, Sabina Bigi, Livio Ruggiero, and Stefano Pirrotta,** *Energy Procedia*. (Subscription may be required.)

A fast and robust TOUGH2 module to simulate geological CO_2 storage in saline aquifers.

The following is the Abstract of this article: "A new $TOUGH_2$ module to simulate geological CO_2 storage (GCS) in saline aquifers is developed based on the widely employed ECO_2N module of $TOUGH_2$. The newly developed $TOUGH_2$ module uses a new non-iterative fugacity-activity thermodynamic model to obtain the partitioning of CO_2 and H_2O between the aqueous and gas phases. Simple but robust thermophysical correlations are used to obtain density, viscosity, and enthalpy of the gas phase. The implementation and accuracy of the employed thermophysical correlations are verified by comparisons against the national institute of standards and technology (NIST) online thermophysical database. To assess the computation accuracy and efficiency, simulation results obtained with the new $TOUGH_2$ module for a one-dimensional non-isothermal radial and a three-dimensional isothermal system are compared against the simulation results obtained with the ECO_2N module. Treating salt mass fraction in the aqueous phase as a constant, along with the inclusion of a non-iterative fugacity-activity thermodynamic model, and simple thermophysical correlations, resulted in simulations much faster than simulations with ECO_2N module, without losing numerical accuracy. Both modules yield virtually identical results. Additional field-scale simulations of CO_2 injection into an actual non-isothermal and heterogeneous geological formation confirmed that the new module is much faster than the ECO_2N module in simulating complex field-scale conditions. Owing to its capability to handle CO_2-CH_4-H_2S-N_2 gas mixtures and its compatibility with TOUGHREACT, this new $TOUGH_2$ module offers the possibility of developing a fast and robust TOUGHREACT module to predict the fate of CO_2 in GCS sites under biotic conditions where CO_2, CH_4, H_2S, and N_2 gases can be formed." **Babak Shabani and Javier Vilcáez**, *Computers & Geosciences*. (Subscription may be required.)

JUNE 2018

An Integrated Carbon Policy-Based Interactive Strategy for Carbon Reduction and Economic Development in a Construction Material Supply Chain.

The following is the Abstract of this article: "Carbon emissions from the construction material industry have become of increasing concern due to increasingly urbanization and extensive infrastructure. Faced with serious atmospheric deterioration, governments have been seeking to reduce carbon emissions, with carbon trading and carbon taxes being considered the most effective regulatory policies. Over time, there has been a global consensus that integrated carbon trading/carbon tax policies are more effective in reducing carbon emissions. However, in an integrated carbon reduction policy framework, balancing the relationship between emission reductions and low-carbon benefits has been found to be a critical issue for governments and enterprises in both theoretical research and carbon emission reduction practices. As few papers have sought to address these issues, this paper seeks to reach a trade-off between economic development and environmental protection involving various stakeholders: regional governments which aim to maximize social benefits, and producers who seek economic profit maximization. An iterative interactive algorithmic method with fuzzy random variables (FRVs) is proposed to determine the satisfactory equilibrium between these decision-makers. This methodology is then applied to a real-world case to demonstrate its practicality and efficiency." **Liming Zhang, Wei Yang, Yuan Yuan, and Rui Zhou**, *Sustainability.* (Subscription may be required.)

Global Carbon Budget 2017.

The following is from the Abstract of this article: "Accurate assessment of anthropogenic CO_2 emissions and their redistribution among the atmosphere, ocean, and terrestrial biosphere – the 'global carbon budget' – is important to better understand the global carbon cycle, support the development of climate policies, and project future climate change. Here [the authors] describe data sets and methodology to quantify the five major components of the global carbon budget and their uncertainties. CO_2 emissions from fossil fuels and industry (EFF) are based on energy statistics and cement production data, respectively, while emissions from land-use change (ELUC), mainly deforestation, are based on land-cover change data and bookkeeping models. The global atmo-

spheric CO_2 concentration is measured directly and its rate of growth (GATM) is computed from the annual changes in concentration. The ocean CO_2 sink (SOCEAN) and terrestrial CO_2 sink (SLAND) are estimated with global process models constrained by observations. The resulting carbon budget imbalance (BIM), the difference between the estimated total emissions and the estimated changes in the atmosphere, ocean, and terrestrial biosphere, is a measure of imperfect data and understanding of the contemporary carbon cycle." **Corinne Le Quéré et al.**, *Earth System Science Data*. (Subscription may be required.)

Diffusivity of Carbon Dioxide in Aqueous Solutions under Geologic Carbon Sequestration Conditions.

The following is the Abstract of this article: "Accurate assessment of the long-term security of geologic carbon sequestration requires knowledge of the mobility of [CO_2] in brines under pressure and temperature conditions that prevail in subsurface aquifers. Here, [the authors] report Raman spectroscopic measurements of the rate of CO_2 diffusion in water and brines as a function of pressure, salinity, and concentration of CO_2. In pure water at 50 ± 2°C and 90 ± 2 bar, [the authors] find the diffusion coefficient, D, to be (3.08 ± 0.03) × 10^{-9} m^2/s, a value that is consistent with a recent microfluidic study but lower than earlier [pressure, volume, and temperature (PVT)] measurements. Under reservoir conditions, salinity affects the mobility of CO_2 significantly and D decreased by 45% for a 4 M solution of NaCl. [The authors] find significant differences of diffusivity of CO_2 in brines (0–4 M NaCl), in both the absolute values and the trend compared to the Stokes–Einstein prediction under [the authors'] experimental conditions. [The authors] observe that D decreases significantly at the high CO_2 concentrations expected in subsurface aquifers (~15% reduction at 0.55 mol/kg of CO_2) and provides an empirical correction to the commonly reported D values that assume a tracer concentration dependence on diffusivity." **Pradeep N. Perera, Hang Deng, P. James Schuck, and Benjamin Gilbert**, *The Journal of Physical Chemistry*. (Subscription may be required.)

Impacts of SO_2 gas impurity within a CO_2 stream on reservoir rock of a CCS pilot site: Experimental and modelling approach.

The following is the Abstract of this article: "In order to evaluate chemical impacts of [sulfur dioxide (SO_2)] impurity on reservoir rock during CO_2 capture and storage in deep saline aquifers, several batch reactor experiments were performed on laboratory scale using core rock samples from the pilot CO_2 injection site in Heletz. In this experiment, the samples were exposed to pure N_2(g), pure CO_2(g), and CO_2(g) with an impurity of 1.5% SO_2(g) under reservoir conditions for pressure and temperature (14.5 MPa, 60°C). Based on the set-up and the obtained experimental results, a batch chemical model was established using the numerical simulation program TOUGHREACT V3.0-OMP. Comparing laboratory and simulation data provides a better understanding of the rock-brine-gas interactions. In addition, it offers an evaluation of the capability of the model to predict chemical interactions in the target injection reservoir during exposure to pure and impure CO_2. The best match between the geochemical model and experimental data was achieved when the reactive surface area of minerals in the model was adjusted in order to calibrate the kinetic rates of minerals. The simulations indicated that SO_2(g) tends to dissolve rather quickly and oxidizes under a kinetic control. Hence, it has a stronger effect on the acidity of the brine than pure CO_2(g) and as a result, increased mineral dissolution and caused the precipitation of sulfate and sulfide minerals. Ankerite, dolomite, and siderite, the most abundant carbonates in the sandstone rock sample, are subject to stronger dissolution in the presence of SO_2 gas. The performed simulations confirmed a slower dissolution rate for ankerite and siderite than for dolomite. The model reproduced the precipitation of pyrite and anhydrite as observed in the laboratory. The dissolution of dolomite observed in the batch reaction test with pure N_2 is assumed to be due to slight contamination with oxygen and modelling supported this. The inclusion of SO_2 increased the porosity over that of the pure CO_2 case, and is thus considered to increase the permeability and injectivity of the reservoir as well. Exposure to SO_2 also increased the concentration of trace elements. The calibrated kinetic parameters determined in this study will be used to model the injection and long-term behavior of CO_2 at the Heletz field site, and may be used for similar geologic reservoirs." **Maryeh Hedayati, Andrew Wigston, Jan Lennard Wolf, Dorothee Rebscher, and Auli Niemi**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Transnational transfer of carbon emissions embodied in trade: Characteristics and determinants from a spatial perspective.

The following is the Abstract of this article: "Based on the multi-regional input-output analytical framework and spatial econometric regression models, this paper analyzes embodied global emissions in trade, so as to unravel the characteristics of spatial emissions transfer for 39 countries from 1995 to 2011, and investigates the determinants of transnational transfer of the global emissions in trade changes from a spatial perspective. One important finding from this study is that the global emissions in trade primarily have flown from developing to developed countries and regions. Notably, however, for those countries endowed with rich natural resources and developed economy like Canada, they have become the net carbon exporters in trade. Another important finding is that such important determinants as energy and industrial structure have spatial spillover effects on the emissions embodied in trade changes. Regarding climate policies, [the authors'] results suggest that the increase in the share of clean energy could curtail the impact of trade on global carbon emissions. Notably, [the authors'] study also finds that improving energy efficiency would not lower the emissions embodied in global trade because the forecasted reduction in energy use and thus carbon emissions that may be lost due to the sum of consumer and market responses." **Zhangqi Zhong, Lei Jiang, and Peng Zhou**, *Energy*. (Subscription may be required.)

Value of performance baseline in voluntary carbon trading under uncertainty.

The following is the Abstract of this article: "Voluntary carbon trading has long been criticized for producing a large number of non-additional offsets. The reason for this production lies primarily in the use of a project-based baseline that misrepresents the business-as-usual (BAU) emissions of individual projects. Performance baseline however, as an alternative baseline approach, does not rely on evaluating individual BAU emissions. Instead, it uses a pre-defined emission threshold for a class of project activities. This paper compares the effects of the two baseline approaches on sectoral emission mitigation and compliance costs by modeling dynamic emission abatement behaviors. In the context of the U.S. commercial building sector, the modeling results indicate that while both baseline approaches are capable of reducing sectoral emissions, the use of performance baseline is especially advantageous under private cost information and uncertain market environments. The performance baseline should be stratified by region to ensure the equity in offset allocation in sectors that are highly diversified in emission magnitudes." **Xiaoyu Liu and Qingbin Cui**, *Energy*. (Subscription may be required.)

General public reactions to carbon capture and storage: Does culture matter?

The following is the Abstract of this article: "[The authors scrutinize CCS] technology from a cross-cultural perspective. The reaction of the public to CCS will considerably affect the development of the technology. Previous research has identified general and local mechanisms in how the general public reacts to CCS. Researchers have noticed that differences exist between countries, but the effects of cross-cultural differences have not been explored in detail. [The authors] argue that it is crucial to understand how public perceptions of the technology emerge and form in their individual contexts or embedded in large-scale cultural frameworks. Public reaction to CCS is structured in two dimensions—risk perception and benefit perception—and [the authors] design a model with individual and national cultural level predictors. [The authors] indicate that effects of individual level variables such as familiarity with technology, or sociodemographic variables such as education, are important but their effects are likely mediated and confounded by the cultural setting people operate in. The results show that, in parallel with other factors such as trust, risk perception is affected by cultural dimensions such as uncertainty avoidance and the society's short-term or long-term orientation. [The authors] provide a framework to understand why and how societies challenge the technology." **Farid Karimi and Arho Toikka**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Exergy and economic analyses of indirect coal-to-liquid technology coupling carbon capture and storage.

The following is the Abstract of this article: "Coal-to-liquids (CTL) technology has been developed steadily for producing gasoline and diesel fuels as the demand for energy security issue and liquid fuels in China outpaces production capacities. In this light, given the importance of CO_2 emissions in climate change, CCS is considered as an integral part of CTL processes. In this study, CTL coupling with CCS technology (CTL-CCS) were simulated using the Aspen Plus software. Based on it, this study conducted exergy and economic analyses to the CTL-CCS system for five different coal types, including anthracite, meager, lean, coking and gas. Results show that the exergy utilization ratios ranged from 40.3% to 43.7%, revealing only a limited effect of the choice of coal type; although anthracite, meager, and gas coal were marginally better. Results also indicate the largest sources of exergy loss to be firstly from gas generation and secondly from the combined process of synthesis and separation. The economic analysis compared the cost, net present value, internal rate of return, and payback period. The cost of liquid fuel produced by CTL-CCS system was in the range from 4117 to 5627 yuan RMB/t, indicating economic feasibility. The system using lean coal revealed the best economic performance, while those using coking coal and gas coal were the second best performers. This research suggests that gas coal can achieve relatively reasonable values for both the exergy utilization ratio and cost in comparison to other coal types processed through a coupled CTL-CCS system." **Li Zhou, Maosheng Duan, and Yadong Yu**, *Journal of Cleaner Production*. (Subscription may be required).

JULY 2018

Developing CCS in the UK and Beyond: Insights from the UK CCS Research Centre.

The following is the Abstract of this article: "The UK Carbon Capture and Storage Research Centre coordinates a programme of research covering all aspects of CCS in support of basic science and UK government efforts on energy and climate change. This paper will present progress and 'lessons learned' from the Centre's activities, with a particular focus on the development and use of pilot scale facilities and encouraging industrial and other stakeholder engagement in research. It will also highlight key features of an extensive programme of international engagement activities undertaken by the Centre, identifying added value for both the UK CCS community and global development of CCS." **Ciara O'Connor, Hannah Chalmers, Steph Wright, Bruce Adderley, and Jon Gibbins,** *Energy Procedia*. (Subscription may be required.)

The Neglected Importance of Corporate Perceptions and Positions for the Long-term Development of CCS.

The following is the Abstract of this article: "Many companies that produce fossil fuels or fossil fuel-derived products show a strong belief in a large and continuing role for fossil fuels in the global economy up to 2050 and beyond. These companies are generally expected to be amongst the primary consumers of CCS technology. So far, however, fossil fuel companies have shown only moderate interest in CCS. Whilst a lot of potential operational barriers to CCS adoption have been identified in the literature, the value of CCS from a corporate strategy perspective has sometimes been assumed, but rarely explored. This paper asks the following question: What are the perceptions and positions of fossil fuel companies on CCS and how does this inform their decision-making on CCS investment and advocacy? This paper addresses this issue by presenting the results of in-depth interviews with high-level CCS experts from major multinational oil and gas companies and major coal mining firms. The results indicate that CCS would require a significant change within the business strategy of fossil fuel companies. This is contrary to the common argument that CCS is attractive because the technology is regarded as not being very disruptive to the incumbent energy system as it leaves most of the existing infrastructure, actor constellations and institutions intact. While fossil fuel companies engage in CCS development, it is often to [familiarize] themselves with technologies that might have future value if markets for these technologies take off. In several cases, CCS engagement has served the strategic need to weaken the link between fossil fuel extraction and climate change, build up shareholder trust, and improve public perception. However, there is little evidence that these companies engage in CCS to develop a strategic insurance against climate policy risks to their core businesses." **Lukas Braunreiter and Simon J. Bennett,** *Energy Procedia*. (Subscription may be required.)

The cost of getting CCS wrong: Uncertainty, infrastructure design, and stranded CO_2.

The following is the Abstract of this article: "CCS infrastructure will require industry—such as fossil-fuel power, ethanol production, and oil and gas extraction—to make massive investment in infrastructure. The cost of getting these investments wrong will be substantial and will impact the success of CCS technology. Multiple factors can and will impact the success of commercial-scale CCS, including significant uncertainties regarding capture, transport, and injection-storage decisions. Uncertainties throughout the CCS supply chain include policy, technology, engineering performance, economics, and market forces. In particular, large uncertainties exist for the injection and storage of CO_2. Even taking into account upfront investment in site characterization, the final performance of the storage phase is largely unknown until commercial-scale injection has started. [The authors] explore and quantify the impact of getting CCS infrastructure decisions wrong based on uncertain injection rates and uncertain CO_2 storage capacities using a case study managing CO_2 emissions from the Canadian oil sands industry in Alberta. [The authors] use SimCCS, a widely used CCS infrastructure design framework, to develop multiple CCS infrastructure scenarios. Each scenario consists of a CCS infrastructure network that connects CO_2 sources (oil sands extraction and processing) with CO_2 storage reservoirs (acid gas storage reservoirs) using a dedicated CO_2 pipeline network. Each scenario is analyzed under a range of uncertain storage estimates and infrastructure performance is assessed and quantified in terms of cost to build additional infrastructure to store all CO_2. [The authors] also include the role of stranded CO_2, CO_2 that a source was expecting to but cannot capture due substandard performance in the transport and storage infrastructure. Results show that the cost of getting the original infrastructure design wrong are significant and that comprehensive planning will be required to ensure that CCS becomes a successful climate mitigation technology. In particular, [the authors] show that the concept of stranded CO_2 can transform a seemingly high-performing infrastructure design into the worst case scenario." **Richard S. Middleton and Sean Yaw,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Cost-optimal design of pressure-based monitoring networks for carbon sequestration projects, with consideration of geological uncertainty.

The following is the Abstract of this article: "Leakage from geologic faults and abandoned wells represents one of the major risks to industrial-scale CCS projects. Current CCS regulations and best practice guidance suggest that operators emplace risk-informed monitoring, verification, and accounting (MVA) plans to protect public safety and reduce property and environmental damage. Deep subsurface pressure monitoring is regarded as one of the most cost-effective technologies for early leakage detection in CCS projects. In practice, however, the number of deep pressure monitoring wells that an operator can deploy often remains limited because of the high costs associated with drilling, instrumenting, and operating these wells. Thus, optimal design of the pressure monitoring network is essential to minimizing monitoring and liability costs and gaining public support. In this work, [the authors] present a general, binary integer programming approach to solve an optimal monitoring well network design problem under multiple constraints. Specifically, [the authors'] approach helps a CCS operator to design a cost-optimal monitoring network that covers all potentially leaky locations (in a worst-case-scenario sense) while satisfying a prescribed CO_2 storage performance criterion and considering geological uncertainty. Instead of using cost surrogates as has been done in many other studies, [the authors'] formulation allows the user to directly assess total costs in terms of monitoring costs and potential economic losses associated with brine and CO_2 leakage. [The authors'] numerical examples demonstrate that a cost-optimal monitoring network may save millions of dollars in total costs, including well construction and leakage costs. Factors exerting the most impact on the cost-optimal monitoring network design are unit leakage damage costs, pressure threshold for leakage detection, and geological uncertainty." **Hoonyoung Jeong, Alexander Y. Sun, and Xiaodong Zhang,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

MRI study on CO_2 capillary trap and drainage behavior in sandstone cores under geological storage temperature and pressure.

The following is the Abstract of this article: "Capillary pressure is an important parameter to characterize the core properties in CO_2 geological storage applications, and it is necessary to study the CO_2 drainage behavior to predict the potential and ensure the safety of storage. In this work, [the authors] conducted CO_2 drainage experiments in two types of sandstone cores (Berea sandstone and synthetic sandstone) under reservoir conditions (800m underground) and measured the capillary pressure using an MRI system. The drainage experiments were repeated in a capillary number range from 5.22×10^{-9} to 5.5×10^{-7} by varying the injection rate. The entry pressure and pore size distribution index were calculated by fitting a straight line on a log-log curve of the effective saturation versus capillary pressure. Relative permeability curves were plotted using the calculated entry pressure and pore size distribution index. The curves were consistent with the properties of the sandstone cores. The capillary desaturation curves gave the irreducible brine saturations for different permeability, wettability, injection pressure and injection direction conditions as a function of capillary number." **Ying Teng, Lanlan Jiang, Yu Liu, Dayong Wang, and Yongchen Song,** *International Journal of Heat and Mass Transfer*. (Subscription may be required.)

Modelling and optimization of a manufacturing/remanufacturing system with storage facility under carbon cap and trade policy.

The following is the Abstract of this article: "Due to rigorous environmental legislations and competitive economics worldwide, a growing number of companies are devoted to recovering and remanufacturing used products. Consequently, over the past few decades, the management of manufacturing/remanufacturing systems has been receiving increasing attention from researchers and companies leaders. Most of the existing research papers in the literature considered that remanufactured products have the same quality and price as new ones. However, in practice, the market perceives new items as higher quality products rather than remanufactured items. This paper aims to bridge the gap in research on manufacturing/remanufacturing supply chain, by investigating an optimal storage and manufacturing/remanufacturing planning, while taking into consideration the difference between new and remanufactured items, random machine failures, carbon constraints and distinct random customer demands for both items types. Furthermore, to make our system more realistic, it is assumed that the return rate of used items depends on the sales in the past periods, machine repair time is stochastic and set-up time period is not negligible. In this study, two models are developed, considering carbon emissions or not, to determine the optimal values of the manufacturing/remanufacturing period lengths and serviceable stock capacities of new and remanufactured items. Numerical results are provided to illustrate the impact of set-up cost, percentage of returned used items, machine availability, carbon cap and carbon trading price on the optimal storage and production planning. Moreover, the influences of carbon cap, carbon trading price and percentage of returned used items on carbon emissions have been analyzed. The results reveal that set-up cost, percentage of returned used items and machine availability have significant impact on storage and production planning of new and remanufactured items. In addition, the results indicate that a lower carbon cap and/or a high carbon trading price, induce the producer to collect and remanufacture used items and curb carbon emissions." **Sadok Turk, Christophe Sauvey, and Nidhal Rezg,** *Journal of Cleaner Production.* (Subscription may be required.)

How to optimize the development of carbon trading in China—Enlightenment from evolution rules of the EU carbon price.

The following is the Abstract of this article: "This paper explores the optimization scheme of carbon trading in China based on a novel energy-saving and emission-reduction (ESER) system with carbon price constraints. With the aid of nonlinear dynamics theory, the dynamics behavior of the novel system is discussed. Genetic algorithm and back propagation neural network is used to identify the quantitative coefficients according to the statistical data of the second period in European Union (EU). Taking the actual situation in EU for instance, the variables which are sensitive to carbon trading [are researched]. Enlightened by the EU's experience, an optimal road of China's carbon trading is put forward. The results show that carbon emissions could be controlled by carbon trading. The investment to carbon trading hampers economic growth in the near future, and ESER technical progress is negatively correlated with carbon trading in the long run. Demand and supply relationship is closely related to carbon price, both are the important issues in carbon trading system. Excessive government control and extortionate carbon price will deliver the opposite effect and even fatal influence on carbon trading system." **Guochang Fang, Lixin Tian, Menghe Liu, Min Fu, and Mei Sun,** *Applied Energy*. (Subscription may be required.)

Carbon trading's impact on California's real-time electricity market prices.

The following is the Abstract of this article: "What is the extent of a real-time electricity market's pass-through of the marginal cost of CO_2 emissions due to a cap-and-trade (C&T) program? This is an important policy question, as an incomplete pass-through would suggest the program's limited effectiveness in achieving efficient pricing of electricity. To answer the question, [the authors] perform a regression analysis of California's electricity market data for a 65-month period of [January 1, 2011, through May 31, 2016]. Based on this newly constructed large sample, [the authors] find that the California Independent System Operator's real-time market prices contain a CO_2 premium that closely tracks the marginal cost of CO_2 emissions of California's natural-gas-fired generation units, which are often at margin that determines the power prices. While the CO_2 premium provides much needed incentives for renewable energy development, it does little to improve the incentive for natural-gas-fired generation investment in California. Hence, procurement of dispatchable generation capacity via long-term contracts continues to be useful for the state to meet the mandatory criteria for resource adequacy and system reliability." **C.K. Woo, Y. Chen, J. Zarnikau, A. Olson, J. Moore, and T. Ho,** *Energy*. (Subscription may be required.)

AUGUST 2018

Detecting subsurface fluid leaks in real-time using injection and production rates.

The following is the Abstract of this article: "[Carbon dioxide] injection into geologic formations for either enhanced oil recovery or carbon storage introduces a risk for undesired fluid leakage into overlying groundwater or to the surface. Despite decades of subsurface CO_2 production and injection, the technologies and methods for detecting CO_2 leaks are still costly and prone to large uncertainties. This is especially true for pressure-based monitoring methods, which require the use of simplified geological and reservoir flow models to simulate the pressure behavior as well as background noise affecting pressure measurements. In this study, [the authors] propose a method to detect the time and volume of fluid leakage based on real-time measurements of well injection and production rates. The approach utilizes analogies between fluid flow and capacitance-resistance modeling. Unlike other leak detection methods (e.g. pressure-based), the proposed method does not require geological and reservoir flow models to simulate the behavior that often carry significant sources of uncertainty; therefore, with [the authors'] approach the leak can be detected with greater certainty. The method can be applied to detect when a leak begins by tracking a departure in fluid production rate from the expected pattern. The method has been tuned to detect the effect of boundary conditions and fluid compressibility on leakage. To highlight the utility of this approach [the authors] use [their] method to detect leaks for two scenarios. The first scenario simulates a fluid leak from the storage formation into an above-zone monitoring interval. The second scenario simulates intra-reservoir migration between two compartments. [The authors] illustrate this method to detect fluid leakage in three different reservoirs with varying levels of geological and structural complexity. The proposed leakage detection method has three novelties: i) requires only readily-available data (injection and production rates), ii) accounts for fluid compressibility and boundary effects, and iii) in addition to detecting the time when a leak is activated and the volume of that leakage, this method provides an insight about the leak location, and reservoir connectivity. [The authors] are proposing this as a complementary method that can be used with other, more expensive, methods early on in the injection process. This will allow an operator to conduct more expensive surveys less often because the proposed

method can show if there are no leaks on a monthly basis that is cheap and fast." **Harpreet Singh and Nicolas J. Huerta**, *Advances in Water Resources*. (Subscription may be required.)

Long-term viability of carbon sequestration in deep-sea sediments.

The following is the Abstract of this article: "Sequestration of [CO_2] in deep-sea sediments has been proposed for the long-term storage of anthropogenic CO_2 that can take advantage of the current offshore infrastructure. It benefits from the negative buoyancy effect and hydrate formation under conditions of high pressure and low temperature. However, the multiphysics process of injection and postinjection fate of CO_2 and the feasibility of subseabed disposal of CO_2 under different geological and operational conditions have not been well studied. With a detailed study of the coupled processes, [the authors] investigate whether storing CO_2 into deep-sea sediments is viable, efficient, and secure over the long term. [The authors] also study the evolution of multiphase and multicomponent flow and the impact of hydrate formation on storage efficiency. The results show that low buoyancy and high viscosity slow down the ascending plume and the forming of the hydrate cap effectively reduces permeability and finally becomes an impermeable seal, thus limiting the movement of CO_2 toward the seafloor. [The authors] identify different flow patterns at varied time scales by analyzing the mass distribution of CO_2 in different phases over time. [The authors] observe the formation of a fluid inclusion, which mainly consists of liquid CO_2 and is encapsulated by an impermeable hydrate film in the diffusion-dominated stage. The trapped liquid CO_2 and CO_2 hydrate finally dissolve into the pore water through diffusion of the CO_2 component, resulting in permanent storage. [The authors] perform sensitivity analyses on storage efficiency under variable geological and operational conditions. [The authors] find that under a deep-sea setting, CO_2 sequestration in intact marine sediments is generally safe and permanent." **Yihua Teng and Dongxiao Zhang**, *Science Advantages*. (Subscription may be required.)

Air quality co-benefits of carbon pricing in China.

The following is the Abstract of this article: "Climate policies targeting energy-related CO_2 emissions, which act on a global scale over long time horizons, can result in localized, near-term reductions in both air pollution and adverse human health impacts. Focusing on China, the largest energy-using and CO_2-emitting nation, [the authors] develop a cross-scale modelling approach to quantify these air quality co-benefits, and compare them to the economic costs of climate policy. [The authors] simulate the effects of an illustrative climate policy, a price on CO_2 emissions. In a policy scenario consistent with China's recent pledge to reach a peak in CO_2 emissions by 2030, [the authors] project that national health co-benefits from improved air quality would partially or fully offset policy costs depending on chosen health valuation. Net health co-benefits are found to rise with increasing policy stringency." **Mingwei Li, Da Zhang, Chiao-Ting Li, Kathleen M. Mulvaney, Noelle E. Selin, and Valerie J. Karplus**, *Nature Climate Change*. (Subscription may be required.)

Assessment of two-phase flow on the chemical alteration and sealing of leakage pathways in cemented wellbores.

The following is the Abstract of this article: "Wellbore leakage tops the list of perceived risks to the long-term geologic storage of CO_2, because wells provide a direct path between the CO_2 storage reservoir and the atmosphere. In this paper, [the authors] have coupled a two-phase flow model with [the authors'] original framework that combined models for reactive transport of carbonated brine, geochemistry of reacting cement, and geomechanics to predict the permeability evolution of cement fractures. This addition makes the framework suitable for field conditions in geological storage sites, permitting simulation of contact between cement and mixtures of brine and supercritical CO_2. Due to lack of conclusive experimental data, [the authors] tried both linear and Corey relative permeability models to simulate flow of the two phases in cement fractures. The model also includes two options to account for the inconsistent experimental observations regarding cement reactivity with two-phase CO_2-brine mixtures. One option assumes that the reactive surface area is independent of the brine saturation and the second option assumes that the reactive surface area is proportional to the brine saturation. [The authors] have applied the model to predict the extent of cement alteration, the conditions under which fractures seal, the time it takes to seal a fracture, and the leakage rates of CO_2 and brine when damage zones in the wellbore are exposed to two-phase CO_2-brine mixtures. Initial brine residence time and the initial fracture aperture are critical parameters that affect the fracture sealing behavior. [The authors] also evaluated the importance of the model assumptions regarding relative permeability and cement reactivity. [The authors'] results illustrate the need to understand how mixtures of [CO_2] and brine flow through fractures and react with cement to make reasonable predictions regarding well integrity. For example, a reduction in the cement reactivity with two-phase CO_2-brine mixture can not only significantly increase the sealing time for fractures but may also prevent fracture sealing." **Jaisree Iyer, Stuart D.C. Walsh, Yue Hao, and Susan A. Carroll**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Estimates of carbon storage in grassland ecosystems on the Loess Plateau.

The following is the Abstract of this article: "Grassland ecosystems play an important role in the carbon (C) balance of arid and semi–arid regions. These ecosystems provide C for grass growth and soil microbial activities and represent one of the main sources of atmospheric C. In this study, [the authors] estimated the C density and storage of 223 sampling sites in grassland ecosystems on the Loess Plateau using elevation, vegetation indexes, precipitation, air temperature, day and night land surface temperature (LSTd and LSTn, respectively), evapotranspiration (ET), percent tree cover and the non–vegetated area to build decision regression tree and generalized linear regression models (GLMs). The results showed that the C density decreased from south to north and ranged from 0.22 to 29.29 kg C/m^2. The average amount of C stored in the ecosystems was 1.46 Pg. The typical steppe and forest steppe stored the most C, and the steppe desert stored the least. The soil (0–1 m) stored most of the organic C, accounting for > 90%, and the belowground biomass (BGB) contained > 3 times the amount of C as the aboveground biomass (AGB). This study provides reference information for the loss of C and associated mitigation strategies on the Loess Plateau." **Yinyin Wang, Lei Deng, Gaolin Wu, Kaibo Wang, and Zhouping Shangguan**, *CATENA*. (Subscription may be required.)

Impact of inner reservoir faults on migration and storage of injected CO_2.

The following is the Abstract of this article: "[Carbon dioxide] geological storage (CGS) is an effective way to mitigate [GHG] emissions, and geological security is one of the most important issues in CGS. The faults distributed in geological formations make multi-layered reservoirs interconnected systems. A three-dimensional (3D) numerical model was established to evaluate the effects of inner reservoir faults on the CO_2 migration and storage capacity of an actual CGS demonstration project in the Ordos Basin of China. The results show that the faults in the layered reservoir system could significantly affect the migration of injected CO_2. The cross-layer faults at the bottom of the faulted reservoir could act as preferential passages between the upper and lower geological formations, causing the CO_2 in the reservoir formation to move upward to adjacent layers rather than to lateral migration. CO_2 migration along the inner-layer faults widely occurred at the top of the reservoir formation, decreasing the pressure accumulation and CO_2 saturation around the injection well. Based on the simulation, CO_2 will have migrated into the Heshanggou Formation after 300 years, and most of the CO_2 will be trapped in the bottom sub-layers, with no CO_2 intruding into the upper caprock. The spatial and temporal evolution of the injected CO_2 was well presented for the faulted reservoir system, suggesting that the faults inside the multi-layered reservoir are beneficial to CGS." **Zhijie Yang, Tianfu Xu, Fugang Wang, Yanlin Yang, Xufeng Li, and Ningning Zhao**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Adaption, mitigation and risk-taking in climate policy.

The following is the Abstract of this article: "The future consequences of climate change are highly uncertain and estimates of economic damages differ widely. Governments try to cope with these risks by investing in mitigation and adaptation measures. In contrast to most of the existing literature, [the authors] explicitly model the decision of risk averse governments on mitiga-

tion and adaptation policies. [The authors] also consider the interaction of the two strategies in presence of uncertainty. Mitigation efforts of a single country trigger crowding out as other countries will reduce their mitigation efforts. This may even lead to lower mitigation on the global scale. In contrast, a unilateral commitment to large adaptation efforts benefits the single country and can reduce the global risk from climate change at the expense of other countries." **Heike Auerswald, Kai A. Konrad, and Marcel Thum**, *Journal of Economics*. (Subscription may be required.)

The role of revenue sharing and first-mover advantage in emission abatement with carbon tax and consumer environmental awareness.

The following is the Abstract of this article: "In this study, [the authors] explore the role of revenue sharing and first-mover advantage in manufacturer's carbon emission abatement effort and the firms' profitability in a linear demand setting, where the government might impose some carbon emission charges and consumers may have environmental awareness. [The authors] consider a supply chain system, consisting of a manufacturer and a retailer. Either of them can move first to offer the other firm a wholesale price contract (WP) or a revenue sharing contract (RS), which is termed as 'abatement level promise strategy' (PR) and 'abatement level requirement strategy' (RQ), respectively. [The authors'] analysis shows that under both PR and RQ, there exists a unique abatement level maximizing the manufacturer's profit in WP and RS, respectively. Moreover, both firms' incentives for abatement are perfectly aligned under PR, but are misaligned under RQ when the marginal abatement cost is large. Contrary to conventional wisdom, RS does not necessarily dull the manufacturer's effort in abatement, it depends on whether she possesses first-mover advantage and whether consumers have environmental awareness. Further, with consumer environmental awareness (numerically) or without, both firms always prefer to possess first-mover advantage, but the system's profit under RQ is smaller than that under PR (numerically). Surprisingly, whether a greater share of revenue benefits a firm depending on whether the firm possesses first-mover advantage (numerically). Finally, under both RQ (numerically) and PR, RS fails to coordinate the system." **Huixiao Yang, Jianwen Luo, and Haijun Wang**, *International Journal of Production Economics*. (Subscription may be required.)

Decentralized optimal multi-energy flow of large-scale integrated energy systems in a carbon trading market.

The following is the Abstract of this article: "This paper proposes a novel decentralized optimal multi-energy flow (OMEF) of large-scale integrated energy systems (IES) in a carbon trading market, to fully exploit economic and environmental advantages of the system considering difficulties of information collection from subareas. The decentralized OMEF is solved by three decentralized optimization algorithms, including auxiliary problem principle (APP), block coordinates down (BCD), and approximate Newton directions (AND). Moreover, a dynamic parameter adjustment is developed for APP and BCD to ensure convergence. So that a cooperative optimization among subareas can be achieved through utilizing only the local information and the boundary information. Finally, case studies of a two-area IES with 8 energy hubs and a three-area IES with 33 energy hubs are carried out to deeply compare the performance of the three decentralized algorithms, together with a thorough analysis about the effect of carbon trading price on the system." **Kaiping Qu, Tao Yu, Linni Huang, Bo Yang, and Xiaoshun Zhang**, *Energy*. (Subscription may be required.)

SEPTEMBER 2018

Understanding key elements in establishing a social license for CCS: An empirical approach.

The following is the Abstract of this article: "This paper presents results of empirical research with the broad aim of exploring societal responses to CO_2 storage, framed around the concept of social license to operate (SLO). [The authors] describe a mixed method approach incorporating stakeholder interviews and focus groups deployed in two case study locations in the UK. The approach helps [the authors] to build up an understanding of the social context in which CCS will be introduced, in terms of the specific local conditions and with reference to the influence of local experiences of other technologies (such as hydraulic fracturing (fracking), for example). This understanding is then used to guide further empirical research, from which [the authors] assess the extent to which an SLO for CCS is emerging. Results show that perceptions of trust and confidence in key institutions to safely manage projects are highly dependent not just on the track record of the [organizations] but are strongly influenced by past experiences with different technologies. While the indications for achieving an SLO for CCS are currently positive, consolidating and maintaining that support depends on the evolving social, industrial and political landscape." **Clair Gough, Rebecca Cunningham, and Sarah Mander,** *International Journal of Greenhouse Gas Control*. (Subscription may be required).

A review of optimization and decision-making models for the planning of CO_2 capture, utilization and storage (CCUS) systems.

The following is the Abstract of this article: "CCUS is considered as one of the key strategies for mitigating climate change. This technology involves CO_2 capture from stationary sources, followed by distribution of CO_2 to different intermediate utilization and/or final storage options. [Carbon dioxide] capture and utilization (CCU) by itself offers resource conservation benefits by displacing the need for extracted CO_2 from natural sources. On the other hand, CCS provides CO_2 emissions reduction by sequestration of captured CO_2 for long-term storage. Combining CCS and CCU can potentially result in valuable symbiosis, but remains debatable due to gaps between the roles of these technologies in energy engineering. Such gaps have resulted in slower commercial deployment of CO_2 capture. Some important issues resulting from these technologies have been addressed in previous studies through process systems engineering (PSE) methodologies, which are able to provide rigorous decision support during CCUS planning. This review paper provides an in-depth discussion of the state-of-the-art of these tools, and also discusses recent developments on integrating CCUS components in large-scale planning. While recent literature in this area reveals the availability of tools for planning and policy-making, further research opportunities are identified through the bibliometric trends that show how CCUS research can develop further." **John Frederick D. Tapia, Jui-Yuan Lee, Raymond E.H. Ooi, Dominic C.Y. Foo, and Raymond R. Tan,** *Sustainable Production and Consumption*. (Subscription may be required)

Element mobilization and immobilization from carbonate rocks between CO_2 storage reservoirs and the overlying aquifers during a potential CO_2 leakage.

The following is the Abstract of this article: "Despite the numerous studies on changes within the reservoir following CO_2 injection and the effects of CO_2 release into overlying aquifers, little or no literature is available on the effect of CO_2 release on rock between the storage reservoirs and subsurface. This is important, because the interactions that occur in this zone between the CO_2 storage reservoir and the subsurface may have a significant impact on risk analysis for CO_2 storage projects. To address this knowledge gap, relevant rock materials, temperatures and pressures were used to study mineralogical and elemental changes in this intermediate zone. After rocks reacted with CO_2-acidified 0.01 M NaCl, liquid analysis showed an increase of major elements (e.g., Ca and Mg) and variable concentrations of potential contaminants (e.g., Sr and Ba); lower aqueous concentrations of these elements were observed in N_2 control experiments, likely due to differences in pH between the CO_2 and N_2 experiments. In experiments with As/Cd and/or organic spikes, representing potential contaminants in the CO_2 plume originating in the storage reservoir, most or all of these contaminants were removed from the aqueous phase. SEM and Mössbauer spectroscopy results showed the formation of new minerals and Fe oxides in some CO_2-reacted samples, indicating potential for contaminant removal through mineral incorporation or adsorption onto Fe oxides. These experiments show the interactions between the CO_2-laden plume and the rock between storage reservoirs and overlying aquifers have the potential to affect the level of risk to overlying groundwater, and should be considered during site selection and risk evaluation." **Amanda R. Lawter, Nikolla P. Qafoku, R. Matthew Asmussen, Ravi K. Kukkadapu, Odeta Qafoku, Diana H. Bacon, and Christopher F. Brown,** *Chemosphere*. (Subscription may be required).

Metamodeling-based approach for risk assessment and cost estimation: Application to geological carbon sequestration planning.

The following is the Abstract of this article: "CCS is being evaluated globally as a geoengineering measure for significantly reducing greenhouse emission. However, long-term liability associated with potential leakage from these geologic repositories is perceived as a main barrier of entry to site operators. Risk quantification and impact assessment help CCS operators to screen candidate sites for suitability of CO_2 storage. Leakage risks are highly site dependent, and a quantitative understanding and categorization of these risks can only be made possible through broad participation and deliberation of stakeholders, with the use of site-specific, process-based models as the decision basis. Online decision making, however, requires that scenarios be run in real time. In this work, a Python based, Leakage Assessment and Cost Estimation (PyLACE) web application was developed for quantifying financial risks associated with potential leakage from geologic carbon sequestration sites. PyLACE aims to assist a collaborative, analytic-deliberative decision making processes by automating metamodel creation, knowledge sharing, and online collaboration. In PyLACE, metamodeling, which is a process of developing faster-to-run surrogates of process-level models, is enabled using a special stochastic response surface method and the Gaussian process regression. Both methods allow consideration of model parameter uncertainties and the use of that information to generate confidence intervals on model outputs. Training of the metamodels is delegated to a high performance computing cluster and is orchestrated by a set of asynchronous job scheduling tools for job submission and result retrieval. As a case study, workflow and main features of PyLACE are demonstrated using a multilayer, carbon storage model." **Alexander Y. Sun, Hoonyoung Jeong, Ana González-Nicolás, and Thomas C. Templeton,** *Computers & Geosciences*. (Subscription may be required.)

An optimization model for carbon capture & storage/utilization vs. carbon trading: A case study of fossil-fired power plants in Turkey.

The following is the Abstract of this article: "[The authors] consider fossil-fired power plants that operate in an environment where a cap and trade system is in operation. These plants need to choose between CCS, CCU, or carbon trading in order to obey emissions limits enforced by the government. [The authors] develop a mixed-integer programming model that decides on the capacities of carbon capture units, if it is optimal to install them, the transportation network that needs to be built for transporting the carbon captured, and the locations of storage sites, if they are decided to be built. Main restrictions on the system are the minimum and maximum capacities of the different parts of the pipeline network, the amount of carbon that can be sold to companies for utilization, and the capacities on the storage sites. Under these restrictions, the model aims to minimize the net present value of the sum of the costs associated with installation and operation of the carbon capture unit and the transportation of carbon, the storage cost in case of CCS, the cost (or revenue) that results from the emissions trading system, and finally the negative revenue of selling the carbon to other entities for utilization. [The authors] implement the model on General Algebraic Modeling System (GAMS) by using data associated with two coal-fired power plants located in different regions of Turkey. [The authors] choose EOR as the process in which carbon would be utilized. The results show that CCU is preferable to CCS as long as there is sufficient demand in the EOR market. The distance between the location of emission and location of utilization/storage, and the capacity limits on the pipes are an important factor in deciding between carbon capture and carbon trading. At carbon prices over $15/ton, carbon capture becomes preferable to carbon trading. These results show that as far as Turkey is concerned, CCU should be prioritized as a means of reducing nation-wide carbon emissions in an environmentally and economically rewarding manner. The model developed in this study is generic, and it can be applied to any industry at any location, as long as the required inputs are available." **Semra Ağralı, Fehmi Görkem Üçtuğ, and Burçin Atılgan Türkmen**, *Journal of Environmental Management*. (Subscription may be required.)

Diffusive leakage of brine from aquifers during CO_2 geological storage.

The following is the Abstract of this article: "The area of investigation in this study is designed around an improved understanding of fundamentals of the diffusive leakage of brine from a storage aquifer into overlying and underlying low permeability layers during geosequestration of CO_2 through development of a theoretical model. Here, [the authors] consider a two-dimensional domain in cylindrical coordinates, comprised of an aquifer and an overburden, where the interaction between the two media is handled by imposing the continuities of pressures and fluid fluxes at the aquifer-overburden interface. This coupled problem is solved by successive implementation of the Laplace and finite Hankel transforms. The developed solutions can be used to analyze diffusive leakage of brine from the aquifer into overburden and generate type curves for average pressures in the aquifer and overburden during injection and post injection periods. The results show that the leakage rate at early times is scaled with $t^{1/2}$ while it remains constant at late times. It is also shown that the average pressure in the aquifer is scaled with t for short and long times. Moreover, the average pressure in the overburden is scaled with t at late times while it is scaled with $t^{3/2}$ at early times. In addition, the results reveal that factors affecting diffusive leakage rate through intact overburden during CO_2 storage are, in decreasing order of significance, thickness of overburden, thickness of aquifer, aquifer to overburden permeability ratio, and aquifer to overburden porosity ratio. However, thickness of aquifer has minimal effect on diffusive leakage of brine within post injection period. To evaluate the theoretical model, case studies for two potential sites in United Kingdom, one in Lincolnshire and the other one in the Firth of Forth, are conducted. The field studies show that the diffusive leakage from the aquifer into the overburden diminishes ~40 years after the injection has ceased for Lincolnshire while it stops after ~12 years for Firth of Forth. The average amount of the brine leaked from the aquifers per standard cubic meter (Sm3) of the injected CO_2 through diffusive leakage was found to be 6.28 × 10−4 m3 of brine (or 0.330 kg of brine/kg of CO_2) over ~70 years for Lincolnshire and 4.59 × 10−4 m3 of brine (or 0.242 kg of brine/kg of CO_2) over ~42 years for Firth of Forth." **Morteza Dejam and Hassan Hassanzadeh,** *Advances in Water Resources*.

The contribution of China's bilateral trade to global carbon emissions in the context of globalization.

The following is the Abstract of this article: "Controlling and reducing carbon emissions for mitigation of climate change are a global common consensus. It is imperative for legitimately and effectively ascertaining responsibilities among countries to study CO_2 emissions embodied in the international trade. As the largest exporter and the second largest importer in the world, the large amount of CO_2 emissions embodied in China's bilateral trade have a significant impact on China's and global carbon emissions. Based on the single region input-output tables using the non-competitive imports assumption, this study estimated CO_2 emissions embodied in China's bilateral trade with 219 countries/regions over the period of 2000–2014, and analyzed the contribution of China's bilateral trade to global carbon emissions under the assumption of non-trade scenario. The results show that, CO_2 emissions embodied in China's exports and imports in 2014 were 2561.1 Mt and 1209.9 Mt respectively, and CO_2 emissions embodied in exports were higher than those in imports throughout the period. It is indicated that China had produced a large amount of CO_2 emissions for other countries through the international trade. And meanwhile, China avoided a large amount of CO_2 emissions with the rapid growth of imports. And furthermore, the net CO_2 emissions embodied in China's bilateral trade had been declining since 2011. At last, China's bilateral trade had extremely little impact on global carbon emissions. It is concluded that there is a possibility of reducing global carbon emissions based on the results of China's bilateral trade with countries along the routes of Silk Road Economic Belt and 21st-Century Maritime Silk Road." **Tao Ding, Yadong Ning, and Yan Zhang,** *Structural Change and Economic Dynamics*. (Subscription may be required.)

Technology-adjusted national carbon accounting for a greener trade pattern.

The following is the Abstract of this article: "Crediting green trade patterns is essential for effective national carbon accounting. Neither production- nor consumption-based accounting satisfies this condition. Thus, Kander et al. proposed a technology-adjusted consumption-based carbon accounting method that focuses on interregional differences in sectoral carbon intensity. The intermediate input structure is also closely related to the production technology level. Therefore, this study recommends a new technology-adjusted consumption-based carbon accounting framework that distinguishes between direct and cumulative exports, forward and backward industrial linkages, and different trade patterns. Based on the consideration that production-based accounting will remain the core indicator for regional emissions in the near future, this study proposes a technology-adjusted production-based accounting framework. The empirical study is based on the World Input-Output Database, and the results indicate that technology-adjusted carbon accounting will redraw the global emissions map if the intermediate input linkage is considered. The technology-adjusted carbon accounting method satisfies the conditions of additivity, sensitivity, monotonicity, and scale invariance, through proper selection of the world average emissions multipliers." Zengkai Zhang, *Energy Economics*. (Subscription may be required.)

REPORTS and PUBLICATIONS

OCTOBER 2017

Second-Generation Toolset for Calculation of Induced Seismicity Risk Profiles.

The following is the Abstract of this NRAP document: "This report describes development and demonstration of the second-generation toolset for NRAP. The toolset provides a probabilistic analysis of hazards and risks from earthquakes that could potentially be induced by increased subsurface pore pressures on faults resulting from CO_2 injection for geological carbon sequestration (GCS). Hazard and risk calculations utilize earthquake catalogs produced by physics-based simulations that incorporate injection-induced pressure changes generated by subsurface fluid flow modeling. The second-generation toolset has the capability of calculating the seismic hazard at an arbitrary number of ground surface sites from events occurring on multiple source faults. Hazard uncertainty bounds are determined using multiple realizations of simulated earthquake catalogs that sample the epistemic and aleatory uncertainty distributions on the input parameters. 'Nuisance fragility functions' for seismic ground motion developed as part of the second-generation work are combined with the hazard curves to estimate the risk of nuisance from ground shaking. Hazard and risk estimates for different time periods before, during, and after CO_2 injection can be compared to assess the impact of the GCS operation and to inform operational decision making. The results described in this report demonstrate the functionality of the toolset based on its application to a hypothetical scenario involving two faults. Further development, including modifications to the current computer code implementation and code parallelization, will be needed to bring the toolset up to full functionality in dealing with large numbers of faults."

Kimberlina, California Site Characterization for Applications to Potential Induced Seismicity.

The following is the Executive Summary of this NRAP document: "This study considered a hypothetical location of a CO_2 injection facility at the Kimberlina site, described [in this document]. The report is divided into four parts: 1) ground motion prediction; 2) ambient (in-situ) stress field; 3) topographic site characterization, and 4) fault characterization. The focus is twofold: [(1) site characterization parameters and methodologies that have been applied to the Kimberlina site, and (2) a more general discussion of site characterization approaches and methodologies that are applicable to general sites of interest.] This study resulted in a number of summary conclusions and recommendations, some of which are specific to the hypothetical Kimberlina site, and many of which are more broadly applicable to the consideration of seismicity in selecting and characterizing future carbon storage sites, including the impact of surface facilities. The methods described herein can be applied to a site with a relatively small amount of measured seismic activity. The benefits of establishing seismic monitoring networks, collecting rock cores, and characterizing peak ground acceleration and velocity have been identified. Further detail regarding these conclusions and recommendations can be found in the final two sections of this report."

Algae Cultivation for Carbon Capture and Utilization Workshop Summary Report.

The following is from the Introduction of this DOE Office of Energy Efficiency and Renewable Energy (EERE) Bioenergy Technologies Office (BETO) document: "BETO works to accelerate the development of a bioeconomy that can strengthen U.S. energy security, environmental quality, and economic vitality. BETO's Advanced Algal Systems Program (also called the Algae Program) is implementing a long-term applied R&D strategy to support the bioeconomy by lowering the costs of production for algal biofuels and bioproducts. The Algae Program works with partners to develop innovative technologies, integrate these technologies in pre-pilot test environments, and conduct crosscutting analyses to better understand the potential and challenges of an algal biofuels and bioproducts industry. BETO's Algae Program regularly hosts algal biofuels strategy workshops to engage stakeholders in discussions of R&D priorities and to facilitate partnerships. On May 23–24, 2017, BETO hosted the Algae Cultivation for Carbon Capture and Utilization (CCU) Workshop in Orlando, Florida. Over 80 attendees participated in the event, providing valuable input through facilitated discussions focused on innovative technologies and business strategies for growing algae on waste CO_2 emissions. Representatives from BETO, DOE's FE's Office of Coal and Power Research and Development, and experts in the fields of waste CCU and algae cultivation considered challenges and opportunities related to the following: [(1) sourcing CO_2, including quality, quantity, siting, and transport; (2) cultivating algae, including biomass productivity, efficiency in CO_2 utilization, and carbon balances of end products; and (3) identifying sustainable 'win-win' solutions to reducing CO_2 emissions while achieving cost savings]."

NOVEMBER 2017

Reduced-Order Model for Leakage through an Open Wellbore from the Reservoir due to CO_2 Injection.

The following is the Abstract from this NRAP document: "Potential CO_2 leakage through existing open wellbores is one of the most significant hazards that needs to be addressed in geologic carbon sequestration (GCS) projects. In the framework of NRAP which requires fast computations for uncertainty analysis, rigorous simulation of the coupled wellbore-reservoir system is not practical. This study developed a 7,200-point look-up table reduced-order model (ROM) for estimating the potential leakage rate up open wellbores in response to CO_2 injection nearby. The ROM is based on coupled simulations using T2Well/ECO2H which was run repeatedly for representative conditions relevant to NRAP to create a look-up table response-surface ROM. The ROM applies to a wellbore that fully penetrates a 20-m thick reservoir that is used for CO_2 storage. The radially symmetric reservoir is assumed to have initially uniform pressure, temperature, gas saturation, and brine salinity, and it is assumed these conditions are held constant at the far-field boundary (100 m away from the wellbore). In such a system, the leakage can quickly reach quasi-steady state. The ROM table can be used to estimate both the free-phase CO_2 and brine leakage rates through an open well as a function of wellbore and reservoir conditions. Results show that injection-induced pressure and reservoir gas saturation play important roles in controlling leakage. Caution must be used in the application of this ROM because well leakage is formally transient and the ROM lookup table was populated using quasi-steady simulation output after 1,000 time steps which may correspond to different physical times for the various parameter combinations of the coupled wellbore-reservoir system."

Influence of Geochemical Processes on the Geomechanical Responses of Overburden Strata during CO_2 Storage in Saline Aquifers.

The following is the Executive Summary of this NRAP document: "Saline aquifers have been identified as types of desirable geologic formations suitable for storage of CO_2 in large amounts. While the impermeable caprock layer(s) in the overburden provides the primary trap for injected CO_2, other trapping mechanisms such as solubility, residual, ionic or mineral trapping help contribute to CO_2 storage. Geochemical reactions alter the petrophysical properties in the target reservoir, and may have an influence on the reservoir storage capacity. When CO_2 is injected for long periods of time, it changes the fluid pressures and overburden geomechanical response. In this study, coupled multiphase fluid flow and geomechanical modeling with geochemical processes was performed to simulate long-term (1,000 years), large-scale injection of CO_2 (up to10 million metric tons per year) into a deep saline aquifer, to investigate the influence of geochemical processes on the geomechanical response of overburden during long-term CO_2 injection. Geochemical modeling results from this study show that geochemical processes such as mineral dissolution and precipitation have very little influence on reservoir rock porosity at the reservoir scale. Results from the coupled fluid flow and geomechanics models with geochemical reactions for large-scale CO_2 injection scenarios indicate that the inclusion of geochemical reactions in the geomechanical models have a very little influence on the computed vertical ground displacements during injection and post-injection periods. Modeling results show that the pressure increases and ground displacements caused due to CO_2 injection decay with time during

the post-injection period. Thus, the study findings are that geochemical interactions have no significant impact on geomechanical response at the reservoir scale. It should be noted, however, that the impacts of geochemistry on geomechanical response at the local scale, such as in faults or fractures that are found in a caprock layer, were not addressed in this study."

Principles for Best Practice Geomechanics for CCS Injection Operations and its Application to the CarbonNet Project.

The following is from the Executive Summary of this Global CCS Institute document: "For the CCS industry to make a significant contribution to global emissions reduction, it must be deployed at scale, worldwide. This 'new' industry will inherit much of the data and experience of the petroleum industry especially as regards safe operation and pressure management. An important element for every CCS project is the identification of subsurface injection pressure limits to ensure CO_2 retention. The purpose of the pressure limits is to protect the overlying aquifers, for surface equipment integrity, and to ensure subsurface geomechanical stability. A high confidence is required that during the operation of an injection project, any geomechanical events will be small and/or relatively [localized] and that adequate safeguards exist to prevent or [minimize] adverse events. Best Practice manuals for CCS are in development worldwide but to date no comprehensive code of practice or manual has been published. Extensive datasets exist in the experience of drilling oil and gas wells in a wide variety of stress regimes. The process of well drilling samples and tests the geomechanical environment in a near-wellbore context (tens to hundreds of [meters]) over a relatively short timeframe of days to months, while injection of fluids leads to a test over a larger spatial extent (km to tens of km) over longer timeframes (years to decades), and therefore a more stringent pressure management approach is required due the larger potential scale of geomechanical effects. Although working pressure guidelines are commonly identified for injection projects, the resultant approaches applied worldwide are inconsistent, since they have been partially guided by local jurisdictions that account for the geomechanical in-situ conditions in different ways."

DECEMBER 2017

Geological Storage of CO_2 in Deep Saline Formations.

The following is a description of this book: "This book offers readers a comprehensive overview, and an in-depth understanding, of suitable methods for quantifying and characterizing saline aquifers for the geological storage of CO_2. It begins with a general overview of the methodology and the processes that take place when CO_2 is injected and stored in deep saline-water-containing formations. It subsequently presents mathematical and numerical models used for predicting the consequences of CO_2 injection. This book provides descriptions of relevant experimental methods, from laboratory experiments to field scale site characterization and techniques for monitoring spreading of the injected CO_2 within the formation. Experiences from a number of important field injection projects are reviewed, as are those from CO_2 natural analog sites. Lastly, the book presents relevant risk management methods. Geological storage of CO_2 is widely considered to be a key technology capable of substantially reducing the amount of CO_2 released into the atmosphere, thereby reducing the negative impacts of such releases on the global climate. Around the world, projects are already in full swing, while others are now being initiated and executed to demonstrate the technology. Deep saline formations are the geological formations considered to hold the highest storage potential, due to their abundance worldwide. To date, however, these formations have been relatively poorly characterized, due to their low economic value. Accordingly, the processes involved in injecting and storing CO_2 in such formations still need to be better quantified and methods for characterizing, modeling and monitoring this type of CO_2 storage in such formations must be rapidly developed and refined."

A Reduced-Order Model of Fault Leakage for Second-Generation Toolset.

The following is the Abstract of this NRAP document: "This report describes the NRAP second-generation fault leakage model. The key features of the new model are: [(1) A three-dimensional (3-D) site model has been developed; (2) Geomechanical changes in permeability due to fault slip are now included; and (3) The Kimberlina reservoir model is used as a reference to specify boundary conditions for pressure and saturation.] This report briefly describes both the high-fidelity leakage simulations and their subsequent reduction to a response-surface model. This response-surface model constitutes a reduced-order model (ROM) that can be incorporated into a system model that predicts the potential for CO_2 or brine to be released from a storage reservoir to an overlying aquifer or the atmosphere. This second-generation ROM builds on the first-generation ROM, which was two-dimensional (2-D) and did not incorporate geomechanical effects. Note that this ROM considered aseismic, quasi-static slip behavior. The third-generation ROM will look at leakage response due to seismic events."

JANUARY 2018

Geological Storage of CO_2 in Deep Saline Formations.

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CSLF Technology Roadmap 2017.

The following is from the Executive Summary of this Carbon Sequestration Leadership Forum (CSLF) document: "The CSLF Technology Roadmap 2017 aims to provide recommendations to Ministers of the CSLF member countries on technology developments that are required for CCS to fulfill the CSLF mission to facilitate the development and deployment of CCS technologies via collaborative efforts that address key technical, economic, and environmental obstacles."

Global Landscape of Climate Finance 2017.

The following is from the Executive Summary of this Climate Policy Initiative document: "Climate Policy Initiative's 2017 edition of the Global Landscape of Climate Finance updates the most comprehensive assessment of annual climate finance flows with data from 2015 and 2016, providing, for the first time, a five-year trend analysis on the how, where, and from whom finance is flowing toward low-carbon and climate-resilient actions globally in order to identify trends, gaps, and opportunities to scale up investment. As with previous reports, the figures identified in this Landscape represent overall global finance flows and should be compared with estimates of total investment needed consistent with the goal of limiting global temperature rise to below 2 degrees Celsius."

FEBRUARY 2018

Reduced-Order Model for the Geochemical Impacts of CO_2, Brine, and Trace Metal Leakage into an Unconfined, Oxidizing Carbonate Aquifer, Version 2.1.

The following is from the Executive Summary of this document: "The National Risk Assessment Partnership (NRAP) is a DOE-funded program to develop and demonstrate a methodology and toolset for predicting long-term risk profiles needed for quantifying potential liabilities at a CO_2 storage project. The approach taken by NRAP is to divide the system into components, including injection target reservoirs, wellbores, natural pathways including faults and fractures, groundwater, and the atmosphere. Next, detailed physics- and chemistry-based models of each component are developed. Using the results of the detailed models, efficient, simplified models, termed reduced-order models (ROM) are then developed for each component. Finally, the component ROMs are integrated into a system model that calculates risk profiles. The groundwater component models are based on two sites: the confined reducing, sandstone High Plains aquifer, which extends from South Dakota to Texas; and the unconfined, oxidizing carbonate Edwards aquifer in south-central Texas. Two ROMs have been developed for each aquifer, one with varied hydraulic parameters, and another with varied geochemical parameters, resulting in four separate groundwater ROMs. This report focuses on [Pacific Northwest National Laboratory's (PNNL's)] development of the geochemical ROM for the Edwards aquifer. The approach used to develop the groundwater geochemistry ROM for the Edwards aquifer was to develop a complex model of groundwater flow and reactive transport in the shallow, urban unconfined portion of the aquifer near San Antonio, Texas. The areal model domain covers a 5×8-km area and is 150-m thick, with upscaled heterogeneous porosity and permeability. This model, using the STOMP (Subsurface Transport Over Multiple Phases) simulator, used a well leak ROM provided by Los Alamos National Laboratory (LANL) to calculate CO_2 and brine leakage rates into the aquifer. The STOMP model included equilibrium, kinetic mineral, and adsorption reactions related to the carbonate and clay minerals in the aquifer reacting with major ions and trace metals in groundwater, as well as CO_2 and brine containing sodium (Na), chloride (Cl), arsenic (As), cadmium (Cd), and lead (Pb) leaking from the wellbore."

Updated short-term traded carbon values used for UK public policy appraisal.

The following is from the Background of this UK Department for Business, Energy, and Industrial Strategy (BEIS) document: "BEIS's short-term traded carbon values for UK public policy appraisal are used for valuing the impact of government policies on emissions in the traded sector, i.e. those sectors covered by the EU Emissions Trading System (EU ETS). Short-term values quoted in this paper correspond to the period up to 2030 and long-term values correspond to the period post-2030. In 2009, the Department of Energy and Climate Change (DECC) set out a methodology for producing traded sector carbon values to 2050 in the paper 'Carbon Valuation in UK Public Policy Appraisal: A Revised Approach' (July 2009). The paper advocated moving from a social cost of carbon/damage cost approach for valuing carbon to a target consistent resource-cost approach. In 2012, the hybrid methodology for producing short-term traded carbon values was adopted and involved using a market-based approach using futures prices to produce short-term traded carbon values in the central scenario, and fundamentals-based high and low scenarios for sensitivity purposes. Since 2012, these values have been updated annually using the BEIS Carbon Price Model (BCPM). These values are being revised again as part of the annual process for updating BEIS's analytical projections and assumptions."

Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters.

The following is the Abstract of this University of Texas at Austin Bureau of Economic Geology document: "The purpose of this atlas is to provide a summary of research undertaken as part of a multiyear study (2009–2014) of Texas State Waters and the adjacent Federal Offshore continental shelf (i.e., near offshore waters of the State of Texas). The goal of the study was to assess and analyze existing data from historical hydrocarbon-industry activities in a regional transect of the Texas coast in order to verify the ability of Miocene-age rocks of the region to safely and permanently store large amounts of anthropogenic (industrial) CO_2. The authors' intent in producing this atlas is to provide a resource for exploring the geological CO_2 sequestration potential of the near offshore waters of the State of Texas by populating the atlas with both large-scale regional, qualitative and detailed quantitative information that can help operators quickly assess CO_2 sequestration potential at specific sites. This is the first comprehensive attempt to accomplish this goal in the near offshore of the Gulf Coast and United States."

MARCH 2018

Reduced-Order Model for the Impacts of Carbon Dioxide and Brine Leakage into an Unconfined, Oxidizing Carbonate Aquifer, Third-Generation.

The following is from the Abstract of this National Risk Assessment Partnership (NRAP) document: "NRAP consists of five DOE national laboratories collaborating to develop a framework for predicting the risks associated with carbon sequestration. The approach taken by NRAP is to first divide the system into components, including injection target reservoirs, wellbores, natural pathways including faults and fractures, groundwater, and the atmosphere. Next, develop a detailed, physics- and chemistry-based model of each component. Using the results of the detailed models, develop efficient, simplified models, termed reduced-order models (ROMs), for each component. Finally, integrate the component ROMs into a system model that calculates risk profiles for the site, using a probabilistic methodology. This report details the development of the groundwater ROM for an unconfined carbonate aquifer, loosely based on an unconfined portion of the Edwards Aquifer in south-central Texas. For practical reasons of computational efficiency, two sets of detailed multiphase reactive-transport simulations were performed separately: one emphasizing complex hydrogeology factors, the other emphasizing detailed geochemistry. These results were combined into a single groundwater ROM that considered both hydrogeologic and geochemical factors that might be expected to influence the fate and transport of brine and CO_2 in a shallow aquifer."

Carbon Capture and Storage Sector: Worldwide Forecast until 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 including 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 secure location. The experts estimate the worldwide [CCS] market to increase at a compound annual Growth rate of ~9.2 percent between 2017 and 2021. [The scope of this report] describes the ongoing situation and its growth expectations of the global [CCS] sector for 2017-2021. To calculate the market value, the industry report examines business dimensions with an eye on individual growth trends and contribution of upcoming market segments. The sector is segmented into the specified segments established on area: Americas; Asia-Pac; [and] Europe, Middle East and Africa (EMEA). The market study, Worldwide Carbon Capture and Storage Sector 2017-2021, has been produced established on a comprehensive and detailed market studies with data coming from specialists of the sector. The study describes the market outlook and its growth expectations over the next years. This study also comprises conversations with top vendors operating in this segment."

The Clean Growth Strategy: Leading the way to a low carbon future.

The following is from an Introduction in this document: "The move to cleaner economic growth is one of the greatest industrial opportunities of our time. This Strategy will ensure Britain is ready to seize that opportunity. [The UK's] modern Industrial Strategy is about increasing the earning power of people in every part of the country. [The UK needs] to do that while not just protecting, but improving the environment on which [their] economic success depends. In short, [the UK needs] higher growth with lower carbon emissions. This approach is at the heart of [the] Strategy for clean growth. The opportunity for people and business across the country is huge. The low carbon economy could grow 11

percent per year between 2015 and 2030, four times faster than the projected growth of the economy as a whole…"

APRIL 2018

Reduced-Order Models for Prediction of Groundwater Quality Impacts from CO_2 and Brine Leakage – Application to the High Plains Aquifer.

The following is the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "In this study, modeling was performed to represent the complex hydrogeological and geochemical conditions in a heterogeneous aquifer by using two separate reduced-order models (ROMs). The first ROM is derived from a high-fidelity model that accounts for the heterogeneous flow and transport conditions in the presence of multiple leakage wells. This ROM, developed by Lawrence Livermore National Laboratory (LLNL) takes into account uncertainties related to flow, transport, and leakage parameters; however, this ROM has a simplified representation of chemical reactions. The second ROM is obtained from models that feature greatly simplified flow and transport conditions, but allow for a more complex representation of all relevant geochemical reactions. This ROM, developed by LBNL takes into account uncertainties related to chemical parameters and reactions. Both ROMs specifically address the physical and chemical properties of the High Plains Aquifer.

Neither ROM can separately provide an accurate prediction of the risk profile volume because of the simplifications inherent in these models. Accurate prediction could be achieved with a very complex three-dimensional (3-D) reactive transport model; however, this model would be quite demanding computationally. Therefore, development of an alternative approach that allows linking of the two ROMs and, in particular, a correction of the risk profile volumes estimated by the two separate ROMs, was conducted. The development of a linking function was accomplished by: (1) the establishment of two simple models — a one-dimensional (1-D) model with homogenous flow and transport field and single leakage point, but including as many chemical reactions as possible—and a two-dimensional (2-D) model considering aquifer heterogeneity but no reactions; (2) the development of a complex model that incorporates all the parameters and physical and chemical processes of both simple models; (3) multiple runs of both simple and complex models; and (4) estimation of the linking functions based on those runs. This report describes the development and usage of the ROMs and linking function."

MAY 2018

Analysis of Field Vertical Seismic Profiling (VSP) Data: Cranfield 3D-VSP Project.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "The investigations in this report address one of the priority research topics of the NRAP Strategic Monitoring Working Group—the research need of quantifying and improving temporal and spatial resolution of monitoring data, in this case three-dimensional (3D) borehole based seismic data. The resulting Cranfield 3D vertical seismic profiling (VSP) study consists of two different investigations of VSP technology as it applies to the storage of anthropogenic CO_2. These investigations are firstly, an examination of the subsurface spatial resolution of 3D-VSP technology compared to more expensive, lower frequency 3D surface seismic technology, including the potential economic and technical value for subsurface monitoring of large volumes of anthropogenic CO_2. The second investigation relates to the value of least-squares, reverse-time migration processing for coping with the sparse distribution of VSP seismic sources and the avoidance of processing artifacts that may mimic low offset faults or other subsurface discontinuities. Such artifacts could result in the incorrect estimation of higher project risk, greater geologic uncertainty, and could result in negative impacts to project schedule or budget. The key findings of this report relate the relative spatial resolution of reflections at the reservoir depth (which are used to monitor the storage of CO_2) and in above zone monitoring intervals (AZMI), which are used to monitor for leakage. For the Cranfield data set, this study found that the 3D-VSP data have only slight improvements over conventional 3D surface seismic in the resolution of the high amplitude, continuous reflector for the Tuscaloosa injection formation, but that a real advantage of 3D-VSP is found in the improved imaging of weakly reflective, discontinuous reflectors in a potential AZMI. At Cranfield such reflectors above the injection formation form an important zone for leakage monitoring. At other sites, the reservoir interval may consist of weakly reflective seismic events whose imaging could be improved by 3D-VSP. This improvement in imaging is essential in being able to detect and quantify changes in subsurface properties related to seismic monitoring."

Global Carbon Account 2018.

The following is the Introduction of this document: "This overview presents key trends regarding the implementation of explicit carbon pricing policies throughout the world in 2018. A timeline, a world map, a detailed table and a graph provide comprehensive information on the jurisdictions that have implemented or plan to implement explicit carbon pricing policies, the type of instrument chosen, the sectors and fuels covered, the pricing levels, and the use of revenues."

JUNE 2018

Performance Evaluation and Integration of Multiple CO_2 Leak Detection Monitoring Technologies.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "Monitoring, mitigation and verification (MMV) is an indispensable part of an integrated geologic [CCS] project. Developing a reliable MMV network is of vital importance in order to avoid threats to public health, the environment, and economic investments in sequestration in case of significant leakage. The large spatial extent of sites and the several decades-long duration required for MMV present a great challenge. The availability of several technologies (soil gas, surface flux, eddy covariance, perfluorocarbon tracers, seismic, pressure monitoring, groundwater chemistry, etc.) allow such networks to be established. However, the large numbers of monitoring devices, operating practices, failure modes, and leakage scenarios dictate the need for an overseeing mechanism that will help to integrate and interpret the signals from the network. This project was carried out to develop such an integrating mechanism utilizing a Bayesian belief network (BBN). A well-established and calibrated BBN can statistically characterize the reliability of a given leakage signal, combining evidence from multiple measurements in a weight-of-evidence framework. Both false positives and false negatives are intended to be reduced, and eliminated if possible, through application of this statistical tool. Once developed, the BBN can be used to predict the probability that a future leak of a given size will be detected. In future studies the final product from this project can also be used to design an MMV network that optimizes detection capabilities for a given expenditure of available resources, and as part of an integrated risk model that includes adaptive management options should leakage be detected."

Why Carbon Pricing Matters: A guide for implementation.

The following is the Preface of this World Business Council for Sustainable Development (WBCSD) document: "Carbon pricing is an accepted concept for managing carbon emissions and many jurisdictions are looking to implement one instrument or another. Many resources describing different carbon pricing mechanisms exist. However, they tend not to be comparative and are relatively high-level. WBCSD and its members believe that carbon pricing is now regarded as one of the most efficient means of driving the transition to a low-carbon world. As an increasing number of jurisdictions have adopted or are considering adopting carbon pricing, this document focuses on the 'what' and 'how' rather than the 'why.' Policymakers need to choose the most suitable carbon pricing instruments and design them appropriately. This document aims to guide policymakers who are considering carbon pricing mechanisms in their choice of instruments and some key design principles. In the process, this document hopes to stimulate further and more detailed discussions between policymakers and business leaders on how best to implement the carbon price so that it can incentivize low-carbon innovation and investment, create a global level playing field and support the attainment of the [United Nations Framework Convention on Climate Change (UNFCCC)] 2°C goal in a sustainable way."

JULY 2018

Experimental and Numerical Modeling Approach to Elucidating Damage Mechanisms in Cement-Well Casing-Host Rock Settings for Underground Storage of CO_2.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) document: "This research project was completed during an ambitious 12-month period encompassing both experimental and modeling efforts to elucidate the potential for damage mechanisms in Class H Portland cement exposed to high temperature, pressure and supercritical CO_2 or carbon dioxide-oxygen cycle (CO_2-O_2). One key goal of this work was to decouple the effects of these three influences to determine which, if any, had the most profound impact on integrity of Class H cement. Experimental work was completed at both Oregon State University (OSU) and NETL-Albany. Modeling work was done at OSU. The results of the experimental work showed that mechanical properties, specifically compressive strength and modulus of rupture were most affected (decreased over the control) at high temperatures (85°C), high pressure (4,200 psi) and in the presence of supercritical CO_2 or CO_2-O_2. The influence of low (23°C) or intermediate temperature (50°C) as well as exposure to a synthetic brine or saturated limewater had negligible effects on mechanical properties. Cement exposed to supercritical CO_2 and CO_2-O_2 were shown to alter the cement specimens from the exterior of paste samples inward as the carbonation front lead to distinct zones of amorphous silica, calcite deposited, calcium depleted, and finally the unaltered cement closer inward toward the center of the sample. While total alteration depths were similar between both sets of exposed samples (CO_2 or CO_2-O_2) the amount of alteration within the altered zone varied between the different exposures, qualitatively. Pore solution analysis reflected the alteration process showing that the concentrations of alkalis (from the Portland cement) reduced over time as the concentration of calcium increased. Inversely, aqueous calcium decreased in the bulk solution. It was also found that sulfate was drawn preferentially at high temperature (85°C). Perhaps the most important finding was verification that the introduction of O_2 into the gas stream resulted in rapid corrosion of the Alloy-20 metal on the interior of the autoclaves used for high pressure, temperature and gas exposure experiments. This represents a significant concern for the long-term sequestration of co-sequestration of CO_2 once oxygen is introduced into the system. The wellbore casing, being made of stainless steel, is subject to deterioration and this could represent a potential leakage pathway."

Clean Air, Clean Industry, Clean Growth: How Carbon Capture Will Boost the UK Economy.

The following is from the Executive Summary of this document: "This Study into the value of CCS investments along the East Coast of the [UK], represents a new approach to evaluating the economic and societal benefits associated with the deployment of CCS. The results provide a robust basis for advancing CCS in the UK. The Study considers a phased evolution of CCS Investments providing essential [decarbonization] options with discrete investment/decision points along the way. The CCS Investments considered are sized and timed to align with the Committee on Climate Change ("CCC") projections for UK carbon emissions reductions targets with each investment demonstrating a significant net positive impact on the UK economy. Successive investments in CCS projects and infrastructure are envisaged that evolve over time into a CCS network. Each phase of East Coast CCS investments is considered as discrete but with each phase building on and using the infrastructure implemented in the previous phases. For modelling purposes, the phases are divided into 5 year periods i.e. the same as parliamentary terms and climate budget periods in the UK. This approach is adopted [recognizing] that policy may change from time to time and technology does not stand still. Options can therefore be maintained and adjusted for UK [decarbonization] policy as circumstances evolve, with successive phases of investment only proceeding if the case for them stands up over time. There is no requirement for investors, the UK and/or Scottish governments to commit to the whole series of investments upfront."

AUGUST 2018

Feasibility of Biogeochemical Sealing of Wellbore Cements: Lab and Simulation Tests.

The following is from the Executive Summary of this DOE/NETL document: "A critical facet of a successful CO_2 storage program in geologic formations—a major component of the DOE Fossil Energy portfolio—necessitates prevention of CO_2 leakage from cement and its interface with host lithologies. To ensure permanence of CO_2 stored in a geologic formation it is essential to maintain the wellbore integrity to prevent leakage of gas to the surface or surficial aquifers. This study builds on advances on the current understanding of behavior of cement under high pressure/temperature and CO_2 conditions and recent reports on the bioprecipitation of calcium carbonate by *Sporosarcina pasteurii (S. pasteurii)* in the presence of supercritical CO_2, to test the feasibility of microbially-mediated sealing of a leaking wellbore. This study used a Portland cement, Mt. Simon sandstone cores (to be supplied by [Pacific Northwest National Laboratory [PNNL] researchers), and a synthetic Illinois Basin brine as the model geologic materials. The Mt. Simon formation has been targeted for supercritical CO_2 injection as a part of the DOE's FutureGen project, and as one of the U.S. DOE-NETL Phase III Regional Partnership programs. The growth rate of *S. pasteurii* on cement and sandstone in various temperature and pressure conditions were measured. For the aqueous experiments, this study focused on the aqueous population of *S. pasteurii* as it allowed a quantitative evaluation of community growth. However, it was also qualitatively evaluated whether this species was able to grow on cement or sandstone that was previously collected from the Mt. Simon formation. It was found that the species grew best at 30°C compared to 40°C, the latter being among the lowest temperatures likely to occur in the Mt. Simon formation. The species was able to have temporarily stable population for a in the brine at 30°C, but failed after 40°C. This study inoculated a brine solution overlaying cement/sandstone 'cement samples' and incubated them at 30°C in the brine with urea augmented. The results demonstrated that the species grew well on the sandstone, and on the cement with an apparent preference for the later."

Role of CCUS in a below 2 degrees scenario.

The following is from the Executive Summary of this European Zero Emission Technology and Innovation Platform (ZEP) document: "The world's economy is built on energy, 80% of which still came from fossil fuels in 2016. The growth in use of fossil fuels worldwide is still far higher in absolute terms than the growth of non-CO_2 emitting energies, so far employed. In Europe, the EU Commission's 2016 reference scenario for primary energy consumption showed similar levels of demand for natural gas and oil in 2050 as in 2010. Meanwhile, the Paris Agreement commits the world to net-zero emissions in the second half of the century, balancing remaining sources with sinks to achieve neutrality. In a European context, the recently agreed Regulation on Governance of the Energy Union commits the EU to meeting net-zero 'as soon as possible'. The EU's Long-term strategy for [GHG] emissions reduction, to be presented at COP 24 in November, will assess how to reach net-zero by 2050. Although a major source for global GHG emissions, the industry sector has largely been shielded from contemporary climate action, postponing relevant measures into the far future. Cash and investment constrained European industry will not make changes to reduce CO_2 emissions without a strong positive business case, which so far is lacking. Within a 32 year timeframe Europe cannot rely on potential breakthrough technologies and fundamental changes in consumer [behavior], but needs to deploy real solutions that are available today to reduce industry emissions. [CCS], along with [utilization] of CO_2 where appropriate (CCUS), is available, scalable, cost effective and suitable to deeply reduce emissions from industrial processes and heat."

SEPTEMBER 2018

History, Sampling, Porosity and Permeability Testing of Salem Limestone, Oriskany Sandstone and Marcellus Shale.

The following is the Abstract of this NETL document: "This report describes measurements of the fluid storage and transmission properties of Salem Limestone, Oriskany Sandstone, and Marcellus Shale. Test results are assessed in the context of confining stress applied to the sample and sample preparation procedures. For perspective, a general geologic description is provided for each rock type. The current regional stress state was also considered in terms of the test specimens' propensity for preferential fracturing. As part of the test program, two different methods for sample testing were used depending on rock type. Combined permeability and porosity tests were performed on small, cylindrical plug samples one inch (2.54 cm) in diameter by at least two inches (5 cm) in length. Helium gas was used in testing for both the Salem Limestone and Oriskany Sandstone, whereas nitrogen gas was used for Marcellus Shale. Porosity to gas and high-pressure, pulse-decay gas permeability were evaluated on all samples at four net confining pressure steps: 500 psi (3.4 MPa), 1,000 psi (6.9 MPa), 1,500 psi (10.3 MPa), and 2,000 psi (13.8 MPa). Test results for each rock type were generally uniform. Under conditions of increasing net confining pressure, the average matrix porosity of the Salem Limestone ranges from 7.62% to 7.83%, and matrix permeability ranges from 1.81 to 1.87 mD. The Oriskany Sandstone's average matrix porosity ranges from 6.05% to 6.43% and matrix permeability ranges from 4.8 to 9.1 mD. The Marcellus Shale plug samples were cut in two different directions; in one group the cylinder axis was cut perpendicular to the bedding plane and the other group was cut parallel to the bedding plane. Porosity measured in the group of perpendicular samples ranges from 4.34% to 7.72% and permeability ranges from null to 0.5 mD. Porosity of the parallel sample group ranges from 0.54% to 1.32% and permeability readings from 0.02 to 1.12 mD. Interpretation of the results concluded that porosity and permeability are relatively insensitive to the sample preparation methods used in this study, and the recorded values are reasonable when compared with published data or other representative samples."

Risk Reduction of CO_2 Storage with Stochastic Simulations.

The following is from the Executive Summary of this NETL Technical Report Series document: "The purpose of this project was to create an efficient and flexible tool based on principal component analysis (PCA) for a generation of differentiable realizations of porosity and permeability fields. Of particular interest were data which had significant connectivity between patches of the same rock type, which is called 'binary.' The efficiency requirement needed a so-called kernel PCA, and the binary images were found with the method called optimization based PCA (OPCA) for which interpretation is provided. The ability to honor given data at particular locations is also incorporated. The tool worked very well and efficiently for two dimensional (2-D) simulations. Furthermore, the tool was applied to a three-dimensional (3-D) dataset and determined that conditioning can be used to maintain the connectivity between vertical layers. Since kernel-based tools need snapshots, several tools that generate snapshots were also created. These tools are based on PCA or on novel filtering techniques. The next steps for this project include new techniques to combine PCA with upscaling, testing models with more data, expanding OPCA and filtering, and extending techniques to work more appropriately with non-Gaussian data."

An independent assessment of the UK's Clean Growth Strategy: From ambition to action.

The following is from the Executive Summary of this UK Committee on Climate Change document: "Under the Climate Change Act, the Government is required to publish a set of policies and proposals that will enable the legally-binding carbon budgets, on track to the 2050 target, to be met. The Clean Growth Strategy, published in October 2017, presents the Government's plans. In this report [the authors] set out [their] assessment of that Strategy. [The authors'] key conclusions are: [1] The Government has made a strong commitment to achieving the UK's climate targets. It has placed the low-carbon economy at the heart of the UK's industrial strategy, framing the Clean Growth Strategy as a positive contribution to the economy (rather than a burden to be [minimized]). It has committed to a position of international leadership. There is great interest internationally in the model provided by the UK Climate Change Act. This makes it all the more important to have plans in place to meet the targets through domestic actions – this is the basis on which the carbon budgets were set. [2] Policies and proposals need to be firmed up. The Strategy includes some new policies to reduce emissions. In other areas – covering the majority of the emissions reductions in the Strategy – it sets out some ambitious new proposals, but policy to deliver those aspirations has not yet been worked up. Development of policy in these areas (e.g. upgrading as many homes as possible to Energy Performance Certificate Band C by 2035, improved standards of new buildings, phasing out the sale of new conventional petrol and diesel cars and vans by 2040) will need to progress urgently. [3] Gaps to meeting the fourth and fifth carbon budgets remain. These must be closed. Whilst the Strategy sets out a '2032 Pathway' for sectoral emissions that would just meet the fifth carbon budget, there is no clear link to the policies, proposals and intentions that the Strategy presents. [The authors'] assessment of the policies and proposals set out in the Strategy indicates that, even if these deliver in full, there remain gaps of around 10-65 $MtCO_2e$ to meeting both the fourth and fifth carbon budgets on the basis of central projections."

ANNOUNCEMENTS

OCTOBER 2017

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.

NETL Releases Updated BPMs for Geologic Carbon Storage.

DOE/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. Developed in conjunction with the *Regional Carbon Sequestration Partnerships (RCSPs)*, the revised BPMs 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.

DOE/NETL Conference Proceedings Available Online.

Proceedings of the DOE/NETL-sponsored "2017 Mastering the Subsurface Through Technology Innovation, Partnerships, and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting," held in Pittsburgh, Pennsylvania, USA, on August 1-3, 2017, are available online. Included are posters and presentations from the three-day meeting.

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. 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 DOE/NETL's Carbon Storage 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.

New International Standards for CO_2 Capture and Storage.

New international standards for the storage and transport of CO_2 will be presented at a seminar at the Norwegian Petroleum Directorate (NPD) in Stavanger, Norway, in fall 2017. The standards relate to the storage of CO_2 and its transportation by pipeline.

UKCCSRC Autumn 2017 Biannual Proceedings Available Online.

Posters and presentations from the United Kingdom Carbon Capture and Storage Research Center's (UKCCSRC) Autumn 2017 Biannual meeting are available online. Held in September 2017, the Autumn Biannual Meeting focused on the UKCCSRC's core research program.

University of Maryland Releases Updated Action Plan.

The University of Maryland (UMD) released an updated action plan outlining strategies to help the university become carbon neutral by 2050. In addition to reducing the university's CO_2 emissions, *Climate Action Plan 2.0* will also fully integrate sustainability into its educational and research efforts. Since the original plan in 2009, UMD has reduced greenhouse gas (GHG) emissions by 28 percent.

NOVEMBER 2017

DOE-Supported Project Reaches Milestone.

The Petra Nova project, DOE's post-combustion carbon capture system, has captured more than 1 million metric tons of CO_2 for use in EOR operations. Located near Houston, Texas, USA, the project demonstrates an advanced amine-based CO_2-capture technology that removes 90 percent of the CO_2 emitted from the flue gas stream. The captured CO_2 is used for EOR at the West Ranch Oil Field, which has increased oil production from 300 barrels per day when it began operations to approximately 4,000 barrels per day currently.

FY 2017 Carbon Storage Newsletter Annual Index Available.

The *FY 2017 Carbon Storage Newsletter Annual Index* is available online in a new, updated format. The document is a compilation of NETL's Carbon Storage Newsletters published over the October 2016 through September 2017 timeframe, organized by section. Outdated information (e.g., conference dates and paper submittals) have been removed.

DECEMBER 2017

NCCC Surpasses Milestone.

The DOE-sponsored National Carbon Capture Center (NCCC) surpassed 100,000 hours of technology testing, marking the research facility's work in the development of advanced technologies to reduce greenhouse gas (GHG) emissions from natural gas and coal power plants. Managed and operated by Southern Company, NCCC was created by DOE/FE in 2009 and offers a pathway to advance novel technologies from the laboratory to demonstration in real-world power plant conditions.

DOE/FE Selects Projects to Receive Federal Funding.

DOE/FE selected two projects to receive funding to assess offshore geologic storage of CO_2 and technology development in the Gulf of Mexico. Selected as part of FE's *Carbon Storage Program*, the NETL-managed projects will focus on assembling the knowledge base required for secure, long-term, large-scale CO_2 storage and assessing technology-development needs. In addition, DOE/FE also *selected two projects to receive funding* for cost-shared research and development (R&D) for the safe storage of CO_2 in geologic formations. The two NETL-managed projects will also support the Carbon Storage Program and are supported through Funding Opportunity Announcement (FOA) DE-FOA-0001725, "*Technology Development to Ensure Environmentally Sustainable CO_2 Injection Operations.*"

Global CCS Institute Releases Report on CCS.

The Global CCS Institute released its "*Global Status of CCS Report: 2017*" at the 23rd Conference of the Parties (COP23) in Bonn, Germany. The report details the importance of CCS to meet international targets, and highlights CCS as the conduit to a new energy economy of hydrogen production, bioenergy, and CO_2 re-use applications.

Global Summit on CCUS.

The International Energy Agency (IEA) held a high-level summit to support investment in CCUS. Attended by energy ministers, government officials, and chief executives of major energy companies, the summit was held ahead of the IEA 2017 Ministerial Meetings and co-chaired by the United States. In addition, IEA offered a document on the "*Five Keys to Unlock CCS Investment.*" A summary of the summit is available on the *IEA website*.

RGGI Report on Secondary Market.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "Report on the Secondary Market for RGGI CO_2 Allowances: Third Quarter 2017" addresses the period from July through September 2017.

Results of 38th RGGI Auction Released.

The nine states participating in the RGGI market-based regulatory program to reduce GHGs announced the results of their 38th auction of CO_2 allowances. The last of 2017, Auction 38 saw 14,687,989 CO_2 allowances sold at a clearing price of $3.80. Bids for the CO_2 allowances ranged from $2.15 to $8.00 per allowance, generating a total of $55.8 million for reinvestment in strategic programs such as energy efficiency, renewable energy, and GHG abatement. Additional details are available in the "*Market Monitor Report for Auction 38*."

JANUARY 2018

Reports on Decarbonizing Australia.

A suite of reports released by Energy Networks Australia has found that decarbonizing gas in Australia by 2050 is achievable with the application of carbon capture and storage (CCS) to Australia's gas network infrastructure. The new report, titled "*Decarbonizing Australia's gas networks*," was conducted by Deloitte Access Economics and builds on a previous report, titled "*Gas Vision 2050*."

Carbon Capture Projects Map Developed.

A company developed an interactive map detailing the carbon capture projects across the world. The map filters projects by application, location, and partners. A database of the projects is *available online*.

Webinar on Decarbonizing Industry Using CCS.

The Global CCS Institute and Gassnova conducted a webinar exploring how Norway is working to realize a full-chain CCS project. In addition to providing an overview of the Gassnova-managed Norway *Full Chain CCS project*, the webinar also covered the value Norway seeks to derive and the key stakeholders involved.

Seminar on Nordic CCS Cooperation.

A recent seminar conducted by Bellona highlighted the role of CCS in reaching Europe's climate targets. According to the stakeholders, cooperation between Sweden and Norway on the development of common CCS infrastructure may lead to decreases in costs and increases in effectiveness.

Paper Published on CCS Market.

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) published an updated paper on their recommendations for the design of the Innovation Fund Delegated Act. The *paper* provides input on how the act can support the development of CCS "Market Makers."

FEBRUARY 2018

Forum on CCS Cooperation.

Bellona held its second forum on Nordic carbon capture and storage (CCS) cooperation, focusing on Norway and Sweden joining forces for CO_2 management. The industry and environmental non-governmental organization representatives from Oslo, Norway, and Gothenburg, Sweden, that attended the forum discussed the reduction of greenhouse gases (GHGs) and how three CCS projects around the Oslo fjord showcase the potential of CO_2 capture plants being built on cement and waste incineration plants.

Report on Role of CCS.

The International Energy Agency (IEA)-established Coal Industry Advisory Board (CIAB) released a report on the investment in CCS. Among other findings, CIAB reported on the Australian government promoting CCS investment and working with industry to co-develop CCS technology projects that are industrially scalable.

Online Tool Calculates Soil's Carbon Storage Potential.

Researchers from the International Center for Tropical Agriculture (CIAT) developed *The Soil Carbon App*, an online tool that can calculate soil's capacity for storing organic carbon. The tool can be used by investors and decision makers to assess to which degree planned efforts to restore degraded land will bind organic carbon in soil and reduce potential CO_2 emissions.

Chilean Government Agrees to CCS Plan.

The government of Chile and the Chilean association of electricity producers have agreed to not build new coal power plants that are not equipped with CCS or equivalent technologies. In addition, the two parties will also establish a joint working group that will focus on phasing out the operation of coal-fired power plants that do not currently utilize CCS or equivalent technologies.

MARCH 2018

NETL Names Acting Director.

The DOE Assistant Secretary for Fossil Energy (ASFE) named Sean I. Plasynski the acting director of NETL. A 28-year veteran of Federal fossil energy research, Dr. Plasynski previously served as the executive director of NETL's Technology Development and Integration Center (TDIC), director of the Strategic Center of Coal, director of the Office of Coal and Power R&D, and Sequestration Technology manager.

DOE Selects Projects to Receive Funding.

DOE's FE and NETL selected nine projects to receive funding for Phase I of the *Fossil Fuel Large-Scale Pilots* FOA. The projects selected have demonstrated technical success at the small-scale pilot stage and are ready to proceed to the large-scale development stage. DOE's FE also selected *seven projects* to receive funding for cost-shared R&D through the "Design and Testing of Advanced Carbon Capture Technologies" FOA. These projects will advance competitive operation of the Nation's fossil-based power-generation infrastructure by reducing energy consumption and capital costs associated with next-generation carbon capture systems. Lastly, DOE's FE selected *six projects* to receive funding under the "Novel and Enabling Carbon Capture Transformational Technologies" FOA. These projects will address the cost and operational challenges associated with current CO_2 capture technologies commercially available for industry.

CCS Facility Demonstrates Success.

The carbon capture and storage (CCS) facility at SaskPower's Boundary Dam Power Station located in Saskatchewan, Canada, was online for the entire month of January 2018, capturing 81,008 metric tons of CO_2 (approximately 81 percent of its max capacity). It marked the third time in more than a year that the facility had been online for the entirety of the month. Since startup in 2014, the facility has captured more than 1.9 million metric tons of CO_2.

Carbon Capture Coalition Launched to Further CCS Adoption.

The National Enhanced Oil Recovery Initiative (NEORI) has *rebranded* as the *Carbon Capture Coalition*, expanding its agenda following the reform and extension of the Federal Section 45Q tax credit for CO_2 storage. The Coalition's mission now includes, among other focus areas, working with government and stakeholders to support the development of CO_2 utilization and storage projects.

RGGI Report on Secondary Market.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "Report on the Secondary Market for RGGI CO_2 Allowances: Fourth Quarter 2017" addresses the period from October through December 2017.

APRIL 2018

NETL Releases CCSI Toolset.

NETL's Carbon Capture Simulation Initiative (CCSI) released the CCSI Toolset as open-source software, making it available for researchers in industry, government, and academia. The CCSI Toolset is a suite of computational tools and models designed to help maximize learning and reduce cost and risk during the scale-up process for carbon capture technologies.

Federal Budget Bill Includes Carbon Tax Credits.

Tax credits for carbon storage were included in a recently passed budget bill. For every qualifying project, the 45Q tax incentive will generate a tax credit of $50 per ton of CO_2 in underground storage and $35 per ton of CO_2 for utilization or EOR.

Scottish Government Recognizes CCS in Publication.

The Scottish government released its Climate Change Plan, which sets out specific policies and proposals for meeting Scotland's potential targets. According to Scottish Carbon Capture and Storage (SCCS), the plan recognizes the potential importance of carbon capture and storage (CCS) in reducing greenhouse gas (GHG) emissions.

SaskPower CCS Surpasses Milestone.

The CCS process at SaskPower's Boundary Dam Power Station in Estevan, Saskatchewan, has prevented more than 2 million metric tons of CO_2 from entering the atmosphere since operations began in 2014. SaskPower's strategy is to reduce its GHG emissions by 40 percent from 2005 levels by 2030.

RGGI States Comment on Proposed Virginia Regulation.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) submitted comments on program elements identified in Virginia's (USA) proposed regulations for emissions trading. The comments focus primarily on regulatory compatibility and address Virginia's meeting of the definition of an RGGI Participating State, as set forth in the 2017 Model Rule.

MAY 2018

DOE's ASFE Delivers Keynote.

DOE's Assistant Secretary for Fossil Energy (ASFE) delivered keynote remarks at a National Coal Council (NCC) meeting. Topics discussed included the upgrading of existing coal-fired power plants, developing technologies for future coal plants, and early-stage R&D on carbon capture, utilization, and storage (CCUS).

Carbon XPRIZE Announces Finalists.

Finalists have been announced for the final round in the Carbon XPRIZE, a global competition in which teams address technologies that convert carbon dioxide (CO_2) emissions from power plants into valuable products. Each of the 10 finalists passed a first-round evaluation based on the amount of CO_2 they could convert into products, as well as the economic value, market size, and CO_2 uptake potential of those products.

Film on CCS.

Norcem, a Norwegian-based cement producer, released a film explaining the process of carbon capture and storage (CCS) at its Brevik cement plant in Norway.

JUNE 2018

SPE Releases CO_2 Storage Resources Management System Document.

The Society of Petroleum Engineers (SPE) released the "*CO_2 Storage Resources Management System (SRMS)*," developed by a subcommittee of SPE's CCUS Technical Section, which engages in collaboration, knowledge sharing, and activities dedicated to the advancement of CCUS and the decarbonization of the petroleum industry. The document establishes technically based capacity and resources evaluation standards.

DOE-Supported Research Wins Award.

A DOE-sponsored report, titled "Geological CO_2 Sequestration Atlas of Miocene Strata, Offshore Texas State Waters," received the *2018 John C. Frye Memorial Award in Environmental Geology*. The award, co-sponsored by The Geological Society of America (GSA) and the Association of American State Geologists (AASG), is for the best publication in the field of environmental geology published by a state geological survey or by GSA during the past three years. Initial research for the report, which was published by the Bureau of Economic Geology at the University of Texas at Austin, was supported by DOE project *DE-FE0001941*; DOE project *DE-FE0026083* supported the final publication efforts.

Company Joins MIT Energy Initiative.

IHI, a global engineering, construction, and manufacturing company, signed a three-year agreement to join the Massachusetts Institute of Technology Energy Initiative's (MITEI) *Low-Carbon Energy Center* for CCUS. The center is one of eight Low-Carbon Energy Centers established by MITEI as part of *MIT's Plan for Action on Climate Change*. In addition to funding research, IHI's membership will support MIT's technical assessment program, which analyzes the technical and economic potential of various CCUS technologies.

JULY 2018

FE Appoints New Head of Clean Coal and Carbon Management.

DOE's FE announced the appointment of Lou Hrkman as the new Deputy Assistant Secretary (DAS) for Clean Coal and Carbon Management, where he will oversee research, development, and demonstration of advanced coal-based power systems.

UK Government Plans Full-Scale CCS Scheme in 2030s.

According to United Kingdom (UK) government officials, Scottish companies are on track to launch full-scale carbon capture and storage (CCS) projects in the 2030s. The UK Department for Business, Energy, and Industrial Strategy (BEIS) announced that a CCS cross-challenge taskforce report will be published that will discuss steps to achieve cost-effective CCS.

Tokyo Announces Sustainability Plan Towards Zero Carbon.

The Tokyo Organizing Committee of the Olympic and Paralympic Games published its Sustainability Plan Version 2. One of the plan's five themes focuses on "Towards Zero Carbon," which refers to efforts to reduce CO_2 emissions generated during preparations and operation of the 2020 Games.

Countries Release Declaration of Ambition on International Policy.

A group of 23 participating countries have committed to exploring the possibilities of enhancing their targets and developing implementation guidelines at the 24th Conference of the Parties (COP24) to the United Nations Framework Convention on Climate Change (UNFCCC), to be held in December 3-14, 2018, in Katowice, Poland.

RGGI Report on Secondary Market.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2018" addresses the period from January through March 2018.

AUGUST 2018

Commitments Made to Reducing GHG Emissions.

At the *China-U.S. High-Level Dialogue on Energy and Climate Change*, held in San Francisco, California (USA), U.S. and Chinese experts discussed several cooperative mechanisms in existence between the two countries and pledged to continue dialogue. In addition, *officials from China and the European Union (EU)* also reaffirmed their commitment, releasing a *joint statement* at the *20th EU-China Summit*, held in Beijing, China. In the joint statement, the two sides committed to policies and measures to limit greenhouse gases (GHGs).

CCUS Taskforce Sets Out Recommendations for the United Kingdom (UK).

The Carbon Capture Utilization and Storage (CCUS) Taskforce presented a report to the UK government, detailing recommendations, opportunities, and the importance of CCUS technology. Among the recommendations is the development of at least two CCUS clusters (incorporating capture plants and carbon dioxide [CO_2] stores) that are operational from the mid-2020s. The CCUS Cost Challenge Taskforce was established in January 2018 with the remit of informing and proposing a strategic plan for supporting the development of CCUS in the UK.

Dutch Policy Measures.

The Dutch government has committed to reducing their national CO_2 emissions by 49 percent by 2030 compared with 1990 levels. In addition to other policy measures, the Netherlands is also considering a national carbon price floor.

SEPTEMBER 2018

NETL Develops Methods and Tools to Estimate Prospective CO_2 Storage in the Subsurface.

NETL has developed a tool to better predict CO_2 storage potential in geologic formations. The CO_2 Storage prospeCtive Resource Estimation Excel aNalysis (CO_2-SCREEN) is an online tool that applies NETL's methods to calculate prospective CO_2 storage resources. CO_2-SCREEN is available on NETL's online collection of capabilities and resources known as the *Energy Data eXchange (EDX)*.

RGGI Releases Secondary Market Report.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2018" addresses the period from April through June 2018.

Record-High Supply, Demand on Voluntary Carbon Markets in 2017.

According to a report by Ecosystems Marketplace, the supply of carbon credits on voluntary markets worldwide reached 62.7 million metric tons of CO_2 equivalent ($MtCO_2E$) in 2017, while 42.8 $MtCO_2e$ offsets were purchased and retired. Both totals are the most on record. The report, titled "*Voluntary Carbon Markets Insights: 2018 Outlook and First-Quarter Trends*," also examines trends from the first quarter of 2018.

Indian State to Estimate Emissions Trends.

The Indian state of Sikkim will assess its carbon footprint and estimate a trend for emissions. The Sikkim Climate Inventory and Monitoring System studies all sectors in the Himalayan state (e.g., transport, tourism, industry, roads, agriculture) to estimate their carbon emissions. The total is then juxtaposed with the carbon storage by the state's forests to find out its carbon footprint.

Cities Sign Net-Zero Carbon Declaration.

Nineteen global cities signed a "*Net-Zero Carbon Building Declaration*," pledging to make "Net-Zero Carbon" buildings by 2030 and upgrade existing buildings to net-zero standards by 2050. The declaration, orchestrated by the *C40 Cities Climate Leadership Group*, builds on a *similar initiative* (in June 2018) from the World Green Building Council that called on businesses to commit to making all new building net zero by 2030.

Reports Assess Economic, Energy, Environmental Implications of Federal Carbon Taxes.

Columbia University's Center of Global Energy Policy (New York, USA) released four reports that assess the economic, energy, and environmental implications of Federal carbon taxes. The independent, peer reviewed reports use state-of-the-art modeling tools to analyze the implications of an upstream carbon tax that starts at $14, $50, and $73 a ton through a hypothetical first decade of policy implementation (2020s).

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

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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